



Policy instruments for building energy efficiency in China

Jun Li

► To cite this version:

Jun Li. Policy instruments for building energy efficiency in China. Humanities and Social Sciences. École Nationale Supérieure des Mines de Paris, 2009. English. NNT : 2009ENMP1621 . pastel-00005310

HAL Id: pastel-00005310

<https://pastel.hal.science/pastel-00005310>

Submitted on 30 Jul 2009

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

M. Jean-Charles HOURCADE	Président
M. Michel COLOMBIER	Rapporteur
M. Mindjid MAIZIA	Rapporteur
M. Pierre-Noël GIRAUD	Examineur
M. Jérôme ADNOT.....	Examineur



PROCES - VERBAL DE SOUTENANCE

DIPLOME DE DOCTORAT ECONOMIE ET FINANCE

Michel COLOMBIER Rapporteurs
Mindjid MAIZIA

Pierre-Noël GIRAUD Examineurs
Jean-Charles HOURCADE
Jérôme ADNOT

NOUS, MEMBRES DU JURY, DESIGNES PAR LE DIRECTEUR DE L'ECOLE
NATIONALE SUPERIEURE DES MINES DE PARIS,

AVONS FAIT SOUTENIR LE **6 mars 2009**

A Monsieur Jun LI

Né le 13 novembre 1978 à Wuhan (CHINE)

UNE THESE AYANT POUR SUJET :

*"Instruments de politiques publiques pour la maîtrise de l'énergie dans les pays émergents
-le cas de l'habitat en Chine"*

ET L'AVONS DECLARE DIGNE DU TITRE DE **DOCTEUR EN
ECONOMIE ET FINANCE**

A, le 6 mars 2009

LE PRESIDENT,

J. C. HOURCADE


LES MEMBRES DU JURY



A compter du 1er janvier 2009, les thèses délivrées par MINES ParisTech ne comportent plus de mention.



**AVIS DU JURY SUR LA REPRODUCTION DE LA THESE
SOUTENUE**

- Titre de la thèse :
"Instruments de politiques publiques pour la maîtrise de l'énergie dans les pays émergents -le cas de l'habitat en Chine"
- Auteur : **LI Jun**
- Membres du jury : Pierre-Noël GIRAUD , Jean-Charles HOURCADE , Jérôme ADNOT , Michel COLOMBIER , Mindjid MAIZIA
- Date de la soutenance : 6 mars 2009

Reproduction de la thèse soutenue :

- ☒ thèse pouvant être reproduite en l'état
- ☐ thèse ne pouvant être reproduite en l'état
- ☐ thèse pouvant être reproduite après les corrections suggérées au cours de la soutenance
- ☐ thèse confidentielle jusqu'en :

Nom et signature du président du jury :

Jean-Charles HOURCADE


INTRODUCTION ET RÉSUMÉ

1 Contexte

La Chine joue un rôle prépondérant en matière d'émissions de gaz à effet de serre compte tenu de son poids démographique et de la structure de sa consommation d'énergie. Le charbon couvre plus de 60% des besoins énergétiques de la Chine et assure 75% de la production d'électricité, le principal secteur émetteur de gaz à effet de serre. La Chine représente 36.2% de la production mondiale de charbon en 2004¹. La contribution de la Chine aux émissions globales de CO_2 était de 13,9% en 2000. Selon le scénario de référence de l'Agence Internationale de l'Energie², les émissions de CO_2 de la Chine seraient de 11.4 Gt à l'horizon 2030, la Chine a déjà dépassé les Etats-Unis et est devenue le premier émetteur mondial de gaz à effet de serre en 2007. La sécurité énergétique constitue un enjeu majeur pour le gouvernement chinois afin de ne pas brider la croissance économique du pays. Cette contrainte conduit le pays à diversifier son approvisionnement mais aussi à mettre l'accent sur la maîtrise de l'énergie, ce qu'il a fait principalement jusqu'à maintenant dans le secteur industriel. Dans un contexte de développement économique urbain rapide, le défi principal est de parvenir à maîtriser la qualité de ses infrastructures, afin de placer le pays sur une trajectoire de croissance sobre en énergie et en émissions de CO_2 .

Bref, il est important de comprendre comment un pays émergent tel que la Chine peut-il agir sur la qualité de ses infrastructures telles que l'habitat ou encore son système énergétique ? Dans quelle mesure des objectifs environnementaux peuvent-ils être tenus dans un contexte de développement urbain rapide ? Quelle peut être la répartition des efforts entre les différents acteurs ? Quels sont alors les instruments politiques susceptibles permettant aux acteurs d'intégrer la problématique de l'efficacité énergétique dans la construction de logements et dans le développement de son système d'approvisionnement énergétique ?

¹BP Statistical review of world energy,2005.

²World Energy Outlook, 2007. La projection d'émissions en Chine a été révisée à plusieurs reprises. Le chiffre indiqué est presque 60% plus élevé que celle prévue en 2002 de l'AIE.

2 Problématique

Il y a deux questions fondamentales auxquelles cette thèse tentera de répondre. 1. Existe-t-il une trajectoire optimale d'évolution des normes relatives à la performance énergétique du bâtiment dans le contexte d'une urbanisation extrêmement rapide en Chine ? 2. Si oui, quels sont des instruments politiques et économiques à mettre en place pour limiter la croissance de la demande énergétique et des émissions de CO_2 dans ce secteur dans le contexte économique et institutionnel chinois ?

L'objet principal de notre travail est d'élaborer des instruments intégrant l'offre énergétique et la performance énergétique du bâtiment avec une approche de l'analyse technico-économique afin de trouver les solutions permettant de minimiser le coût de l'ensemble du système. Pourtant, la mise en oeuvre des politiques nécessite un cadre institutionnel adapté, la prise de décision est parfois très délicate parce que les gouvernements locaux sont souvent soumis à une double contrainte : 1. le développement économique à court terme ; 2. l'épuisement des ressources ainsi que l'impact environnemental à moyen et long terme, cela soulève la question fondamentale des sciences économiques, comment peut-on maximiser l'utilité sociale avec des ressources limitées.

Une ville chinoise (Tianjin) est choisie comme l'étude de cas dans cette recherche. Le choix de la ville est pertinent du point de vue des perspectives énergétiques et économiques. Premièrement, la ville de Tianjin est représentative en termes de condition climatique dans la majorité des villes dans la Chine du nord, où les besoins de chauffage ne cessent d'augmenter dans le secteur du bâtiment. La ville de Tianjin est située dans la zone officielle de chauffage où les chaudières et les centrales de cogénération centralisées distribuent de la chaleur.

Deuxièmement, l'économie et le niveau de vie des habitants vont continuer à s'accroître rapidement dans les prochaines décennies. Le PIB par tête à Tianjin devrait atteindre 20,000 US\$ en 2020, équivalent au niveau des pays moyennement industrialisés dans les années 1990. En effet, le confort d'été est aussi une grande problématique énergétique dans le secteur résidentiel, la ville de Shanghai représente la zone climatique en transition où l'utilisation de climatiseurs fonctionnant à pompe à chaleur (air-air) domine la consommation résidentielle d'électricité, il paraît également nécessaire d'effectuer une analyse des économies d'énergie de climatisation dans le secteur du bâtiment à Shanghai. Pourtant, notre analyse prospective est focalisée sur la problématique du chauffage dans la partie du nord de Chine sous contrainte de données disponibles, ainsi seule la ville de Tianjin fait l'objet de l'exercice de modélisation dans cette recherche, l'analyse succincte de la situation de Shanghai est présentée dans l'annexe.

La littérature explorant les expériences dans les pays développés montre que la demande des services énergétiques dans le résidentiel est étroitement corrélée avec le niveau de vie des habitants. Les ménages de la classe moyenne et supérieure peuvent accroître leur consommation de services

énergétiques à un moindre coût que les ménages à bas revenu. Cette observation intuitive implique que la future demande d'énergie dans les bâtiments dans les grandes villes chinoises sera beaucoup plus importante si aucune mesure de la maîtrise de l'énergie (MDE) n'est prise à court terme car les contraintes de revenu seront progressivement relâchées à mesure que les ménages s'enrichiront.

3 Méthodologie

Une approche quantitative est employée pour identifier la trajectoire optimale de l'évolution de la performance énergétique du parc de logements et le choix du système d'offre d'énergie à l'échelle d'une ville. Il s'agit de modéliser les conséquences énergétique, environnementale et économique afin de trouver le(s) choix pertinent(s) permettant de minimiser le coût social. Le modèle sélectionné (LEAP) dans l'analyse de la ville est de type bottom-up, adapté pour simuler les scénarios des politiques de MDE mises en place. Nous simulerons à la fois la puissance de charge ainsi que la consommation d'énergie finale et primaire en fonction des hypothèses sur la performance du bâti et sur le système énergétique. Les coûts suivants sont pris en compte dans le calcul du modèle.

- coût de l'amélioration du rendement énergétique, y compris le coût des matériaux de construction efficace, l'enveloppe d'isolation, de ventilation, mesures spécifiques du système de régulation, etc.
- coût des sources d'énergie (charbon, gaz naturel, pétrole, électricité), le prix du marché est utilisé comme le proxy du coût social (shadow price) des ressources naturelles, le benchmark price des combustibles est retenu comme la référence du coût
- coût du capital de l'installation de nouvelle puissance de la production de chaleur et d'électricité pour répondre à la demande croissante)
- coûts fixe et variable des *O&M*
- coût des externalités de l'environnement

Dans le modèle, nous déterminons deux catégories de facteurs influençant la demande énergétique, par conséquent les résultats économiques du système :

1. critères socioéconomiques
population, taux d'urbanisation, revenu (représenté par le PIB par tête), surface moyenne par habitant, taille de ménage, taux de pénétration des équipements électroménagers et d'appareils électriques.
2. critères techniques & physiques
caractéristique thermique de l'enveloppe (représentée par la *U*-value), température chauffée à l'intérieur du bâtiment, période de chauffage, le rendement de production et de distribution,

performance énergétique de l'ensemble du système de fourniture de l'énergie, application de nouvelles technologies avancées (e.g. CCS³).

Certaines variables sont interdépendantes telles que le niveau de confort et le revenu de ménage. De fait, les facteurs se décomposent en variables exogènes, explicitées directement selon nos hypothèses, et variables endogènes, calculées par le modèle en fonction de l'input des variables exogènes. Nous établissons les interactions des variables par une série d'équations.

4 Structure de la thèse

La thèse se constitue en deux parties principales. Dans la première partie, j'exposerai d'abord la motivation de la recherche ainsi que la méthodologie employée. Ensuite, je présenterai les différentes trajectoires du développement de la performance énergétique des bâtiments et des technologies d'offre d'énergie (chauffage individuel, chaudière, usine de chaleur fonctionnant au charbon, énergie renouvelables etc) et les conséquences économiques et environnementales dans la ville de Tianjin en basant sur l'approche de modélisation.

Dans la deuxième partie, j'aborderai l'aspect institutionnel de l'organisation des marchés énergétique et immobilier dans les deux villes, l'analyse se focalise sur les jeux d'acteurs du marché. Une revue générale des théories économiques sur les institutions, incitations et le choix social sera effectuée pour constituer le cadre d'analyse. Par la suite, en combinant les résultats de la modélisation et de l'analyse institutionnelle, je présenterai les résultats de la thèse et formulerai des recommandations d'instruments politiques et économiques. Ces outils seront conçus pour inciter les acteurs à mieux prendre en compte les enjeux de la maîtrise de l'énergie du bâtiment neuf et les choix technologiques de l'offre de l'énergie afin d'anticiper la nécessaire transition vers une économie décarbonée.

5 Résumé des chapitres

Le chapitre 1 explique la motivation de la recherche et la problématique de recherche et présente également la structure de la thèse et ses composants. La première partie de ce chapitre se consacre à la description du panorama de la consommation d'énergie et les implications d'émissions de CO_2 dans les villes chinoises. Il explique la raison pour laquelle nous devons insister sur l'importance de la prise en compte immédiate de l'efficacité énergétique dans le bâtiment dans un contexte d'urbanisation sans précédent en Chine. Une vue d'ensemble de l'économie de l'efficacité énergétique ainsi que les barrières techniques et institutionnelles à la mise en œuvre des politiques

³carbon capture and storage

de maîtrise de l'énergie dans les secteurs résidentiel et tertiaire sont présentées dans la deuxième partie de ce chapitre.

Le chapitre 2 commence par un bref descriptif de la littérature présentant différents modèles consacrés à l'analyse prospective de la demande d'énergie à moyen et long terme, i.e. les différents scénarios de la demande d'énergie dans le secteur du bâtiment résultant des politiques de la MDE. L'analyse des scénarios élaborés dans les études précédentes montrent que la consommation d'énergie dans les bâtiments en Chine pourrait être réduite de 100-300 millions de tonnes d'équivalent pétrole (Mtep) en 2030 par rapport au *business as usual*(BAU), ce qui signifie que 600-700 millions de tonnes d'émissions de CO_2 pourraient être évitées par la mise en œuvre des politiques énergétiques appropriées dans un cadre institutionnel adapté. L'essentiel des économies d'énergie réside dans le chauffage urbain au nord de la Chine. Pour cela, l'amélioration de la performance thermique du bâtiment ainsi que la qualité de production et de distribution de chaleur devront jouer un rôle majeur dans la maîtrise de la demande énergétique et des émissions de CO_2 .

Par la suite, le chapitre explore les implications sociales, économiques et environnementales et les limites des études de modélisation. En examinant les hypothèses et les méthodes utilisées dans la littérature existante, nous montrons que les cadres de modélisation dans la littérature existante n'ont pas abordé directement la question fondamentale de nos recherches et insistons sur la nécessité de trouver la réponse pertinente. Nous concluons à la fin du chapitre que l'analyse prospective de la demande énergétique et des émissions de CO_2 dans le secteur du bâtiment est nécessaire pour répondre à notre question fondamentale et expliquons pourquoi le processus de modélisation est basée sur deux échelles différentes : analyse d'un quartier "type" et de l'ensemble de la ville.

Le chapitre 3 présente la méthodologie et le cadre de modélisation permettant de remédier aux limites des travaux précédents relatifs au choix optimal de la performance énergétique du bâtiment, mentionnés dans le chapitre 2. Nous décrivons la philosophie de la construction du modèle et les choix des scénarios dans la seconde moitié de ce chapitre, la question sur les taux d'actualisation sera également abordée.

Le chapitre 4 présente les résultats de la modélisation à l'échelle d'un nouveau quartier d'habitation où 70% du bâti est d'utilité résidentielle et 30% des bâtiments sont conçus à des fins commerciales. L'étude du quartier est basée sur plusieurs modules dans lesquels les différents portefeuilles de technologies (performance du bâti, système d'approvisionnement en chaleur) sont testées afin de comparer les coûts et les avantages de différents niveaux de la construction conformément aux normes d'efficacité du bâtiment résidentiel dans une nouvelle zone d'aménagement de la ville de Tianjin. Il s'agit d'une évaluation de la décision d'investissement prise lors du développement d'une nouvelle zone d'aménagement où l'ensemble des logements sont construits en même temps. Nous évaluons les exigences de la performance thermique de différentes stratégies afin d'identifier les

normes optimales pour une période de 20 ans. Le résultat montre que la réglementation thermique actuelle en Chine ne permet pas d’atteindre le niveau optimal (coût social minimisé) du point de vue social, on observe que la norme la plus exigeante d’aujourd’hui (équivalente à celle de la Suède) génère un coût global moins élevé que la réglementation, lorsque les coûts des externalités (coût d’émissions de CO_2) ne sont pas pris en compte). Le calcul montre également que quelque soit la prise en compte ou non du coût des externalités (émissions de SO_2 ; CO_2), la construction des bâtiments conformément avec une performance énergétique équivalente aux exigences dans la norme française (RT 2005) combinée avec la cogénération fonctionnant au charbon à l’échelle du quartier permettrait d’atteindre l’optimum pour la période 2005-2020, tandis que l’équivalent de la norme suédoise serait préférable lorsque le prix du carbone est explicite et suffisamment élevé. La politique dite “*fuel switch*” préconisant la substitution massive du charbon par le gaz naturel dans la production d’énergie en ignorant la performance énergétique du bâti se révèle être un choix non pertinent car le coût serait extrêmement élevé. Le bilan *carbone* serait cependant nettement supérieur aux *options charbon* les meilleures.

Le chapitre 5 poursuit le cheminement des travaux du chapitre 4 en introduisant la dynamique du parc. L’objectif central est de comparer les différentes stratégies d’investissement dans maîtrise de la demande et les technologies d’offre afin d’identifier les options optimales. L’enjeu capital pour l’autorité publique est d’établir le pont entre la décision d’investissement d’aujourd’hui et la capacité de transformer les bâtiments en infrastructures de basse intensité énergétique et faibles émissions de carbone à l’avenir. Il s’agit d’un arbitrage d’investissement à différents horizons de temps, puisque une grande partie du parc existant peu performant construit avant 2005 devra être réhabilité et que l’infrastructure du système d’offre d’énergie (e.g. chaudières au charbon) devra être renouvelée à l’horizon 2015-2020. Ce sera donc l’occasion de faire des choix d’investissement tant du côté de l’offre que celui de la demande. En matière d’offre d’énergie, soit la ville pourra opter pour le “fuel-switching” en substituant massivement le gaz au charbon dans les chaudières ; soit elle pourra introduire les “*low-carbon technologies*” (CCS entre autres) progressivement en maintenant la structure dominante du charbon. Or ces nouvelles orientations d’investissement dans les technologies d’offre requiert nécessairement la capacité de financement qui, à leur tour, dépendent directement de la qualité de la performance énergétique du parc que l’on construit dès aujourd’hui jusqu’en 2030. L’amélioration de l’efficacité énergétique du bâtiment va générer des rentes financières grâce à la réduction des coûts d’exploitation du système tout au long de la période. Les décideurs politiques pourront transformer les rentes en capacité d’investissement dans de nouvelles technologies d’offre à partir de 2015-2020 dans un contexte institutionnel adapté. Il s’agit donc de comparer les différents modèles d’investissement à la fois dans la demande et dans l’offre. Les coûts et bénéfices séquentiels seront illustrés comme résultats de modélisation afin de savoir

comment l'autorité locale doit arbitrer les décisions d'investissement dans les différents temps sous contraintes des ressources économiques limitées.

Ce chapitre modélise les conséquences énergétique, environnementale et économique des stratégies envisagées (traduites en scénarios dans le modèle) avec les résultats chroniques (profil annuel) résultats annuels et cumulés pour expliciter leurs coûts et avantages respectifs. Contrairement au chapitre 4 dans lequel un parc "statique" (construction neuve) est pris en compte, le chapitre 5 intègre également le parc existant dans le calcul total, autrement dit, nous modélisons la dynamique de l'ensemble du parc du bâtiment (construction neuve, démolition, réaffectation, réhabilitation etc.). Nous simulerons une dizaine de scénarios selon le niveau d'exigence des normes des bâtiments et les différentes technologies du système de fourniture énergétique. Par ailleurs, une variante de *non réhabilitation du parc existant en 2005* sera aussi simulée dans chaque scénario pour comparer les coûts actualisés. Les options de l'offre d'énergie considérées dans ce chapitre couvrent presque toutes les technologies disponibles de la production de chaleur et d'électricité, de manière plus complète que dans le chapitre 4. Dans les scénarios sous contrainte *carbone*, le prix du carbone sera introduit pour prendre en compte les coûts environnementaux. Les résultats de l'analyse sont assez similaires à ceux trouvés dans le chapitre précédent, les exigences équivalentes à la norme suédoise seraient le choix optimal dans la plupart des cas étant donné les technologies d'offre d'énergie. Les scénarios *fuel switch* et la mise en œuvre généralisée du CCS sont des choix extrêmement coûteux pour la société, il sera d'autant plus difficile d'adopter ces technologies que les bâtiments construits sont peu performants et induisent des coûts de fonctionnement élevés. La décision d'investissement dans la demande et l'offre énergétique doit être prudente afin de minimiser le risque de *lock-in* de long terme. L'exigence du bâtiment *low-carbon* (ultra performant énergétiquement) serait souhaitable dans les scénarios où le coût des émissions de CO_2 est très élevé.

Les chapitres 6 et 7 constituent la deuxième partie de la thèse et cherchent à élaborer des instruments économiques et politiques pour faciliter la convergence vers la trajectoire optimale telle que définie dans la première partie.

Le chapitre 6 porte sur l'analyse institutionnelle du marché énergétique et de l'immobilier dans la ville de Tianjin et Shanghai. Nous aborderons les aspects suivants : l'organisation et le fonctionnement du marché immobilier et les critères déterminants des composants des prix des logements ; les prix de l'énergie ; les jeux d'acteurs dans un système complexe liant énergie, aménagement et bâtiment.

La première partie du chapitre 7 est consacrée à l'étude des théories économiques de l'institution et des incitations. Dans la seconde partie du chapitre, nous essayerons d'élaborer des instruments politiques pour surmonter les barrières institutionnelles et techniques à la mise en œuvre des mesures

de la MDE dans le secteur résidentiel, tel que les mécanismes applicables qui relient la performance énergétique du bâtiment avec le marché du carbone international. Nous analyserons les conditions de mise en œuvre du *Mécanisme du Développement Propre* (MDP) dans le cadre du protocole Kyoto pour la MDE du bâtiment. D'autre part, nous suggérerons que les promoteurs et constructeurs puissent être incités à mieux prendre en compte la qualité de la performance énergétique du bâtiment par le biais du tarif foncier et de la réglementation spécifique de l'usage du sol destiné à la construction de logements. L'une des recommandations principales repose sur la flexibilité de l'allocation du coefficient d'occupation du sol (*COS*) en fonction de la l'efficacité énergétique globale de la construction. Le coût d'abatement de CO_2 dans les projets d'amélioration de la performance énergétique du bâtiment serait de l'ordre de 16 US\$ par tonne CO_2 . Le programme immobilier de construction neuve pourra bénéficier d'un *COS* spécifique suivant l'échelon de la performance énergétique spécifique du bâti, tout en dépendant du système intégral d'approvisionnement d'énergie en amont. Nous décrirons comment tenir compte des intérêts de chaque acteur ce processus (le fournisseur d'énergie, le promoteur, le consommateur et le gouvernement). Pourtant, la mise en place de ces mécanismes semblerait nécessiter un changement fondamental du processus administratif de développement de la ville. Les résultats de calcul montrent que l'augmentation du tarif de chauffage de 15-20% ⁴serait indispensable pour accompagner les instruments proposés sans quoi ni le promoteur ni la compagnie de chauffage aura l'intérêt d'investir dans la maîtrise de l'énergie dans le bâtiment. De ce point de vue, la restructuration et la réforme institutionnelle du marché de l'énergie et de l'immobilier seront indispensables pour pouvoir atteindre les objectifs de l'optimalité telle que définie dans la thèse.

Le chapitre 8 conclut la thèse. Il reprend les grandes lignes des résultats des analyses quantitatives et institutionnelles dans l'optique de la réalisation des trajectoires optimales de la MDE dans les bâtiments en Chine. Les limites de cette recherche ainsi que la perspective de travaux futurs seront finalement présentées.

⁴En effet, cette fourchette d'augmentation du tarif permet aux consommateurs d'être indifférents vis-à-vis de la facture de l'énergie.

ABSTRACT

More than one billion square meters of housing should be built in Chinese cities by 2020. At the same time, demand for energy services of Chinese households is very likely to increase as a result of continually improved living standards. Space heating already accounts for almost 40% of energy consumption in the residential sector in China. Thus the energy performance of buildings in Chinese cities represents a major challenge for ensuring energy supply security and combating climate change in the next decades. Several regulations relating to the requirement of the thermal performance of housing entered into force in China successively since the 1990s, the long term consequences of failure in enforcement and implementation have been examined from both energy security and climate protection perspectives. Nevertheless, few of studies in literature have addressed the issue from the perspective of economic investment decision. None of previous studies have studied the extent to which the current decision on more or less efficient standards in the large-scale urban infrastructure like buildings will have ultimately impact on the financing capacity in transforming the society toward low-carbon energy supply and consumption model, and the role the energy efficiency in buildings will play in enabling the public authority to harness the benefits resulting from reduced operation costs in early stage to facilitating the investment in new technology research and development and deployment in the future. The thesis seeks to answer two fundamental questions : 1. Is there an optimal development path to buildings energy performance standards in the context of extremely rapid urbanisation in China? 2. If so, what are political and economic instruments to put in place to limit growth in energy demand and CO_2 emissions in this sector by taking the economic and institutional characteristics into account? Based on a modelling approach, we compare a variety of strategies to manage energy demand in buildings and their economic costs in a Chinese city by 2030. Our quantitative analysis in the first part of thesis shows that the adoption of current Chinese BEE standards not only fails to achieve an optimal level from societal point of view, but would also be the most costly among the technical options available today even without taking into account any cost of environmental externalities. Inclusion of carbon price will certainly favour the high-efficiency construction technology. More importantly, the city-level long-term modelling results show that failing in implementation of building energy efficiency today will result in tremendous difficulty in transforming the whole infrastructure under climate and economic constraints. Financing the new generation of low-carbon supply technologies such as renewable heating and carbon capture and storage require taking into account the buildings thermal quality without any delays, otherwise the whole urban infrastructure would be locked in low efficiency and high operation costs dilemma for several decades because both retrofitting and alternative energy supply in this case would be extremely costly and difficult to undergo.

Therefore we strongly recommend that efficiency issue must be attached serious attention and the current thermal regulations should be strengthened significantly and quickly to avoid irreversible carbon lock-in deadlock in the next two decades. Indeed, financial shortage appears not to be the unsurmountable barriers to upgrading the current efficiency standards based on our modelling results, instead the institutional aspect may be the main obstacle to the no-lose strategy that allows benefits creation and redistribution. Several economic and policy instruments are analysed in the second part to accompany the actions of buildings performance amelioration with removal of institutional barriers. We develop three main models to accompany the learning of high-efficiency construction technology and processing industry : 1). establishment of a carbon financing system via the integration of the Clean Development Mechanism of the Kyoto Protocol into the construction sector ; 2). flexibility of land use regulations on property developing and city zoning ; 3). creation of economic incentives to facilitate third-financing of energy efficiency in buildings, including the involvement of municipal heat companies. In this regard, district heating pricing reform must be carried out accordingly.

Remerciements

Je tiens à remercier vivement mon directeur de thèse, Monsieur le Professeur Pierre-Noël GI-RAUD, pour avoir accepté de diriger ce travail de recherche. Ses conseils et critiques avisés, son expérience et sa rigueur scientifique m'ont guidé tout au long de ce travail.

J'aimerais également remercier Monsieur Jean-Charles HOURCADE, Directeur de Recherche au CNRS, qui m'a fait l'honneur d'exercer la fonction de président du jury.

J'exprime mes remerciements à Monsieur Mindjid MAIZIA qui a bien voulu accepter d'être le rapporteur de ce travail.

Mes remerciements vont également à Monsieur Jérôme ADNOT, Directeur de Recherche au Centre Énergétique et Procédé de l'École des Mines de Paris, pour son encouragement et ses conseils précieux pour mon travail, qui m'a fait aussi l'honneur d'être membre du jury.

Je remercie tout particulièrement Monsieur Michel COLOMBIER pour son encadrement de ce travail doctoral et pour toutes les heures qu'il m'a consacrées. Au cours de ces années, sa grande disponibilité, son enthousiasme sur le sujet et ses précieux conseils m'ont permis de travailler dans les meilleures conditions.

Je souhaiterais exprimer ma gratitude à Madame Carine BARBIER, j'aimerais lui dire à quel point j'ai apprécié son encouragement et son soutien affectif sans faille ainsi que sa grande disponibilité pour la relecture des documents que je lui ai adressés tout au long de cette période.

Mes remerciements s'adressent également à mes collègues de l'Iddri pour leur accueil, support, aide et amitié.

Je remercie l'Ademe qui a financé cette thèse en m'accordant une bourse de recherche.

Enfin je ne saurais oublier mes parents, ce travail n'aurait jamais vu le jour sans leur soutien inconditionnel et encouragement pendant ces années de thèse.

Table of Contents

Chapter 1	Introduction	5
1.1	<i>Motivation</i>	5
1.2	<i>Economics of building energy efficiency</i>	7
1.3	<i>Cross-review of previous scenarios analysis</i>	10
1.4	<i>Drivers of increase in energy demand in buildings</i>	16
1.5	<i>Foundation of BEE</i>	17
1.6	<i>Barriers to building energy efficiency in Chinese context</i>	21
1.7	<i>The fundamental question and structure of thesis</i>	23
1.8	<i>Structure of thesis</i>	24
Chapter 2	Lessons from the long term scenarios analyses	27
2.1	<i>China's construction dynamics and energy demand in building</i>	27
2.2	<i>Mitigating CO₂ emissions from building sector</i>	30
2.3	<i>Review of previous scenario analyses of energy demand in building sector</i>	32
2.4	<i>Lessons from scenario and contribution of the research</i>	39
2.5	<i>Conclusion of the chapter</i>	43
Chapter 3	Methodology	47
3.1	<i>Framework of analysis</i>	47
3.2	<i>Assessment of energy models</i>	50
3.3	<i>Description of LEAP</i>	54
Chapter 4	Economic analysis of BEE in a new residential area	61
4.1	<i>Introduction and summary</i>	61
4.2	<i>The current status of mandatory codes for BEE</i>	63
4.3	<i>Methodology</i>	65
4.4	<i>General buildings typologies and characteristics</i>	66
4.5	<i>Parametres of BEE improvement portfolios</i>	68
4.6	<i>Costs</i>	73
4.7	<i>Economic benefit of implementing BEE</i>	79
4.8	<i>Benefit of CHP deployment</i>	80
4.9	<i>Results and discussions</i>	81
4.10	<i>Chapter conclusions</i>	91
Chapter 5	Modelling the long term trajectories in Tianjin City	97
5.1	<i>Introduction and summary</i>	97
5.2	<i>Economic theory of optimal BEE trajectory</i>	99

5.3	<i>Criterion of social optimum and boundary of costs</i>	100
5.4	<i>Determining variables of buildings energy consumption</i>	102
5.5	<i>Key variables</i>	108
5.6	<i>Description of Scenarios</i>	117
5.7	<i>Energy supply system</i>	139
5.8	<i>Estimation of cost</i>	155
5.9	<i>Result of simulations</i>	165
5.10	<i>Model calibration of reference scenario</i>	171
5.11	<i>Commercial electricity consumption by energy use</i>	180
5.12	<i>Primary energy demand and emissions</i>	183
5.13	<i>SYS2 primary energy supply and emission</i>	190
5.14	<i>Results of alternative scenarios</i>	193
5.15	<i>Alternative scenarios of primary supply</i>	205
5.16	<i>Cost implications of scenarios</i>	219
5.17	<i>Cost scenarios with carbon constraints (Inclusion of CO₂ emission costs)</i>	234
5.18	<i>Decision on optimal BEE choice in SYS2 energy supply system</i>	241
5.19	<i>System 3 energy supply scenario</i>	243
5.20	<i>Conclusion of the chapter</i>	253
Chapter 6	Institutional analysis of energy planning and property market organisation	259
6.1	<i>Introduction</i>	259
6.2	<i>Institutional analysis of property market in Tianjin</i>	261
6.3	<i>Institutional aspect of district heating supply in Tianjin</i>	284
6.4	<i>District pricing and reform perspective</i>	292
6.5	<i>Institutions in the property and energy efficiency</i>	297
6.6	<i>Institutional barriers to full implementation of BEE standards</i>	301
Chapter 7	Policy instruments design	313
7.1	<i>Summary</i>	313
7.2	<i>Policy instruments for BEE</i>	314
7.3	<i>Review of policy and economic instruments for BEE</i>	318
7.4	<i>Proposition of instruments</i>	327
7.5	<i>Policy assessment</i>	352
7.6	<i>Conclusion</i>	354
Chapter 8	Conclusion	359

List of Acronyms and Abbreviations

BEE	Building energy efficiency
HSCWZ	Hot summer and cold winter zone
BNA	Tianjin Binhai New Zone
TEDA	Tianjin Economic Development Area
NCMEDRI	North China Municipal Engineering Design and Research Institute (Headquartered in Tianjin)
SRIBS	Shanghai Research Institute of Building Sciences
NDRC	National Development and Reform Commission
MOC	Ministry of Construction (renamed to Ministry of Housing and urban & rural Development since March, 2008)
MOF	Ministry of Finance
STSB	State technology supervision bureau
NBS	National bureau of statistics
GEF	Global environment facility
WB	The World Bank
HXJD	Huaxiajindian real estate development program
HVAC	heating, ventilation& air conditioning
HDD	Heating Degree Day
CDD	Cooling Degree Day
DH	District Heating
CHP	Combined Heat and Power
CCGT	combined cycle gas turbine
IGCC	Integrated Gasification Combined Cycle
CFBC	Circulating Fluidized Bed combustion
GT	Gas Turbine
ST	Steam turbine
CFB	Coal Fired Boiler
HP	high pressure
LP	low pressure
GHG	green house gas
CO ₂	carbon dioxide
SO ₂	sulphur dioxide
DSM	demand-side management
NPV	Net present value
IRR	Internal Rate of Return
DPP	dynamic payback period
RMB	Chinese monetary unit or Yuan (Approx.1 US\$=8.01 RMB 2005 price)
EPBD	energy performance of building directive
CDM	clean development mechanism
PR	plot ratio

HPF	housing provident fund
EAH	economically affordable housing
LRH	Low-rent house
GUP	general urban planning
RDP	Regulatory detailed planning
COS	Coefficient d'occupation de sol (identical to PR)
HQE	Haute qualité environnementale
HPE	Haute performance énergétique
PA	Per annum

Energy unit conversion

GJ	giga joule (1 Gj=277.8 kWh)
TOE	Ton of oil equivalent (1 toe=11630 kWh)
TCE	Ton of coal equivalent (1 TCE= 7.0 GCal = 29.31 GJ = 8314 kWh)

Chapter 1 Introduction

1.1 Motivation

The scientific community has reached a strong consensus regarding the science of global climate change. Fossil energy combustion is biggest responsible for greenhouse gas emission contributing to global warming. Therefore, increasing the energy performance now is of crucial importance in order to contain the soaring demand and avoid supply capacity disruption as well as mitigating global warming. Barbier (2003) pointed out that along with physical and human capital, environmental resource should be viewed as important economic assets and which is called “natural capital”. Arrow *et al.* (2005) also affirmed that economic activities are sustainable only if the life-support ecosystems on which they depend are resilient. But the changing climate regime will jeopardize the environmental carrying capacity since it will change the whole eco-system and threatens agricultural activity and thus food supply security in the world, in particular, the developing and poor countries.

Buildings account for nearly one-third of global CO₂ emission (Levine *et al.*, 2007) and can play a major role in mitigating climate change in the short- to medium-term, since substantial reductions in CO₂ emissions from their energy use can be achieved over the coming years (Ürge-Vorsatz *et al.*, 2007). Although a variety of technical solutions exist, many buildings still use much energy than they should do. Reducing energy related GHG emissions in building sector become a priority of climate policy making across the international community today.

Heating and hot water consumption represent two-thirds of energy demand in buildings in China. Most of the power and heat plants use fossil fuel, in particular the coal which has a tremendous environmental implication in terms of CO₂ emission, improving energy efficiency in buildings will be therefore a substantial contribution to the mitigation of global warming. Significant reduction of building energy consumption achieved after the implementation of 1995 Energy Efficiency Standard for New Residential Buildings in 1995. However, the energy consumption for heating in an efficient house in China (20W/m²)¹ is still more than twice as much as that of most efficient houses in Sweden, Denmark, The Netherlands and Finland (11W/m²). The thermal performance and heating system efficiency need to be improved dramatically in order to contain the soaring energy demand tendency and mitigate the GHG emissions.

China’s policy makers have to address simultaneously the issues relating to security of energy supply, environmental concerns and people’s well-being in the course of economic growth in China over the coming years. Energy efficiency will be the backbone of China’s energy policy with regard to multiple challenges; economists are concerned about the increase in social-welfare through energy efficiency

¹ This figure indicates the average building performance in the building code in most of northern part of China, the final consumption for heating is about 160 kWh/m²a; the heating consumption in the severe cold region (e.g. Harbin) is much higher.

improvement. The question about the social cost and benefit is fundamental in the public policies appraisals. In this regard, finding out the answer to the question about how to make right choice now in order to minimise the social cost tomorrow arises is of crucial importance. Therefore, the fundamental question arises about how China should shape the development prospects of energy supply and demand to ensure the GHG emission stabilisation over the next decades? Because the decision made today regarding the quality of buildings efficiency likely to have sequential impact on technological transition of energy supply and capacity building in dealing with the long term greenhouse gas emission mitigation to combat the global warming over the next decades.

However, from economic analysis perspective, investment decision on improving efficiency in the long life large-scale infrastructure such as buildings raises a question about the rational choice of investment strategies relating to technological performance. Economists argue that market should be able to select out the best competitive technologies through the price and regulatory instruments, while the technical experts consider that it is already possible to deploy the most advanced efficiency technologies at scale. Judging between these arguments requires a systematic approach to combining the frameworks of both technical and economic analyses. The underlying question on the trade-off between the long and short-term investment should be addressed. Based on analysis of previous studies on China's energy demand prospects and environmental implications, we found that the research findings in existing literature do not allow us to identify an optimal trajectory of investment decision on buildings energy efficiency improvement and different strategies of development of energy supply infrastructure in China. The motivation of this research is to bridge the gap between the macroeconomic analyses and sectoral strategy in light of determining an optimal trajectory to building energy efficiency development such that the social costs can be minimised to create future benefits that can be used to finance investment in new technology innovation and deployment. The research attempts to construct a new framework to identify the optimal trajectory of Chinese building efficiency regulation over the next 25 years based on a case study in a northern city, along with the analysis of institutional organisations of property and energy market. The primary scope in this research is to assess the impact and consequences of investment decision taken today on the city's financing capacity in adopting new technology of sustainable energy supply and decarbonisation in the future based on a quantitative analysis approach. By modelling different storylines of building energy performance uptake scenarios, an interactive dynamic link can be set up to bridge the gap between now and tomorrow's decision priority on investment in demand and supply side technologies. The first part of research attempts to identify appropriate strategies of buildings energy efficiency improvement within a long-term techno-economic analysis framework based on two different scale: today's strategy in buildings construction in a new residential area; 2). a dynamic building stock in a whole city throughout the period 2005-2030. A sequence of decision on investment in quality improvement in both supply side and demand side infrastructure will be assessed in this case. Consequently, the findings of modelling will be taken as basis of policy instruments design in part two in which we try to identify

effective economic and policy mechanisms to facilitate efficiency upgrading implementation to achieve the optimal trajectory in the context of fast- growing urban development in China.

1.2 Economics of building energy efficiency

The economic dimension is far from negligible in analysing the policy instrument for building energy efficiency. The choice of energy performance made for large-scale and long-life infrastructure like buildings implies a strategy of trading off the long and short-run investment. Investing in building efficiency to reduce the demand does not pretend to compete for financing resources with supply-side technological innovation (CCS, clean coal technology for example). Investing in efficiency enhancement in energy-consuming infrastructure today anticipates the increasing demand for energy services and facilitates transition and scale-up of these new low-carbon technologies tomorrow. In other words, the question arises for policy makers about whether we should invest immediately in the high-end new technology while ignoring potential soaring demand if the infrastructure constructed today lack efficiency and it will become very difficult and costly for the society to replace and retrofit before retiring or alternatively, we accept a reasonable increase in up-front construction cost to ameliorate the efficiency performance of buildings to reducing significantly lifecycle costs associated with supply capacity addition , energy resources consumption and environmental impacts over several decades.

Building energy efficiency practices are supported by a number of persuasive arguments. As summarized in *“the Best Practices Guide: Economic and Financial Evaluation of Energy Efficiency Projects and Programs”*, improving energy efficiency is based on two-tiled analysis: energy supply and efficiency (The Energy Group Institute of International Education Washington, DC; Econergy International Corporation Boulder, Colorado).

1.2.1 Energy Supply

Investing in supply is a capital intensive undertaking, usually paid primarily in foreign exchange adding currency risk to the investment equation. Already a large part of public investment budgets, additional investments in supply can have difficult financial consequences and damaging environmental impacts. Even if the money is available, it is difficult to expand supply capacity quickly. Increasing energy supply involves building generating facilities funded with equity and long term non-recourse debt. The variety of funding sources includes equity from developers, investment funds, venture capitalists, utilities; and debt from capital markets, development banks, or commercial banks. Revenue is realised from the electricity generated and sold, typically through power purchase agreements with utilities. The significant direct project costs include designing, building, operating, and retiring a generation facility, while the indirect project expenses include social and environmental costs. In building additional supply capacity there are formidable performance risks, fuel cost fluctuation risks, and credit risks.

1.2.2 Energy efficiency

Energy efficiency, on the other hand, reduces the need to build additional capacity by reducing energy demand. It decreases the environmental impacts of increased generation through avoided demand. Energy efficiency decreases life cycle costs to consumers while also reducing system-wide capital costs. Efficiency can be achieved through improvements to a variety of systems including HVAC, motors, drives, lighting, and controls.

Projects can be funded via grants, low-interest loans, market-rate loans, leases, or performance contracts from funding sources including Energy Services Companies (ESCOs), utilities, capital markets, equipment vendors, or development banks. Energy cost savings result in cash flows for energy efficiency projects. Direct project costs include design, installation, and maintenance of the energy efficiency measures. Energy efficiency projects tend to be on a much smaller scale than generation projects, occurring at numerous sites with highly engineered technology. However, BEE projects entails risks perceived by the actor, such as the possibility that actual measured savings may not meet projections, credit risk, currency risk, and the potential for facility operating changes.

1.2.3 BEE and Security of Supply

China is on a crossroad of its economic development and the build-up of a well-being society. An average growth rate of 9.7% per annum has been sustained over the last 20 years. With a fifth of global population, China contributed to 13.8% of global economy growth over the period 2002-2005 (China Daily 2007). The fast growing economy was accompanied by spectacular increase in energy demand and amounting concerns about the environment impact associated with economic expansion. China becomes a net oil importer since the 1993. . As shown in Figure 1-1, China has experienced a steady growth of oil demand in the past 20 years and is more and more relying on imported oil which increased strongly by 75 per cent between 2002 and 2004 (Zaouali, 2007). Given this extraordinary need for oil, the domestic offer in oil resources is no longer able to keep up with the Chinese demand. In 2006, China contributed to 80 per cent of world oil consumption growth and oil import dependence reached 60 per cent and is likely to surpass 80 per cent by 2030 (IEA, 2007).

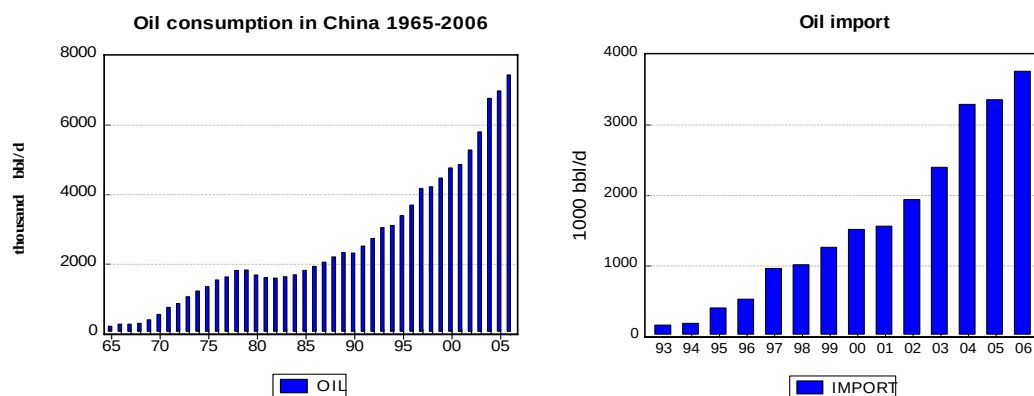


Figure 1-1 China's oil consumption 1965-2006 and net oil import since 1993 (BP, 2007)

A snapshot of energy supply security in China is summarised in Box 1-1.

Box 1-1. Security of energy supply

Despite the impressive achievements in the energy sector, China's policy makers face growing concerns about the country's energy future. From the early 1980s to the mid 1990s, China managed to achieve high economic growth with near self-sufficiency in energy supply. However, during the second half of the 1990s, China gradually emerged as a net importer of energy, and by 2006, its dependence on oil imports had soared to about 60 per cent of consumption as much as 80 per cent of oil consumed in China will be imported in 2030 (IEA,2007).

Energy sources in China are unevenly distributed, most of coal and hydropower sources are located in the west of the country, and the most important natural gas field is also situated in the far West in the province of Xinjiang. Whereas most of demand for energy consumption come from the Eastern part, in particular coastal area, and Central provinces of China. Coal transport represents about 50 per cent of domestic railway transport in China. Although China is generously endowed with renewable like hydropower, wind and biomass; only 27 per cent of total potential of hydropower has been exploited in China, and biomass is mainly used in China's rural area (mainly the firewood and crop stalks), biomass has a huge a potential of energy in China, it is estimated that the total exploitable energy potential of crop stalks in China amounts to as much as 519 Mtoe per annum (Jiang,2007).

Oil and gas Reserves will be insufficient to meet the projected growth of demand if current trends continue, the prospect of a continuing rise in oil imports and high price, geopolitics complex have led the Chinese government to seek to curb the growth in demand drastically. Thus Energy savings through the improvement of energy efficiency in all the sectors becomes the top priority of China's energy policy. Energy targets have been set for all provinces; the Chinese government has recently increased the tax on energy-intensive products(IEA,2007).

Energy efficiency has attained ever greater prominence over the past years as the main approach to addressing both energy security and environmental concerns (IEA, 2007). The National Development and Reform Commission (NDRC), China's energy policy formulation authority, set out specific energy efficiency improvement targets for industry, transport and building sectors in the long and medium-term energy conservation plan.

Managing the increasing energy demand from demand side can also strengthen the security of supply of coal indirectly. Coal supply accounts for nearly 50 per cent of China railway transport as most of major consumption sites are far away from the mining source. Coal production and transport related accidents in China accounts for nearly 80 per cent of the world and coal mining is the most deadly job in China (China Daily, 2004-11-13).

1.3 Cross-review of previous scenarios analysis

China has become a key player on the global energy market with a share of 15.6% of the world's total energy consumption (BP, 2007). China's energy demand has increased spectacularly to keep in pace with rapid expansion of the industrial and commercial sectors, as well as that of households, which are experiencing a new standard of living. China is now the second biggest energy consumer behind the USA and is expected to top the latter by 2010 (IEA, 2007).

The primary energy demand in China increased from 416 Mtoe in 1980 to nearly 1700 Mtoe in 2006, with an average growth rate of 5.55% per annum over the period. Historical primary energy demands in China and energy supply structure in the world are plotted in Fig.1-2. Nevertheless, as pointed out by (Kahrl and Roland-Host, 2006), this average growth rate is somewhat misleading, since primary energy consumption grew by an annual average of 3.2 % by 2000; but 10.8 % between 2000 and 2004². Energy consumption increased sharply over the period 2002-2005 and dominated GDP's growth, the energy elasticity with respect to GDP exceeded 1, and annual energy demand growth rate is 15.9% in 2004! Coal is overwhelmingly predominant energy source in China accounting for nearly 70% of total energy consumption. About 1080 mtoe of coal was consumed in 2005, equivalent to 37% of the global coal consumption in the world. By comparison, the world average level was only 23% in 2002 (IEA, 2004) and 28% in 2005 (BP, 2006).

² Here we use the NBS' official energy statistics in China, whereas the data of BP 2006 or IEA 2006 will give quite different output resulting from divergence of energy data collection in their statistics. For instance, BP's statistics reveals an average growth of 5.1% per year over the period 1990-1999 and 10.2% from 2000-200-. Similarly, IEA's statistics include non commercial energy consumption (biomass in rural area) which is not taken into account in NBS's compilation.

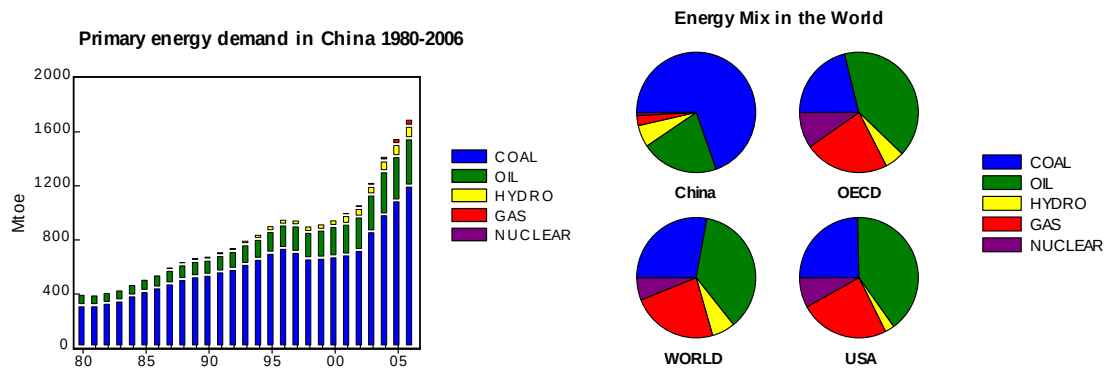


Figure 1-2: Primary energy demand in China and primary energy mix in the world (BP 2007, biomass excluded)

1.3.1 Approach in previous studies

Energy demand scenario analysis has become increasingly important in recent literature on economic modelling of climate change due to the fact that energy sector is the foremost contributor to greenhouse gases emission. A large number of recent researches forecasted the medium and long run energy consumption in China at different time horizons (2010, 2020 or 2030) and assessed relevant economic and environmental consequences. Different methodologies have been employed and the relevant results vary significantly.

NDRC (2004) and ERI (2003) report energy projection to 2020 with a bottom-up approach of both on demand and supply sides. On the other hand, IEA (2004, 2006, 2007), Jiang and Hu (2006), EIA (2006) provide forecast to 2030 with general equilibrium model or specific emission scenario model. They integrated in their models the interaction dynamics between energy demand and China and the world's economic prospect.

Moreover, some technology-oriented models have shown the way of modelling the energy system development path with the given environmental constraints in the future. From energy system optimisation perspective, one of prominent paper is done by Larson *et al.*, (2003) who calibrated the MARKAL-China model which represents China's energy system comprising all sectors of the economy and including both energy conversion and end-use technologies. Their scenarios portrayed a general picture of energy-supply and demand in China from 1995 to 2050. The most striking point in the conclusion of their analysis is that even when significant limitations on carbon emissions were stipulated, an advanced energy technology strategy on the basis of the author's technology-cost assumptions would not incur a higher cumulative (1995–2050) total discounted energy system cost than the business-as-usual strategy. This result has a strong energy and environmental policy implications in China. From econometric analysis prospective, models work quite well for near term energy demand projection based on the historical time series data. However these models are not very consistent with time-dependant fast-evolving factors due

to failure to capture the unpredictable political or economic structure change and technological breakthrough in the longer term.

1.3.2 Results of scenarios

1.3.2.1 Technology models

NDRC (2004) and ERI (2003) have explored China's energy future on the basis of bottom-up approach to evaluating the energy technological change and environmental implications of specific policy implementation. These results represent the official perspective of the Chinese government regarding the long run energy policy. The main purpose of these studies was to help the Chinese policy-makers clarify the energy and environment implications under different socioeconomic development patterns and geopolitical context in order to prepare relevant strategies.

1.3.2.2 Integrated model

Jiang and Hu (2006) elaborated different energy demand and production scenarios in China over the period of 2000-2030 by using IPAC (integrated Policy Assessment for China) model which integrates selection of available efficiency technology, energy and environment policies. The model can evaluate the impacts of the energy use on environment both from a national and inter-regional scope. Three scenarios have been formulated in their projections. Primary energy demand in China would amount to 2100 mtoe in 2020 and 2700 mtoe in 2030 in the baseline scenario, with an annual growth rate of 3.6%. Coal will still be the dominant energy source in China in 2030, sharing about 58% of total energy demand. The high energy demand scenario projected that primary energy demand would be 2900 mtoe, which implies a strong increase of energy demand in China, resulted in high concentration of energy intensive activities in China and better integration in global economy without difficulty of energy imports. On the other hand, the policy scenario favours energy conservation policies and imposes environmental constraints. Consequently, primary energy demand will be reduced by 12% in 2020 and 10% in 2030 by comparison with baseline scenario. It is worthy noting that the authors asserted in their conclusions that the policies should be formulated quite early to lowering the energy demand since the lifespan of technologies is very long and replacement needs a huge investment.

The International Energy Agency (IEA) publishes the global energy projection in World Energy Outlook (WEO) biannually. WEO (2006) included two scenarios in China, 1. Reference scenario: China's current economic development and energy consumption and supply technology tendency will continue, energy efficiency policies are not fully implemented in the country. 2. Alternative policy scenario under which it is assumed that more energy efficiency programs and renewable energies development would be realized which is obviously more sustainable. In this case, China will develop more rapidly the alternative energies: wind, geothermal, solar and biofuels etc., and will also improve energy efficiency in all end-use sectors. It

is projected that China's energy demand would increase to 2509 mtoe in 2015 and 3395 mtoe in 2030 in reference scenario, which accounts for respectively 17.8% and 20% of the total demand of the world. Alternatively, energy demand could be reduced by 5% and 15% in 2015 and 2030 respectively in policy scenario.

In WEO(2007), three scenarios of energy demand growth in China up to 2030 are formulated. Primary energy demand will increase from 1515 Mtoe in 2005 to 2626 Mtoe in 2015 and 3592 Mtoe in 2030 under the baseline scenario, this scenario represents a vision how china's energy demand will grow if there were no change in current trend over the projection period. In contrast, in the policy scenario, energy demand could be reduced by 14.5% in 2030 with introduction of new efficiency policies besides the existing ones. Energy growth will be more sustainable and energy supply related investment can be reduced substantially. More efficient use of energy has huge environmental benefits compared to reference scenario. The CO₂ emission in China can be stabilized soon after 2020. Besides the reference and policy scenarios, a high growth scenario in China is elaborated, under which China would have a higher economic growth rate resulting in faster increase in energy demand. Total primary energy consumption and energy related CO₂ emissions would be 23% higher than in reference scenario. There would be a huge increase in investment of energy supply infrastructure, accumulated increase amounts to 5.1 trillion dollars in 2006 price compared to reference case (IEA, 2007).

The US Energy Information Administration (EIA) constructed three scenarios in *International Energy outlook 2006* on the basis of different assumption on world economic development perspective in the horizon of 2030. The degree of increase energy demand is highly dependant on economic growth scenario in China in their model. The energy demand and environmental implications vary significantly among these scenarios. For China, total energy demand would range from 2390 to 3018 mtoe in 2020 , and from 2890 to 4278 mtoe in 2030. Likewise, CO₂ emissions also depend largely upon the economic development perspective, the forecast projected the emissions would vary between 7164 and 9287 Mt in 2020 , and between 8652 and 13312 Mt in 2030 respectively. With the high economic growth pattern, energy demand will be 12.4% and 22% higher than the reference case in 2020 and 2030 respectively and energy related CO₂ emission would be 13.7% and 24.2% higher respectively.

1.3.2.3 Econometric model projection

Crompton and Wu (2005) provided a forecast of energy demand in China in 2010 by using BVAR approach. As mentioned earlier, energy demand in China increased dramatically from 2002. The forecast projected that natural gas will grow the most rapidly between all the fuels during 2004-2010 with an average growth rate of 6.6 per cent per year, compared to 3.3 per cent for coal. Demand for coal will reach 1421 million ton of coal equivalent (Mtce) accounting for 65.4 per cent in total primary energy demand in 2010. Indeed, demand for coal increased sharply in China since 2004, jumping 9.6 per cent to reach 1660 Mtce in 2005 and 10.6 per cent in 2006 (NBS Statistics Communiqué 2005, 2006). The forecast of Crompton and Wu (2005) on China's primary energy demand is relatively conservative, in fact, the energy demand in 2010 projected in their forecast were already exceeded in 2005. Also, the forecast aggregated all the energy

consumption sectors, which does not allow us to analyse in detail the energy demand prospect by sector with different technology choices, i.e. the energy use in buildings.

Since coal will remain the dominating energy source in the coming decades, evolution of coal demand and supply capacity will have significant implications in terms of economic growth and environmental impact. Lin *et al.*(2007) employed a co-integration approach to projecting the coal consumption in China by 2015 by testing the long term coal consumption elasticity with respect to GDP's growth and concluded that China would hardly be able to meet the growing coal demand under high GDP growth scenario. The empirical study showed that GDP growth Granger-causes the rise in coal demand based on the historical data, but not vice versa, i.e. the rise in demand for coal is not the Granger cause of GDP growth. Tables 1-1 through 1-3 summarise and compare the modelling results regarding primary energy demand and CO₂ emission consequences in the aforementioned studies.

Table 1-1.Comparison of primary energy demand projection.

	2005	2010	2015	2020	2030
	million toe	million toe	million toe	million toe	million toe
ERI (2003)					
Ordinary effort				2149	
Promoting sustainability				1910	
Green growth				1600	
NDRC(2004)					
A		1158		1774	
B		1129		1609	
C		1017		1361	
EIA (2006)					
Reference		1940	2313	2686	3505
High economic growth		2013	2495	3018	4278
Low economic growth		1869	2147	2391	2890
Jiang&Hu(2006)					
Baseline				2100	2700
high demand				2300	2900
policy				1855	2420
IEA(2004)					
Reference		1662		2072	2539
Alternative Policy		N/A		1877	2205
IEA(2006)					
Reference			2509		3395
Alternative Policy			2385		3006

Table -1-2. Comparison of CO₂ emission projections (Million metric ton)

	2010	2015	2020	2030
ERI (2003)				
Ordinary effort				
Promoting sustainability				
Green growth				
NDRC(2004)				
A	1158		1774	
B	1129		1609	
C	1017		1361	
EIA (2006)				
Reference	5857	7000	8159	10716
High economic growth	6110	7608	9287	13312
Low economic growth	5614	6442	7164	8652
Jiang and Hu(2006)				
Baseline				
High demand				
Policy				
IEA(2004)				
Reference	4386		5708	7144
Alternative Policy			5053	5856
IEA(2006)				
Reference		7744		10425
Alternative Policy		7298		8801

Source: NDRC(2004); ERI (2003); Jiang and Hu (2006); IEA(2006); IEO 2006.

Table 1-3 EIA's projection on China's economy and GHG emission

	Population	Reference case			Low growth scenario			High growth scenario		
		GDP (trillion US\$)	Energy (quadrillion Btu)	GHG billion tons of CO ₂	GDP (trillion US\$)	Energy (quadrillion Btu)	GHG billion tons of CO ₂	GDP (trillion US\$)	Energy (quadrillion Btu)	GHG billion tons of CO ₂
1990	1155	1.8	27.0	2.24	—	—	—	—	—	—
2003	1299	6.0	45.5	3.54	—	—	—	—	—	—
2010	1355	10.1	77.0	5.86	9.7	74.2	5.61	10.6	79.9	6.110
2015	1393	13.5	91.8	7.00	12.3	85.2	6.44	14.9	99.0	7.61
2020	1424	17.6	106.6	8.16	15.3	94.9	7.16	20.3	119.8	9.29
2025	1441	22.6	121.7	9.35	18.7	104.2	7.86	27.3	142.5	11.13
2030	1446	28.8	139.1	10.72	22.7	114.7	8.65	36.5	169.8	13.31
03/30 (%)	0.4	6.0	4.2	4.2	5.1	3.5	3.4	6.9	5.0	5.0

Source: Lu *et al.*, 2006. GDP=2000 Price

The results of IEA and EIA forecasts are much higher than those undertaken by the Chinese researchers. Two main reasons seem to be able to explain this considerable gap. First, year 2004 was taken as the base year of the IEA (2006)'s projection, while the other authors took 2000 as the reference year. However, energy consumption increased dramatically from 966 mtoe in 2000 to 1412 mtoe in 2004, with an increase of almost 50% within only 5 years. Thus the pursuing of the tendency 2000-2004 may lead to a much higher demand scenario. Second, IEA's energy balance sheets comprise the biomass energy primarily used in China's rural areas, whereas these energies are traditionally considered as "free" sources and not considered in the energy balance compilation in Chinese official energy statistics in which only commodity energies are taken into account. EIA's projection assumes that energy elasticity of GDP in China would remain unchanged in the following decades, thus the high growth of GDP leads necessarily to fast growing energy demand.

From local energy demand analysis perspective, a cost-benefit evaluation of environmental policies was conducted in Gielen and Chen(2001) by using the MARKAL model in order to evaluate the energy policy in Shanghai with a departure from 1995 up to 2020. The author found the *no-regret* option is limited in terms of emission reduction since Shanghai has already improved significantly its energy efficiency, in particular in industry sector. More interestingly, an additional carbon emission tax of 100 Yuan/tCO₂ (12.5 euro/t)³ allows for 11% reduction of CO₂. Five sectors have been analyzed in their model: power, industry, transport, residential. Since MARKAL is an optimisation model, consequently the modellers try to find out the optimized energy supply technology portfolio (least present cost), but the result of model doesn't tell much about the sectoral policy of energy efficiency improvement since the model calculates the whole energy demand and supply by comparing the substitution elasticity of different technologies. Wang *et al.*(2004) explored the energy and environmental policy implication of low-carbon emission economy development by a sectoral disaggregating approach in the Model LEAP. Five alternative scenarios were formulated; Total energy demand in Shanghai can be reduced by 17% by enhancing energy efficiency and reducing energy intensity in end use without introducing any specific fuel switch policy in 2020, accounting for 45% of Shanghai's total energy demand in 2000. Consequently, energy related CO₂ emission could be reduced by 20%, or 65 Mt per year in 2020 in comparison with baseline emission scenario.

1.4 Drivers of increase in energy demand in buildings

China is undergoing rapid socioeconomic transformation. In a strong demographic, economic and urbanisation growth perspective, nearly 60% of its population is expected to be living in urban areas in 2030 while the current level is around 45% (NBS,2006b). The Chinese government plan is committed to quadrupling the country's GDP by 2020 relative to 2000 and to building an all-round well-off society

³ 2001 price.

(*xiaokang*). China's GDP is expected to quadruple in 2020 relative to 2000 and per capita income will increase to 3000 US\$ (\$10000 in PPP terms). Average per capita living area of urban household average living area will reach 30 m² (16th National Party Congress).

Urban residential building living space increased by 50% between 2000 and 2005, from 9.3 billion square metres to 14 billion. A rapid double-increase in urban population and in per capita living area explains this phenomenon. A nationwide programme of housing privatisation initiated in the late 1990 and the introduction of domestic banking mortgage in property market both have contributed to the boom of construction. In 2005, more than 1300 million square metre of housing were constructed, greater than overall housing construction in the rest of the world.

On the other hand, international experiences show that improved living standard and urban growth are usually accompanied by demand for more energy services in residential and commercial sectors. Most of energy uses in these sectors occur in buildings. As more and more rural households will migrate towards newly urbanized areas and substitute the modern energy to the traditional biomass energy. Energy demand in buildings would increase significantly at an unprecedented growth rate over the next decades associated with the urban transformation dynamics and aspiration for better residential quality. Hence, building energy efficiency should be considered now to anticipate the huge growth potential and avoid irreversible carbon lock-in tomorrow.

1.5 Foundation of BEE ⁴

1.5.1 Rationale

A typical residential house can save more than 40% life-cycle energy consumption compared to a non-efficient design, life cycle energy consumption can be reduced by more than 60% if buildings are constructed in compliance with the equivalent thermal performance standards in the Swedish code which is the most stringent in the world today ⁵. A house constructed by employing the Passivhaus technique can even save further more energy. Benefits of implementing building efficiency can be analysed from different actors' perspectives.

- From consumer's prospective, building Efficiency contributes to large drop of energy expenditure for the households, consequently, this allows lowering significantly the financial burden for the low-income families through improved building performance and provision of better quality of energy services. Efficiency can also improve indoor quality of air to reduce the risk of environmental hazards and infectious disease occurrence, thus an effective contribution to lowering significantly the burden of social security through improved public health.

⁴ In this research, except additional mention, the building energy efficiency measures in this research refers to any measure allowing reducing heating and cooling demand in the buildings.

⁵ The details of calculation are reported in the Appendix

- From the energy producer's perspective, more efficient dwellings and commercial buildings will reduce capital intensive investment in constructing new capacities to meet the growing demand, and also allows for reducing the operation cost associated with load management, especially for the electricity suppliers and distributors, high efficient buildings means reduced marginal costs associated with peak load period. This also holds for the combined heat power plants. BEE can also reduce risk of hazardous event to enhance grid security and risk management.
- From the local government and city planner's perspective, improved building energy efficiency can lower greatly the explicit or implicit energy subsidies, consequently reducing the financial burdens for the government and make energy market more competitive and healthy. Improved local environment resulting from less combustion of polluting fossil energy favours the inward investment and therefore bring in more advanced technology and create more job opportunities, a great benefit for the local economy and fiscal revenue of public authority, the financial gain will allow the local government to supply better quality public goods to improve social welfare. Savings can then be redistributed to development of clean high-speed mass transit system, and education or retiring.

1.5.2 Economics of implementing energy efficiency in buildings

From purely economists perspective, some economists (Brookes, 1991; Saunders, 1992; Inhaber and Saunders, 1994) argued that improved energy efficiency of economics may lead energy use to grow more rapidly than it would in a world with fixed technology⁶. Howarth (1997) refuted this argument with a economic production model, he concludes that energy efficiency improvements will not give rise to increased energy consumption unless 1) energy costs dominate the total cost of energy services and 2) expenditures on energy services constitute a large share of economic activity. Since both of two hypotheses are not plausible in empirical study, improvement in energy efficiency will yield the long-run energy demand reduction compared the scenario with fixed technology. And Schipper and Meyers (1992) emphasised the importance of grounding energy demand analysis on specific technologies and end-use activities.

1.5.3 Barriers to implementation

Although improvements in energy efficiency contributes to reducing energy demand and associated GHG emission, the energy efficiency gap still remains in all economic sectors due to market and non-market barriers: principal-agent problem, information asymmetry, high transaction costs (difficult in acquiring unfolding relevant information about information and often time-consuming), and bounded rationality⁷

⁶ Their main arguments are that efficiency improvement may be viewed as a form of technological change that reduces the cost of energy services and stimulates economic activity, thus energy demand in the long-run, may increase more rapidly as the productivity improves.

⁷ In real world, perfectly rational decisions are often not feasible in practice due to the finite computational resources available for economic agents who are often partly rational in decision-making. Bounded rational agents experience limits in formulating and

(DeCanio,1997; Howarth, 1997). Moreover, the uncertainty on benefits of energy efficiency and the fact that energy consumption still accounts for relatively small part of economic spending also give rise to reduced possibility of realising optimal energy efficiency .

The Chinese national building codes was introduced in 1995 and came into force in 1996⁸, a large number of houses still don't comply with the mandatory building energy efficiency requirements, only a small part of buildings in China were in compliance with the national or local building codes (Zhou, 2007). Enforcement and implementation of BEE regulations encounter difficulty in the new construction of residential and commercial buildings due to weak institutional capacity of enforcement and monitoring and also the lack of appropriate market incentive. More specifically, most property developers and constructors consider that BEE implementation of BEE will entail substantial increase in construction cost and therefore narrow their margin. The barriers to full implementation of energy efficiency options in china's building sector can be explained by economic theories:

- Option value

The economic dynamic in the property market often generates huge profits for the investor, but the incentive which urges the actors of the sector to take into account the quality of buildings energy performance, though the choice of large-scale infrastructure like housing development will shape a city's energy demand profile over decades. Property developer and investor make arbitrage between energy efficiency and other components of constructions to maximise his profits. In many cases of adoption of energy efficiency in buildings, one can derive "option value" form waiting for more information before making potential risky and irreversible investment. For example, application of the state-of-the art BEE techniques appears to face systematic resistance or reticence by a given housing developer or constructor until it will be proved largely practicable in other similar projects to a certain degree of "mature". Moreover, this option value is not captured in the social discount rate in economic analysis (Rivers and Jaccard, 2005). Thus promoting high efficiency technology in early stage (niche market) will face daunting change if no complementary measure is introduced accordingly. Inertia of actors relating the option value is a major barrier to deployment of BEE at scale.

- Information asymmetry

When a housing developer sell a house to a customer, the latter cannot know whether this building is efficient or not and how much energy he (she) can save compared to a conventional house in the market. The information about the construction regarding the energy performance is not shared between the constructor and consumers evenly, many constructors have incentive to cheat to not comply with the

solving complex problems and in processing (receiving, storing, retrieving, transmitting) information" (Williamson, p. 553, citing Simon). Additionally, the energy efficiency uptake is often undermined by artificial low energy price and explicit or implicit subsidy.

⁸ For more details about the Chinese building codes, see chapter 4.

building codes. So therefore, the information asymmetry problem could drive all the efficient buildings out of the market and results in the market for lemon eventually (Akerlof,1970).

- Principle agent problem

The principal-agent problem is considered to be a major barrier to the diffusion of efficient technologies (Murtishaw and Sathaye, 2006; IEA, 2007). For new residential buildings in the property markets, builders are not the ones who end up paying the utility bills, so have little incentive to add to the construction costs by incorporating energy efficiency features (design, insulation, passive heating or cooling, natural ventilation etc) and renewable energy integration (e.g. solar, geothermal). Landlord and builders have scant incentive to invest in energy efficiency on the tenants or buyers' behalf.

In efficiency terms, a market failure arises when a technology which is both cost-effective and saves energy is not implemented. Jaffe and Stavins (1994) describe the common case of the landlord-tenant problem as a principal-agent problem. "If the potential adopter is not the party that pays the energy bill, then good information in the hands of the potential adopter may not be sufficient for optimal diffusion; adoption will only occur if the adopter can recover the investment from the party that enjoys the energy savings. Thus, if it is difficult for the possessor of information to convey it credibly to the party that benefits from reduced energy use, a principal/agent problem arises."

- Comply or non-comply game

In the property market, housing developers and the local government play a game to maximize each of their profit, in economic terms the utility of investment in BEE and supervision of thermal quality of housing. In fact, the degree of effort that a developer makes to comply with the building code depends on the probability of being supervised at random and the compulsory fine or seriousness of penalty in case of non compliance, settled by the local government. The constructor will make a best decision on the degree (less than 100%) of compliance rate such that his utility can be maximized. Likewise, from the local authority's perspective, total control of every new constructed house's energy performance means an excessive cost and certainly not an optimal choice, it defines rather a fine or penalty incentive to maximise the compliance rate otherwise the cost of attaining the same objective would be extremely high. It can be demonstrated that the solution of this game is a Nash equilibrium, thus not the first best and does not necessarily mean the best global payoff for all the players involved in this game. Since when regulators (government) and property developer /constructor cooperate effectively (builder will comply and regulator will lower the tax and reduce the control frequency), the social benefits can be maximised while negative impacts (energy insecurity and carbon emission) will be minimised.

Global experiences on building energy efficiency have been compared in a recent study conducted by UNEP, the authors concluded that the major impediments to increase energy efficiency in the building sector are institutional barriers and market failures rather than technical problems (UNEP 2007, p 44).

Likewise, although a number of building efficiency measures are already available in China, many buildings are still designed and constructed in inefficient way which will remain as a large stock of energy-intensive and high-carbon infrastructure throughout the five to eight decades, a dangerous signal to security of energy supply and climate security. It is commonplace that the main difficulties in energy efficiency implementation is not related to lack of technical knowledge but mainly attributable to the institutional barriers and market failure.

An integrated approach should be adopted by balancing the interests between all the actors concerned by property and energy market, ranging from local authority to end-users. Thorough implementation of building energy efficiency policies requires creating a synergy between different actors and using a holistic approach by intervening from three dimensions: 1. technological; 2. economic, and 3. institutional. It is unrealistic to expect the constructors to enhance efficiency performance spontaneously without any monetary or in-kind incentives. Enforcement and implementation of China's energy efficiency standards require an appropriately designed institutional framework. The international experiences show that an integrated policy should be formulated by combining the energy infrastructure quality, building energy efficiency and public policies; this will generate significantly benefits given the fast-growing urbanisation process and the number of buildings that will be constructed in the next 20 years in Chinese cities.

1.6 Barriers to building energy efficiency in Chinese context

The Chinese central government devised a national building energy conservation scheme in NDRC (2004b). Comprehensive multi-sectoral energy conservation plan which would allow the building sector to save 50 million tons of standard coal and 290 million kilowatt-hours over the period 2006-2010 if the specified measures are combined appropriately. However, realising the saving potentials will confront strong inertia of building actors. However, the actual enforcement and implementation rate is relatively low in many medium and small cities due to inadequate technical and institutional capacities.

1.6.1 Technical barriers

The development of more efficient building designs suitable for Chinese conditions, and more energy-efficient windows, building materials, envelope insulation and ventilation options create large opportunities to save energy in the near future and over a long term since buildings can last over 40 years. Heating in the northern urban areas in China is the most important energy consumer in building sector. Each year, more than 130 million tce (ton of coal equivalent) are burned for heating which represents about 52% of total energy used in China's urban buildings (Jiang, 2005). Despite significant reduction of building energy consumption achieved after the implementation of 1995 Energy Efficiency Standard for New Residential Buildings in 1995, the average energy consumption for heating in China's northern

provinces is about 90~100 kWh/m²a⁹ which is still almost twice of that in Sweden, Denmark, The Netherlands and Finland (40~50 kWh/m²a). Furthermore, the low-efficient heating system leads to enormous energy loss and causes a serious problem of environmental pollution during winter time. Figure 2 illustrates the regulatory thermal performance requirement in Chinese building codes in comparison with developed countries, it should be pointed out that the smaller the U-value is, the more efficient are the building components.

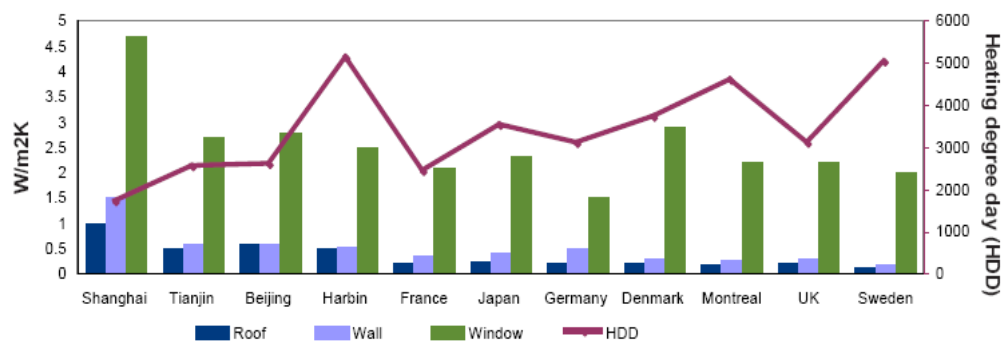


Figure 1-3: Cross-national comparison of efficiency compliance standards of building envelope U-value

Source: National building code 1996; 2001; Tianjin building code 2004; Beijing Building code 2004; RT 2005 of France; UK building regulation 2000 and 2006 update.

Furthermore, development of efficient alternative materials is of extremely importance contributing to energy saving and energy related environmental hazard reduction. Clay brick has been the major building materials in China, more than 700 billion brick are produced every year which necessitate 1.4 billion metre cube of soil, more than 660 million square metres of agricultural lands are deserted because of clay brick production. In 2000, the Chinese government issued a four-ministerial guideline to phase out the use of land-made brick in all new construction in 170 large and medium cities by 2004¹⁰. Implementation of this regulation is likely to stimulate further of use of steel and concrete-structure buildings both in urban and rural China, which are less efficient than traditional brick-laid buildings.

1.6.2 Institutional barriers

In most of northern cities, heating service is still widely being considered as welfare provided by the government's subsidy but not a commercial good. Heating consumption is billed on the basis of floor space area instead of actual consumption. The consumers are not given any price signal to conserve energy, no economic incentive is available for property developers to build more efficient houses than building codes. Although the central government issued in 2003 a guideline which urged the local governments to launch nation-wide heating reform, the billing and pricing system remains almost intact. A handful individual billing services and consumption-based heating pricing are only implemented in the pilot projects for

⁹ Heating consumption in the severe cold region is much higher than this figure.

¹⁰ The four ministries are NDRC, Ministry of Construction, Ministry of Agriculture, Ministry of Land and Natural Resources. The guideline is available at http://www.ndrc.gov.cn/hjbh/hjjsjyxsh/t20050912_45900.htm.

demonstration purpose. The pricing reform has lagged systematically behind the government's reform schedule. More specifically, most of energy suppliers and building constructors remain reluctant to installation of individual heat metres and thermostatic valves at the expense of energy loss, the consumers are not allowed to regulate indoor temperature according to ambient environment and comfort requirement diversities. The cost reflective method should be promoted to supplement the technical intervention in building energy efficiency improvement; consumers must be given appropriate price signal to save energy without compromising thermal comfort, otherwise the saving resulting from efficiency improvement would be offset by the significant energy consumption rebound in absence of consideration of cost.

In addition, the development of distributed energy system such as small and medium-size high efficient CHP confronts many difficulties in competing with the low cost coal-fired small boilers due to institutional barrier in terms of power grid purchasing contract. The central government encourages the development of CHP only with large generating capacity to the detriment of distributed small-size cogeneration with flexible regulation capability.

1.7 The fundamental question and structure of thesis

There are two fundamental questions to be answered in this research: 1. what will be the optimal building energy efficiency standards development paths in Chinese cities? And to what extent an emerging country like China can afford to tackle the quality of infrastructure such as dwellings and its energy system in terms of energy efficiency? 2. What should be the appropriate policy instruments to be taken such that the environment objectives can be achieved in the context of rapid urbanisation process given the institutional organisation?

The primary purpose of this research is to bridge the gap between economic analysis and energy demand scenario analysis to define the optimal building efficiency improvement path in the following decades. Note that "optimal" does not necessarily result in only one solution but can vary with respect to the standpoint and the degree of climate constraints. The second objective is to design a policy portfolio incorporating different technical solutions of energy supply and building efficiency to achieve the social optimum (least discounted cost). Implementing these policies requires necessarily an adapted institutional framework, decision-making is very delicate because the cities are subject to two-tile constraints: 1. rapid economic growth and improvement of standards of living; and 2. energy and environmental resource depletion and deterioration associated with energy use, this raises the fundamental question of economics, how to maximize the social utility with limited resources.

The city of Tianjin is selected as the case study in this research from both energy and economic analysis perspective for the following reasons:

- First, as a representative large city in northern China, space heating is account for a major part of buildings energy consumption. Tianjin is situated in China's official heating zone, where most of buildings are distributed by centralised CHP or distributed district boilers ;
- second, situated in the centre of cross-strait Bohai economic zone , Tianjin is one of China's most fast-growing economy in northern China, it is projected that the per capita GDP in Tianjin is likely to reach 20.000US\$ by 2020, equivalent to that of industrialized countries in 1990s. Previous economic papers suggest that energy service demand is closely correlated with household's income and standard of living. People living in these two cities will be sufficiently affluent to afford their increasing energy demands comparable to those in the Western cities in residential and commercial sector. Households will require higher quality of energy services and more thermal comfort as the budget constraint will be gradually removed in the future.
- Third and most importantly, the city of Tianjin has launched district heating reform since 1990s, cost-reflective billing and pricing has been practiced in part of the city. Thus the city would be an ideal place for pilot project and experimentation of institutional innovation.

1.8 Structure of thesis

The thesis consists of two major parts. In the first part, I firstly explain the motivation and methodology of this research, and then I present the modelling results that allow us to determine the optimal pathway of buildings energy efficiency in the city of Tianjin. In the second part, I analyse the current institutional organisation and role of main actors in the energy and property markets in Tianjin, and try to tailor relevant economic and policy instruments to help approximate optimal paths defined in part 1.

Chapter 1 explains the motivation of research and the main problematic to be addressed; it also presents the Chapters' structure and their components. An overview China's energy demand prospects and the economics of BEE is presented in the second half of this chapter.

Chapter 2 begins with a brief review of the literature on scenario analyses of the long and medium-term energy demand in China's building sector to explore social, economic and environmental implications and the limitations of existing modelling studies. By synthesising and comparing the assumptions and methods used in these studies, it concludes that the existing modelling framework has not addressed directly the first fundamental question of my research and proposes an approach to finding out the answer to the question. I explain why it is necessary to undertake a two-step modelling process based on 2-scale analysis: a new residential district and the whole city.

Chapter 3 presents the methodology to address the limitations in previous studies in the previous chapter. The methodology is demonstrated by constructing the energy demand modelling framework. The rationale

for model selection is explained in the second half of this chapter. Lastly, the question on discount rate is also addressed in this chapter.

Chapter 4 presents the results of scenarios in which different portfolios of technologies (heat supply system) are tested in order to compare the cost and benefit with various levels of building efficiency standards in a new residential district in Tianjin where 30% of buildings are designed for the purpose of commercial use.

Chapter 5 demonstrates the optimal trajectory by scenario analysis of energy demand prospect in the whole building sector in the city of Tianjin up to 2030.

Modelling results from the chapter 4-5 are synthesized in this section. I review the main results found of the research of energy demand scenario modelling and the criteria of optimal efficiency development trajectory.

Chapters 6 and 7 constitute the second part of thesis. The two chapters aim to develop economic and policy instruments to facilitate approximating optimal trajectory defined in the first part of thesis. Chapter 6 analyses institutional organisation of the housing construction and energy production and supply chain in the city of Tianjin. I explain why the building efficiency policies confront obstruction in the case of Chinese cities and key aspects that need to be addressed to make the current situation move toward expected development pathway.

Chapter 7 seeks the relevant policy and economic instruments to overcome the institutional barriers and converge to the optimal efficiency development path defined in the part 1 based on the scenario analysis. It first reviews theoretical and cross-national implemented economic and policy instruments for energy efficiency improvement, in particular in the buildings sector. Both theories of institutions and incentives are discussed. I show the rationale in analysing the economic and political instruments to address the energy efficiency implementation. Second, I try to synthesise the interest with simple game model representation and find the best solutions. Third, I test the possibility of introducing different mechanisms (regulatory and economic) for BEE based on policy implementation theory, especially the climate financing approach such as Clean Development Mechanism (CDM) and land use regulations (plot ratio flexibility). A proposition of heating pricing reform scheme is also discussed in the instruments design.

Chapter 8 concludes the research findings. It remarks and discusses the policy implication of achieving the optimal buildings energy efficiency development trajectory in Tianjin based on the scenario analysis. The limitation and perspective of the research are addressed at the end of this chapter.

References

- Akerlof, G. (1970). The market for lemons: quality uncertainty and the market mechanism. *Quarterly Journal of Economics*, 84(3), 488-500.
- BP 2007. BP Statistical Review of World Energy.
- Chatham House. (2007). *Changing Climates: Interdependencies on Energy and Climate Security for China and Europe*. Chatham House. UK. 101 p.
- China Dailey Oct 12th 2007 "China propels global growth" http://www.chinadaily.com.cn/bizchina/2007-10/12/content_6168704.htm
- China Daily 2004 Nov 13th. Coal mining: Most deadly job in China. http://www.chinadaily.com.cn/english/doc/2004-11/13/content_391242.htm
- Crampton,P., Wu, Y. 2005 Energy consumption in China: past trends and future directions. *Energy Economics* 27 (2005) pp.195– 208.
- Gielen, D., and Chen, C. 2001. The CO2 emission reduction benefits of Chinese energy policies and environmental policies : a case study for Shanghai , period 1995-2020. *Ecological Economics* 39, 257-270.
- IEA. 2004. *Energy Balance in different countries*.
- IEA. 2007. *World Energy Outlook 2007: China and India Insight*. International Energy Agency. Paris.
- Jiang, K. 2007. *Energy's historic developments*, The Energy Research Institute, Beijing.
- Levine, M., D. Ürge-Vorsatz, K. Blok, L. Geng, D. Harvey, S. Lang, G. Levermore, A. Mongameli Mehlwana, S. Mirasgedis, Lu, X. Pan, J. Chen, Y. 2006. *Sustaining Economic Growth in China under Energy and Climate Security Constraints*.
- National Bureau of Statistics (NBS). 2006. *China Statistics Yearbook 2006*.
- Novikova ,A., Rilling, J., Yoshino, H. 2007: Residential and commercial buildings. In *Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [B. Metz, O.R. Davidson, P.R. Bosch, R. Dave, L.A. Meyer (eds)], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. 60 p.
- Report of the 16th National Congress of Chinese Communist Party. 2007.
- Rivers, N. and Jaccard, M. (2005). Combining Top-down and Bottom-up Approach to Energy-Economy Modelling Using Discrete Choice Methods. *The Energy Journal*.vol.26 (1). pp 83-106.
- Simon, Herbert (1991). Bounded Rationality and Organisational Learning, *Organisation Science* 2(1): 125-134.
- UNEP 2007. *Buildings and climate change. Status, Challenges and Opportunities*.
- Ürge-Vorsatz, D.,Harvey, D., Mirasgedis,S., Levine, M. 2007. Mitigating CO2 emissions from energy use in the world's buildings. *Building Research & Information*, Volume 35(4), pp. 379 - 398
- Wang, Y., Chen, C., Huang,C., Zhao, J., Dai, X.2004 (in Chinese) . Analysis of air-pollutant and CO2 emission under low-carbon development: the case for Shanghai. *Energy Research and Information*. Vol 20 (3).
- Zaouali, S. 2007. Impact of higher oil prices on the Chinese economy, *OPEC Review: Energy Economics & Related Issues*, Sep2007, Vol. 31 Issue 3, p191-214.
- Zhou, N., McNeil, M., Fridley,D., Lin,J., Price, L., De la Rue du Can, S., Sathaye, J. and Levine, M.(2007). *Energy Use in China: Sectoral Trends and Future Outlook*. Lawrence Berkeley National Laboratory. 96 p.

Chapter 2 Lessons from the long term scenarios analyses

This chapter explains the origin of the fundamental questions of the research on the basis of comprehensive analysis of the existing literature on long-term energy demand in China's building sector. Previous studies regarding the prospects of energy demand in China, in particular in building sector analyzed different energy conservation technology and policy options. Although most of the literature on energy demand and economic analysis of climate change mitigation policy emphasized the contribution of buildings to GHG emissions, their findings do not allow us to define the optimal path of building energy performance standards evolution and the relevant energy system development strategies in a specific way. The underlying policy instruments in these studies focused mainly on implementing Chinese actual building code and improving the supply technologies, we consider that the multi-sectoral analysis framework will not necessarily lead to the best pathway of efficiency amelioration from economic analysis perspective, in particular in a perspective of strong carbon emission constraints. Most of the scenarios presented in the chapter are dependent on the current and future situations of macroeconomic development trends (energy price, population growth, GDP, technological change etc), specific analysis in buildings should be integrated into the general context based on the whole energy-economy system. 2.1. illustrates the current energy consumption situation and construction dynamics of China's building sector. 2.2. reviews the forecast results of scenario analysis and discusses the relevant environmental implication of huge increase in energy demand. 2.3 draws lessons from previous study of scenario analysis and demonstrates the limitation of theses studies. 2.4 presents the originality of the research and contribution to addressing the economic dimension arising from building energy performance in China.

2.1 China's construction dynamics and energy demand in building

Figure 2-1 shows that space heating and water heating and space cooling together account for more than 60% in residential buildings in China, as cooling represent one half of appliance consumption of households. They represent together approximately 60% total final energy use in residential sector and 84% in commercial sector in China (Zhou *et al.*, 2007).

However, heating consumption is still very low compared with the OECD-Europe countries where heating consumption amounts to nearly 60% of final energy demand in residential buildings (Bowie and Jahn 2003). Figure 2-1 illustrates the breakdown of final energy consumption in the Chinese buildings sector in 2004. The fact the China's provinces are divided into official heating zone and non heating zone help explain the actual gap, most of residents in the transition climatic zone use primarily electrical air-conditioner for space heating in winter in a very parsimonious way because they are concerned about electricity consumption cost. Residential demand for energy services of heating, water heating and air conditioning are likely to increase further as the living standards improve gradually. Electrical appliance consumption is also expected to increase steadily in the following years, appliance like printer and computer (indicated as other

in the graph) consumption in China is still extremely low, less than 4% of total final consumption due to household's income revenue constraints (Zhou *et al.*, 2007). Electricity consumption in residential sector is extremely low compared to the developed world (See Fig. 2-2) . This implies that electricity demand will increase significantly in the next decades in China's residential sector. In addition, this consumption lag disguises the fact that there exists a substantial gap between the developed and less advanced provinces within China. For example, a consumer in Shanghai consumes more than three times that of China's average (NBS ,2006). China is undergoing a large-scale urban development and this rapid urban expansion implies a huge potential of energy use increase in urban buildings as people getting more and better-off. Figure 2-2 depicts the trend of new construction of buildings since 1990, nearly 20 billion square metres of floor space have been constructed in the last ten years.

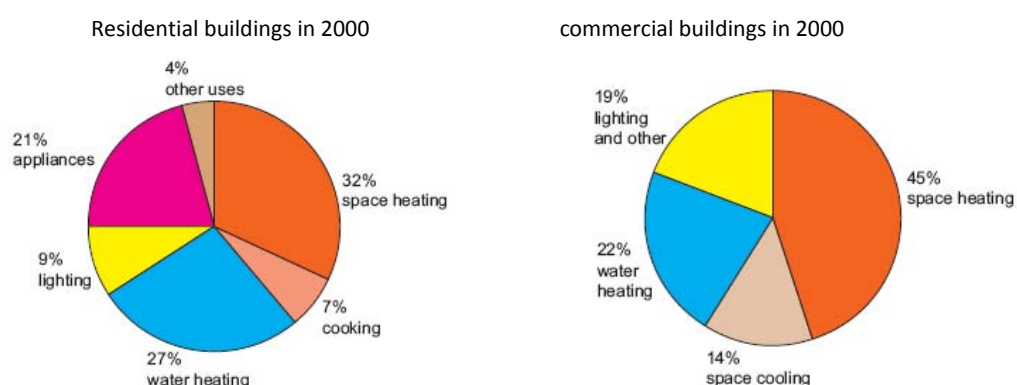


Figure 2-1 Residential and commercial building energy consumption by end-use in China (Levine et al. 2007, Zhou *et al.*, 2007)

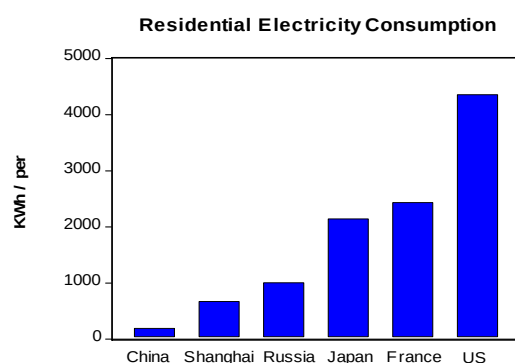


Figure 2-2. Per capita electricity demand in residential sector in different countries (IEA,2004)

In this research, unless explicitly mentioned, BEE refers to improvement in buildings thermal performance that allows reducing the heating and cooling demand in buildings since they represent the major part of final consumption in both residential and commercial buildings. In 2004, heating in the northern urban area represents more than one half of total consumption in buildings (Jiang, 2004). Buildings in the urban

area in the cold climate zone of China are primarily delivered by coal-fired central or district heat plants or CHP. Urban residential building stock in cold climate region stood at about 4 billion square metres in 2004 and could grow to 9 billion square metres by 2020, if the average annual construction in the past decade is maintained. Most of these new buildings will be connected to coal-fired district heating system. The future demand for heating services will be determined by (i) the inherent energy efficiency of the buildings and the heating systems; (ii) availability of equipment for end-users to control heat consumption and the knowledge and incentives for them to conserve energy, and (iii) technologies, incentives, and know-how for heat suppliers to operate efficiently and invest in improvements(Liu, 2006).

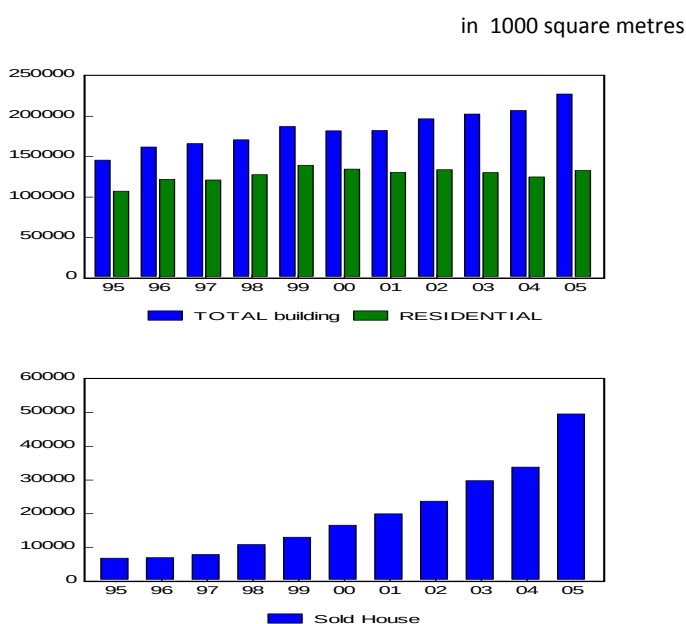


Figure 2-3 Floor space area of new construction and sold houses 1995-2005 (NBS 2006)

As mentioned earlier, energy consumption in China grew sharply from early this century; the multiplication of large-scale fixed capital investments was the major trigger of the sharp increase in the rapid expansion of energy intensive activities, in particular, property development boom, which was one of the strongest driving forces. In 2005, buildings consumed nearly 173 million tonnes of steel accounting for more than half of China's steel output, in which 76% are used for buildings in urban buildings construction (China construction daily, Sep 19th-2007). Nearly 70% of cement production of China is consumed in building sector. Steel and cement industry are traditional the most energy and carbon emission intensive industrial sector.

Building materials regulation

Development of efficient alternative materials is of extremely importance contributing to energy saving and energy related environmental hazard reduction. Clay brick has been the major building materials in

China, more than 700 billion bricks are produced every year which necessitate 1.4 billion cubic metres of soil, more than 660 million m² agricultural lands are deserted because of clay brick production. In 2000, the Chinese government issued a four-ministerial guideline to phase out the use of clay brick in all new construction in 170 large and medium cities by 2004¹¹. Application of this regulation is likely to stimulate further use of steel and concrete structure buildings both in urban and rural China, consequently driving the materials manufacturing-related consumption much higher.

2.2 Mitigating CO₂ emissions from building sector

As said in the beginning in Chapter 1, buildings account for nearly one-third of global CO₂ emissions, reducing CO₂ from this sector is an imperative to enable the world to achieve the long-term climate objective. There exist various technical solutions to address the CO₂ mitigation in building sector which range from building insulation to fuel switch, and new technologies such as the installation of *carbon capture and storage* (CCS) in the coal-fired thermal plants, however, the cost-effectiveness and relevance should be considered the primary criteria in assessing the mitigation policies. Table 2-1 and Fig. 2-4 and illustrate the mitigation costs analysis in different studies in recent literature of cost-effectiveness of mitigating carbon emissions measures in different economic sectors.

Table 2-1: CO₂ emission mitigation technical solutions and costs

Mitigation measures	CO ₂ mitigation with		Cost (US\$/ t CO ₂)	
	net benefits	economic	2004	2020
Thermal insulation	Yes		Zero even negative	idem
Fuel switch from coal to gas in boiler in district heating ^a	No		37 ^a	
Fuel switch from coal to PV for distributed electricity generation ^b	No		550-600	200
DSM (electrical appliance improvement)	Yes		Zero or negative	idem
CCS	No		50-100	25-50

^a Calculated based on lower heating value(LHV) of fuels and price level in China in 2005; water and pumping system energy consumption in heating system are excluded.

^b Calculated based on lower heating value(LHV) of fuels and on the average cost of rooftop PV generation in China; \$5000/KWe is assumed for the installation of PV, the embodied energy in PV components manufacturing process is ignored.

Source: Gielen and Podkanski 2004; Ürge-Vorsatz and Novikova 2008; Greenpeace China 2007.

¹¹ The four ministries are NDRC, Ministry of Construction, Ministry of Agriculture, Ministry of Land and Natural Resources. The guideline is available at http://www.ndrc.gov.cn/hjbh/hjjsjyxsh/t20050912_45900.htm.

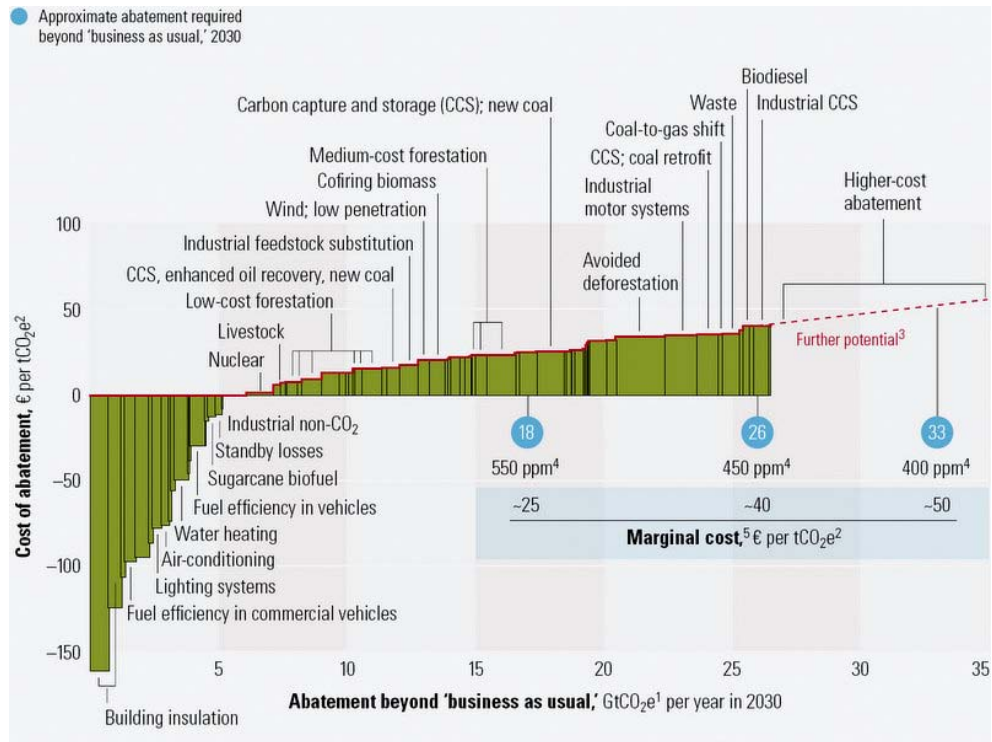


Figure 2-4. Costs curve of different mitigation actions (McKinsey, 2007)

Ürge-Vorsatz and Novikova(2008) conducted a global cost-effective CO₂ mitigation scenarios in buildings based on review of studies across 80 countries in the world in which china is included. They conclude that efficient electrical appliances and lighting (CFLs) ; water heaters; efficient gas cooking stove; efficient AC; wall and roof insulation can all allow tapping cost-effective energy and CO₂ savings potentials with net economic benefits. However, cost analysis in these studies is primarily based on review of separated national studies which extremely diverse characteristics of energy supply infrastructure. The marginal abatement of cost of building insulation illustrated in Fig. 2-4 disguises the extremely diverse situation in different parts of world in terms of national climate situation and local technical and financial capacity. For example, the incremental costs of positive energy buildings or solar PV integrated houses are still significantly higher than the most common practice in the construction sector. Moreover, these studies do not explicitly indicate what should be the mechanism that can accompany the mitigation measures taken when moving from negative costs to how to pass from negative area to the positive area on the mitigation cost curve. In addition, only the engineering costs of the new technology and its installation has been taken into account in general, though the institutional and technical capacity is a determining key issue in enabling the success of actual implementation. And none of these studies investigated the long-term optimal building energy efficiency strategy in their specific context based on a quantitative approach. Yet we know that energy and climate policies must be country and region-specific, and measures should be diversified since a global technological silver bullet does not exist. For instance, fuel-switching and or Renewable heating may be an appropriate policy in some regions in the world but not necessarily an optimal choice in others. Similarly, the miraculous “zero” even “negative” cost of buildings insulation

(McKinsey, 2008) can only be applicable to a tiny part of buildings in a specific area, but not applicable to other regions in the world. Adoption of higher-efficient buildings energy performance does entail a cost including technological learning, institutions adaptations and implementation, and also requires capacity of new material manufacturing industrialisation. However, these studies have not established the bridge between the investment strategies between today and tomorrow and their relevant consequences. Our thesis is concerned with the question if there is an investment strategy combining supply-side technology and demand-side management measures to achieve an optimal result without an opposing standpoint (not simply a 0 or 1 dichotomy). The modelling work strives to find a plausible way among all the feasible technology options through minimising the costs.

2.3 Review of previous scenario analyses of energy demand in building sector

Although industry remains the largest energy consumption sector in China, building sector has become increasingly important as more and more people move into cities under the wave of urbanisation and interregional migration. Currently, residential and commercial buildings account for 18%¹² of final energy consumption and around 20% of the electricity consumption in the country. Overall, buildings account for about 25-27%¹³ of total commercial energy demand and contribute to around 18% of global CO₂ emissions of the country. In comparison, building sector represents more than 40% of energy demand in the developed countries to date, this implies a great potential of increase in energy consumption in China's residential and commercial sectors in the next years in the context of rapid economic development.

2.3.1 Approaches of modelling energy demand prospect in China

Energy demand perspective in buildings has become one of focal points in scenario analysis in a broad body of literature concerning the energy and climate prospect. A large number of recent researches forecasted the medium and long-run energy consumption in China up to different time horizons (2010, 2020 or 2030) from energy, economic and environmental perspectives. Different methodologies have been employed and the relevant results vary significantly.

NDRC (2004) and ERI (2003) report energy projection to 2020 with a bottom-up approach specifying both on demand and supply-side technology advancement. On the other hand, IEA (2004, 2006, and 2007), Jiang and Hu (2006), EIA (2006) provide forecast up to 2030 with general equilibrium model (GEM) combined with specific emission scenario model. They integrated in their models the interaction dynamics between energy demand in China and the world's economic prospect.

¹² Biomass in rural area is not included

¹³ It is calculated by using LC approach by including the production and transport of building materials, and the consumption during the construction phase as well. Thus the effective energy consumption during building's operation period is lower than this figure. Long (2006) estimate that final energy consumption in buildings represents about 20% of total energy use.

Some scenarios in the aforementioned studies provided detailed information on energy consumption in buildings. ERI(2003), NDRC(2004) and Kang and Wei (2005) have all projected building energy demand to 2020 with LEAP model which is a Bottom-up model. Energy demand in buildings is estimated by the projection of the trend of evolution of per capita living area and the average energy intensity per square metre. Only actual Chinese building code have been considered which requires the improvement of supply-side energy performance (boiler generation and heating system distribution efficiency etc).

Jiang and Hu (2006) used an integrated model combining a technology selection model (AIM Tech) with a macroeconomic model (IPAC-emission model). The IPAC-AIM/Technology model is a single region model for China, developed on the basis of AIM/end-use model. This model includes three modules (i.e., energy service demand projection, energy efficiency estimation and technology selection). The model disaggregates the energy demand into different sub-sectors and specifies more than 400 technologies for both supply and demand of energy services. The least-cost technology portfolio will be selected to meet the given energy service demand (Jiang and Hu, 2006).

From econometric analysis prospective, VAR and BVAR models are quite suitable for short-term energy demand projection based on the historical data. However these models are not very consistent with time-dependant fast-evolving factors which fail to capture the unpredictable political or economic structure change and technological breakthrough for the longer term. For example, Crompton and Wu (2005) provided a forecast of energy demand in China in 2010 by specifying a BVAR model whose projection in terms of primary demand in China in 2010 was already surpassed in 2006 in reality. Lin *et al.*(2007) modelled the demand for coal in China in 2015 with a co-integration approach, the result of projection (2249 Mtoe) is consistent with the projection of IEA(2006, 2007).

2.3.2 Results of buildings energy demand modelling

2.3.2.1 Bottom-up model projections

ERI (2003) projected three energy demand scenarios in which buildings would represent about 26% of total energy demand by 2020. Energy demand in buildings would be maintained below 327 mtoe in *green growth* scenario which is 27% lower than ordinary effort case.

Kang and Wei (2005) explored the energy saving potential in China's building sector with LEAP model, the energy demand would increase to 614 Mtoe in 2020 under the BAU scenario, which could be reduced to 343 mtoe, or by 44% in the scenario of full implementation of building energy efficiency policies in all the new buildings in China from now onward.

Similarly, Zhou *et al.* (2007) specified a projection model by using LEAP to simulate the energy demand prospect by 2020 and investigated the feasibility of Chinese government's objective of reducing energy

intensity by 20%. Energy service is disaggregated into corresponding end-use to represent the whole energy use picture in residential and commercial building sectors. GDP and population growth is the key drivers of increase in floor space in the model; while increase in household income is taken as proxy of living standards to give people more aspiration to better services in buildings, translated into accrued demand for energy services, in particular space cooling and office appliance in commercial buildings. The constructed floor space of commercial buildings is forecasted by regression model specified by the historical data on construction area and GDP growth. The sensibility test of GDP elasticity in the scenarios shows GDP growth can lead to a wide range of constructed floor space, therefore could have significant impact on energy demand in commercial buildings. Final energy demand in commercial buildings would approach 190 mtoe per annum in 2020, while primary energy demand would increase from 204 Mtoe in 2000 to 490 Mtoe in 2020 under the BAU scenario, with an average growth rate of 4.5% per annum, their models demonstrated that the total urban residential energy use will outpace that of rural households in 2012 as a result of fast growing urbanisation process in China.

2.3.2.2 Integrated-model projections

Jiang and Hu (2006) specified energy demand development trend in China's building sector and emissions from corresponding scenarios with the IPAC model. Their model projected that coal use will be replaced progressively by gas and electricity in Chinese building sector, electricity would represent 42% and 48% of final consumption in 2020 and 2030 respectively in the *baseline* scenario. They projected that energy demand in buildings would increase steadily to reach 417 Mtoe in 2020 and 666 Mtoe in 2030 in the baseline scenario. On the other hand, by implementing vigorously the efficiency improvement policies in new construction and existing buildings as well as upgrading appliance efficiency, energy demand could be reduced by 17% in 2020 and 28% in 2030 respectively under policy scenario. Building energy performance improvement and other measures such as distributed heating and cooling, heat pump promotion and appliance efficiency improvement (cooking, office, air conditioner, lighting appliance etc) are considered in the "policy scenario". They also pointed out that there is still room for further energy savings if more advanced technologies could be fully deployed.

Buildings would account for around 28% of final energy consumption in 2030 under the reference scenario, and 26.7% for policy scenario (IEA, 2006). EIA (2006)'s reference case projected that China's buildings energy consumption would reach 282 mtoe in 2015, 312 Mtoe in 2020 and 401 Mtoe in 2030 respectively. Table 2-2 summarises the major results of different scenarios of buildings energy consumption modelling.

Table 2-2. Comparison of final energy consumption scenarios in buildings

	2015	2020	2030
	mtoe	mtoe	mtoe
<i>Without biomass</i>			
ERI 2003			
Ordinary effort		448	
Green effort		327	
NDRC 2004			
A		396	
B		372	
C		331	
EIA 2006 Reference case	282	312	401
<i>With biomass</i>			
IEA 2006 *			
Reference scenario	502	549	642
Policy scenario	463	487	534
Jiang and Hu 2006			
Baseline scenario		417	666
Policy scenario		347	479
Zhou 2007 (commercial buildings)		190	

* values in 2020 of IEA (2006) 's projection are interpolated by the author ;

Source: NDRC(2004); ERI (2003); Jiang&Hu (2006); IEA(2006); IEO 2006: data of IEA (2006) is derived from WEO 2006 by the author.

Almost all the scenarios projected that solid fuel will be gradually substituted by electricity in buildings in the final demand in buildings sector over the next decades, fore example, Jiang and Hu (2006) estimate that electricity would account for more than 50% of final energy consumption by 2020 for two main reasons: 1. more and more rural households will switch from biomass to electricity for cooking and water heating; 2. electrical appliances penetration will develop steadily both in urban and rural households in the coming years.

Figures 2-5 and 2-6 show the breakdown of final energy demand by energy carrier in 2004, 2020 and 2030 under two different forecast assumptions.

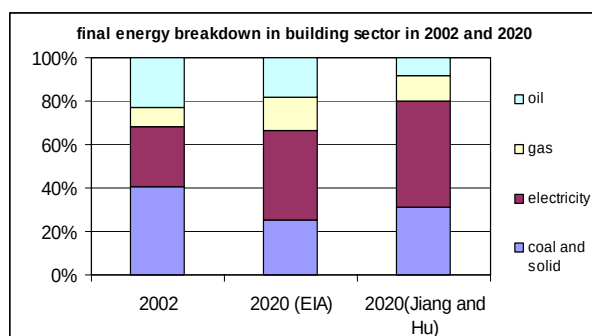


Figure 2-5 Final energy consumption breakdown in building in 2004 and 2020 (source: SSB 2004, IEA 2006, EIA 2006, Jiang and Hu 2006)

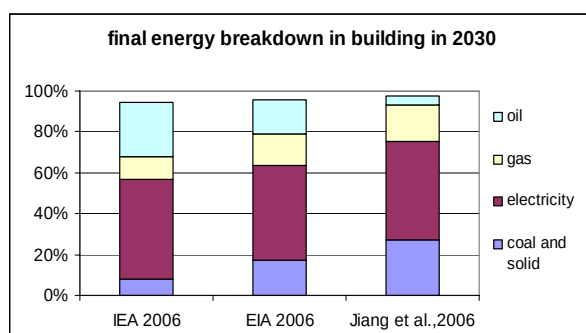


Figure 2-6: Final energy breakdown in building in 2030(Source: idem).

Residential energy demand would increase dramatically given the improvement of the standard of living and household structure evolution. The amelioration of living condition and further development of urbanisation process will stimulate energy services demand such as heating and cooling in building sector in the cities. Furthermore, low-income people and rural residents will gradually switch to modern energy such as natural gas or electricity to replace conventional biomass energy (mostly straw and stalk) which is currently widely used in rural areas for cooking and heating. The pursuit of Western life style will inevitably accelerate this process. The tension between energy supply and demand could be sustained if no energy efficiency policies will be implemented effectively in building sector.

2.3.3 Environmental implications of increase in energy demand in buildings

2.3.3.1 Projection of CO₂ emission in all the sectors

The results of projection of IEA (2006) regarding the CO₂ emission are plotted in Figure 2-5 and 2-6 which represents reference and alternative scenario respectively. China's CO₂ emissions could amount to 7744

Mt in 2015 and 10425 Mt in 2030 under the reference scenario (IEA, 2006). By implementing energy efficiency measures and enhancing the development of renewable and nuclear power, China's CO₂ emissions could be cut by 15.6% compared with the reference scenario. Coal-fired electricity generation could have a serious incidence on environment if no technology breakthrough will be realized in China's power sector, nearly 50% direct CO₂ emissions in China came from coal-fired electricity and heat generation plants in 2004. By comparison, coal contributes to 23% of CO₂ emission worldwide. If coal use in final consumptions is also taken into consideration, the coal use related CO₂ emission would be 3800 Mt accounting for nearly 80 % of total CO₂ emission in China (IEA, 2006). Consequently, the electricity saving measures in the end-user side in buildings will make a substantive contribution to the CO₂ emission mitigation. Since coal consumption in agriculture is very tiny and almost negligible, we can derive from (IEA, 2006) that energy-related CO₂ emissions in buildings could be as much as 1162 Mt, roughly 25% of China's total CO₂ emission in 2004.

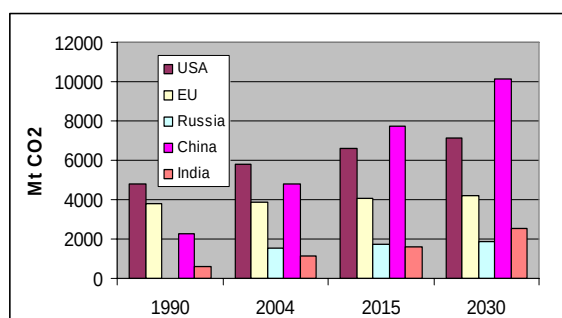


Figure 2-7 . IEA's projection of CO₂ emission in the biggest countries 2004-2030 (Source: IEA 2006. reference scenario)

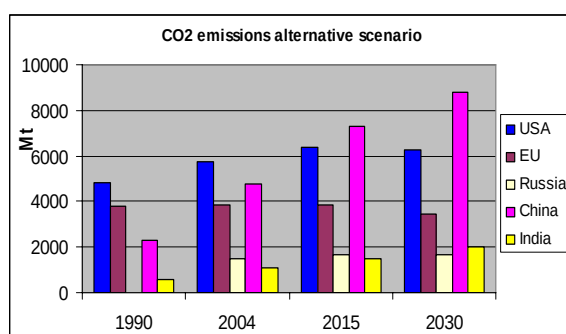


Figure 2-8 Projection of the same countries under the policy scenario (Source: idem)

Note: Russia's data in 1990 is not available

2.3.3.2 CO₂ emission from buildings sector

Most of scenarios in the reviewed studies do not provide enough details about the primary energy consumption allocation by sector except the study of NDRC (2004), which reports detailed information on CO₂ emission breakdown by sector. In order to calculate building's share in CO₂ emission resulting from

electricity generation in the power plant, it is necessary to calculate the share of electricity consumption by sector. Buildings sector accounts for 24% of final electricity consumption (IEA China energy balance 2004) and thus generates the same proportion of CO₂ emission in upstream power sector. In IEA's energy balance, all the biomass and other renewable energies are counted in residential consumption and have virtually no greenhouse gas emission. Non-residential consumption in agriculture sector is extremely low, thus almost negligible. Hence we assume that this use in agriculture sector will maintain current level throughout the projection period, emission related to energy consumption in buildings can thus be derived from the general emission results from IEA's scenarios. Energy-related CO₂ emission in building sector is not reported in Jiang and Hu (2006), we derive CO₂ emission level from their energy demand prediction and conventional emission factor by fuel source used in China.

Furthermore, we assume that building's share in total electricity demand range between 25% and 30% by 2020 and 2030 and then reallocate the projected CO₂ emission by sector to estimate the total emission relative to energy consumption in building sector. Relevant estimate of CO₂ emission in building sector (Mt CO₂) is reported in Table 2-2 with percentage number in parenthesis indicating the share of buildings in total emission in China in specified year of projection.

Table 2-3 Scenarios of energy-related CO₂ emission from buildings sector in China in the models (in Mt)

	2010	2015	2020	2030
NDRC(2004)				
	946		1800 (26.2%)	
A	(19.9 %)			
B	902 (19.7%)		1599 (25.3%)	
C	810 (19.8%)		1379 (24.9%)	
IEA(2006)**				
reference		1786(23%)	2108	2751(26.4%)
		1636		2170
alternative Policy		(22.4%)	1814	(24.7%)
IEA(2007)				
		1590		2523
reference		(18.4%)	1901	(22%)
		1507		1893
alternative Policy		(21.3%)	1636	(18.6%)

* Not every model we reviewed provided specific value of the CO₂ emission from buildings

** values in 2020 are interpolated from IEA's projections

The largest potential of energy savings and CO₂ mitigation in building sector is offered by space heating consumption in all the scenarios. Improvement of energy efficiency by tightening the building code will lead to a reduction of 112 mtoe energy use in 2020, that means almost 100 Mt of CO₂ emission could be avoided (ERI, 2003). Ten most cost effective energy efficiency improvements policies in the major carbon dioxide emission contributors are identified in (IEA, 2006) under the alternative scenario where a series of energy efficiency improvement programmes will be carried out. CO₂ emission could be cut by 8% compared to the reference scenario. Among others the consumer-side management measure is the most effective and co-benefit means with regards to climatic change mitigation. The full implementation of the DSM Policy of electricity consumption in building sector in China may lead to a reduction of 347 million tons of CO₂ in 2030, and the active development of renewable energies and nuclear power in the electric production would allow to reduce further 390 million tons of CO₂ during the same period compared to the reference scenario (IEA, 2006). Overall, the reduction of CO₂ emissions in building sector could be as much as 700 Mt per year in 2030, almost one half of India's total emission in the same year.

2.4 Lessons from scenario and contribution of the research

2.4.1 What to learn from the scenarios?

Previous studies on scenario analysis show that demand for energy services in buildings sector in China will increase significantly in the following decades, a large quantity of building stock would risk being locked in energy-intensive scenario if no attention of buildings efficiency will be paid immediately given the fast-increasing construction boom. The scenario projection results vary widely across all the scenarios. Should biomass used in rural households is excluded, final energy demand can be ranging between 310 and 450 mtoe in 2020 and between 400 and 666 mtoe across all the scenario. The strong increase in energy demand would have tremendous environmental implications. CO₂ emissions related to energy use in buildings sector would be as high as 1.8 Gt in 2020 and 2.75 Gt in 2030 in the high energy demand growth scenario. These projections confirm the urgency of act immediately on efficiency improving in building stock to avoid the energy and carbon lock-in.

Almost all of the analyses set the objective of building energy performance improvement in different scenarios to quantify the subsequent emission implication. A series of technologies have been considered in their models, however the social cost of these policies have not been evaluated systematically. Lessons learned from these energy demand prospect analysis is that modellers are more concerned about the physical consequences (fuel, CO₂ emission), but the economic aspect has not been addressed thoroughly. In the models of IEA(2006, 2007), Gielen and Chen (2001) and Jiang and Hu (2007), cost issue have been addressed by taking into account the evolution of energy price and endogenous technological change by the dynamics of elasticity's of substitution between the different technologies, price have been defined such that the energy and technology choice follows the rule of elasticity of substitution. But these costs are

not directly linked with the efficiency standards evolution of buildings. Whereas the models of ERI(2003), NDRC(2004) and Kang and Wei(2005) only explored the energy saving potentials but leave the cost-benefit issue untapped. Zhou *et al.*(2007) modelled the energy growth depending on GDP elasticity, but no optimal building performance can be determined for their scenarios. More specifically, they modelled China as a whole although dividing it into several regions, but building efficiency should be addressed by the local actors. A *silver bullet* policy option does not exist.

The divergence between the models can be confirmed by the projection results reported in Table 2. For example, ERI (2003) projected that energy demand in buildings can be reduced by 27% in green scenario compared with ordinary effort, Kang and Wei (2006) even projected a reduction of 44% , while the policy scenario in IEA(2006) and Jiang and Hu(2006) would only allow 11.3% and 16.8% reduction in comparison with BAU scenario in the same year. Likewise, NDRC (2004) projected that CO₂ emission from building sector can be reduced by 23.4 % by implementing energy efficiency in all the new buildings, while IEA (2006) estimates a reduction rate of about 14% in policy scenario which takes into account energy efficiency improvement portfolios ranging from building code enforcement to appliance efficiency updating in the future, which is much less optimistic than ERI and NDRC's models. From this regards, we should therefore be very careful in interpreting the results of different scenarios since the assumptions and determining variables differ from each other among the energy and climate models.

Notwithstanding methodological difference, all scenarios in the models demonstrate the perspective of energy demand and carbon dioxide emission in buildings by adopting different policy options, which can be served as strong arguments to policy makers to uptake the efficiency improvement measures immediately since the models explain that waiting for new technology to resolve the energy deficit would be too late and also risk leaving the buildings in carbon lock-in situation.

Although not all the evolving factors can be captured by the energy models because of uncertainty about technological change and socioeconomic development (GDP, Population etc), these forecast models outlined clearly implication in the different scenario of energy demand and CO₂ emission over the next twenty to thirty years. It is clear that BAU scenario is not an option both in terms of security of energy supply and climate change challenge. China can not wait for the oil and coal production to reach their maximum capacity to cover the fast-growing domestic demand which could leave a significant fuel deficit. China's immediate decisions about its energy infrastructure performance and patterns of consumption such as in buildings will have a decisive impact on global greenhouse gas emissions stabilisation and reduction in the future, given the huge potential of increase in new construction and demand for energy services in the coming years. Due to the inertia of building's energy consumption pattern, efficiency improvement in buildings needs to be implemented as soon as possible to avoid the energy and carbon intensive lock-in dilemma of buildings in the future.

Energy efficiency improvement to drastic reduction of heating consumption in Northern urban buildings of China comprise promising potential in reducing energy consumption and carbon dioxide emission. Urban residential building stock in cold climate regions stood at about 4 billion square metres in 2004 and could grow to 9 billion square metres by 2020, if the average annual construction in the past decade is maintained (Liu, 2006). Since most of these new buildings will be connected with coal-fired central heating systems, the building energy efficiency and energy performance of heating system's equipment will determine in fine the future energy demand and emission regime of this large stock of new buildings during several decades. Both technological know-how of building efficiency and institutional reform such as cost-reflective energy price should be promoted to give energy suppliers and end-user incentives to save energy in order to contain the considerable growth potential of energy demand.

Enforcement and implementation of energy efficiency regulations and building codes are critical to the energy future of buildings in China tomorrow. As mentioned earlier, buildings last for at least 60-80 years before retiring. Thermal retrofit of an inefficient house entails an extraordinary high cost for both the house owner and occupier and also creates social problems.

2.4.2 Technology options and energy price

Coincidentally, in all the reviewed scenario studies, it is assumed that there will be no fundamental technical change or institutional reform in China, coal will still play a major role in fuelling economic growth in most of areas in China. All the models tested the hypothesis that China will enforce the actual building code and make gradual improvement in the following years. As mentioned earlier, the Chinese building code is still somewhat backward compared with the building efficiency standards practiced in developed countries to date, in particular the Northern European countries. It is reasonable to make an assumption that building codes in all the provinces will be tightened much more quickly than the reviewed policy scenarios, furthermore, if these measures are combined with supportive policy in favour of efficiency and renewable and distributed energy use in buildings, it is likely to formulate a scenario which allows for reduction of energy demand and relative CO₂ emission by a factor of two or even more in comparison with BAU scenarios. The high-performing buildings model seems to be robust if we look backward the energy intensity decrease rate over the past twenty-five years in Europe, in particular for the heating consumption in buildings.

2.4.3 Buildings efficiency and fuel-switching policy in response to CO₂ mitigation

Mitigating CO₂ mitigation in the building sector should opt for an integrated approach by combining a variety of technological measures and energy policy. Actions need to be taken in both supply-side technological innovations such as fuel switch from coal to gas, renewable (e.g. building integrated

photovoltaic panel) and CCS in thermal power plants and demand-side measures such as building energy efficiency improvement. Otherwise the cost of emission abatement or decarbonising infrastructure will be excessively costly to the society.

For example, the CCS can only be commercially viable at large scale by 2020 or even later. High potential of increase in oil and gas prices will also render the fuel switch policy to decarbonise power and heat sectors in China very risky in terms of security of energy supply. Technical difficulty and availability also limit the application of wind and PV system in buildings at scale in the short-term. In fact, demand and supply-side solutions are not substitutable but complementary. The economic gains created from enhanced buildings energy efficiency will contribute to investment in new technologies (CCS, solar, bioenergy etc) to realise the long-term decarbonisation objective. However, ignoring the importance of building energy efficiency by opting immediately for low-carbon supply technology would be extremely costly for the society.

2.4.4 Carbon price

Although some of these models such as IEA (2006) and Jiang and Hu(2006) allow testing the climate change sensibility in response to the degree of increase in energy demand for these models considered the climate constraints in energy demand modelling, no explicit carbon tax have been imposed in buildings or power and heat generation sectors in China in all the reviewed models in the policy scenarios. However, the low-carbon technologies can be commercially viable if and only if appropriate prices are defined to CO₂ emission allowance. The Kyoto carbon financial mechanism has not yet been implemented explicitly in buildings sectors to addressing the financing barriers to energy efficiency in buildings both in energy performance improvement of buildings envelope and appliance efficiency. Uncertainty of mitigation cost of technology options and evolution of carbon price and post-Kyoto climate regime of developing countries such as China persists in these models in terms of carbon constraints and price. The lack of carbon constraint in energy demand and CO₂ emission scenario would render the implementation of cost-effective building efficiency policies more difficult and low-carbon technologies less competitive, low-carbon perspective of buildings in China will hardly be realizable under these scenarios.

In short, the literature on scenario analysis of energy demand in China has not specified the investment strategies in very detailed efficiency operation such as level of building's thermal efficiency and energy supply technology options. Furthermore, most of these studies have not addressed the question on the cost and benefit sharing in the efficiency programme in buildings except IEA(2006,2007) which mainly focused on investment in electrical appliance efficiency programme rather than buildings energy performance. The appropriate extent to which action on buildings and energy infrastructure quality can address energy and climate challenge should be justified by economic rationale, this is a fundamental principle in public policy decision making. Debating energy efficiency and climate urgency without considering the cost will not help make a rational decision.

2.5 Conclusion of the chapter

The review of recent literature on energy modelling in this chapter shows that huge potentials for energy savings and CO₂ emissions reduction can be tapped in China's buildings sector. Around 600-700 Mt CO₂ could be reduced in 2030. The analysis also showed that an integrated approach that combines both energy supply-side and demand-side management measures should be adopted. More specifically, the improved building energy efficiency will also contribute to facilitate the penetration of low-carbon supply technology such as fuel-switching, CCS and renewable heating.

However, all of the previous studies focusing on the building sector in China have limitation in the sense that the results of quantification in these studies do not allow us to determine an optimal energy efficiency trajectory in buildings, consequently, the enabling policy and institutional implications have not been specified. Although the results from these scenarios present the urgency and importance in addressing the efficiency issue in buildings, they tell much less about concrete solutions in terms of standards of practices and practicable measures that the local authority and other actors are requiring in the real construction.

In the next chapters, we try to investigate the optimal BEE development path combining the energy efficiency improvement and the underlying strategies of supply technologies by empirical studies in the city of Tianjin. In order to answer these questions, a new modelling framework is established to assess every possible technical improvement solution for building efficiency and the corresponding economic and environmental implications. These points are extremely important from policy analysis perspective, since the policy-makers need to make decisions about the magnitude and timing of energy environment targets and about the specific policy package that would be the best to achieve them in terms of the usual policy making criteria: economic efficiency, environmental effectiveness, and administrative-political feasibility (Hourcade *et al.* 2006).

References

- BP 2007. BP Statistical Review of World Energy.
- CCICED (China Council for international Cooperation on Environment and Development), 2003. Proceedings of the 2nd and 3rd phase of CCICED.
- Chan, H and Lee, S. (1996). "Forecasting the demand for energy in China", *Energy Journal*, 17(1), 19-30.
- Chatham House. (2007). *Changing Climates: Interdependencies on Energy and Climate Security for China and Europe*. Chatham House. UK. 101 p.
- Crampton, P., Wu, Y. 2005 Energy consumption in China: past trends and future directions. *Energy Economics* 27 (2005) pp.195– 208.
- Department of Energy (DOE), Washington. US. <http://www.energy.gov/> EIA.
- European Commission Directorate General for Energy and Transport. 2001. Information and Communication.

Fisher-Vanden, K., Gary H. J., Liu, H. and Tao, T. 2004. What is driving China's decline in energy intensity. *Resource and Energy Economics* **26** (2004), pp. 77–97.

Gielen, D. and Podkanski, J. 2004. Prospects for CO₂ Capture and Storage. IEA. Paris.

Greenpeace China 2007. China PV Development Report. Beijing.

Grubb, M., Köhler, J., and Anderson, D., 2002. Induced technical change in energy and environmental modelling: Analytic Approaches and Policy Implications. *Annual Review of Energy and the Environment*. Vol. 27: 271-308

International Energy Agency Energy Statistics Database www.iea.org.

IEA 2006. World Energy Outlook. Paris. 2006.

IEA 2007. World Energy Outlook. Paris. 2007.

International Energy Outlook. 2006. DOE, Washington. 2006. *Energy Issues*, 24 (3/4).

ERI. 2003. China's Sustainable Energy Future. Beijing.

He, J., Liu, B., Zhang, A. 2006. Analysis of the effect and potential of energy conservation in China. *Energy Policy* (34). pp.3702–3708.

International Energy Agency Energy Statistics Database 2004 www.iea.org.

IPCC 2007. *Mitigation*. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.[B. Metz, O.R. Davidson, P.R. Bosch, R. Dave, L.A. Meyer (eds)], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. 60 p.

Jiang, K., Hu, X., 2006. Energy demand and emission in 2030 in China : scenarios and policy options. *Environmental Economics and Policy Studies*. 7 (3). pp.232-250.

Jiang, Y. 2005(in Chinese.) Current situation of building energy consumption and effective conservation means. *HV&AC* 2005 (35).

Kahr, F., Roland-Holst, D., 2006. China's Carbon Challenge: Insights from the Electric Power Sector . Berkeley.

Kang, Y. and Wei, Q. 2005. Analysis of the impact of building energy efficiency policies and

Koeppel, S. and Ürge-Vorsatz, D. 2007. Assessment of policy instruments for reducing greenhouse gas emission from buildings. UNEP-Sustainable Buildings and Construction Initiatives.

Larson, E., Wu, Z., DeLaquil, P., Chen, W. and Gao, P. 2003. Future Implications of china's energy technology choices. *Energy Policy* 31 (12). pp. 1189–1204

Li, J. 2008. Towards a low-carbon future in China's building sector—A review of energy and climate models forecast. *Energy Policy*, Volume 36(5): 1736-1747.

Lin, B., Wei, W., Li, P., 2007. The long-term demand for coal in China: impact and policy options. *Economic Study*. 2007 (2), pp 48-58.

Long, W. 2007 (in Chinese). On scientific point of view of building energy efficiency. *Building Science*. Vol (23) 2.

Lu, X. et al., 2006. Sustaining Economic Growth in China under Energy and Climate Security Constraints. *China & World Economy*. Vol. 14(6).

McKinsey Consulting. 2007. A cost curve for greenhouse gas reduction. *The McKinsey Quarterly*. 2007(1).

Ministry of Construction of China (MOC). 2003. <http://www.cin.gov.cn/INDUS/speech/2003111801.htm>

MOC 1996. Energy conservation design standard for heating in new residential buildings. Beijing.

National Bureau of Statistics (NBS) 2006. China Statistical Yearbook 2006. Beijing.

NDRC. 2004. China's energy development strategies and policy implications (Scenario Analysis on Energy Demand) Beijing.

National Bureau of Statistics (NBS). 2006. China Statistics Yearbook 2006

Report of the 16th National Congress of Chinese Communist Party. 2002

Sinton, J., Fridley, D. 2000. What goes up: recent trends in China's energy consumption. *Energy Policy* 28(10). pp.671-687.

Technical improvements on China's future energy demand. *International Journal of Global*

The World Bank 2001. *China : Opportunities to improve Energy efficiency in Buildings*. Washington.

THUBERC 2007. Annual report on China building energy efficiency. Tsinghua University. Beijing.

Ürge-Vorsatz, D. and Novikova, A. 2008. Potentials and costs of carbon dioxide mitigation in the world's buildings.

Energy Policy (36), 642–661.

Zhou, N., McNeil, M. A., Fridley, D., Lin, J., Price, L., De la Rue du Can, S., Sathaye, J. and Levine, M. (2007). *Energy Use in China: Sectoral Trends and Future Outlook*. Lawrence Berkeley National Laboratory. 96 p.

Chapter 3 Methodology

In Chapter 2, we reviewed previous studies on energy demand scenario in buildings sector in China and the limitation of scope of these studies. This chapter presents a modelling framework LBEEE (LEAP-building-energy-environment-economy) to address the limitations of scope presented in Chapter 2.

We explain the methodology of research and specify the model used in our scenario analysis in order to answer the fundamental question of thesis. 3.1. highlights the research method; 3.2 provides a brief comparative analysis between different energy-economy modelling tools and their major characteristics and explains the pertinence of choice of the model LEAP for the end of the research. 3.3 discusses the question about the choice of discount rate which is a key parametre determining the results of long-run energy and climate policy making and the debate on choosing the appropriate rate in economic analysis is far from general consensus.

3.1 Framework of analysis

A quantitative analysis approach will be employed in the research. In chapter 4, I perform an economic and technical life-cycle analysis with respect to investment pattern to meet the energy demand for space heating and water heating consumption in a new would-be residential district in the city of Tianjin.

In chapter 5, I model the energy demand to compare the economic performance in the whole city of Tianjin up to 2030. The reason of analyzing both a “district” and a “city” is that heating service is usually distributed by district heating system in China’s northern area, where individual heating is so far very rare, thus heating supply infrastructure is incorporated in the land use planning in the initial phase of property development. By contrast, in the transition area where is located the city of Shanghai, heating and cooling services are met by individual appliances which is powered by electricity. No large-scale centralized heating and cooling services are considered in most of time except in some large commercial buildings¹⁴.

For the heating analysis in the case of Tianjin, I will perform two categories of technical-economic analysis: the first analysis assesses the strategies of efficiency investment in a city’s new residence district; in this case, the housing stock is static and has no dynamic of movement, we analyze how to adjust the initial building efficiency improvement level and the selection of the relevant energy supply system to minimize the global discounted cost for a period of 20 years. I compare the economic performance between the different choice of investment both in buildings and energy supply system in five scenarios in terms of global cost. Different level of energy efficiency in buildings and supply technology are introduced and compared.

¹⁴ There are heated debates on the necessity to extend official heating zone towards the central China and Yangtze provinces. Experts’ view on efficiency and engineering feasibility diverge widely. Some schools are promoting the gas-fired district or building based central system (heating and cooling). The opposite part argues that central heating and cooling system is not necessarily more efficient than individual appliance in residential buildings for technical reason.

The objective of the district analysis is to demonstrate that there is a rationale for initial energy efficiency investment plan for housing construction in the context of rapid urban development. This district-level analysis can be used as a model to be scaled up later in the city-level analysis.

I will then perform a city-level prospective analysis on the choice of optimal path of buildings' efficiency improvement and technology of energy infrastructure. The two analyses share some similarities but also distinguish one from the other. In the new "district" level study, we analyze a static new housing stock and try to find out the relevant technical choice and the relevant economic implication; i.e. Investment in building energy efficiency and installation of new generating capacities are considered as a sink-cost. Whereas in "city-level" housing energy demand modelling, a technical-economical analysis approach is used to describe the energy demand dynamics in buildings sector in interaction with urban growth, this dynamics is quantified in a structured model. The dynamics of housing construction and demolition and the energy demand evolution will be simulated in a prospective way. The main task is to perform a systematic study in the whole evolving stock in order so as to prove the existence of optimal path of development of buildings energy efficiency. I am inclined to explore the economic and environmental consequences of decisions by taking into account the building efficiency.

Case studies will be carried out in the city of Tianjin to address heating efficiency in buildings, heating and cooling consumption is closely related to building's energy performance unlike other DSM techniques such as appliance efficiency improvement or behaviour savings. Also, heating (including water heating) and cooling together account for the great majority of energy consumption in buildings.

The primary criterion of determining the optimal path follows the neoclassical theory to maximise the social welfare by minimising the present value of the total cost throughout the whole analysis period. Hence, the goal of modelling is to identify the least-cost option that minimises the present value of investment of the whole energy system including the costs of construction of housing which vary with the thermal quality (i.e. a more efficient house needs more overnight investment to improve the insulation, ventilation, integration of renewable etc.), cost of environmental externalities (among others, greenhouse gases) will be considered as well in our analysis.

As to the cost related to building construction, sole the part relating to energy efficiency improvement is taken into account in the model. In our analysis in order to specify the boundary of calculation and to simplify the analysis complexity, we focus on the economic evaluation of realistic and technically available solutions portfolio of building efficiency progress and relevant energy supply system development.

The model assumes implicitly that the overall social welfare is increased when the buildings are constructed efficiently by using less energy compared to the conventional one. The arguments for the

welfare improvement are multiple and straightforward as well, improved thermal comfort and healthier indoor condition, energy bill savings for end-users, cut of capital investment in new heat and electricity generating capacity, reduction of greenhouse gases emission and local air pollution by burning less fossil fuels, alleviation of the tension of insecurity of energy supply, creation of new job opportunities in the area of building energy efficiency; etc. Nevertheless, it is out of the scope of the research to take into account the welfare change of all the economic sectors. The model considers the following costs in the calculation boundary.

- energy performance enhancement cost including efficient building materials, envelope insulation, ventilation, metreing, regulation system etc
- Fuel cost (coal, natural gas, oil, electricity¹⁵)
- capital cost of heat and electricity (average and marginal investment in increasing new generating capacity to meet the growing demand)
- fixed operation and maintenance cost
- variable O&M cost
- cost of environment externalities

Breakdown of costs can be schematized in the following diagram

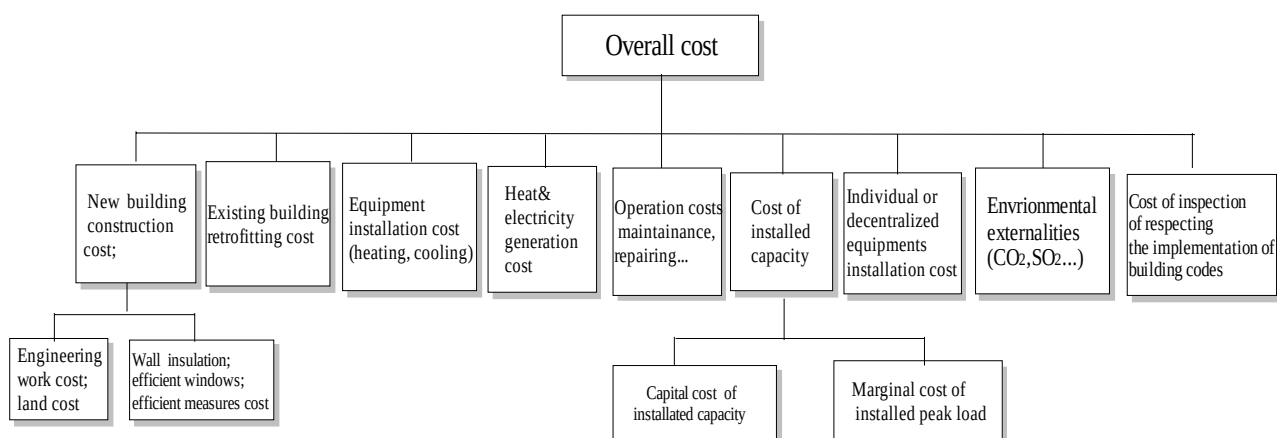


Figure 3-1 Breakdown of analysed cost in the model

As explained above, the fundamental objective of modelling process is to identify an optimal BEE improvement strategy that will allow minimising the overall social costs during the entire trajectory (pathway). This pathway will be identified based on the results of simulation of different scenarios in which a variety of costs associated with buildings quality in terms of energy performance, energy supply and demand technologies and environmental impact (global warming) will be considered. Our scenario study is mainly drawn based on modelling approach because:

¹⁵ Electricity cost is calculated in the transformation modular, see the Appendix for more details

- The modelling simulation would allow, through the scenarios building with plausible assumptions of socio-economic evolutions to anticipate the energy demand consequences as well as possible environmental impacts due to economic development.
- Once quantified in the scenarios, it is possible to compare the energetic and economic stakes implied in the results of technology selection and the energy production and the consumption in building sector. The long-run forecasting of energy demand by modelling method will make it possible to explore the possibility of socially optimal portfolio combining the energy system and buildings energy performance improvement policies;
- Various policy instruments for energy efficiency such as tax, ling; carbon emission tax could be introduced respectively for testing the sensitivity of the variables. The quantification of energy demand in elaborated scenarios will facilitate identification of efficient policy instruments and allow minimizing the social cost over the period under consideration.

The scenario BAU defines the reference level to which the alternative scenarios will be elaborated according to assumptions formulated on the variables: economic growth perspective, household's income, population, urbanisation rate, the building construction; equipment penetration in households, technology selection, the evolution of building thermal comfort level; existing buildings rehabilitation and retrofitting; long-term energy supply and energy mix structure evolution. Once the parametres of reference are determined, it will be straightforward to analyse different simulation results by varying the assumptions.

3.2 Assessment of energy models

Policy making in the energy sector is strongly influenced by models designed to forecast the effects of policies on energy demand, economic output and energy-related pollution. Over the past quarter of century, substantial efforts have been made in developing number of energy models for quantitative analysis so as to provide policy making recommendation. A number of models have been developed internationally. The increasing environmental concerns on global warming has been stimulating the energy modellers to develop more sophisticated energy models coupled with climate change assessment models. Both process analysis and econometrics have been used in the development in the models for energy policy assessment. The process approach provides for the incorporation of information on future technological and structural changes based on detailed engineering studies. The econometric approach is well adapted to the description of aggregative consumer behaviour and economic activity (Hoffman and Jorgenson, 1977).

The purpose of using an energy model in scenario analysis relies on three rationales (Heaps, 2002)

1. Model can reflect complex system in an understandable form
2. Helps to organize large amounts of data.
3. Provides a consistent framework for testing hypotheses.

As the climate change become a heated debate subject in energy economy analysis ,policy makers are more and more interested in the effectiveness and cost of policies aiming at shifting the energy system toward more environmentally desirable technology paths(Hourcade *et al.*,2006). Over the past quarter-century, the increasing energy demand and environmental concerns spurred the creation of many economy-energy models which can be classified into two major categories (Rivers and Jaccard, 2005).

1. Top-down models and Bottom-up models. Which describe the energy system in terms of aggregate relationships derived empirically from historical data
2. bottom-up models, which determine the financially cheapest way to achieve a given target based the best available technologies and process

Also, the development of sophisticated energy models have been largely supported by fast development of computer based calculation software.

3.2.1 Top-down (T-D) model

SGM (general equilibrium) , TIMER are the most representative example is this category of models. Besides, World Energy Model (WEM) is developed by the International Energy Agency (IEA) which has provided medium to long-term energy projections. The WEM is a partial equilibrium model consisting of a large-scale mathematical interrelation to replicate how energy markets function. Unlike SGM in which the model seeks the optima (the best-solution), some TD model use dynamic simulation methodology , represented by the model IMACLIM-R (Crassous *et al.*, 2006) which use a recursive solution with equilibrium in each time period.

3.2.2 Bottom-up models

- Energy sector optimisation model

MARKAL (MARKet ALlocation) and MESSAGE (Global energy systems model from IIASA) are the most typical energy system optimisation models. These models are used typically to identify least-cost configurations of energy systems based on various constraints (e.g. a CO₂ emissions target) and to select among technologies based on their relative costs.

- Simulation models (Poles)

They allow the modellers to simulate behaviour of consumers and producers under various signals (e.g. prices, incomes, policies), although this may not be “optimal” behaviour. The iterative approach is used to find market clearing demand-supply equilibrium. More specifically, energy prices are endogenous in this kind of model. Theses models enable the modeller to explicitly specify outcomes rather than simulate the

behaviour of a system in which outcomes are unknown. Main function is to manage data and results. LEAP, MEDEE are classified in this type of models

Two key parameters are integrated in Top-down models , 1. Elasticity of substitution (ESUB) which defines how easily one aggregate input can be substituted for another as their relative prices change; 2. Autonomous energy efficiency index (AEEI) , which defines how quickly energy efficiency increases in economy. These two parameters are usually estimated from historical data.

Generally speaking, economists are more familiar or attracted from TD prospective in energy-economy modelling while technology experts' optimisation growth models are usually very limited in terms of technological details (Bosetti *et al.*, 2006). Traditionally , BU models have modelled technological change through learning-by-doing (learning curve function), while TD models have focused on investment in R&Ds of new energy supply technologies (Hourcade *et al.*, 2006).

Both types of models are used to predict the potential economy effects of energy-focused environmental policies in particular climate change mitigation policies (Rivers, 2005). The main drawback in the Top-down model is that there is no guarantee that values derived from past experience will remain valid into the future (Grubb *et al.*,2002). It may also happen that consumer's preference change due to increase in environmental risk awareness. In fact, the AEEI and ESUB index can change dramatically in the future as financial costs of technologies change rapidly. Past experiences show that cost of emerging technologies follow a diminishing function due to economies of scale and learning-by-doing mechanism, the rate of decrease can be modelled mathematically; e.g. With every doubling of cumulative capacity or cumulative energy production, the costs fall by a constant fraction of the original costs Typical learning rates within the renewable energy sector are about 20% for photovoltaic (referring to cumulative installed capacity), 18% for wind energy¹⁶ (Edenhofer,2005).

3.2.3 Hybrid model (e.g. WEO-ECO; Imaclim-R)

Finally, some energy modellers strive to bridge the gap between Top-down and Bottom-up models. These models link macroeconomic impact on final consumers' decision and has more specific technology options. This often means that BU models include macro-economic feedbacks or micro-economic realism for technology choices in their architecture or TD models incorporate explicit technology description in their general equilibrium framework (Roques et Sassi,2007 citing Manne and Wene, 1992; McFarland *et al.*, 2004 and Rivers and Jaccard, 2005). The hybrid model aim to create interactive dialogue between economists and engineers to improve robustness and relevance of energy and economic models.

China energy research institutions also developed a series of models based on Chinese economy characteristics. A large amount of effort of integrating the general equilibrium model and technology

¹⁶ referring to cumulative installed capacity

section model has been made. For example, Chinese Energy Research Institute integrated bottom-up models (AIM/Tech, Message, AIM/Local) into Top-down models (SGM, TIMER, IGEM) to simulate China's energy demand and emission scenario. Jiang and Hu(2006) use IPAC model to predict building energy demand in China up to 2030.

A model to be used for climate policy analysis should be able to capture the dynamics of technical change and the relationships between technical change and the main economic and policy variables(Bosetti *et al.*,2006). Hourcade *et al.*(2006) outlined three fundamental dimensions in energy-environment policy modelling: 1. technologically explicit , 2.behaviourly realistic and 3.macroeconomic feedback linking energy supply and demand to the evolution of economy's structure.

Although there are increasing effort in integrating technology explicitly in the TD energy-economy models, the energy supply technology and demand behaviour are still much less than in the bottom-up models. However, compared with Top-Down energy models, there exists nevertheless some drawbacks of BU models in which the endogenous learning are limited in their characterisation of technology diffusion and innovation, the important aspects of diffusion behaviour that are captured in top-down representations are generally lacking and they neglect important general equilibrium impacts (such as the opportunity cost of redirecting R&D support to the energy sector (Berglund and Söderholm 2006). Our primary concern is to construct different hypotheses that make meaningful sense in terms of economic and technological feasibility. The modelling process is comprised of following steps:

1. Formulate different options or strategies (demand and supply) which are coherent both from political and technological point of view
2. Simulate the scenarios and compare subsequent energy , environmental and economic consequences in order to find the most pertinent strategy of BEE improvement and appropriate supply technologies.

It must be pointed out that the model we try to develop is not an optimisation model (e.g. MARKAL) but a simulation model. For ease of discussion of modelling results; the most appropriate strategies selected from simulated scenarios are termed simply by “optimal choice” which should not be interpreted as mathematical optimisation programming.

The modelling objective is to create dialogue with the decision makers by assessing different investment strategies (supply and demand) in different time horizons (now and future) and respective consequences. Our modelling focuses on studying the different policy scenario relating the technical choice to the economic assessment. We choose the model LEAP to perform the research tasks mainly for its transparency and user-friendly characteristics and also for the following reasons

1. LEAP is a simulation model that allows modellers to simulate different plausible scenarios of energy demand and carbon dioxide emissions

2. it is a transparent model which consists of four major module: assumptions (where we construct all the variables of the model) , demand (where different categories and sectors of demand for energy services are specified), transformation (different supply and conversion technologies are available) and energy production (energy resources extraction and refining: coal, oil, gas...)
3. We analyze the cost and benefit of certain strategies given building energy performance and energy system, in other words, this is a closed system without direct interaction with the non-energy sector. The purpose is to draw different storylines (scenario) about the consequences of investment trade-off, i.e. investing more today in efficiency enhancement to avoid spending more tomorrow when the demand increases progressively, or invest immediately more in supply without consideration of demand side efficiency improvement. No general or partial equilibrium of economy-energy system is required in our analysis; energy price is an exogenous variable in the model can is not simulated endogenously; this facilitates the comparison of economic consequences of decision made now.
4. LEAP allows the modellers to compare different technology portfolio in very detailed way, in our case, we can clearly test the different technical intervention package on building's thermal performance in different time span and quantify the relevant energy demand and the relevant cost, both demand and supply side technology can be introduced in flexible way without constraints of equilibrating energy price on macroeconomic level. As mentioned above, in a typical Top-down model, Technology option is decided in competitive way through the CES mechanism, we loose the flexible interface for calibration on bottom-up technology expertise. In other words, modellers cannot direct define the share of different technology in the Top-down model since their market shares are allocated endogenously in the model. While we can explicitly test all the possible technology portfolio combing both demand and supply efficiency improvement, whereas the conventional TD models represent technological change as an abstract , aggregate phenomenon –implicit in the substitution elasticity , an approach well suited to helping policy-makers assess economy-wide price instruments such as taxes and tradable emission permit, but have difficulties in assessing the combined effect of these price-policies with technology-specific policies(Hourcade *et al.*, 2006). Even in the hybrid models, technology selection still have limitation (Köhler *et al.*,2006) and focus mainly on supply-side technology options , in particular in power sector (PV combustion, IGCC, CCGT, CCS etc.), thus can not address directly the question raised in the research.

3.3 Description of LEAP

LEAP is an Energy-Environment integrated model and consists of following components (Module):

- Assumption of model
- Demand
- Production & transformation
- Resource

3.3.1 Description of the modelling process

LEAP consists of four interlinking modules; each of them has a specific characteristics to represent assumption, energy demand, energy supply (production and distribution) and natural resources respectively.

In the “Assumption” module, we formulate a number of hypotheses: economic growth, population, urbanisation, per capita living area, building energy performance, appliance ownership, thermal comfort requirement, evolution of new building code, policy of retrofitting existing buildings etc.

In the “demand” module in LEAP, energy demand in buildings sector is disaggregated into different homogenous energy service sectors: heating, cooling, lighting, cooking, electrical appliances¹⁷ etc. The level of demand for that service is determined by the criteria in the exogenous variables including socio-economic factors, technology, and energy price. The heating consumption is particularly influenced by the thermal quality of constructed buildings; nevertheless the consumers’ behaviours are far from negligible. It is thus of great interest to find out how the people’s demand for energy service will be moving with respect to the socioeconomic development, in our model, the degree of demand for thermal comfort of residents are modelled exogenously, mainly through the parameters of indoor temperature setting and heat degree days.

The “technology” module brings together all the data relating to technological characteristics, and applies the corresponding energy efficiency to each specified end use; final energy demand can be derived from the calculated specific usage (service) and employed technology (e.g. gas boiler or coal oven). For example, electricity is used to run the air conditioner or the solar water heater and is generated in a thermal power plant that we define in the of energy supply.

Once energy demand (energy source, intensity) of the end users has been identified, the energy flow will simultaneously routine to the modular of “transformation” module, where the model calculates the total consumed primary energy consumption.

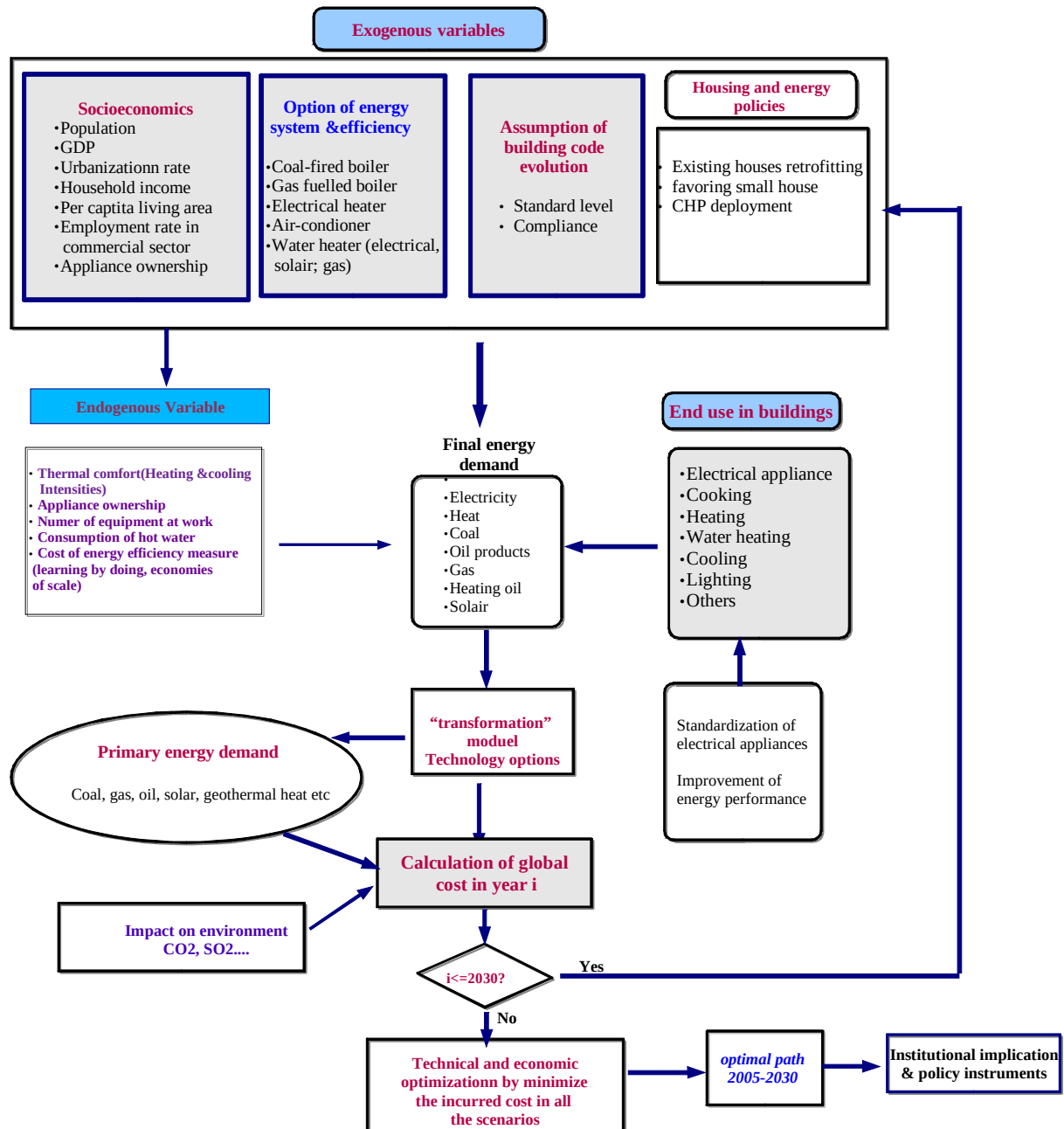
We build step by step an operating account that traces all induced costs: capital cost in increase in power and heat generating capacity, fuel cost, cost of building efficiency measures, O&M cost (maintenance, labour, taxes); cost of technical process (e.g. desulphurisation). All the costs associated with energy demand of buildings are set year by year, will be levelised in order to render them comparable at present.

Consequently we compare all the results of formulated scenarios, finally we are allowed to select the optimal scenario which refers to the investment portfolio in energy efficiency operations and supply

¹⁷ Consideration of cooking, lighting and other appliances energy use is to better calibrate the model to supply-demand balance, while energy efficiency of buildings doesn’t have direct impact on these consumptions.

infrastructure that minimizes the levelised social cost for the society throughout the entire path of development, environmental externalities costs will also be considered in the case representing the pressing climate constraints. Similarly, we can model in different scenarios the long term public policies to adjust energy demand. In this section, we can introduce the specific policy initiatives such as existing building retrofitting or fuel switch.

The prospective analyses enable us to explore the energy saving potential in the buildings in the two cities and then to compare the respective costs according to assumptions, whose results will lead us to approach socially optimum point. However, scenario analysis does not equal to prediction energy demand future, nor to claim in a normative way to simulate exactly energy consumption patterns for consumers in the cities, instead we adopt a positive view point by demonstrating the likely pictures reflecting the energy policies adopted in different time horizons. i.e. what could be the future of the energy demand in the buildings along with socio-economic development with the various choices of investment in the energy system and in the building ? Based on the output of scenarios, we evaluate consequences induced from the economic, energy, and environmental perspectives. The structure of model is presented in the following diagram.



3.3.2 Estimate of energy demand in buildings

- residential buildings

Energy demand in residential building sector is calculated on the basis of energy intensity and activity level; this can be represented straightforward by the equation 1

$$FD_r = \sum_{i=1}^m \sum_{j=1}^n \frac{EI_{ij} \times A_{ij} \times SR_{ij}}{EE_{ij}} \quad (1)$$

where

FD	is the total final consumption in buildings sector over the period
EI_{ij}	is the energy intensity of end-use i ($i = 1, 2, \dots, m$) in building in year j ($j = 1, 2, \dots, n$), which captures the thermal performance and technological change over the simulated period; in KW/m^2
A_{ij}	is the level of activity of end-use i (e.g. floor space area, ownership of appliances) in year j
SR_{ij}	is the saturation rate of energy use i in year j
EE_{ij}	is the energy efficiency of service i in year j

- commercial buildings

For energy demand of commercial building modelled in the district analysis in Tianjin, we apply a simplified method, represented by the equation 2

$$FD_t = \sum_{i=1}^m \sum_{j=1}^n FS_{ij} \times FC_{ij} \quad (2)$$

where

FD_t	is total energy demand in commercial buildings
FS_{ij}	share of fuel i in heated or air conditioned floor space area in year j in per cent
FC_{ij}	consumption of fuel of type i in kWh/m^2 in buildings in year j

3.3.3 Discussion on discount rate in economic assessment for scenario analysis

To address uncertainty of future, economists use discount rate to balance the risk on investment on new technologies such as high performing energy efficient technologies¹⁸, since the benefit of investment(today) will be received gradually in the future (tomorrow), the assessment should in this regard address the difference in both time and space dimensions. Generally, to render the cost and benefit between now and future comparable involves an analysis of time preference (discount function) and risk preference (utility function) between the different agents. This is why a discount rate should be applied when analyzing a project of long-term investment such as building energy efficiency improvement to avoid carbon lock-in.

¹⁸ For example, financial risk in all the renewable energy supply system, biogas production, or fuel cell technology has to be considered for private investors and utility companies.

In economics, to determine what is the appropriate discount value, one has to ask at what value of “ r_d ” in the way one is indifferent between an amount of “ P ” today and an amount $F_n = \frac{P}{(1+r_d)^n}$ one year from now. “ r_d ” is referred to as private discount rate. The major difficulty in benefit –cost analysis of environment and energy-related issues is that the discount rate may not necessarily be the same from one to another. But in many circumstances, when consumers and firms face a program of adopting new technologies, the relevant risks are not perceived in the same way; since time preference varies from one to another in the society. So therefore, an alternative which called the social discount rate is used as the proxy of whole population in the energy and climate economic analysis literature. Economically speaking, this social discount rate is determined by the tangent point between the curve of social time preference and social production frontier curve. The time preference curve represents the marginal rate of substitution of present to future consumption. But what discount rate should be applied to social investments? It is standard to use the market interest rate, thereby respecting private preferences. Caplin and Leahy (2004) argue that under more reasonable conditions, policy makers should be more patient than private citizens, whose choices define the most short-sighted Pareto optimum. The debate on the choice of appropriate discount rate in environment policy analysis is hotly debated in many environment related literature, in particular, the issue of intergenerational equity in climate policy analysis (Arrow *et al.*, 1996) .

In this research, the time span onward to 2030, a medium run compared to the time horizon in the literature of economic analysis of global warming in which modellers have to project very long term climate consequences generally extending to 2100 and onward, as climate change will only take effect in several generations. Therefore we exclude in our research the intergenerational equity concerns in the energy supply and demand analysis.

Moreover, as mentioned in the previous section, our major objective is to identify the building efficiency regulation development path which accounts for the least cost within the boundary of energy system by taking into account of environmental impacts relating to the use of energy-consuming devices in building sector such as space heating and cooling, water heating etc. The choice of discount rate is rather based on risk adverse principal from a social planner’s perspective in order to avoid the controversial academic debate on the way of valuing appropriately the benefit or loss of future generation, which is a key issue to be addressed in most of literature of economics of climate change. For instance, Stern Review (Stern, 2006) uses an extremely low social discount rate (0.1% per year) for the sake of taking fully into account of environmental hazards in the future caused by climate change from global perspective.

The underlying difficulty in economic analysis of energy efficiency program is that the high marginal rate of return on investment in private sector, in particular on the property market in China today results in a high social discount rate used in public and private investment project appraisal. In our research, we

determine the discount rate in assessing the cost based on the rate of return on traditional project appraisal of investment in public works. Hence we adopt 8% as discount rate with respect to the benchmark of long-term credit interest rate set by the People's Bank of China (7.83%)¹⁹. This is consistent with common literature regarding the environment and energy studies in China, among others, Lu and Liu. (2005); Liu (2006).

References

- Arrow, K.J. *et al.* (1996), "Intertemporal Equity, Discounting, and Economic Efficiency", in IPCC (1996), *Climate Change 1995: Economic and Social Dimensions of Climate Change*, Contribution of Working Group III to the Second Assessment Report of the Intergovernmental Panel on Climate Change, edited by J.P. Bruce, H. Lee and E.F. Haites (Cambridge: Cambridge University Press).
- Berglund, C and Söderholm, P. 2006. Modelling technical change in energy system analysis: analyzing the introduction of learning-by-doing in bottom-up energy models. *Energy Policy*; Vol. 34 Issue 12, p1344-1356.
- Caplin, A and Leahy, J. 2004. The Social Discount Rate.
- Heaps, C. 2002. Integrated Energy-Environment Modelling and LEAP. 2002. Powerpoint presentation. SEI-Boston and Tellus Institute.
- Hourcade, J.-C., Jaccard, M., Bataille, C., Gherzi, F. (2006) Hybrid Modelling of Energy-Environment Policies: Reconciling Bottom-up and Top-down. Special Issue of the *Energy Journal*.
- Hoffman, K.C. and Jorgenson, D.W. 1977. Economic and technological models for evaluation of energy policy. *The Bell Journal of Economics*, vol.8 (2), pp.444-466.
- IEA, 2000. Experience curve for energy technology policy, International Energy Agency, Paris, France .
- Köhler, J., Barker, T., Anderson, D., Pan, H. 2006. Combining Energy Technology Dynamics and Macroeconometrics: The E3MG Model. *The Energy Journal*. 2006. Special Issue.
- Lu, X. and Liu, D. (Eds). 2005. *Clean Development Mechanism in China*. Tsinghua University Press. 177 p.
- Liu, F. 2006. World Bank Interim Report on Tianjin GEF project.
- Nakicenovic, N. 1997. Technological Change and Diffusion as a learning process. *Perspectives in Energy* 4(2), pp.173-189.
- Mao, Y. 2002. Debate on social discount rate.
- Rivers, N. and Jaccard, M. (2005). Combining Top-down and Bottom-up Approach to Energy-Economy Modelling Using Discrete Choice Methods. *The Energy Journal*. vol.26(1). pp 83-106.
- Söderholm, P. 1998. The modelling of fuel use in the power sector: a survey of econometric analysis. *The journal of energy literature* 4(2):3-27.
- Thompson, P and Taylor, T.G. 1995. The capital-energy substitutability debate: a new look *Review of economics and statistics* 77(3), pp.565-569

¹⁹ Available at the website of the Chinese central bank (The People's Bank of China).

Chapter 4 Economic analysis of BEE in a new residential area

4.1 Introduction and summary

This chapter attempts to investigate the optimal strategy of building energy efficiency (BEE) standard and energy supply infrastructure development in a new housing construction programme in the city of Tianjin, a typical northern city in China²⁰. The primary objective is to find out what is the best strategy for the Chinese local authority in the development of a new residential zone where buildings and energy supply infrastructure will be constructed. The envisaged investment in technologies in this chapter consists of one time decision strategy since the object of analysis is new buildings that will be constructed in the same area simultaneously. By evaluating the global costs of buildings construction, energy supply infrastructure development and buildings operation and environmental impact, we compared the energy consumption and relevant environmental and economic implications of implementation of different BEE code prescriptions. The results demonstrate that the current BEE standard implemented in the Chinese cities should be tightened further in order to achieve a socially optimal level. Without considering the externality costs associated with carbon dioxide (CO₂) emission, current BEE standard need to be upgraded to the equivalent level of the French *RT2005* standard coupled with a properly designed district coal-fired combined heat and power (CHP). In contrast, the performance standard that equals to the Swedish building code (Best Practiced Technology) is preferably to be implemented in the case of explicit carbon emission restriction so long as the marginal cost of carbon emission (carbon tax price) is sufficiently high.

Strikingly, we find that the discounted global costs of adopting the energy performance complying with the Swedish building code (the best available practices and one of the most stringent in the world) will be lower than implementing the current TJ2004 BEE standards even without any considerations of carbon value. implying that that China needs to tighten the BEE standards to achieve the optimum level even without any specific climate objectives. In addition, we compare two strategies of decarbonisation of energy consumption in buildings.

Strategy 1: pursuing the current building code , i.e. business as usual and switch from coal to natural gas in energy supply immediately; or

Strategy 2: construct more efficient buildings complying with the Swedish BEE standards and switch to from coal to gas to reduce carbon emissions

The results of economic analysis show that cost of CO₂ emission abatement would be four time costlier in strategy 1 than in strategy 2. This gives a strong policy guidance for China in dealing with the increasing concerns about carbon emissions mitigation in large-scale long-life infrastructure such as buildings; improvement in the energy performance (quality of buildings) should be considered as the top priority and

²⁰ We studied the city of Tianjin based on its typical characteristics of energy supply organisational structure and a generalised city-wide urban district heating infrastructure that has been well developed in the city since 1980s.

must be taken before considering low-carbon supply options such as fuel-switching or renewable heating (solar, biomass CHP etc) , because better energy efficiency of buildings is more likely to facilitate the penetration of low-carbon supply and will allow to achieve carbon emissions reduction more cost-effectively compared with the actions taken solely on supply-side solution. The results provide meaningful guidance to the buildings energy efficiency and environmental policy for the decision makers in China.

As mentioned in Chapters 1 through 3, the concerns about building energy efficiency in China has received considerable attention in recent literature (Lang, 2004; Wang *et al.*, 2007; Zhou *et al.*, 2007; Lam *et al.*, 2008; Li, 2008). A recent review study suggested that buildings energy-related CO₂ emission in China could be reduced by 24% in 2020 and by nearly 25% in 2030 in policy scenarios compared with business-as-usual (BAU) scenario(Li, 2008). Wang *et al.* (2007) developed an interesting approach to set up an indicator that allows for evaluating the most cost-effective way of buildings wall insulation in a northern city in China from a building life-cycle analysis perspective. Lee and Chen (2008) employed a benchmarking approach to assess the efficiency performance of the Chinese building efficiency regulations relative to the Hong Kong building code. However, most of these studies focus on the demand-side efficiency improvement in buildings and few of them have integrated the dimension of energy supply and fuel choice options, in particular in the context of large-scale district heating in northern China where huge potentials of energy conservation and carbon emission mitigation remain untapped.

Although all these studies suggested that the current Chinese BEE regulation could be upgraded without significantly incremental costs, explicit quantitative objective regarding the optimum of building efficiency advancement from economic analysis perspective has not been specified in none of previous studies. The modelling approach is employed extensively for exploring the energy savings potentials relating to sectoral efficiency policy implementation in all energy consuming sectors. In the following sections, we model the energy demand scenarios and quantify the relevant cost implications on the basis of a physical accounting model consisting of space heating and water heating consumption in residential and commercial buildings in a representative northern city of China, along with the upstream energy supply technology options. The primary objective of this study is to investigate the different BEE scenarios and energy supply options in order to identify the optimal prospective choice of thermal efficiency requirements in the building code specification for new construction in the context of rapid pace of urbanisation in China. Both the calculations with and without CO₂ emission costs are undertaken.

The following section briefly reviews the building consumption situation and current building efficiency regulatory framework. Section 4.3-4.8 describes the methodology of quantification approach and assumptions on determining variables. Section 4.9 discusses the modelling results and policy implications. Some conclusions are provided in section 4.10.

4.2 The current status of mandatory codes for BEE

4.2.1 National building codes

Lang (2004) describes comprehensively the progress in mandatory building energy-efficiency codes for residential buildings in China. In the framework of BEE and heat supply reform pilot project in Tianjin, in collaboration with the World Bank and GEF, Liu(2006) outlined a brief description on the process of China's building energy efficiency regulatory standards enforcement and implementation , in particular in the cold climate regions, the case of the city of Tianjin is highlighted in this study.

Lee and Chen (2008) tried to benchmark the Chinese and Hong Kong building code (HK-BEAM) to compare the respective performance in the context of warm climate where cooling demand dominates other energy uses in the buildings. Their results show that compliance with the Chinese building code is about 50% more efficient in energy use than the adoption of Hong Kong code.

The object of this study is centred on buildings heating efficiency; the air conditioning (cooling) respect is out of the scope of this study. The following lines summarises succinctly the historical development of the China building codes.

China is divided into five climate zones according to the national “Standard of climatic regionalisation for architecture GB50178”, severely cold, cold, hot summer and cold winter, hot summer and warm winter and moderate zone respectively (MOC, 1993). The current regulatory framework for buildings energy efficiency in China related to energy conservation stipulates thus the efficiency technical standards for the corresponding climatic zones and types of buildings. So far, four national building efficiency codes constitute the essential regulatory body setting mandatory efficiency requirement for both residential and commercial buildings.

The first building efficiency code (evaluation version) “Energy conservation standard for heating in new residential buildings JGJ26-86” was released as a document for comments (not mandatory) in 1986. The revised version, JGJ26-95, with an energy savings goal of 50% was stipulated in 1996, referred to as RBEEDS-95 hereinafter. The RBEEDS-95 includes minimum energy efficiency requirements for newly constructed (or expansion of) residential buildings and associated central heating systems. The RBEEDS-95 aimed to reduce the specific space heating energy consumption of newly-constructed residential buildings in the cold regions by 50%, compared to the typical housing design in the early 1980s, by improving building envelope thermal integrity as well as heat supply energy efficiency.

Since then other building codes have been issued successively to regulate the building energy efficiency in the zones other than the cold climate zones. Building code, JGJ134-2001, is implemented to enhance electricity consumption efficiency for heating and cooling in residential buildings in the so-called hot

summer and cold winter zone which covers basically the Yangtze River basin. RBEEDS-2003, introduced in 2003, was aimed at instituting technical standards for residential buildings in the warm climatic zone (southern provinces) to reduce the cooling load in hot period. In addition, the PBEEDS-2005 (GB50189-2005) becomes effective since 2006, prescribing compulsory provisions of minimum energy performance for public and commercial buildings throughout the country²¹.

In addition to these building codes, the Thermal Design Code for Civil Buildings (GB/T50176-1993) established residential, commercial and public buildings underlying energy performance design standards and marked the cornerstone of building efficiency design. Major technical intervention measures and solutions for improvement in building heating energy conservation and thermal comfort amelioration are described in depth in this code.

Similar to the building codes implemented in other countries, two compliance approaches coexist in the Chinese building codes which focus on buildings envelope performance (Lee and Chen, 2008). One is prescriptive which stipulates the maximum allowable heat transfer coefficients (*U*-value) for various building envelope components at the prescribed shape factors (ratio of area of building envelope to the floor area). Heat transfer coefficients, shape factors, window-to-wall area ratios based on orientations are stipulated for different climate zones. If the design of the residential building cannot satisfy the prescriptive requirements, the performance-based approach is used to assess the integral building efficiency. This approach stipulates the maximum allowable heating/cooling consumption of a building compared to the baseline case, very commonly employed in the building energy efficiency assessment in the hot summer and cold winter climate zone where the designer can tradeoff between the heating and cooling performance since the code regulate the overall energy consumption of a building.

Although building efficiency has improved significantly since the enforcement and implementation of the aforementioned building codes, in particular in the northern cities where districting heating represent more than 50% of buildings energy consumption (Zhou *et al.*, 2007), the average heating intensity is still much higher than developed countries, especially in the Scandinavian countries.

4.2.2 Technical specification in the Tianjin building energy efficiency Standard (1997 and 2004 update)

The building codes are enforced by the Ministry of Construction (MOC) and their provincial subsidiary (commission of construction). In the current building energy efficiency regulatory framework, to enhance the implementation of national codes, the local authorities are responsible for setting up local and more specific standards regulating the building energy conservation design and employment of materials, on the

²¹ The PBEEDS-05 differs from the previous residential building codes since in terms of scope of intervention, it regulates not only heating and cooling consumption, but also defines mandatory values for lighting, ventilation, electric appliances& end-use equipments as a whole.

basis of national standards mentioned above. Major cities and provinces like Beijing, Tianjin, Shanghai, Hubei, and Guangdong have all adopted local building efficiency regulations to address the locally specific difficulties related to building energy use. Provincial and municipal regulations and codes play an important role in implementing the national standards (Lee and Chen, 2008).

Tianjin was one of the pioneer cities to implement the building energy efficiency policies in residential sector in China during the 1980s. As mentioned above, National RBEEDS-95 set the general guideline for efficiency design, it is then up to local construction administration (Municipal Commission of Construction in general) to transform the national standard into local building code by taking into account architectural and climatic characteristics. Tianjin adapted the National RBEEDS-95 into Tianjin RBEEDS in 1997 (TJRBEEDS-97), and introduced a revised RBEEDS in 2004 (TJRBEEDS-04), which raised the stringency of thermal integrity requirements and introduced requirements for heat metering and user control and regulation installations in new residential buildings. Compliance with TJRBEEDS-04 would result in a further reduction of specific heating energy consumption of new residential buildings by 30% from the level achieved by complying with TJRBEEDS-97.

To compare the cost-effectiveness of compliance with different levels of energy performance in the building codes in Tianjin and other countries, we selected three foreign countries as the benchmark, Canada, France, Sweden; all three have enforced and implemented the most stringent building codes in the corresponding climate.

4.3 Methodology

We construct different building energy performance scenarios for a new residential buildings development programme in which energy supply infrastructure is also taken into account. Then we elaborate the scenarios of different strategies of BEE improvement and energy supply infrastructure options. Various costs will be incurred at different stage of the development of this new zone, including upfront capital costs in buildings construction and energy supply development, in operations (fuel consumption and maintenance of system), and lastly the environmental externalities (represented by CO₂ emissions). A technical-economic model is elaborated to combine the building and heat supply efficiency and economic analysis, allowing identification of optimal combination of building efficiency and upstream energy supply system by minimising the global costs. The analysis process is divided into two major steps. First, we simulated the total final heating requirements in different BEE implementation scenarios in which buildings are designed to be in compliance with the performance standards in relevant regulations and codes. Second, based on the assumptions on types of space heating and water heating supply system, primary energy supply and fuel combustion-related emissions will be estimated accordingly. Five heating supply technology options are considered in the model, their relevant features will be compared with detailed description in section 4.7. The modelling time frame cover a 20-year period, starting from 2006 to 2025,

consistent with the lifetime of building insulation materials²² and small and medium-sized heat supply boilers. The discount rate used in the calculation is 8%, approximately equivalent to the indicative value of the long-term housing mortgage loan interest, set by the Chinese central bank. This is consistent with today's marketplace real interest rates and savings rates in the widespread benefit-cost economic analysis approach on climate change. The debate on intertemporal and intertemporal discounting of the economics of the climate change is out of the scope of this study, for more details see (Mendelsohn, 2007, Nordhaus, 2007a, 2007b, Stern, 2007, 2008).

4.4 General buildings typologies and characteristics

We model the final energy demand and primary energy supply in a virtual new developed residential district where different energy supply infrastructures can be envisaged. The main assumptions on residential buildings development and energy supply infrastructure are as follows. The district covers an area of 10 sq. Km² in the new development zone, located in the southeast of the new urbanised area (Binhai New Area) of Tianjin. It is assumed that the plot ratio of land use within the district is 2.1. Residential and commercial buildings are supposed to account for 70% and 30% of the built-up floor area, respectively. Two types of housing and three types of commercial buildings are considered in this model area. It is assumed that all dwellings built in this area are multi-apartment as the single detached house is very rare in China's urbanised area, with exception of high-end luxury property. For housing, it is housing floors of 5-6 and 10-12 storey heights most common in Chinese cities. They represent respectively 40% and 60% of the total housing floor area. In addition, offices, hotels and shopping centres are included in the model to calculate the heat load and energy consumption. The main characteristics of buildings are summarised in Table 4-1.

Table 4-1. Breakdown of floor area by building types

	Residential		Commercial buildings		
	Low-rise buildings (<6 floors)	High-rise buildings (>10 floor)	Office	Hotel	Commercial centre
Single building size (in m ²)	5476	6507.5	20000	14000	17000
Number of buildings	161	90	21	3	10
% in the total area in the zone	42%	28%	20%	2%	8%

²² Most of good quality of insulation materials (e.g. expanded or extruded polystyrene) can last more than twenty years, however the thermal characteristics will deteriorate significantly under unfavourable weather after this period.

4.4.1 Heating intensity estimation

Five BEE scenarios are considered in the model, denoted by TJ-97 TJ-2004, TJ-CAN, TJ-RT2005 and TJ-SWE respectively. The three alternative scenarios require compliance with the current Canadian, French, Swedish efficiency requirements (building envelope thermal characteristics) in the new construction in Tianjin.

Heating intensity is calculated by using a simplified steady-state heat transfer equation. Two specific indicators are defined specifically, namely U_{env} and D_{bldint} , they are used a proxy of the overall building envelope performance and buildings integrated energy efficiency (including air tightness performance), respectively. They are defined in equation 4.1 and 4.2 respectively.

$$U_{env} = \frac{\sum_{i=1}^i U_i \cdot A_i}{F_{env}} \quad (4.1)$$

and

$$D_{bldint_m} = \frac{\sum_{i=1}^i \psi_i U_i A_i + C_p \rho N}{F S_{bld}} - \frac{IHG}{\Delta T} \quad (4.2)$$

D_{bldint_m} is the integrity energy efficiency parameter of building type m

ψ_i is the correction coefficient to take into account the solar heat gain of envelope i

U_i is the heat transfer coefficient of building envelope i (wall, window, roof, floor etc)

A_i is the corresponding area of the envelope

C_p is the heating value of air in Wh/kgK

ρ is the air density in kg/m^3

IHG is internal heat gain in w/m^2

ΔT is the average outdoor/indoor temperature difference during heating season

N is the air exchange rate in V/h or m^3/h

$F S_{bld}$ is the floor space area (m^2)

The simulation of the heating consumption is carried out with the degree-days method by deriving the overall thermal transmittance value of building envelope (U_{env}) from the U -values of each façade and the overall floor area of the building. The per square metre useful energy demand for space heating in a specific year n of building type m is then calculated simply by equation 3, where HDD stands for heating degree day.

$$UE_{mn} = D_{bldint_m} \times HDD_n \times 24 \quad (4.3)$$

The calculated values will allow benchmarking the overall envelope performance of compliance with relevant building codes in different countries. In the residential sector, household's demand for thermal comfort increases with income level, the more a family is affluent, the higher level of comfort a household is like to achieve. The current heating consumption level of most Chinese households is still significantly lower than that in developed countries. As economy will continue to grow rapidly in China, it is reasonable to project that the both the comfort temperature and heating period is likely to increase gradually as a result of positive income effect. To capture the household's behaviour change, indoor temperature is assumed to increase from 16 °C in 2005 to 22° C in 2025. Increase in temperature is translated into larger HDD value, consequently, it can be easily seen that the heating intensity will increase by equation 4.3.

4.4.2 Water heating consumption

- Residential sector

The annual water heating energy consumption in residential buildings is calculated by equation 4.

$$Q = C(T_h - T_c)qN365/3600$$

Where

(4.4)

Q is energy consumption for water heating : KW

C is the specific heat capacity of water : 4.19 KJ/Kg.K

T_h is the distributed temperature of hot water: °C

T_c is the temperature of cold water : °C

q is the daily hot water consumption per capita : litre per person per day

N is the household size : person/household

It is assumed that the household sanitary hot water consumption will increase from 30 l/per/d in 2005 to 65 l/per/d in 2020, equivalent to the current level of Japanese household's hot water consumption. This hypothesis is consistent with that in Zhou *et al.*(2007) in which annual household water heating consumption will increase from 3600 Mj per household in 2005 to 8500 Mj / a per household in 2020 for urban household in China. Centralised hot water supply is assumed to be available in the case of district CHP system. Individual independent gas boiler is assumed to meet the household water heating demand in the case of individual heating scenario.

4.5 Parametres of BEE improvement portfolios

Two types of buildings are considered to be erected in this virtual new residential zone.

1. Building low rise concrete-structure residential buildings
2. Reinforced concrete structure (in site casting)

From buildings architectural and thermal characteristics viewpoint, the latter is more efficient due to the lower value of shape factor which has significant impact on thermal performance of buildings. Furthermore, the brick-laid low-rise building is excluded from this analysis because the use of clay brick has been outlawed in urban area since 2005.

The typical housing design plans according to the 1983 standard are chosen for a 6-storey (low-rise) and 11-storey building (high-rise) respectively to establish the base case parametres for the construction of housing in Tianjin. The general characteristics of the baseline building envelope include the brick-laid exterior walls of (365mm) and reinforced concrete roof without thermal insulation , single-glazed windows with steel frame, and open the entrance (no doors) the building. Table 4-2 summarises the building envelope thermal performance improvement measures in different scenarios for the high-rise building in the model.

Table 4-2 assumptions on intervention of buildings envelope performance enhancement with *U*-value in parentheses

BEE Scenario	Roof	Exterior wall	Window	exposed floor	Air tightness (V/hr)	Maximum heat load (W/m ²)
Base case	-100mm steel reinforced concrete floor;		Simple- glazed with steel frame (6.4)	Concrete floor: 100 mm	0.6	47.7
(without thermal insulation)	-20 mm cement mortar;	-20mm of interior ;		20mm exterior plaster		
	-4mm water proof;	- mortar190mm concrete block				
	-4m joint mortar;	-90mm decorative brick			(4,37)	
	- 40mm stone concrete (2.0)	(1.6)				

TJ-97	+ 50mm EPS (0.59)	+ 40mm EPS (0.67)	Double-glazed in northern, Eastern and Western façade, simple-glazed in south façade (4.7 ;2.7)	50mm EPS panel (0,7)	0.5
TJ- 2004	+80mm EPS (0.42)	+60mm EPS (0.51)	Double glazed with PVC frame (2.7)	+20mm EPS panel and 35mm XPS panel plus finish (0,52)	0.5
TJ-CAN (≤3500 HDD)	+90mm EPS (0.4)	+80mm EPS (0.42)	6 Low-E+12 air filling + 6 transparent , ratio of window to wall is 25% (2.9)	+20mm EPS panel and 35mm XPS panel plus finish (0,52)	0.45
TJ-RT2005	+80mm EPS (0.44)	+70 mm EPS (0.43)	6+ 12mm argon filling +6 , PVC 25% of window surface (2.6)	+20mm EPS panel and 35mm XPS panel plus finish (0,52)	0.35
TJ-SWE	+220mm XPS (0.12)	+210mm EPS (0.17)	6mm Low-E with argon filling (2.0)	+20mm EPS panel and 35mm XPS panel plus finish 0,52	0.3

Note: U -value of PVC window frames: $2.7 \text{ W/m}^2 \cdot \text{K}$

U -value of metal window frames: $5.3 \text{ W/m}^2 \cdot \text{K}$

Building envelope integrity U -value

Note that inefficient high-rise building (without insulation) is less efficient than the case of low-rise building. However, the BEE measures are more effective. For example, U -value is reduced by more than 25% in high-rise building than low-rise building, mainly due to the shape coefficient differentiation.

Fig. 4-1 and 4-2 show the performance of 6-storey building constructed according to different BEE standards prescriptive values and relevant costs. In the case of compliance with equivalent energy performance requirements in Canadian, French and Swedish standards, reduction of heat loss through the renewal of air is also taken into account, which is reflected in declining quantity of cold air seeped into the heated interior spaces. The U_{env} values vary between 0.4 and 1.46 depending on adopted efficiency standards. U_{env} is reduced by more than 2 times when building complies with the Swedish building efficiency code compared to the TJ-97 standard. Note that air infiltration loss is also taken into account in the calculation of useful energy consumption, as shown in equation 2. The calculation implies that the RT-2005 and Swedish codes are more favourable to reducing cold air infiltration energy loss by enhanced double-flux ventilation and heat air recovery system.

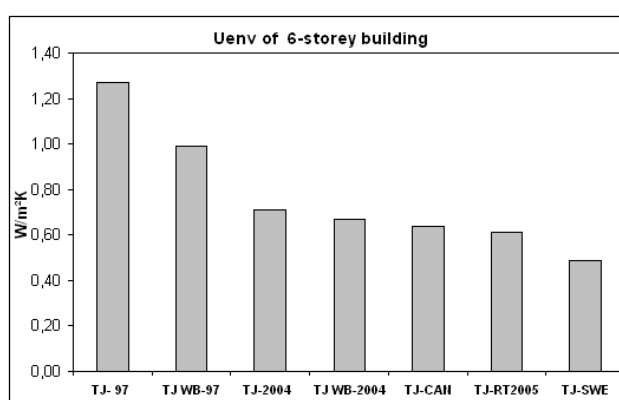


Fig 4-1 overall U -value in low-rise buildings

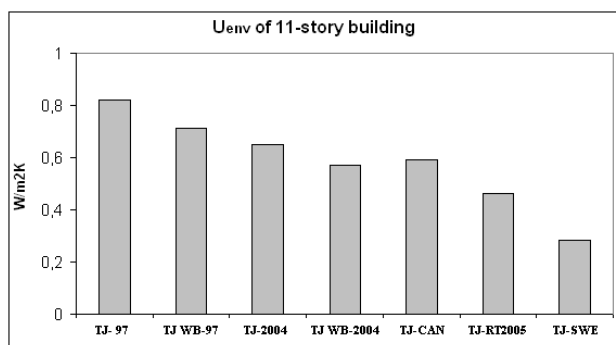


Fig 4-2. Overall U -value in high-rise buildings.

Note: The values of TJWB97 and TJ WB 2004 in figures above refer to actual energy performance of buildings constructed in compliance with TJ 97 and TJ 2004 in the World Bank /GEF project , data is extracted from Liu(2006)

The final heating demand of 6-storey building varies between 40-143 kWh /m² depending on the efficiency level and design temperature during the heating season. As can be seen in the figures, for the low-rise buildings, the TJ-2004 is quite performing compared to the Canadian building standard which is 10% more efficient. In contrast, the French RT2005 and Swedish codes are 21% and 40% more efficient, respectively in terms of final heating intensity. In the case of high-rise buildings, however, difference is

more significant, TJ-CAN, TJ-RT2005 and TJ-SWE are 15%, 35% and 50% more efficient respectively than the TJ-2004 building code.

Figure 4-3 and 4-4 illustrate how the final heating consumption may vary with the indoor thermal temperature given the same building efficiency standard. The current building code requires that the minimum temperature during the heating period should not fall below 16°C, which is much lower than the comfort level in developed country, in general 20-22°C depending on climate zone and household's consumption behaviour.

According to microeconomics theory, the consumer's willingness to pay for the energy services is influenced by both household income and prices of energy in the residential sector. It is quite often to observe that people tend to use more energy than that projected in the engineering models in which consumer's behaviour factor is not necessarily captured. However, consumer's decision on choosing comfort level may vary with the building efficiency and perceived fuel price signal. Typically, in a retrofitted house or with efficient appliance, households are likely to consume more energy than habitude since Energy-efficient measures reduce the marginal price of the services they deliver. Thus this rebound effect results from decrease in the price of effective comfort of end users. Thus actual energy conservation is below engineering estimates for heating and cooling in the residential sector (Durbin *et al.*, 1986; Haas *et al.*, 2000). As can be seen in figures 4-3 and 4-4, in each of the scenarios of BEE compliance, differentiating the comfort requirement may result in 16-35% variation in the final energy demand. In other words, the benefit in terms of energy savings compared to the baseline would be offset by 7-30% as a result of improved thermal comfort. Also, it is interesting to note a diminishing trend of reduction caused by rebound effect, the more the building is efficient (well insulated), the less the rebound effect will affect the actual consumption level. As said before, income rise will be the major driven of demand for higher level energy services. It is plausible to estimate that comfort level demanded by households in Tianjin and current European families will eventually converge at the end of this modelling period. Therefore, indoor comfort temperature in all scenarios will approach universally 22°C regardless of types of house.

So far, no empirical study on rebound effect in the Chinese residential building energy consumption has been undertaken with robust technical-econometric models, this study uses the standard engineering modelling approach to estimate the heating energy consumption. In our modelling framework, the consumer's behaviour change in terms of increased thermal comfort is captured by the factor of incremental indoor temperature and extended heating period in terms of *HDD* over the modelling period. Indoor heating temperature is expected to converge with that in developed countries.

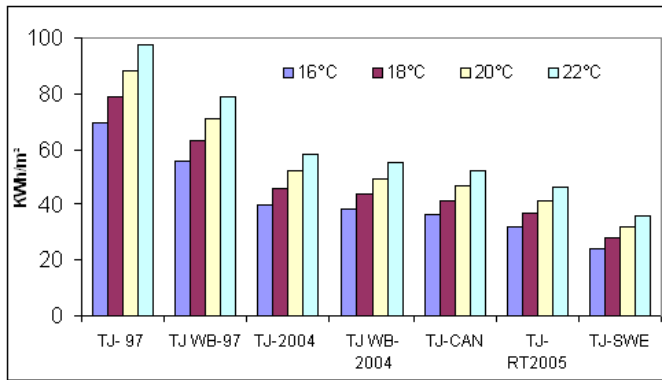


Figure 4-3. Useful energy demand in 6-storey building according to BEE levels under different comfort assumptions

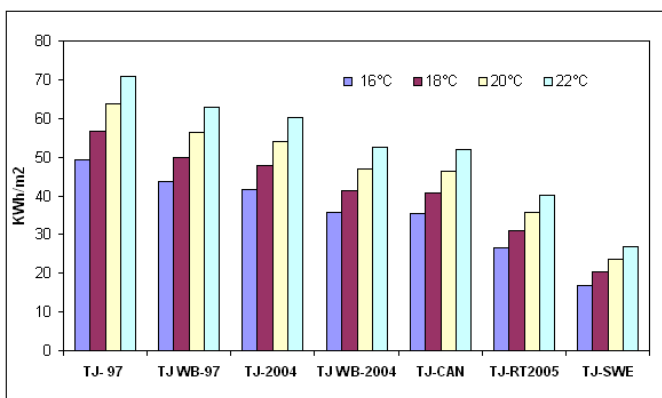


Figure 4-4 Useful energy demand in 11-storey building according to BEE levels under different comfort assumptions

Besides the energy efficiency measures employed in the residential buildings, no alternative scenario is simulated regarding the BEE improvement in commercial buildings sector since our study objective is focused primarily on residential energy efficiency building codes. The default values related to heating and water consumption in commercial buildings in China are used in the model.

4.6 Costs

As mentioned above, the determining criterion of the optimal choice of BEE standard and relevant energy supply system requires that the total cost be the lowest among all options over the modelling period. The programme is then to minimise the present value of total cost induced in option BEE scenario *i* with supply system *j* over the assessment period, expressed by mathematical formula, expressed in equation 4.5;

Optimal BEE choice

$$\begin{aligned}
 & \text{s.t} \\
 & \text{Min } LCC_{ij} = BEC_i + \sum_{k=1}^{20} CC_{ij}(1+a)^{-k} + \sum_{k=1}^{20} FC_{ij}(1+a)^{-k} \\
 & + \sum_{k=1}^{20} OMC_{ij}(1+a)^{-k} + \sum_{k=1}^{20} EC_{ij}(1+a)^{-k}
 \end{aligned}
 \tag{4.5}$$

Where

LCC_{ij}	is the present value of the life-cycle cost of BEE option i coupled with energy supply system j
CC_{ij}	is the capital cost of energy supply system j subject to compliance option i of buildings
BEC_i	is the buildings envelope cost of BEE option i
FC_{ij}	present value of the fuel cost of BEE option i coupled with energy supply system j
OMC_{ij}	is the present value of the operation and maintenance cost of energy supply system j subject to the implemented BEE option i
EC_{ij}	is the present value of externality cost related to energy consumption in supply system j subject to the implemented BEE option i (emission of carbon dioxide and sulphur dioxide)
a	is the discount rate

4.6.1 Incremental costs associated with BEE

This cost refers to the up-front incremental cost related to building envelope performance enhancement in relevant efficiency compliance scenarios. Estimation of costs related to insulation materials is based on (Liu, 2006) and author's personal interviews in China in 2007 and 2008.

Additional costs related to BEE enhancement relative to the *basecase* described above are accounted on the per unit floor area basis. Figures 4-5 (a) and 4-6 (a) illustrate the relationship between the building envelope costs and the thermal performance in terms of integrity U -value(U_{env}), while Figure 4-5 (b) and 4-6 (b) delineate the rate at which the building costs increases with the performance requirement in relevant efficiency standard in low-rise and high-rise buildings, respectively.

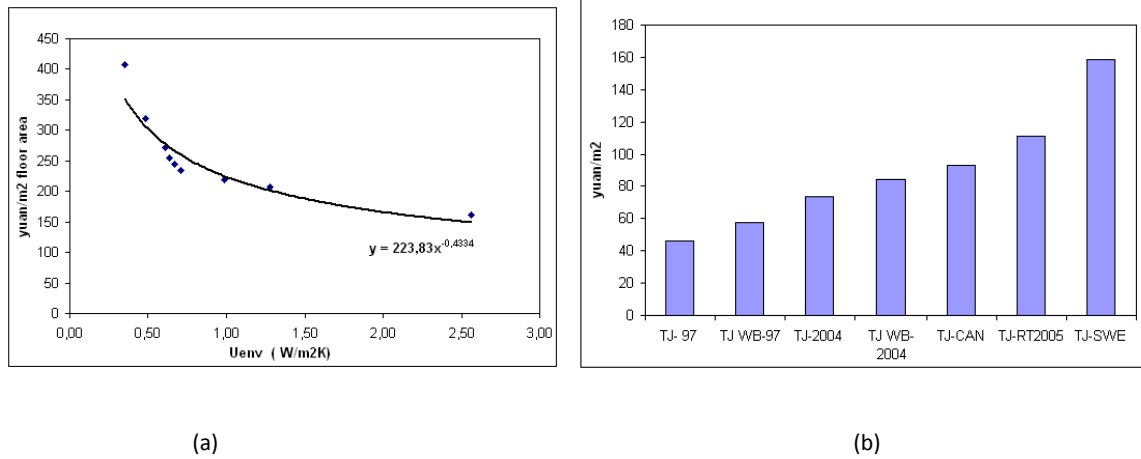


Figure 4-5. (a) low-rise building envelope cost with the envelope integrity thermal efficiency

(b) Additional cost related to BEE measures in 6-storey building

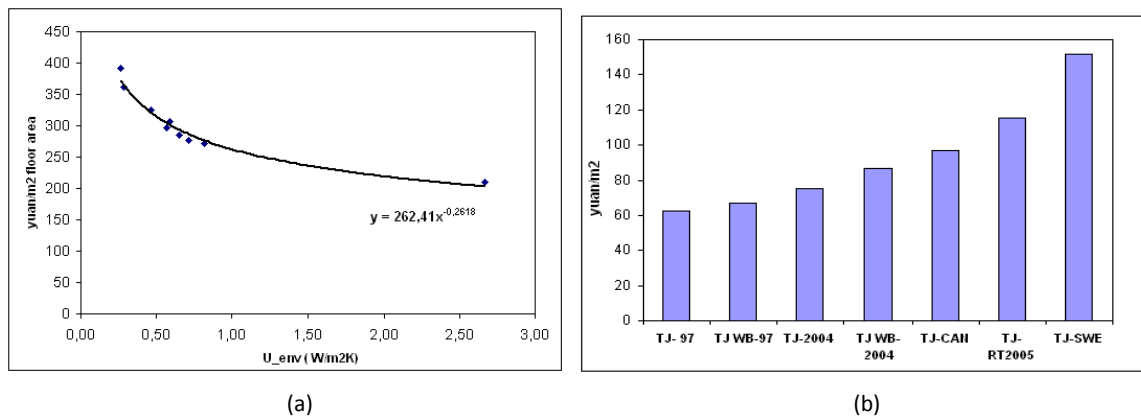


Figure 4-6 (a) high-rise building envelope cost with the envelope integrity thermal efficiency

(b) Additional cost related to BEE measures in 11-storey building

4.6.2 Capital cost in energy supply system

Both coal-fired and gas-fired energy supply systems are considered in the model. According to the municipal district heating plan, considerable capacity of coal-fired large CHP is expected to be added over the next decade(TJEG,2007). To keep our analysis as simple as possible, large-scale renewable energy-based district heating system (solar, biomass, heat pump) is not considered in this study for their share still remain and is very likely to remain relatively small in medium-term, although the ground-resource heating pump becomes very common in some new residential area in Tianjin, yet, uncertainty about the reliable renewable resources to guarantee the continuous supply in large-scale residential buildings has not been addressed both in terms of technical and economic feasibility. According to the latest municipal heating development scheme, ground-source heat pump and other renewable will only account for 7% of

total heating capacity in Tianjin in the medium-term planning objectives. Analysis integrating renewable heating is hopefully to be explored in detail for prospective research.

On the other hand, the discussion about where China should opt for radical fuel-switching policy, primarily from coal to natural gas has led to intensive debates among the international energy analyst. Inside China, different schools have also been debating extensively on the question of rapid development of natural gas-fuelled energy supply infrastructure to tackle the atmosphere pollution and acid rain associated with intensive coal use in the power generation and district heating in the northern cities, and also allow curbing the CO₂ emissions, yet to a less extent. However, few empirical studies have quantified what the economic implications are likely to be if China chooses to opt for natural gas-fuelled power and heat generation in building sector at a local scale. The objective of integrating the gas-fired heating supply system is to examine both environmental and economic implications of fuel-switching policy. In the residential sector, in particular in the context of carbon emission restriction scenario. In sum, four heating supply options based on the size of capacity and fuel are considered for heat supply. Namely

1. district coal-fired heat only boiler (heat only, 1.4-7MW/unit),
2. district medium-sized CHP (7-14MW/unit, or 10 to 20 t/hr)
 - a. coal-fired CHP
 - b. fired CHP
3. municipal district heating (coal-fired CHP, 116MW/unit)
4. individual heating with gas boilers (20-50 KW/household)

In the commercial buildings, gas and coal-fired boilers will be installed in the case where the district heating networks are not available. Note that presently the options 1 and 3 are the most common way of district heating, gas-fired boilers hardly exist in the context of gas supply shortage due to the large-scale district heating fuel-switching programme actually being undertaken in Beijing. Individual gas boiler for both space heating and sanitary hot water(conventional and condensing) is considered in the case of “coal to gas” fuel-switch, which is unlikely to occur to a large scale and will remain marginal in the total share of space heating energy supply system.

The last category of heating system presents an extreme fuel-switching scenario, under which all buildings constructed in this area will be supplied with natural gas, individual gas boilers is installed in all household and small gas-fired hot-water boilers are installed in commercial buildings to meet space and water heating demand. This scenario implies sufficient gas supply in this zone over the modelling period. Their respective technical characteristics and costs are presented in Table 4-3 and Table 4-4.

Table 4-3 Energy conversion efficiency * in different supply systems considered in the model

	capacity	Plant thermal efficiency η_{th}	Electric efficiency η_{ele}	Distribution networks efficiency η_{dist}	Heat to power ratio
District coal fired boiler	20 t /h	60%		90%	
District coal-fired CHP	20t/h + 2000KW _e	50%	15%	90%	3.3
District gas-fired boiler (heat only)	14 MW	85%		90%	
District gas-fired CHP	11 t/h + 4000 KW _e	51%	25%	90%	2
Municipal gas-fired plant	3 ×116 MW _{th}	40%	20%	85%	2
Household gas boiler		88%		100%	

* All efficiency numeraires refer to the average operation efficiency instead of rated efficiency which may vary depending on the load factor and actual operation condition.

Table 4-4 Costs in different heat supply systems

	Capital cost		O&M cost	
	Yuan/KW _{th}	Yuan/KW _e	yuan/MJ (heat)	Yuan/kWh (electricity)
District coal fired boiler	450		0.0035	
District coal-fired CHP		8500	0.0056	0.05
District gas-fired boiler (heat only)	660		0.006	
District gas-fired CHP		5000	0.007	0.042
Municipal gas-fired plant		4500	0.00675	0.0536
Household gas boiler	600		16 yuan/KW/an	

Note: Heating supply system capital costs and O&M cost in the thermal power plants is estimated based on Liu(2006) in which a dozen of both public and private heat supply utility companies have been interviewed; Ye *et al.*, (2001); Cummins(2004); NCMEDRI (2006).

4.6.3 Cost of fuel resources

Economic theory argues that the opportunity cost of the resource consumption should be used in social cost-benefit analysis since the market price does not necessarily reflect the real social cost (shadow price) of consuming the natural resources, however, it is often very difficult to value this social cost in practice, we use the market price as a proxy of resource consumption cost. Market price of fuel is at 0.086 yuan/kWh (LHV) for coal and 0.201 yuan/kWh (LHV) for natural gas in the base year. Price escalation for coal and natural are assumed to average 1.5% and 1% per year respectively.

4.6.4 Costs of externalities

The energy consumption associated emissions of pollutants and greenhouse gases provoke damage costs and are externalities such that these costs are not reflected in the prices of energy. In the cost-benefit analysis of social project, the damage costs, also called external costs, should be considered (Rabl and Spadaro 2006).

From social cost point of view, it is common that the integrated costs should be accounted for in the life-cycle analysis (LCA) which internalises the external costs related to environmental impact of energy consumption and production. In our analysis, the pollution control is expected to be installed in all the coal-based supply systems presented below, in particular the process of removal of sulphur dioxide (SO₂) from flue gas. SO₂ emission in power plants is being strictly regulated by the Chinese environment agencies. We assume that all coal-fired heat generation plants will be equipped with appropriate device to control the emission below the mandatory threshold prescribed in environmental regulations. Currently, environmental regulation agencies levy SO₂ discharge at 0.7 RMB yuan per kg in coal-fired power plants. This tax is considered as the desulphurisation benchmark cost in the model. It is assumed that the emission allowance price of SO₂ discharge will continue to rise to reach 3 yuan per kg eventually.

The GHG, in particular the CO₂ emission is considered the largest global externality that the world has seen (Stern,2007). Although China is not yet subject to any compulsory CO₂ reduction scheme and the post-Kyoto regime is still ambiguous, a global carbon emission restriction scenario is very likely to occur under which China is also likely to implement carbon emission cap and trade scheme to limit the carbon emission and allocate the financial resources more efficiently across different sectors to attain the mitigation goals. The social opportunity costs of CO₂ (shadow price) is existing regardless of whether or not the mitigation

actions will be undertaken. A tax-like carbon is assumed to be levied from 2010 in the *carbon emission restriction* scenario in the model.

Carbon price may vary depending on the Chinese government's environmental policy and emission control goals, resulting in a price range between \$10 and \$ 50 dollars per metric tonne CO₂ emitted.

The global social cost of CO₂ averages around US\$12 per tonne on in 2005 (IPCC, 2007) but differs significantly depending on estimation assumptions (-3\$-100 US\$/tonne). In the early phase of the modelling period, the CERs transaction price of CO₂ mitigation in the Clean Development Mechanism (CDM) projects in China is regarded as the opportunity cost of CO₂ emission. The average market price of CO₂ is about 6.5 US\$ par tonne in Julu project which is the first corporation listed in Chinese stock market that is involved in CDM project (<http://xk.cn.yahoo.com/articles/070613/1/jjq.html>). From the long-term analysis perspective, the CO₂ price is expected to rise more rapidly in the context of increasingly tightened objectives of global GHG emission mitigation.

In the different scenarios simulation, two carbon price evolution perspectives, low and high-price scenarios will be simulated throughout the modelling period, In the low-price scenario, carbon emission is priced at 10 US\$/tCO₂ while in the high-price scenario, carbon price starts at 30 US\$/tCO₂ throughout the modelling period²³. The exchange rate of RMB is assumed to continue to appreciate against the US dollar, the exchange rate is supposed to fall from 8.01 in 2005 to 6.5 in 2030.

In fact, the chemical process of desulphurisation may result in extra CO₂ emission; the quantity may vary depending on the process adopted. To simplify our analysis, the calculation of emission of CO₂ is focused on the fuel combustion-related emission since the desulphurisation-related emission must be estimated case by case. Additionally, technological advancement will allow significant reduction in the CO₂ emission originating from the desulphurisation process. For example, a new technology based on a combined removal system for separating carbon dioxide and sulphur oxide gases from furnace flue gases (Nolan, 2002) will lead to promising prospects of sulphur and CO₂ emission control in the coal-fired power plants.

4.7 Economic benefit of implementing BEE

The benefit related to implementation of energy efficiency policies in buildings result in reductions of following costs, it includes

²³ The presumed carbon emission cost lies within the lower range of projected carbon prices in the previous literature on climate change economy modelling. For example, in IPCC (2007), lower carbon price ranges (\$5 to \$65 per ton CO₂-eq in 2030, and \$15 to \$130 per ton CO₂-eq in 2050) may achieve the stabilisation levels if policies that induce technological advances are implemented.

1. the installed capacity necessitated to meet the peak demand for heating when the weather are the most unfavourable
2. the capacity charge associated with incremental heating demand
3. resource cost associated with heating consumption, maintenance and operation costs in the heat supply plants
4. environmental pollution control costs, in particular the sulphur dioxide (SO₂) emission from coal-fired boilers

The cost associated with the development of heat supply infrastructure (networks, substations, exchangers etc) are accounted for in the cost of investment in energy supply.

4.8 Benefit of CHP deployment

4.8.1 Electricity sale benefit in cogeneration units

In this study, the surplus electricity generated in the local or municipal CHP plants is assumed to be sold to electric power grid and thus is considered as actual benefits (negative costs) in the cost-benefit analysis. Electricity wholesale price varies with production and quantity of MWh sold, load factor and so on. We assume that the price follows a constant growth pace with 1-3% annual rise per year over the modelling year to be consistent with the actual electricity pricing development trend.

4.8.2 Carbon emission reduction benefit in cogeneration units

Apart from increased energy efficiency in CHP plants, electricity generation in CHP permit to reduced carbon emission compared with separated power and heat generation. Because the electricity is generated as a co-product in CHP otherwise it needs to be produced in power-only plant whose overall efficiency is significantly lower than CHP. Thus the calculation of carbon emissions in CHP should be deduced by the part associated with electricity that otherwise would be produced in the power plants in the baseline case. Sub-critical coal-fired power plants are considered as reference case of power generation. In 2005, the average heat rate in China's power sector is around 350 gce/kWh_e, with 7% loss in distribution and transformation of power grid, thus the primary energy supply of kWh electricity consumed by the end users in buildings is 376 gce/kWh_e, and average emission factor of steam coal in China is around 90 t C/GWh. Thus it can be easily deduced that reference emission factor in power plants in the base year is approximately 1.03 KgCO₂/kWh_e; thermal efficiency to improve 0.5 % per year and grid loss is assumed to decrease 1% per year throughout the period. Thus emission factor in reference power generation plants will fall to 0.92 KgCO₂/kWh_e in 2025. This assumption on reference carbon content of electricity is rather robust since hydro power only represents a very small part of North China Grid.

4.9 Results and discussions

4.9.1 Primary energy supply and carbon emission

Table 4.5 through 4.10 reports the results of primary energy and carbon emission simulation of all scenarios discussed above. As can be seen in all the scenario, incremental improvement of BEE standard in buildings allows for significant reductions both in primary energy demand and subsequent carbon emission. Implementation of the French RT-2005 in all residential buildings is likely to result in 29-30% reduction compared to TJ-97 case in 2025, and upgrading to Swedish code would allow for 35-38% reduction in the same year.

However, more caution is needed when interpreting the difference between the energy supply options. First, the scenario of heat-only, in particular the individual gas boiler option appears to be the best scenario in terms of primary energy savings, but it disguises the fact that electricity is also generated in all the scenarios with cogeneration option. Indeed, the primary demand in these scenarios must be much higher if upstream energy consumption for electricity generation is taken into account. Second, gas-fuelled energy supply system is preferred to coal-fired district heating if the principal objective is CO₂ emission mitigation. However, fuel switching policy should be assessed much more deeply than just comparing the carbon emission outcome, therefore, it follows that the economic analysis should be more convincing regarding the choice of energy supply system.

Table 4-5 Coal-fired district boiler

	2006		2015		2025	
	<i>GWh</i>	<i>1000 t C</i>	<i>GWh</i>	<i>1000 t C</i>	<i>GWh</i>	<i>1000 t C</i>
TJ- 97	3577	297	3982	318	4524	341
TJ- WB97	3192	265	3560	283	4059	303
TJ 2004	2825	235	3156	250	3615	266
TJ- WB04	2703	225	3023	239	3468	254
TJ-CAN	2648	220	2962	234	3402	249
TJ-RT2005	2438	203	2731	214	3147	228
TJ-SWE	2177	181	2421	189	2784	198

Table 4-6 Coal-fired district CHP

	2006		2015		2025	
	<i>GWh</i>	<i>1000 t C</i>	<i>GWh</i>	<i>1000 t C</i>	<i>GWh</i>	<i>1000 t C</i>
TJ- 97	4115	370	4561	410	5157	464
TJ- WB97	3692	332	4096	369	4645	418

TJ 2004	3288	296	3653	329	4157	374
TJ- WB04	3154	284	3506	315	3996	360
TJ-CAN	3094	278	3439	309	3923	353
TJ-RT2005	2862	258	3185	287	3643	328
TJ-SWE	2575	232	2844	256	3243	292

Table 4-7 Gas-fired district boiler (heat only)

	2006		2015		2025	
	<i>GWh</i>	<i>1000 t C</i>	<i>GWh</i>	<i>1000 t C</i>	<i>GWh</i>	<i>1000 t C</i>
TJ- 97	3225	172	3573	191	4042	216
TJ- WB97	2896	155	3211	171	3644	195
TJ 2004	2568	137	2850	152	3247	173
TJ- WB04	2479	132	2753	147	3140	168
TJ-CAN	2431	130	2700	144	3082	165
TJ-RT2005	2273	121	2526	135	2891	154
TJ-SWE	2061	110	2279	122	2605	139

Table 4-8 Gas-fired district small CHP

	2006		2015		2025	
	<i>GWh</i>	<i>1000 t C</i>	<i>GWh</i>	<i>1000 t C</i>	<i>GWh</i>	<i>1000 t C</i>
TJ- 97	3741	100	4147	112	4688	128
TJ- WB97	3356	95	3724	105	4223	120
TJ 2004	2989	89	3321	98	3779	111
TJ- WB04	2868	88	3187	96	3633	109
TJ-CAN	2812	87	3127	95	3566	108
TJ-RT2005	2602	84	2895	92	3312	103
TJ-SWE	2341	80	2586	87	2948	96

Table 4-9 municipal large CHP

	2006		2015		2025	
	<i>GWh</i>	<i>1000 t C</i>	<i>GWh</i>	<i>1000 t C</i>	<i>GWh</i>	<i>1000 t C</i>
TJ- 97	5266	163	5803	197	6500	242
TJ- WB97	4706	146	5188	177	5823	217
TJ 2004	4171	129	4600	157	5177	193
TJ- WB04	3994	124	4406	150	4964	185
TJ-CAN	3914	121	4318	147	4867	181
TJ-RT2005	3607	112	3981	135	4496	168
TJ-SWE	3228	100	3531	120	3966	148

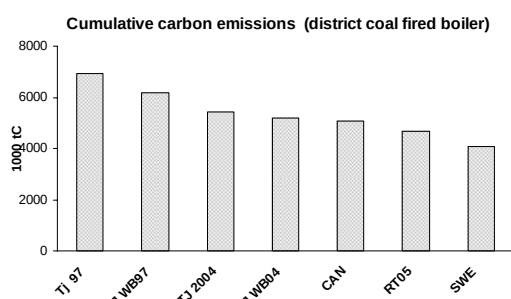
Table 4-10 individual gas boiler

	2006		2015		2025	
	<i>GWh</i>	<i>1000 t C</i>	<i>GWh</i>	<i>1000 t C</i>	<i>GWh</i>	<i>1000 t C</i>
TJ- 97	2227	119	2453	131	2755	147
TJ- WB97	2011	107	2216	118	2493	133
TJ 2004	1804	96	1989	106	2244	120
TJ- WB04	1736	93	1914	102	2161	115
TJ-CAN	1705	91	1880	100	2124	113
TJ-RT2005	1586	85	1750	93	1981	106
TJ-SWE	1440	77	1575	84	1776	95

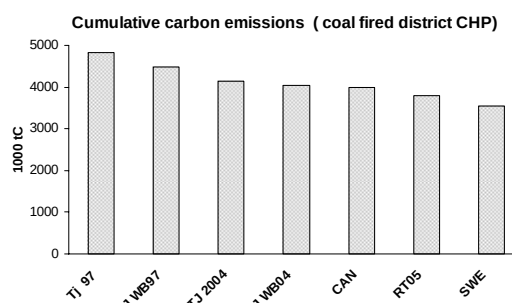
Note : primary energy demand consumed for electricity generation in CHP is not deducted in the tables above, this explain why CHPs have higher primary energy supply.

4.9.2 Comparison of total carbon emissions

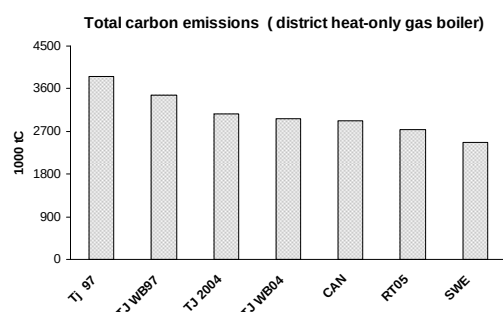
The total carbon emissions in different BEE and energy supply scenarios are plotted in Fig. 4-7. Buildings constructed with current national level supplied by coal-fired boiler has the highest cumulative emissions (nearly 6.9 million tonnes C), which could be divided by a factor of 4 in the case where buildings construction complies with TJ-SWE standard supplied by individual gas boiler giving the lowest emission value (1700 Mt).



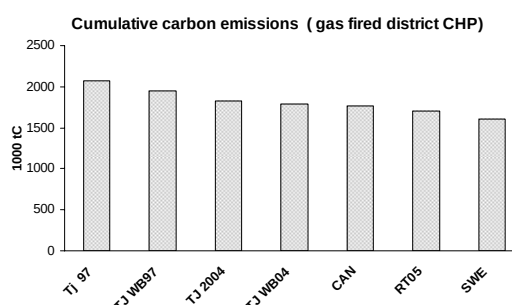
(a)



(b)



(c)



(d)

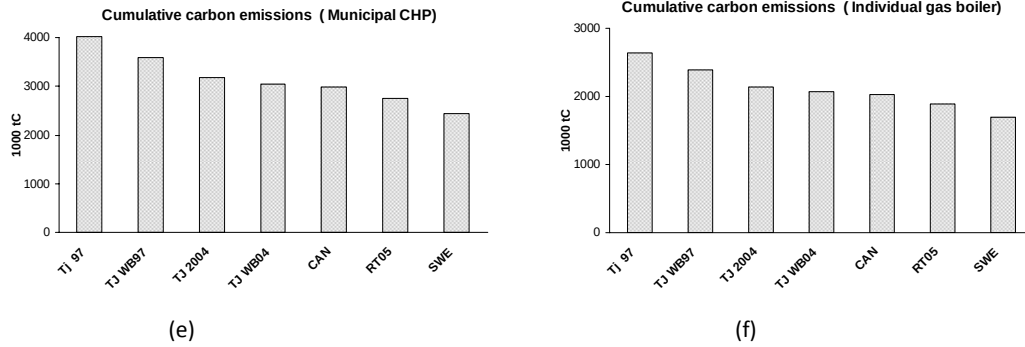


Figure 4-7 Total carbon emissions in different BEE implementation scenarios

From Fig.4-7, it can be seen that carbon emissions decrease as BEE standards upgrade in all scenarios regardless of specific energy supply systems. In general, coal-fired system is more carbon intensive than gas supply. District coal-fired boiler is the most emissive supply option compared with other technical measures. CHP technology offers great potentials for carbon emissions reduction over the entire period. For example, in current implementation of current BEE standards, cumulative carbon emissions in coal-fired heat supply system can be reduced by 24% with CHP technology, if the developer decides to switch to gas, CHP will allow the buildings to reduce nearly 40% total carbon emissions. However, to choose the optimal level of BEE and energy supply system, it is necessary to compare the global costs.

4.9.3 Comparison of total costs across the scenarios

All costs incurred in buildings and energy supply-side are discounted to the base year (2006) and are accounted for as yuan per square metre floor space to facilitate the comparison, as the unitary incremental cost related to BEE measures is expressed systematically in construction sector. Cost analysis with and without carbon emission cost are both examined.

4.9.3.1 Exclusion of carbon emission cost

Figure 4-8 illustrates the total costs in all BEE and energy supply scenarios. Some important remarks can be drawn immediately by comparing the different scenarios:

1. As can be seen in this figure, all scenarios show that the current national BEE standard (97 level for Tianjin) is the most costly option, in fact, the global costs of business as usual is the most expensive option for the society.

2. In spite of considerable progress compared with national objective , the BEE standard implemented in Tianjin (TJ2004) is not sufficiently efficient to allow achieving an optimal level since the present value of total costs incurred during a 20-year period can be reduced further by tightening the building code, even with a relatively high discount rate (8%).
3. Without any carbon price imposed, The optimal choice for the buildings regulator seems to be the current French RT-2005 building efficiency standard couple with small district coal-fired CHP , which allows leading to the lowest present value of the overall discounted costs (490 yuan/m² floor space) almost all scenario except for the gas-fired district CHP.
4. lastly but most strikingly, keeping the current most common energy supply system unchanged, i.e. the case (a) where district coal-fired boiler is installed, we observe that adopting the best available technology (BAT), or the equivalent energy performance prescribed in the Swedish BEE standards is less costly than the current BEE regulations enforced in China and Tianjin.

This sends a very strong signal: China should tighten the BEE objective and needs to move quickly to adopt higher efficiency standards in buildings since an obvious economic gain can be tapped. Direct switching without any action in demand side is not a rational choice regardless of the obvious energy resources conservation and relevant environmental benefits.

Not surprisingly, fuel-switching (gas supply) option is more expensive than coal-based supply technology despite much lower carbon emissions. More importantly, the gas-fuelled scenarios turn out to be more costly than coal-fired system no matter if the desulphurisation cost is taken into account or not. The overall cost of district gas-fired small CHP is 27% -36% higher than properly-sized small coal-fired CHP.

Individual gas option is most interesting option in terms of carbon emissions minimisation, however, the global costs are still much higher than coal-fired options. According to the result, the municipal large thermal power plant is a second-optimal choice in terms of global costs and total carbon emissions. High O&M cost and more energy loss due to long distance of distribution is the main reason despite higher electrical efficiency in the large CHPs. Although coal-fired boilers have lower capital costs than municipal CHP, the lower efficiency and higher sulphur and pollutant emissions make this option less interesting.

If the municipality decides to decarbonise the energy supply infrastructure, the SWE BEE is unambiguously the best strategy except for individual gas option. However, it must be noted that the individual gas heating option is the most costly scenario despite its apparent benefits of energy savings and low-level carbon emission. Further, the result of benefit-cost would be even worse in this case if the electric power consumption is taken into account (from electricity-only power plants). Also, individual gas heating will still remain a marginal part in the context of Chinese buildings sector and their heat supply infrastructure in the northern Chinese cities.

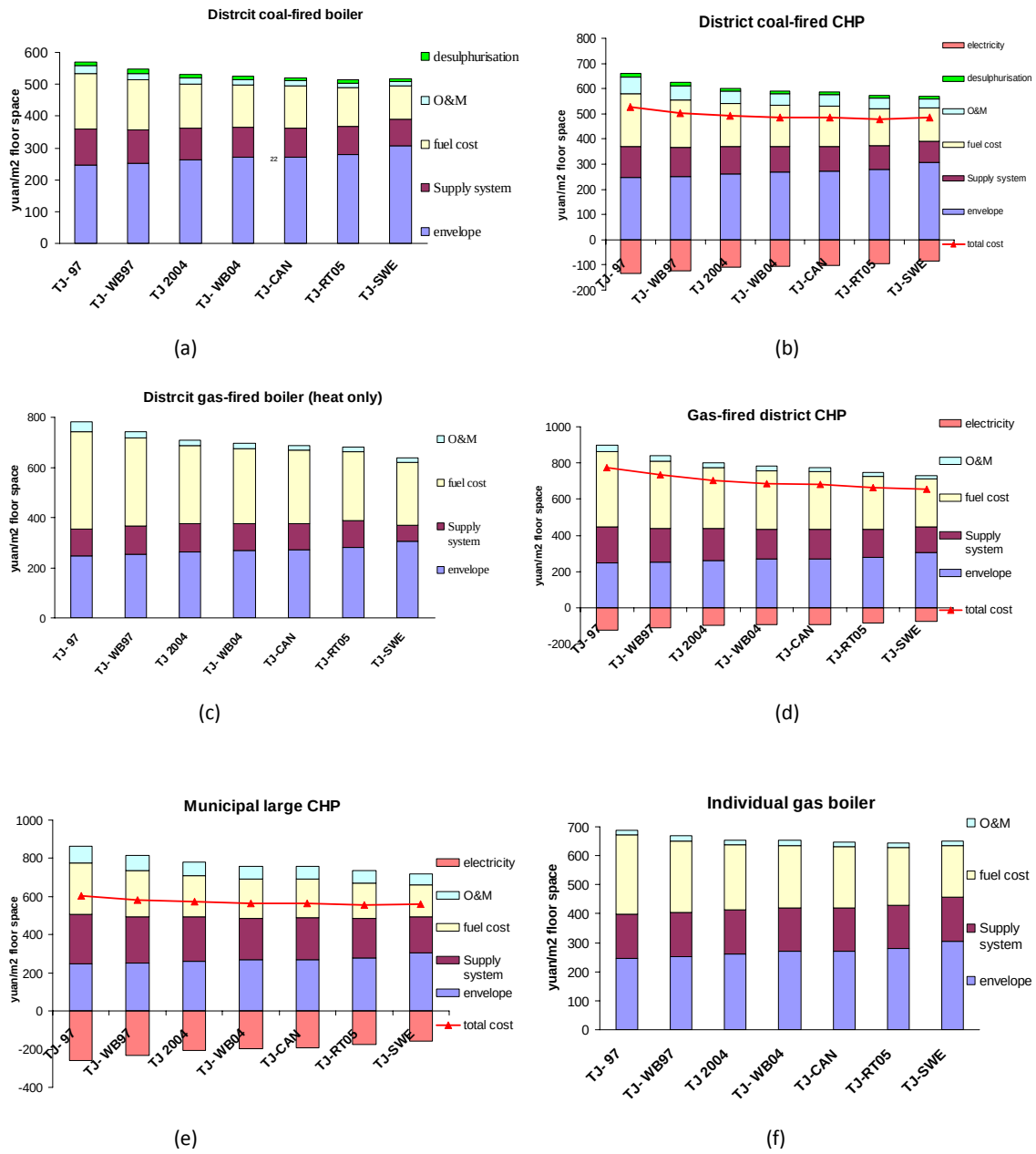


Figure 4-8 Comparison of discounted total cost in different energy supply options

4.9.3.2 Inclusion of carbon emission cost

As mentioned earlier, we simulated two carbon tax scenarios: low and high respectively, the results are presented below. In fact, the sensibility test shows that the results remain almost identical regarding the optimal supply system under all carbon tax assumptions. The option of coal-fired small CHP remain preferable regardless of the carbon tax rate imposed over the modelling period. However, with medium and high carbon tax assumptions, the Swedish code becomes more attractive than the RT 2005 in almost all the scenarios except for the individual gas heating which is quite insensible to the carbon tax, primarily due to the low-level emission. RT-2005 is the best choice for heat-only system (coal or gas) but loses its

competitiveness in the cogeneration system subject to the carbon tax. Under high carbon tax scenario, RT-2005 and Swedish code yield almost identical overall discount costs, this implies that uptake of the Swedish code is more preferable for the sake of energy savings and carbon mitigation. Furthermore, the gas-fuelled supply systems are still significantly higher than the coal-based system even under high carbon tax rate constraint. This confirms that the choice of coal-based energy supply infrastructure in the Chinese cities is the most pertinent decision in the future.

A. low carbon price

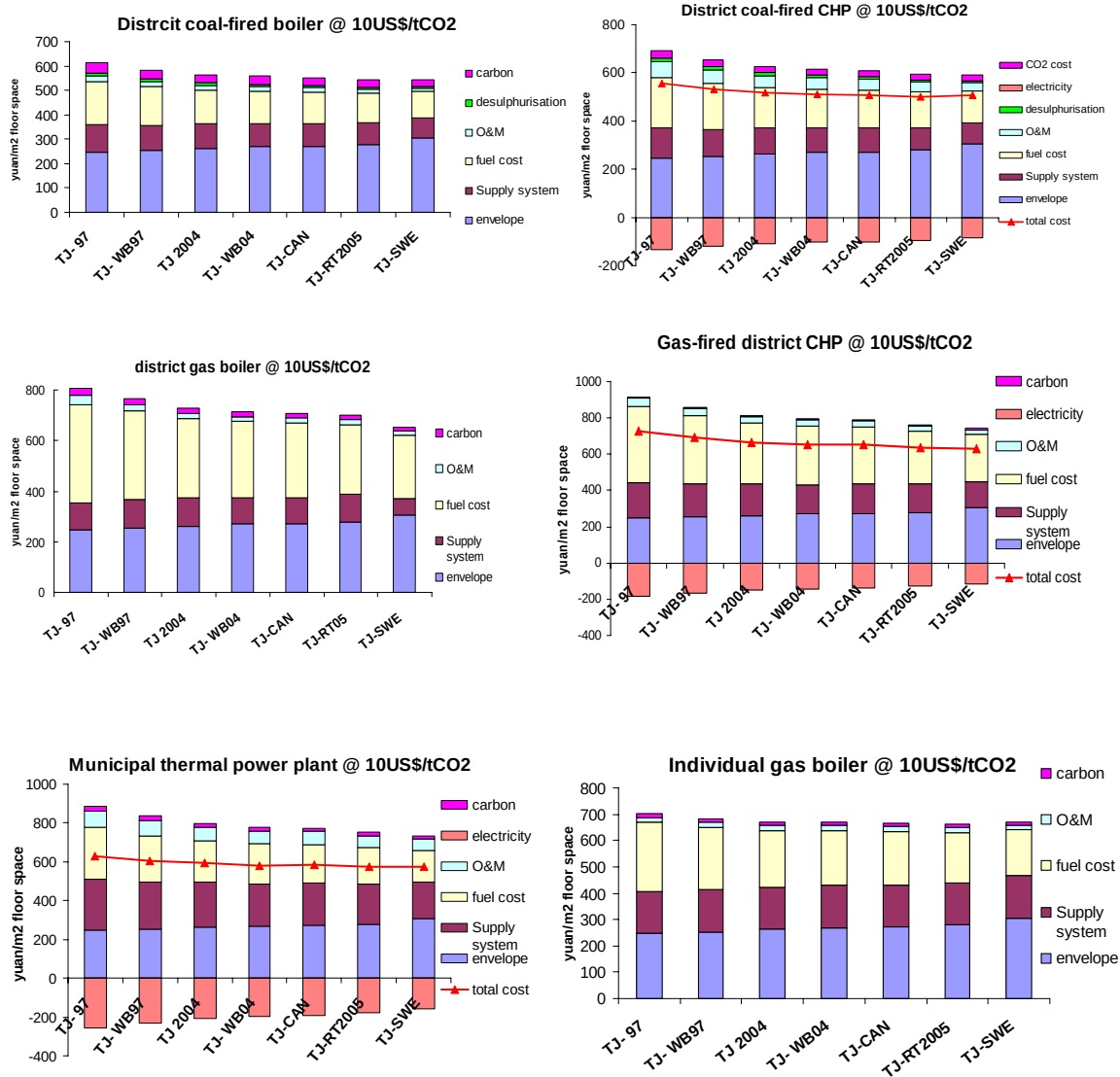


Figure 4-9 Comparison of total costs with low carbon price in different scenarios

As can be seen in Fig. 4-9, putting in place a low-carbon price does not change the preference order of scenarios and energy systems. Coal-fired systems are still less expensive than gas-fired supply system. District coal-fired CHP is still the least cost option among all the scenarios. RT2005 is still the optimal BEE

strategy in this scenario. The discounted total costs of current national building code are almost 10% higher than the SWE BEE standard. Individual gas boiler option is still the most costly supply option.

B. high carbon price

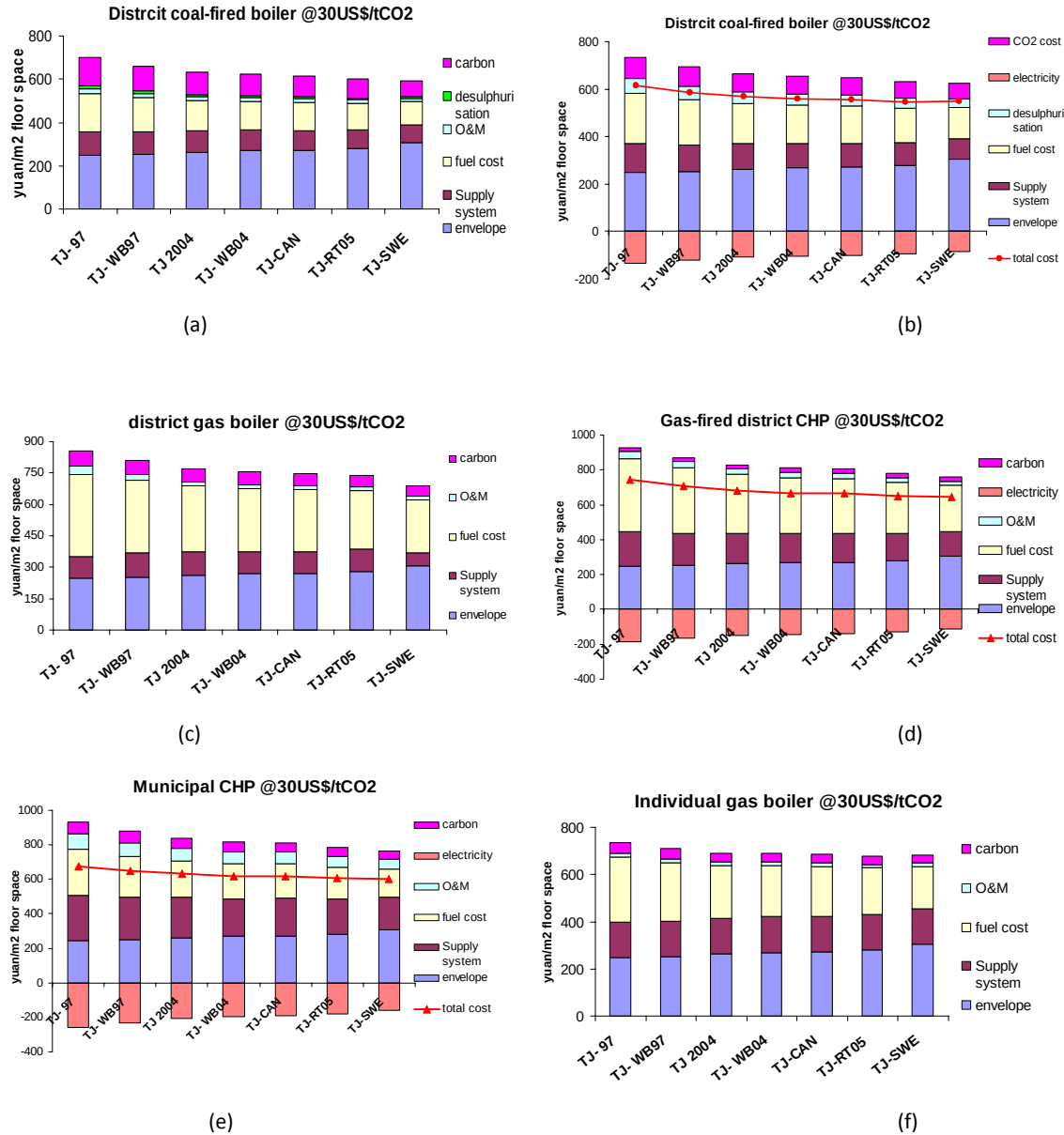


Figure 4-10. Comparison of total costs with high carbon price in different scenarios

Instituting high carbon price will change the preference order among different BEE scenarios. SWE performance become the least costly strategy in all energy supply systems, both in coal and gas –fuelled heating. Coal-fired small CHP remains the best supply solution.

Discussion

No matter whether carbon price is taken into account or not, SWE is the best strategy for the gas-fired system excluding the individual case. As shown in Fig 4-8, the best scenario in terms of carbon emissions mitigation is SWE BEE standards in the gas-fired CHP supply option (NGCC). However, simulation results of discounted total costs in all of the three cases in this section show that this option is one of the most costly among all the scenarios.

The comparison of scenarios results in the section 4.11 gives clear guidance for the Chinese decision makers and has strong policy implications in terms of CO₂ emission mitigation in China's buildings sector.

1. The most important observation is that without fuel-switching policy, mitigation costs may be negative when a 20-year life-cycle of buildings operation is taken into account (note that building life time should be even much longer), as shown in Fig 4-8 (a) and 4-9 (a). For example, updating TJ-97 (equivalent national building energy efficiency level) to TJ-SWE standard will allow reducing life-cycle emissions by 40%, while total costs being lowered by 9% without considering externalities of carbon emissions. The cost of carbon reduction in this case is roughly -30 US\$/tCO₂ with 6% discount rate.
2. If Chinese energy policy needs to decarbonise district heating in the northern cities' building sector by favour fuel-switching policy, they have basically two strategies, namely S1 and S2 ;

- a. S1

New construction continues to adopt the current national BEE standards and switch directly from coal-fired boiler to gas-fired CHP solution

- b. S2

Unlike S1, a two-step approach is adopted in S2 which implements first SWE BEE standard in new construction, and then switches to gas-fuelled CHP supply option.

To determine the cost-effectiveness of carbon emissions of S1 and S2, a quick calculation of discounted CO₂ abatement cost (AC) can give insightful indications, AC is calculated by using a simple formula as follows

$$AC = \frac{\sum_{i=1}^{20} \frac{C_{ms_i} - C_{ref_i}}{(1+a)^i}}{\sum_{i=1}^{20} \frac{Em_{ref_i} - Em_{alt_i}}{(1+a)^i}} \quad (4.5)$$

where

- C_{ref_i} is the cost of reference scenario in year i
- C_{ms_i} is the cost of mitigation scenario in year i
- Em_{ref_i} is the CO_2 emission in the reference scenario in year i
- Em_{Alt_i} is the CO_2 emission in alternative scenarios in year i
- a is the discount rate selected, here 6%

The reference scenario refers to TJ97 BEE performance standard supplied by coal-fired district boiler. And alternative scenario is SWE supplied by gas-fired CHP. We have shown that the total costs of SWE BEE is lower than TJ97 and TJ04 BEE in the baseline energy supply case (coal-fired), this means the first step of S2 will generate an economic gain (difference between their respective total costs) which will offset in part the cost of switch from coal to gas. The payoff of the two strategies is presented in Tab. 4-11.

Table 4-11. Pay-off of baseline and decarbonisation strategies

	total emission kg CO ₂ / m ²	total cost Yuan/m ²
baseline	583	570
decarbonisation strategy		
S1	206	770
S2	155	650

All numbers shown in this table is levelised in starting year with 6% discount rate (2005).

By using the result of simulations of emission and costs presented in Tab 4-11 and equation 4.5, it can be easily found the mitigation costs in S1 and S2 (by taking the official exchange rate between US dollar and Chinese Yuan in 2005).

S1 : AC= 61 US \$/ t CO₂

S2: AC= 18 US \$ /t CO₂

We see immediately that cost of abatement in strategy 1 is more than 3 times costlier than strategy 2. More specifically, if the stakeholders need to search for international carbon financing mechanism (for example the CDM in Kyoto Protocol which will be discussed in detail in chapter 7), S2 will be more probable than S1. This can be illustrated by Figure 4-11. **cost of different strategies of fuel-switching** which delineates how the fuel-switching can be realised at more cost-effective way. The

environmental performance in terms of CO₂ emissions of S2 is significantly higher than strategy 1 with reduced total discounted costs! This conveys a very strong policy message, Chinese local decision makers must reinforce the BEE standards if the city needs to decarbonise the energy supply systems to minimise the social costs of fuel-switching policy and to maximise the economic and environmental performances.

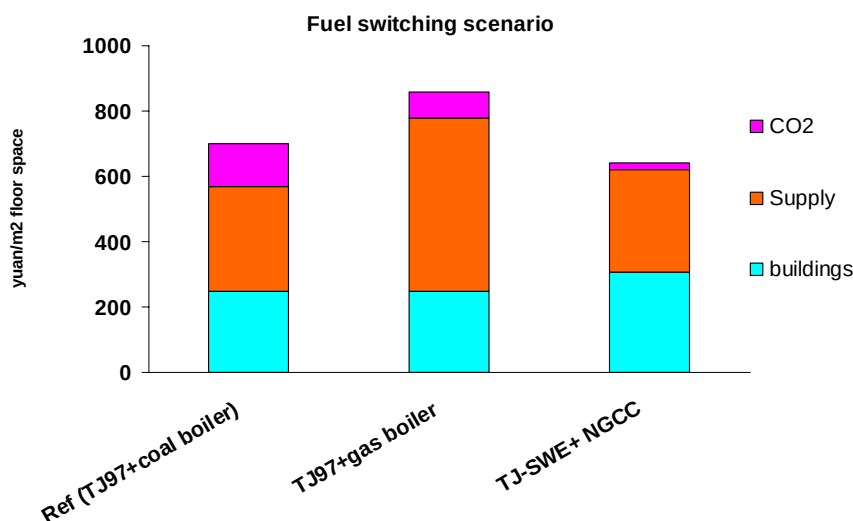


Figure 4-11. cost of different strategies of fuel-switching

In other words, S2 is strictly dominating S1 in decarbonisation options for the Chinese policy makers. The international carbon financiers will also require the Chinese buildings stakeholders to update first to SWE standard and then covers extra cost associated with fuel-switching.

4.10 Chapter conclusions

In this Chapter, we analysed the optimal choice of building energy efficiency standard coupled with appropriate energy supply system in the context of district heating services in Chinese city, by taking the city of Tianjin as a study object. We compared the energy consumption and relevant economic and environmental implications of implementation of different BEE prescriptions. The results allow use to distinguish the optima choice of BEE and relevant energy supply system from all other options assumed in the mode.

The analyses strongly indicate that the current BEE standard implemented in the Chinese cities is not an optimal choice and should be tightened immediately in order to achieving a better energy and environmental performance while reducing the associated social costs. Improvement of BEE standards can be justified by the co-benefits accompanying the energy savings and carbon emission mitigation. Without considering externality costs of carbon dioxide emission, the model suggests that the French code *RT-2005* (30% improvement in terms of building envelope performance and overall efficiency compared to the current building code) allows for the lowest net present value of overall life cycle costs thus should be adopted by BEE policy maker in China. By contrast, energy performance equivalent to the Swedish code

(Best Available Technology) is preferred in the case of explicit carbon emission restriction if and only if the marginal cost of carbon emission (carbon tax price) is sufficiently high (25-35 US\$/tCO₂ by 2020). This conveys clear economic implications in the context of the current international debate in the field of political economy of climate change. The show price that could enable the Chinese constructors to adopt much more energy-efficient building standards is of the same orders of the current CO₂ emission allowance price in the EU-ETS 2008-2012 CO₂ price²⁴ that averages 30 US\$/t CO₂.

In addition, recent literatures on economics of climate change and energy modelling all suggest that the benchmark CO₂ price such as EU-ETS carbon allowance price and or the marginal abatement cost (MAC) of CO₂ in the European countries and other parts of the world are likely to range between 30 to 40 US\$/tCO₂ on the time horizon 2020-2030 (Anderson, 2006; IPCC, 2007; Stern, 2007; Blanco and Rodrigues, 2008; Colombier *et al.*, 2008). Although it is still difficult to predict precisely longer-term EU-ETS CO₂ price depending on various factors, yet the rising trend of CO₂ allowance price is almost certain since the European Union has committed to attaining more stringent objectives of energy efficiency, renewable energy supply and CO₂ emission reduction by 2020 (Council of European Commission, 2007). Tougher mitigation objective is one of major drivers that make CO₂ price move upwards further.

In fact, financing the enhanced buildings energy performance in China turns out to be more cost-effectively compared to investment in equivalent CO₂ mitigation by low-carbon technologies such as renewable power supply or Carbon Capture and Storage (CCS) projects in developed countries. For example, the CO₂ price that would be needed to keep wind power financially viable in most European countries will range between 30 to 67 US\$/tCO₂ (Blanco and Rodrigues, 2008). Similarly, the levelised cost of CO₂ avoided by installing the CCS in the coal-fired power plants in the US averages around 50 US\$/tCO₂ when considering cost of transport (Rubin *et al.*, 2007). In other words, the opportunity cost of renouncing the more stringent energy performance in new buildings is actually higher than the incremental cost that would be incurred for the building constructors. In this regard, the international financing system such as Clean Development Mechanism could play essential role to influence both Chinese and international decision makers in financing the improvement of building efficiency in China. Market-based financing tool may help to ensure an optimal output of carbon emission burden sharing between different international players.

From energy supply viewpoint, despite the obvious environmental benefits in terms of polluting gases reduction, the fuel-switching policy (from coal to natural gas) in the urban district heating system can hardly be justified for this policy implies significant increase in social costs, the present value of overall cost of natural gas-fired district heating system is 30-35% higher than the coal-fired CHP with desulphurisation process, depending on building efficiency options. The French RT2005 equivalent building energy performance combined with a properly designed district small coal CHP (20 t/h +2MW_e) can be viewed as

²⁴ The dramatic drop in allowance price in May 2007 is mainly due to over-estimation of emission level in the National Allocation Plan (NAP) in the first period of EU-ETS. This technical *incident* is unlikely to happen again in the future.

the best choice of BEE standard and heat supply infrastructure given the underlying assumptions in the model. The Swedish code equivalent energy efficiency or even more stringent objective should be targeted provided either in a high carbon emission tax scenario, or that the local authority will opt for large-scale fuel-switching policy in district heating, which is, however, unlikely to occur in a foreseeable future given the energy supply security priority in China.

Although the economic analyses suggest that the distributed small CHP is preferred to the municipal large-size heat plants in terms of economic performance, their development is confronting the institutional barriers. The State Council's decision (State Council *et al.*, 2007) on closing down all small capacity thermal power plants (less than 50 MW) does not distinguish the small cogeneration plants from the inefficient electricity-only condensing units. Many small-sized efficient CHP were obliged to be closed down following the central and provincial governments' guidelines. Further, small CHP units face financial risk and policy uncertainty since there is virtually no guarantee of electricity purchase by the grid company. The national reform in Chinese power sector in 2002, which aimed at introducing competition mechanism in electricity generation market, put the small CHP plants back to the wall (Wang, 2003). Our analysis results suggest that the discriminatory policy prioritising the development of small and medium-sized CHP for district heating is reasonably recommendable.

Another important aspect related to centralised district heating is the pricing mechanism, the model used in this study implies sustained and stable financing in the district CHP development and operation, however current heating billing and pricing system do not necessarily allow for viable functioning in these plants because final heat consumption is priced proportional to occupied area instead of real joules consumed. More transparent heat price is the prerequisite condition to achieve the BEE implementation. In this regard, the Tianjin building efficiency and heating reform pilot project²⁵ in collaboration with the World Bank may be served as an example for the national reform in the next step.

In summary, four key concluding remarks can be derived from the results of techno-economic analysis :

1. The current Chinese building energy efficiency standard (TJ 97 is a local equivalent to the national 95 building code that aims at 50% of heating energy consumption reduction) is the most costly scenario and must be updated in all northern zones
2. The improvement in BEE standards (represented by TJ 2004) is not sufficient
3. Without consideration of carbon price for CO₂ emissions , the optimal level of building energy efficiency would be RT 2005, in other words, the current building code could be improved by 30% with enhanced insulation and ventilation system.
4. Strikingly, the global costs will be lower if China adopts the most stringent BEE standards (Swedish code equivalent) in buildings even without any consideration of carbon price, implying that

²⁵ Individual billing and consumption-based pricing is practiced in this project.

CO₂ emissions mitigation is negative if the current national buildings codes is updated to the reference level of the world's best practiced techniques (SWE equivalent standards)

5. Energy supply decarbonisation strategy should integrate buildings energy performance improvement scheme, otherwise the cost of CO₂ mitigation may be three times costlier than otherwise

Indeed, point 4 and 5 convey very strong political signals to the Chinese policy makers in the area of energy efficiency policies. China needs to upgrade the energy performance regulations in buildings let alone climate protection objectives. And if cost-effectiveness of CO₂ emission mitigation should be taken into account, the stakeholders still need to consider upgrading BEE standards before choosing fuel-switching policy. Indeed, adopting high efficient building codes (SWE) will require necessarily both technical and institutional capacities. For example, diffusion of new techniques of construction, scaled industrialisation commercialisation of efficient buildings materials, training of qualified workforce in construction sector. These need fundamental transformation of buildings supply chain. Furthermore, implementation of new building codes should take into account the technical and socioeconomic realities in different geographic and administrative zones in China given tremendous diversity between different provinces and municipalities, and between urban and rural area.

We can not expect the market transform itself fortnightly with a magic stick, a continuous and gradual approach has to be adopted to anticipate the sectoral evolution in the near future.

As argued above, improving building energy performance could produce benefits compared with the business as usual case, the gain could be used to finance research and development of more efficient low-carbon heat supply system such as NGCC, biomass and urban wastes-fuelled district heating supply. They could be used to substitute partly the fuel combustion in the district coal-fired CHPs to address the double challenge of energy supply security and carbon emission mitigation. Biomass co-firing and refuse incineration for heat and power generation have been recognised as promising technologies to CO₂ emission mitigation in power sector. Further improvement in BEE standard in residential buildings is the prerequisite condition before switching massively to this low carbon supply technology in order to minimise associated costs. A more efficient housing stock is more likely to facilitate the technological transformation and will open a broad perspective of sustainable district heating in China's northern cities in the following decades.

References

- Anderson, D. 2006. Costs and Finance of Abating Carbon Emissions in the Energy Sector. UK: HM Treasury.
- Blanco, M. and Rodrigues, G. 2008. Can the future EU ETS support wind energy investments? *Energy Policy*, Vol. 36 (4) 1509–1520.
- Centre Scientifique et Technique du Bâtiment (CSTB). Réglementation Thermique 2005 Th-CE. 2006.

Colombier, M., Crassous, R., Criqui, P. 2008. EPE Étude FONDDRI « Scénarios sous contrainte Carbone ». Powerpoint presentation. Paris, May 2008.

Council of the European Union, 2007a. 7224/1/07 Rev: Brussels European Council, 8–9 March 2007. Presidency Conclusions. Available at /www.consilium.europa.eu

Cummins Inc. 2004. Comparison of different CHP systems. PowerPoint presentation. In proceedings of the 5th Annual Conference of World Alliance for Decentralized Energy and CHP. Beijing, 2004.

Durbin, J., Miedema, A., Chandran, R. 1986. Price effects of energy efficient technologies: a study of residential demand for heating and cooling. *Rand Journal of Economics*. Vol 17(3): 310-325.

Framing the Future in Light of the past, Annals of the New York Academy of Sciences, **1076**, pp. 516-526

Haas, R., Biermayr, P. 2000. The rebound effect for space heating Empirical evidence from Austria. *Energy Policy* 28 (6) : 403-410.

Hao, X. Zhang, G., Chen, Y. 2008. Role of BCHP in energy and environmental sustainable development and its prospects in China *Renewable and Sustainable Energy Reviews*, Volume 11, Issue 8, October 2007, Pages 1827-1842

Intergovernmental Panel on Climate Change (IPCC). 2007. Residential and commercial buildings. In *Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. UK: Cambridge University Press.

Lang, S. 2004. Progress in energy-efficiency standards for residential buildings in China. *Energy and Buildings* Vol. 36(12), pp. 1191-1196.

Lee, W.L. Chen, H. 2008. Benchmarking Hong Kong and China energy codes for residential buildings. *Energy and Buildings*, Volume 40, Issue 9, 2008, Pages 1628-1636

Mendelsohn, R. 2007. Comments on the Stern Review. In *Yale Symposium on the Stern Review*, Chapter 8, 93-103. New Haven, CT: Yale Centre for the study of globalisation.

Li, J. 2008. Towards a low-carbon future of China's building sector—a review of long term models forecast. *Energy Policy*. Vol 36(5), pp. 1736-1747.

Li, J. Colombier, M., Giraud, P.-N. 2009. Decision on optimal building energy efficiency standard in China—The case for Tianjin. *Energy Policy*. In press.

Liang, J.; Li, B., Wu, Y., Yao, R. 2007. An investigation of the existing situation and trends in building energy efficiency management in China. *Energy and Buildings*, Volume 39, Issue 10, October 2007, Pages 1098-1106.

Liu, F. 2006. Economic Analysis of Residential Building Energy-Efficient Design Standards in Northern China : A Case Study of Tianjin City. World Bank Interim Report.

Ministry of Construction (MOC) 1993. Thermal Design Code for Civil Buildings (GB/T50176-1993)

----- 2005 National General administration of quality supervision and monitoring and Inspection and Quarantine. National Standard of the People's Republic of China (GB50189-2005). Design Standard For Energy Efficiency Of Public Buildings. Ministry of Construction Enforcement, April 4, 2005.

----- .1995. Industrial Standard of the People's Republic of China (JGJ 29-95). Energy Conservation Design Standard for New Heating Residential Buildings. Ministry of Construction Enforcement, July 1, 1996.

----- 2001. Industrial Standard of the People's Republic of China (JGJ 134-2001), Design Standard For Energy Efficiency Of Residential Buildings In Hot Summer And Cold Winter Zone. Ministry of Construction Enforcement , October 1, 2001.

-----2003. Industrial Standard of the People's Republic of China (JGJ 75-2003). Design Standard For Energy Efficiency Of Residential Buildings In Hot Summer And Warm Winter Zone. Ministry of Construction Enforcement, July 1, 2003.

Natural Research Council Canada. 2005. The 2005 National Building Code.

Nolan, Paul S. 2002. Combined flue gas desulphurisation and carbon dioxide removal system. United States Patent 6399030.

Nordhaus, W. 2007a. A Review of the Stern Review on the Economics of Climate Change. *Journal of Economic Literature*, 45(3): 686-702.

Nordhaus, W. 2007b. Critical Assumptions in the Stern Review on Climate Change. *Science* 13 July 2007, 317(5835): pp. 201 – 202.

North China Municipal Engineering Design & Research Institute (NCMEDRI). 2007. District Heating Planning of Tianjin Binhai New Area .

Rabl, A. And Spadaro, J.V. (2006). Environmental Impacts and Costs of Energy. *Living in a Chemical World*:

Rubin, E., Chen, C., Rao, A. 2007. Cost and performance of fossil fuel power plants with CO₂ capture and storage. *Energy Policy* 35 (2007) 4444–4454.

State Council; National Development and Reform Commission; National Office of Energy. 2007. Notice on accelerating closing down the small thermal power units.

Stern, N. 2007. The Economics of Climate Change: The Stern Review. Cambridge, UK: Cambridge University Press.

Stern, N. 2008. The Economics of Climate Change, Richard T. ELY Lecture. In proceedings of the 2008 Annual Meeting of American Economic Association. *American Economic Review*: paper and proceedings 2008, 98:2, 1-37.

Swedish Board of Housing, Building and Planning. 1993. BBR 2006:22. Building Regulations Mandatory provisions and general recommendations. 2006 revision.

Tianjin Jinneng Energy Group (TJEG). 2007. Tianjin Municipal CHP Development Planning 2005-2015.

Tianjin Municipal Commission of Construction. 2004. Tianjin Residential Buildings Energy Efficiency Design Standard. 2004 (DB-1-29-2004), 2007 update. June 1, 2007.

Wang, Y., Huang, Z., Li, H. 2007. Cost-effectiveness assessment of insulated exterior walls of residential buildings in cold climate. *International Journal of Project Management*, Volume 25, Issue 2, February 2007, pp 143-149.

Wang, Z. 2003. An Essay on history, current situation and prospective of CHP development in China.

Ye, Y., Shi, Z., Wu, X., Zhang, H., Zhang, R., Li, X., Sha, X., Fan, J., Zhou, J., Zhao, Y., Zhao, Y., Xiong, W., 2001. *Research on Urban Heating Supply System In Beijing* (in Chinese). China International Engineering Consulting Co. Available at <http://www.china5e.com/focus/bluesky/1-21.htm>

Zhou, N., McNeil, M. A., Fridley, D., Lin, J., Price, L., De la Rue du Can, S., Sathaye, J. and Levine, M. (2007). Energy Use in China: Sectoral Trends and Future Outlook. Lawrence Berkeley National Laboratory. 96 p.

Chapter 5 Modelling the long term trajectories in Tianjin City

5.1 Introduction and summary

In the previous chapter, we discussed what the optimal decision on BEE standard uptake is when a Chinese authority is confronting with a programme of developing a new residential area in the northern area today. We investigated different strategies of demand-side technology contributing to enhanced buildings energy performance coupled with relevant supply technological options such as coal-fired district boilers or gas-fired cogeneration.

As pointed out by Pindyck and Rubinfeld (1997), economics is concerned with the explanation and prediction of observed phenomena. The scope of modelling is to predict how the future energy demand in buildings will increase based on different assumptions of BEE policy implementations. In fact, each of the scenarios of implementation of BEE policies, an underlying investment strategy is implied. The envisaged investment in technologies in chapter 4 consists of one time investment strategy since the object of analysis is new buildings that will be constructed together at the same time. In other words, the analysis was concerned with a static building stock, no additional construction or demolition was considered during the evaluation period. In short, the one time capital investment and O&M costs were taken into account in the analysis in chapter 4. Yet the high-efficient and low-carbon technologies (CCS, renewable heating) could hardly be incorporated in today's decision due to their prohibitive costs at current stage. In contrast, this chapter deals with a dynamic building stock in the city of Tianjin over the period 2005-2030, both continuing new construction and change in existing buildings stock constructed prior to 2005 will be considered throughout the period. Both the scope and objective of this chapter are broader than those in chapter 4 in which a "static" building stock was treated.

Considering a dynamic buildings stock over several decades will need to address the issues of buildings thermal rehabilitation and supply infrastructure renewal for the old equipments that must be decommissioned and retired when reaching lifetime limit (20-30 years in general). Importantly, a new investment strategy needs to be considered at this point with regard to alternative energy supply technologies. Moreover, climate-friendly technologies such as CCS or biomass heating could commence to be deployed at commercialisation scale from 2020 when the decreased costs will allow widespread of new technologies as a result of technological advancement and economies of scale. Investment strategies differ one from another by the fact that the nature of intervention in buildings and supply-side technologies is differentiated. What the economic analysis in chapter is distinguished from chapter 4 is that it will deal with a sequential investment decision on demand-side technology (building energy performance improvement) and adoption of technological innovation in energy supply in the future. These sequential costs will delineate the trajectory of operation costs of buildings stock under certain efficiency level. The policy makers will take decision on a series of successive investment in buildings and energy

supply infrastructure. The results will allow us to assess the impact and consequences of investment decision taken by public authority today on the city's financing capacity in adopting new technology and low-carbon supply infrastructure in the future. In other words, the modelling aims to set up an interactive dynamic to bridge the gap between now and tomorrow's investment priority for the stakeholders.

The economic analysis quantifies the future economic consequences of the decision made today on infrastructure quality in terms of energy performance. For instance, two distinguished investment strategies of decarbonisation can be compared; 1) invest in high-efficient buildings construction techniques since the early stage of the modelling period and harness the benefits associated with reduced operation costs to invest in low-carbon supply technologies in the future; 2) keep the current practice of buildings construction; i.e. business-as-usual techniques and invest immediately in low-carbon supply options. From 2020, different strategies will also be envisaged: i) retrofitting the inefficient buildings constructed before 2005; ii) switch to natural gas or biomass heating. Furthermore, CCS could be incorporated into the supply package from 2020. Economic consequences of these investment strategies will then be compared. Specifically, we try to find out what is the optimal investment strategy which integrates upstream investment in infrastructure quality into the downstream supply technologies in the future. The optimality criteria should take into account simultaneously two kinds of cost: i) total cumulative costs; and ii) yearly costs. The former gives a comprehensive view of investment strategy and determines the economic performance of investment strategy over the whole period; the latter gives a future image of the society confronting with heritage of buildings stock constructed from today and decision on supply options selection. Note that the choice of future society is closely dependent upon the choice made on the quality of infrastructure constructed today, since the capacity of financing new supply technologies will be certainly strengthened with improved energy efficiency. A priori, enhanced energy efficiency in buildings constructed today will generate gradually economic benefits which in turn will enlarge the room for investing in promising decarbonisation technologies when old equipment must be retired and replaced by new system from the year 2015-2020, provided that local authority can establish appropriate institutions to collect and redistribute the underlying benefits to the society accordingly. The analysis aims at bridging the gap between today's investment strategy and tomorrow's decision on decarbonising the whole infrastructure subject to economic resources constraints. It is shown that the single-minded focus on switching to magical supply technologies may cause deciders to neglect the importance of buildings efficiency performance at early stage. However, huge quantity of low-efficient buildings will ultimately result in tremendous difficulty in financing the decarbonising infrastructure due to lack of financing capacity, thus a failure in attaining the socioeconomic objective from the long term climate change mitigation perspective. In this regard, the fundamental question of dynamic modelling in this chapter is related to optimising the investment strategies given the economic resources constraints.

This chapter employs a bottom-up approach to modelling the scenarios of adopting different BEE standards in the city of Tianjin and investigating both environmental and economic implications. Storylines

are constructed based on LEAP-model to examine the different probable BEE development trajectories in order to define the optimal building energy efficiency advancement that should be undertaken in the Chinese city. Consequently, the results will allow us to identify optimal BEE technological progress in the residential buildings in Tianjin over the period 2005-2030. The optimal path is referred to as the means by which the present value of overall cost is minimised, consistent to vast majority of economic literature on cost-benefit analysis. The model is not equilibrium in the sense that the technical energy efficiency (translated into the energy consumption) is not affected by the imposition of energy tax or carbon tax. We consider that the energy demand is more likely to be driven by improvement in people's livelihood, in other words, household are more inelastic with respect to the energy price. So increase in demand for better thermal comfort of residents is driven by the rise in households income, yet the influence of energy price variation (when) is relatively small thus ignored in the model. In developing economies, this is true in particular in the long-term energy demand modelling framework in which income has greater impact on economic agent's consumption behaviour than the price of energy services.

In a typical energy system optimisation model framework (e.g. MARKAL), the total cost of energy system over the entire time horizon is minimised subject to limited resource supply and other constraints (a set of linear equations or inequalities), such as CO₂ emission abatement. Our approach is to describe the different scenarios of buildings energy efficiency technologies (new construction, retrofitting, heating appliances and other final energy consuming equipment) advancement paces and relevant energy supply systems (capacity installation) subject to the objective of minimising total costs incurred in the time horizon. Energy resources supply is not considered as exogenous constraints in our modelling framework. However, we look for the solutions that minimise the primary energy supply in meeting the increasing demand for energy services in the buildings.

This chapter consists of three major parts. Section 5.2-5.9 explains the optimality criteria, modelling approach and all the assumptions employed in the scenarios. A detailed modelling results of the reference scenario (what would happen under current trend of urban development and BEE policy) in section 5.10-5.13. Section 5.14-5.20 describe major findings of alternative scenarios and discusses the rationale in selecting the best development trajectory as defined above. Section 5.21 concludes the chapter. The results presented in this chapter are considered as the arguments of policy instruments design in chapter 7.

5.2 Economic theory of optimal BEE trajectory

The question of what is the optimal BEE development path consists of minimising the present value of all the costs incurred over the period of construction and operation of buildings. In terms of economic analysis, the social costs are associated with a broad array of economic sectors. Generally, society faces two types of costs associated with BEE improvement. First, there is cost for taking action on BEE, for example, the

additional cost incurred by improving building's shell integrity performance during initial construction stage. Second, the costs related to energy supply and consumption during the operation stage of buildings. Moreover, the environmental externality related to GHG emission from buildings is also required to be integrated into the cost-benefit analysis for there is an increasingly concerns about global warming, accelerated by large scale fossil energy combustion in the world. In terms of economic analysis, the socially optimal solution is one that minimises the sum of the construction cost plus the operation cost and environmental damages associated with the greenhouse gas emission. In this thesis we take a strict definition of social cost which covers essentially costs associated with building construction, buildings energy use, investment in energy supply capacity as well as the externality such as negative environmental impact of energy use in buildings. The model calculates the long-term economic costs of energy demand in buildings for a 25-30 years time span. Most energy and climate models simulated different scenarios of policy options for 30-50 years (IEA, 2006, 2007; EIA, 2006; Jiang and Hu, 2006; Zhou *et al.*, 2007;), 100 years (Nordhaus, 1991; Manne *et al.*, 1995; Pearce *et al.*, 1996; Plambeck *et al.*, 1997; IPCC, 1995, 2001, 2007) , some even predict the scenarios for the next 200 years (Tol, 2002; Stern, 2006).

Consequently, in order to take time into account, an economic analysis must measure the present value of cost of implementing energy efficiency and CO₂ mitigation in buildings over the whole modelling period²⁶. Future cost and benefit should be adjusted on when they occur so that all are measured in the same units (current dollars for example) by using a consistent discount rate²⁷(Mendelsohn, 2008). The choice of discount rate is of course of extreme importance since too low discount rate may favour much more investment in BEE since the present value of future energy savings is higher than if a low discount rate applies, it means the economic agents are more concerned about their future cost and benefits in the sense that more ambitious BEE improvement programme can be justified.

5.3 Criterion of social optimum and boundary of costs

The Kaldor-Hicks criterion is widely applied in welfare economics and managerial economics. For example, it forms an underlying rationale for cost-benefit analysis. In cost-benefit analysis, a project is evaluated by comparing the total costs, such as building costs and environmental costs, with the total benefits, such as airline profits and convenience for travellers. (However, as cost-benefit analysis may also assign different social welfare weights to different individuals, e.g. more to the poor, the compensation criterion is not always invoked by cost-benefit analysis.). A related problem is that any social welfare functions based on Kaldor-Hicks criteria are cardinal in nature, and therefore suffer from the aggregation problems associated with discrepancies between the marginal value of money of rich and poor people.

²⁶ This is inspired by the argument mentioned in Mendelsohn (2008) which discusses the economic efficiency of global GHG emission abatement options. The efficient solution for climate change problem is to minimize the sum of abatement cost plus the climate change damages.

²⁷ It is out of the scope of the thesis to discuss the question of consistency of discount rate from intertemporal point of view. We just take the reference of market return on investment as the opportunity cost of BEE improvement.

Under the “Hicks criterion”, an activity will contribute to Pareto optimality if the maximum amount the losers are prepared to offer to the gainers in order to prevent the change is less than the minimum amount the gainers are prepared to accept as a bribe to forgo the change. The Hicks compensation test is from the losers' point of view, while the Kaldor compensation test is from the gainers' point of view. After several technical problems with each separate criterion were discovered, they were combined into the Scitovsky criterion, more commonly known as the “ Kaldor-Hicks criterion”, which does not share the same flaws.

In our modelling framework, marginal benefit of improvements in every individual’s thermal comfort is assume to be equal from the whole society’s point of view, further we believe that all individuals have the same right to thermal comfort in their dwellings regardless of their social class and revenue. Thus the individual difference between rich and poor’s people’s marginal gain of BEE amelioration can be neglected since this is not taken into account in the general cost and benefit analysis.

The boundary of cost is concerned with the extent to which the scope of economic analysis extends. From life cycle analysis (LCA) perspective, energy consumption in buildings includes both the operational and embodied energy. The embodied energy of a building is the energy used to acquire raw materials and manufacture, transport and install building products in the initial construction stage of buildings. Figure 5-1 describes the whole life-cycle procedure of a building. In most countries in the world, approximately 85% of energy use is associated with buildings operations, while materials manufacturing and building construction together only account for about 10–15% of overall life cycle energy consumption (WBCSD, 2007).

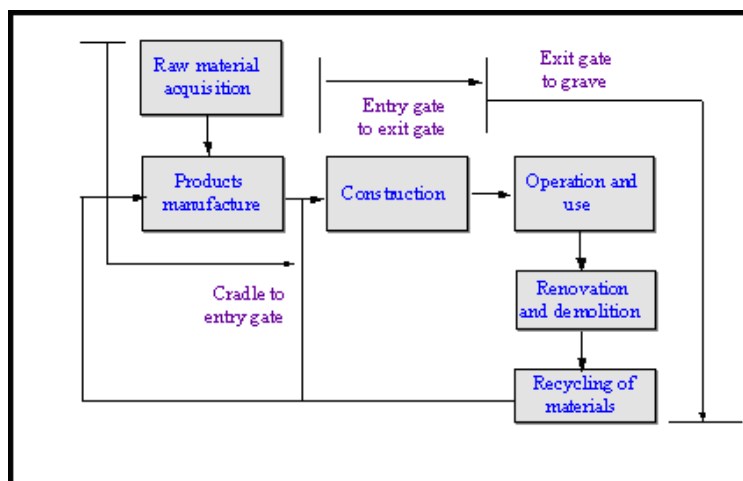


Figure 5-1 schema of Life-cycle of buildings (adapted from Yau and Cheng , 2006)

Energy required for maintaining buildings operation can be reduced considerably by improving BEE such as enhanced exterior insulation and/or fenestration, and heat recovery system of ventilation as well. Although the efficient building materials require more embodied energy than conventional technique, a

large amount of extra energy consumption associated with manufacturing insulating material can be offset by energy savings during the first years of occupancy of buildings. Therefore the up-front investment can be paid back by the financial stream generated by energy savings during buildings operation stage. The energy efficiency measures will enable consumers to reduce eventually significant energy bills, consumers will be then better-off compared with living in a poorly insulated house. Embodied energy in production phase has more important share in the total energy needed in the low energy buildings; however, material recycling and combustion after the demolition offers a potential of reducing 40-50% of embodied energy in the northern European countries such as Sweden (Thormark, 2001). This implies that public authorities should integrate the whole construction chain into the BEE policies so as to minimise the negative impact on social welfare. As far as the capital in new generating capacity expansion is concerned, the model's cost boundary in the power generation plants. However, the operation costs associated with upstream coal mining and crude oil refinery are ignored in the model due to lack of sufficiently detailed data.

In the remainder of this chapter, both of costs incurred during building's construction and operation stage are taken into account. The former includes the cost of investment in building energy efficiency improvement measures like envelope insulation. The latter is comprised mainly of fuel cost and capital cost of investment in energy supply system. In addition to these buildings-related costs, the cost of externalities is accounted for to take into account the environmental impact of energy consumption in buildings. Both the EU-ETS carbon finance price index and China's CDM carbon transaction price are used as a proxy of internalising the environmental externality. By definition, equilibrating CO₂ price is equal to the marginal cost of mitigation and marginal social benefit of CO₂ emission control in competitive market. However, price distortion can be observed in presence of market imperfection or market failure.

5.4 Determining variables of buildings energy consumption

5.4.1 Climate condition and thermal comfort

From economic analysis point of view, energy consumption in residential sector is to meet the consumer's utility, the optimal BEE measure is by definition a technical intervention in buildings energy efficiency that deliver the required energy services by minimizing the social cost. Our model is parametrised to simulate the present social cost among the different technology option scenarios. From regulatory point of view, indoor temperature is specified in different international standards such as international level ISO (International Organization for Standardization), CEN (European Committee for Standardization) and ASHRAE (American Society of Heating, Refrigerating and Air Conditioning Engineers) concerning indoor environment.

The most internationally used standard for ventilation and indoor air quality is ASHRAE Standard 62.1 (2004). New concepts have been introduced in a European Technical Report, CR 1752 (1998). Heating

temperature regarding thermal comfort is classified into three categories of thermal environments (Olesen 2004),in which indoor temperature ranges between 19°C and 25°C, as shown in Table 5-1.

Table 5-1 Indoor thermal environment international standard

Category	Thermal state of the body as a whole		Operative temperature °C		Max. mean air velocity m/s	
	PPD %	PMV	Summer (0,5 clo) Cooling	Winter(1 clo) Heating	Summer(0,5 clo) Cooling	Winter(1 clo) Heating
A	< 6	-0.2 < PMV < + 0.2	23,5 – 25,5	21,0 – 23,0	0,18	0,15
B	< 10	-0.5 < PMV < + 0.5	23,0 – 26,0	20,0 – 24,0	0,22	0,18
C	< 15	0.7 < PMV < + 0.7	22,0 – 27,0	19,0 – 25,0	0,25	0,21

Source: ISO EN 7730, 2005, CR 1752, 1998.

Note: PMV represents the predicted *mean vote* (on the thermal sensation scale); PPD is the predicted per cent of unsatisfied people at each PMV.

Indoor temperature and duration of heating period are used as proxy of thermal comfort requirement of residents. Both of them are to be extended as people's living standard improves. The indoor temperature required for space heating in current building code of Tianjin (16°C) is still significantly lower than that in developed countries. Empirical studies show that consumer tends to have higher temperature as living standard improves, for example, indoor thermal comfort temperature in European countries and US ranges between 19°C and 22°C, and higher in some cases, stated in most residential heating consumption survey. Our model assumes that indoor temperature required by residential consumers in Tianjin and that of their counterparts in western countries will converge eventually, as a result of increase in household income. It is also assumed that duration of heating period will be eventually extended to five months (from the beginning of November to the end of March) even longer, this assumption can be justified in the sense that outdoor temperature profile in Tianjin during winter time resembles that of Paris where heating season covers on average six months from mi-October to mi-April. Figure 5-2 delineates the hourly temperature profiles in a year in Tianjin and Paris, it can be seen very clearly that exterior average temperature in Tianjin is lower than Paris in winter. This implies that the heating degree day (HDD) derived from Paris benchmark would be much higher than that prescribed in Tianjin's local BEE design standards which set an official heating period starting on November 10 and ending on March 15 next year. Thermal comfort improvement is identical in all of the scenarios except for the "temperature" scenario in which indoor temperature will be kept at 16°C throughout the modelling period, reflecting a static vision on future evolution of people's demand for better comfort.

Furthermore, the current Chinese *Residential Buildings Design Regulation* (2003 update of GB 50096—1999) prescribes that indoor temperature of living space and bedroom in residential buildings should not

be lower than 18°C and the indicative design temperature for heating load calculation is 20 °C, and 15°C and 14°C is applied for kitchen and stairway, respectively.

Indoor design temperature during heating season

Usage	Temperature (°C)
Bedroom, living room, toilet*	18
Kitchen	15
Heated Stairway and corridor	14

* 25°C for WC equipped with bathing or centrally distributed hot water premises

Source: Chinese Residential Buildings Design Regulation 1999, 2003 update

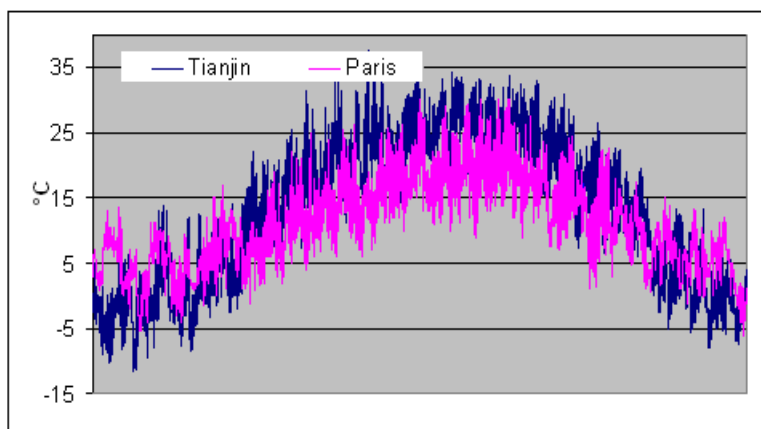


Figure 5-2. Hourly Outdoor temperature profiles in Paris and Tianjin in a year (8760 hours from January 1st to December 31)

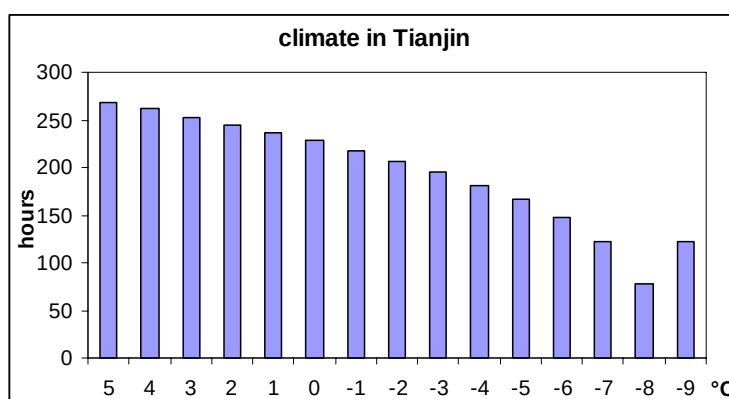
Source: CTYW meteorological data is supplied by the US Department of Energy.

According to the national residential building energy efficiency design standard, heating degree day (HDD) based on 18°C is 2700 degree days. It is easy to calculate that HDD based on 20°C, 22°C are 2948 and 3678 degree days, respectively, heating period is being held constant as presumed in the official documents in baseline scenario, while HDD will be higher if the heating season covers a period longer than the official recommendation. Table 5-2 summarises the HDD in Tianjin under different assumptions. Fig. 5-3. depicts the profile of outdoor temperature in winter time in Tianjin.

Table 5-2 HDD variation with indoor temperature and length of heating period (degree-day)

Indoor temperature	Tianjin Official period Nov 10 to Mar 15	Period extended Nov 1 st to Mar 30	Paris heating period (mi-Oct to mi-April)
16°C	1488	1735	1855
18°C	2284	2465	2585
20°C	2948	3195	3315
22°C	3678	3925	4045

Source: adapted from CTYW data (US DOE).

**Figure 5-3. Outdoor temperature variation and duration in Tianjin(source: NCUEDl).**

5.4.1.1 Estimation of thermal comfort improvement and heating consumption

Previous literatures on residential energy estimated residential energy use is by using econometric models in which energy use is related to variables such as household disposable income and short- and long-run elasticity with respect to fuel prices variation , provided historical data on residential information (dwelling, tenure, income, energy use, fuel price, tax etc.) is available. This approach is pertinent for the analysis of the effects of policy instruments which are designed to act on the underlying economic factors (Shorrocks and Dunster, 1997). However, as argued by Shorrocks and Dunster (1997), many policy instruments act more directly at the level of the physical factors which influence energy use (e.g. policies aimed at increasing the uptake of insulation measures). These are more readily addressed using a physically based model. This is why a physically-based bottom-up approach is used to estimate dwellings energy use in the city of Tianjin on the basis of housing stock simulation.

In previous chapter, we discussed the technical model in heating consumption estimation which implies that the HDD is constant. In this chapter, the future demand for thermal comfort will be introduced in the energy demand projection, the assumptions of constant HDD over 25 years seem unrealistic and do not hold in the long run.

Thermal calculation in buildings in this chapter uses the methodology as the previous chapter, again the technical parametre, D_{bldint} (W/m^2K), is employed as a proxy to represent the building's integrity energy efficiency, heat loss from buildings shell, infiltration and air exchange are captured by this unique value to allow the variation of indoor temperature and heating period in energy consumption modelling. This parametre offers flexibility in terms of variation of heating comfort indicators in the modelling framework.

In fact, equation 4.2 loses to some extent robustness in the sense that internal gain is settled in forfeit. In fact, the improved wall insulation favours indoor heat gain, also, equation 4-2 implies that improved insulation decreases the U-value with detriment to the solar heat gain. HDD variation captures relevant socioeconomic factors depending upon the required comfort temperature and heating period, specified in each scenario. Unlike U-value, the D_{bldint} is not a constant physical value over the modelling period, the right-hand side of equation 4-2 captures the difference between outdoor and indoor temperatures which decreases gradually based on the aforementioned assumption on climate change prospect, or building global thermal efficiency "worsens" as a result of rise in thermal comfort temperature, since the global warming factor has a marginal impact, rising demand for comfort's influence on building overall energy performance is thus far from neglectable.

As explained in the introductory section in this chapter, the improvements to inhabitant's living standard is mainly driven by income effect, translated into extended heating period and rise in comfort temperature, producing higher HDD values. From equations 4.1-4.3 in Chapter 4, it can be seen that given a certain level of BEE standard D_{bldint} (say TJ-2004 design standard), the change of heating intensity is mainly driven by change of HDD when other factors being held constant, increasing quality of people's life is implied in the assumed the rise in HDD values.

Household thermal comfort is projected to progress accordingly to keep pace with increasing living standard, we assume that the inhabitants in Tianjin and people in developed country will converge eventually, translated into the fact that the indoor temperature will be approaching the international comfort standard, it is assumed in the model that heating temperature will pursue continuous upward trend to approximate 22°C to converge with international level eventually. Note that the actual standard heating temperature is settled at 16°C (as said before, this may even fall below 14°C in poorly insulated houses). Also, the heating period will extend longer for the same reason, we estimate that it is likely to reach 162 days per year at the end of modelling period, roughly equivalent to that of Paris. To minimise the effect of average outdoor temperature deviation, we assume that the reference average annual temperature will increase 0.02°C each year to keep with line with the tendency in the context of global

warming, +0.5°C at the end of the modelling period is likely to fall within the lower range of the projection of the stabilisation scenarios in the IPCC's Fourth Report (IPCC, 2007)²⁸ and Ren *et al.*, (2005).

Increase in temperature and heating period is assumed to follow a logistic function, implying that HDD will increase the most quickly during 2010-2020 when households will be more affluent as a result of economic growth. Mathematically,

$$HP_i = HP_s / (1 + A * b^{-(Y_i - 2000)}) \quad (5.1)$$

$$T_{ci} = T_s / (1 + A * b^{-(Y_i - 2000)}) \quad (5.2)$$

The heating degree in i^{th} year over a period j is calculated by integrating the part between indoor and outdoor temperature

$$HDD_i = \int_{j=0}^{HP_i} (T_{ci} - T_{ei}) d_j \quad (5.3)$$

where

- Y_i is the specific year of estimation
- HP_i is the heating period in year i (day)
- T_{ci} is the comfort temperature in year i
- T_{ei} is the average outdoor temperature during the heating period in year i

A and b are parametres in the logistic increase function, their value have been parametreised based on historical data. In equation 5.1, A and b are 1.12 and 1.152, respectively ; while in equation 5.2, A and b are 1.53 and 1.151, respectively. Combining these factors will give the underlying thermal comfort indicator, the heating degree day whose development trend is plotted in Fig.5-4.

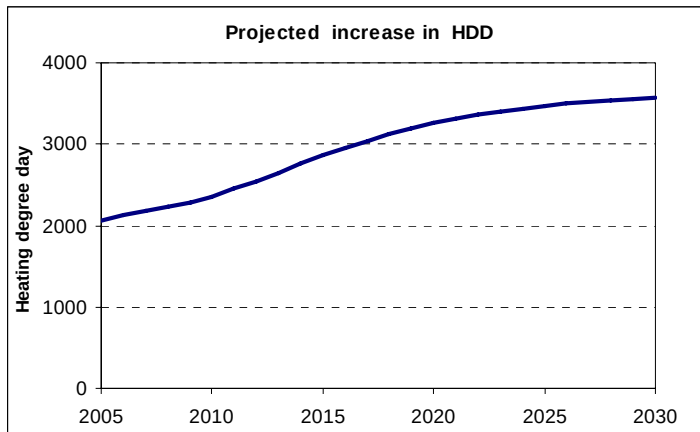


Figure 5-4. Projected HDD over the period 2005-2030.

²⁸ Stabilising GHG emission at 445 ppm to 535 ppm would limit the future temperature rise to rise to about 2 to 3°C by 2030 in the stabilisation scenarios of IPCC (2007). The Chinese meteorological researchers predicted that average yearly temperature would rise 1.3-2.6°C by 2020 compared to the average of 1961-1990, and 3.9°C—6.0°C by 2030 under the BAU scenario (Ren *et al.*, 2005).

Finally, by using equations 4.1-4.3 in previous chapter, the heating intensity of a newly built house in year i can be easily calculated. The result of simulated heating intensity (useful energy) when TJ-2004 is applicable in both high-rise and low-rise apartment house is presented in Fig.5-5. Identical thermal comfort improvement is applied in the same way in all alternative scenarios except for “Temp” scenario in which thermal comfort is being held constant over the period.

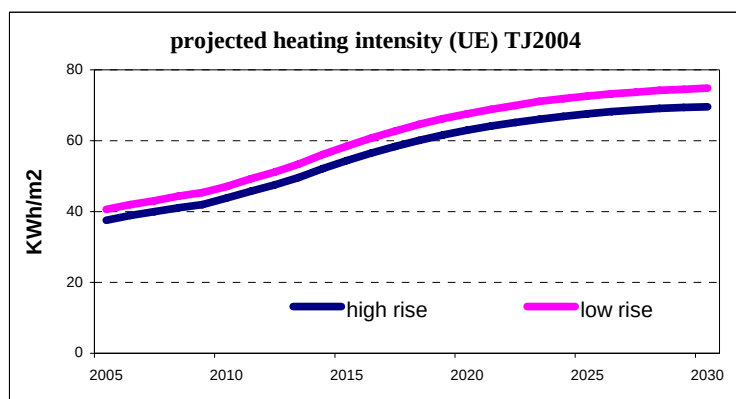


Figure 5-5. Projected change of residential spacing heating energy intensity (useful energy)

5.4.2 Buildings energy efficiency

A large part of existing residential buildings in northern China has been constructed without adequate consideration of BEE technology; shell insulation and double-glazing have not been deployed universally in the construction practice until very recently. Inefficient buildings result in huge amount of heat loss and environmental degradation during heating season in many northern cities in China (World Bank, 2001). Before the national BEE design regulation (JGJ 1995) single-glazed window has been widespread in the existing and new construction as well as poorly insulated exterior wall in residential buildings sector. Together with the startling energy loss, the poor indoor thermal environment turns out to be a serious issue due to inefficient buildings envelope and obsolete heat supply system in many northern cities. It is quite common that measured indoor temperatures in inefficient houses is only 12-14°C during winter time and can even fall below 8-9°C in some extreme cases(Xu,2006).

5.5 Key variables

5.5.1 Macroeconomic forecasting

Real data on household income is unavailable for the long-term forecast, instead the real per capita GDP is used as proxy of household income. Real GDP is assumed to increase by 5.9% during 2005-2020 and 2.3% between 2020 and 2030, with an average growth rate of 4.4% per annum throughout the modelling period. As mentioned earlier, residential demand for better comfort is mainly driven by increased income.

Heating intensity in new house complying with TJ-2004 BEE standard is projected to increase 85% during the period, with an average growth rate of 2.5% per year, implying an average income elasticity of 0.57.

5.5.2 Buildings stock change modelling

5.5.2.1 Housing stock modelling approach in literature

Various housing stock models have been set up in developed countries to simulate the energy use and CO₂ emission savings scenarios, such as BREHOMES in the UK (Shorrock,1997), DOE dwelling model of EIA in the US (DOE), and the French housing stock-energy analysis model developed by Traisnel(2001) and Maizia(2007), stock modelling method has been utilised in housing stock prediction in these models (Natarajan and Levermore, 2007). Three deterministic methods for predicting future trends of housing stock are identified in Natarajan and Levermore(2007).

-Weighted average method

-matrix method

-Iterative method

The advantage of the model is that housing stock vintage could be easily identified to take account of renovation, retrofitting, demolition actions throughout the modelling period. Johnstone (2001) states that in the housing mass and flow model, the energy and mass flows required to sustain dwelling services (heating, lighting, etc) can be established and quantified only within the framework of a stock and flow model of the total housing stock. In fact, in this model, the simulated housing stock can be visualised as a multi-level stack where each level of stack represents the age of a dwelling cohort.

From housing energy analysis perspective, distinguishing different dwelling cohort is very important since the efficiency measures and type of fuel consumed; appliance efficiency will not be the same between the different time intervals. To calculate energy use for a dwelling, the housing stock model such as BREDEM requires information on the areas of the different dwelling elements (walls, roof, floor, windows, doors) together with their thermal characteristics (*U*-values), as well as data on heating system characteristics (fuel type and efficiency), internal temperatures and heating patterns, number of occupants, external temperature etc.

5.5.2.2 Stock and turnover and retrofitting in existing housing stock in Tianjin

At present about 55% of existing houses in Tianjin were constructed before 1990(more than 15 years), this is generally the low-rise housing with brick-laid structure. The model considers that the housing demolition programme will be concerned mainly with this category of housing over the modelling period given characteristics of housing turnover, whereas the recently built houses with new construction techniques

will not be demolished, housing rehabilitation and retrofit measures will be undertaken in these buildings instead.

On the other hand, houses built more than 15 years ago hardly comply with the relevant building codes that had not been well enforced and implemented until 1998. Double-glazing and exterior wall insulation had not been deployed systematically in these buildings. We estimate that only 30% of low-rise brick-laid houses comply with TJ97, consequently, both demolition and housing retrofit programme will be carried out in the old-style and inefficient buildings stock in the model.

Due to lack of comprehensive historical data regarding the dwelling age and construction type, existing housing stock in Tianjin is roughly disaggregated into three sub-categories: 1. brick-laid low rise buildings; 2. modern low buildings with Concrete frame-structure; 3. high-rise buildings with concrete-framework or sheer wall structure.

Total existing housing stock of Tianjin was 143 million square metres in 2005. Due to lack of consistent housing vintage data, estimating accurately the yearly demolition floor areas of old house based on stock turnover principle is quite difficult. Our estimation is in fact relying on empirical study conducted during field survey in Tianjin, one-third of existing housing stock in 2005 is likely to be demolished or transformed over the next 30 years, or nearly 1.5- 1.7 million square metres of old houses need to be demolished or decommissioned per year.

5.5.2.3 Forecast of new housing construction floor area

In the model, the construction of new houses is driven by two major factors:

1. demolition of old houses
2. accommodation of new dwellers and new immigrants to the city

The official forecast of housing supply area up to 2010 is much higher than the projection in our model. The main reason is that per capita living area value in the base year (2005) is much lower than the official number published in the statistical yearbook in which all the immigrant population is not accounted for. This results in the fact that annual increase in per capita housing floor space is significantly lower in the first years in our model compared with official numerical. The other reason is related to the uncertainty about the demolished area. We estimate that about 1.5 million square metres will be demolished each year in the model, whereas the actual number may be either much higher in the case of modified urban planning of infrastructure development and old houses replacement.

5.5.2.4 Estimation of commercial building stock

Total existing area of commercial buildings in Tianjin is 67.8 million square metres in 2005. Simulation of commercial buildings (different types of buildings are considered in the model, namely office, hotel,

hospital, commercial complex, education institutions) floor space is based on the methodology in Zhou *et al.*(2007) in which the new construction of commercial buildings is closely correlated with GDP growth, the relationship in terms of floor area's elasticity with respect to GDP growth was identified by statistical regression on historical data. A simple mathematical relationship between floor area and GDP is used by assuming that public buildings area increase rate has an elasticity of 0.7 with respect to the real GDP growth rate.

5.5.3 Methodology of estimation of house size and household number

None of previous studies described explicitly the approach to estimate the number of houses constructed in Chinese cities, either in national or regional level. Generally the number is derived from the ratio of total constructed area to the average living area per household, which in turn is derived from the multiplication of household size by per capita living area. Alternatively, the household number can be simply derived from the number of inhabitant and household size (person per household) in corresponding year. The main drawback of this method is that the demolition floor area and individual demand for new houses are completely exogenous and decoupled from the new construction forecast, house number is only related to one indicator—the per capita living area which is in turn quite rigid since the value is more or less subjective, in many cases it is officially projected housing objective in the Chinese cities. This method also simplifies the household nature and structure. For example, the difference between house owner-occupier and apartment tenant. In most developed countries, the secondary market of housing rent and sale is quite developed, where more than half of urban residents are actually tenant in their apartment in some circumstances, the landlords do not live necessarily in the city.

In addition, the interactive dynamic between the demolished area and corresponding compensatory new area is not considered with explicit manner and is merely implied in the total new construction area. Also, this method disguises the significant difference in terms of floor area between the newly constructed house and old house since the existing housing stock is not catalogued by their vintage. This means that model projection is not responsive to the variance of demolition of old houses in this case. Therefore, the added new house numbers by this method is not necessarily consistent with the actual demand for housing which may be deviated in the estimates. However, the difficulty in considering the demolished area in housing floor area forecasting is that the continuous and consistent historical data is hardly available; its forecast is even more complicated in the sense that it may be dependent upon various macroeconomic factors that a simple bottom-up model cannot control.

Prediction of per capita floor area²⁹ is far from trivial due to the fact that it may be subject to housing policy uncertainty in the future. For example, central government has issued a construction guideline to limit strictly the development of large houses in favour of small-size houses in urban areas since 2005 for the purpose of efficient land use and make house ownership more affordable to medium- and low-income

²⁹ This notion is greater than the term of “living area”, mostly used in European countries.

urban households (see chapter 6 for more details), combined with the urbanisation factor, the actual per capita floor area may decrease if the number of new urban immigrant is large enough. So the assumption of presumably continuous growth in per capita floor area will be less robust when facing this kind of counterexample. Per capita floor area is expected to approach 30 square metres by 2020 according to the national housing development program (MOC), we assume that it will continue to rise such that it is approaching approximately 35 square metres per capita in 2030. Average house size will increase more slowly after 2020. Coupled with the household size in 2030, average housing floor space will then be around 96.5 square metres, roughly equivalent to current level in Japan³⁰ and the average of EU-15 in 2004³¹. The projected per capita floor space is plotted in Fig 5-6.

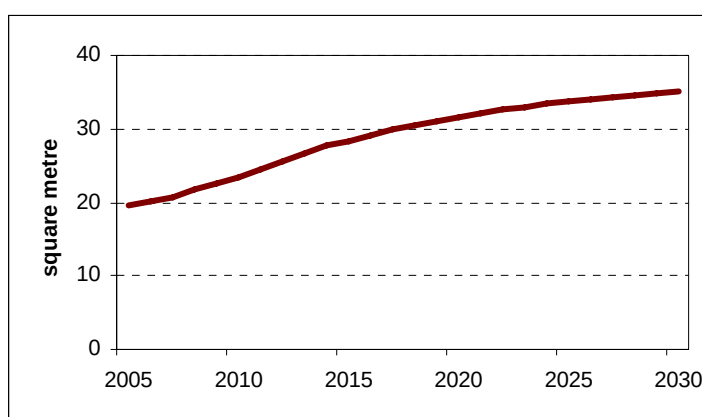


Figure 5-6 Projected per capita living area in Tianjin's urban area (based on logistic regression model)

This figure illustrates a rapid increase in average living area during the period 2005-2015, the catch-up dynamics is considered consistent with the macroeconomic trend. The next ten years will indeed be a high-speed urban development period in major Chinese cities, stimulated by steady economic growth and urbanisation process.

Notwithstanding the small size of houses for most urban residents, a number of commodity houses supplied in the housing market have even exceeded this target threshold. It is quite common to see a 100-120 square metre house being sold in the property market in big cities like Beijing and Shanghai. This implies that actual number of built houses may not necessarily match the predicted number of households in our model, consequently, the modelled appliance consumption based on household number may deviate from the actual consumption.

³⁰ Average per house floor area in Japan is 92.45 square metres in 2003, note that the definition of housing floor space may differ from one another in different countries. In most European countries, the most frequently used term is the net disposable floor area per household of which the projected area of wall and stairway is excluded. (Source: Statistical Survey Department, Statistics Bureau, Ministry of Internal Affairs and Communications, Japan). We take the example of Japan since China is more likely to follow the Japanese development pattern due to their common land resources constraint in urban area and cultural similarity in terms of consumption behaviour. Note the heating intensity in Japanese residential sector is the lowest among all the OECD countries; dweller mind-conservation is far more than negligible apart from the advanced residential buildings efficiency measures and stringent end-use appliance efficiency standards.

³¹ Housing size ranges between 75 and 110 square metres, the average is about 91 square metres in EU-15 in 2004 (Bosseboeuf, 2007).

Moreover, the increasing number of vacant houses poses another difficulty in the estimation of residential consumption, vacancy rate can be relatively high in the new constructed houses, accounting for 30-50% of totally constructed houses in the very year of completion.

In the model, new constructed floor area of buildings in each year is simply modelled as the difference of total existing floor area in current year (HS_i) minus the value in the previous year (HS_{i-1}). Regarding the residential buildings, the total existing area in year i is estimated by the following formula:

$$HS_i = UP_i \times PCFS_i \quad (5.4)$$

$$NH_i = HS_i - HS_{i-1} + DA_i \quad (5.5)$$

where

- HS_i is the total housing area in year i
- UP_i is the urban population in year i
- $PCFS_i$ is the floor area per head in year i
- DA_i is the demolished housing area in year i

DA_i is around 1.5 million square metres since it is assumed that the housing stock existing prior to 2005 will decline 1.5 million square metre each year. In contrast, no stock-flow dynamic is simulated for the commercial buildings, it means that no energy efficiency characteristics are distinguished between new and existing stock in commercial sector, an average performance level is used instead to simplify the analysis as our study is focused on energy efficiency in the residential sector.

5.5.4 Population growth

Urban population growth data is derived from Toth *et al.*(2003) which formulated three demographic scenarios in China by regional population dynamics modelling³², year 2000 is the base year in their simulation. The main advantage of their model is that total population growth in China is disaggregated into different regions and provinces and municipalities. The city-level data for Tianjin is available. Yet we have to interpolate their data since the modelling results only provide sufficiently detailed information in 2000, 2015 and 2030. Total population in Tianjin is expected to rise from 10980 thousand in 2005 to 11 936 thousand in 2030, with an average growth rate of 0.33% per annum. Accordingly, urban population³³ will increase from 8 490 thousand in 2005 to 9 846 thousand in 2030, with an average growth rate of 0.59% per annum. Figure 5-7 plots the projected evolutions of total and urban population in Tianjin.

³² The discrepancy of official urban population statistical coverage was removed by readjustment of data in the specification in their model.

³³ The term refers to the official definition in NBS 2000.

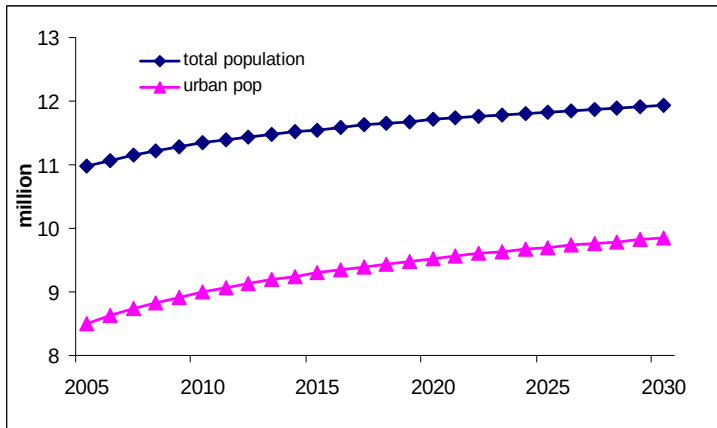


Figure 5-7. Projected population growth in Tianjin(interpolation based on Toth *et al.*, 2003)

5.5.5 Result of housing stock increase projection

By combining assumptions described above, the change of total housing stock can be easily simulated.

Figure 5-8 delineates the change in housing stock in Tianjin over the modelling period.

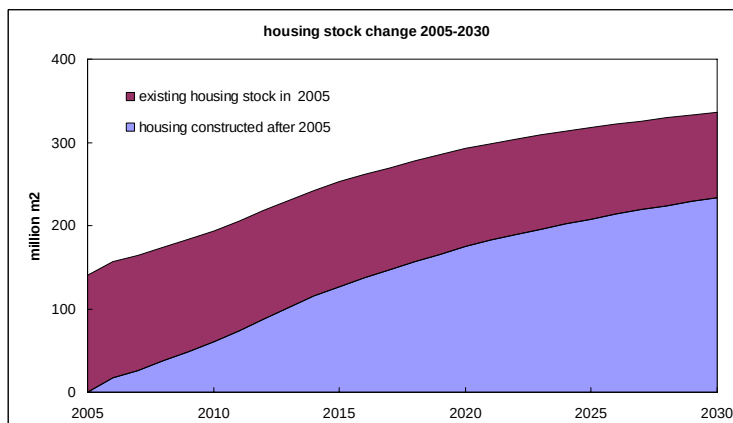


Figure 5-8 change in housing stock during 2005-2030

5.5.6 Prospects for improvement in people's livelihood and assumption on variables

In most of energy economic models, people's livelihood is represented by changes in following variables: income (proxied by real per capita GDP), floor space area, indoor temperature (thermal comfort), and quantity of hot water consumption, residential electric appliance ownership and use frequency.

According to microeconomic theory, individual demand for services depend on two main factors : price effect ($dQ/dP < 0$), demand falls when service price goes up (ordinary goods and services); while there is a positive association between the household income and residential demand for energy services, called revenue effect (i.e. $dQ/dR > 0$) which means that a consumer requires more energy-related services if his or her income increases. Therefore, the foreseeable steady economic growth will drive the increase in household revenue (this is based on the assumptions on macroeconomic development prospects, the

serious economic recession is unlikely to occur in Tianjin over the modelling period) which in turn, will induce the rise of demand for residential energy services.

No direct mathematical representation is used in the model to specify the revenue effect influencing the decision of consumer's demand for energy services such as space and water heating and electrical appliances. Instead, the projection of increase in demand for energy services in the residential sector is based on benchmarking international experiences, in particular previous observation in developed countries. The per capita GDP (ppp) is taken as a proxy to predict the level of household demand for comfort and other services in their houses. So therefore, we assume that Tianjin's residents' demand for space and water heating and the current level in OECD countries will converge eventually in the modelling timeframe (25 years) as per capita revenue in Tianjin in 2030 is projected to approximate the current level in most of developed economies. Chinese economy (in per capita term) is likely to catch up with the mid-ranking western countries over the next decades as labour productivity and multifactor productivity in industry, service and agricultural sectors in China and developed world are likely to converge eventually. This catch-up and convergence processes have been observed within OECD countries in the past decades, in particular in service sector (Dowrick and Nguyen, 1989; Bernard and Jones, 1996; Wong, 2006). The annual economic growth catch-up rate was around 2% per year. More specifically, Dowrick and Nguyen (1989) found that there has occurred a systematic process of catching up in levels of total factor productivity in OECD countries in their economic growth during the period 1950-1985.

Figure 5-9 depicts the historical development of per capita GDP (PPP) in China and representative developed economies in the world during 1990-2006. We see immediately that Shanghai and Tianjin are much more productive than China's average. A clear tendency of catch-up of economic growth can be seen from the figure, the catch-up dynamic is particularly strong since 2000 in the city of Tianjin and Shanghai. Contrarily to Taiwan and South Korea, the Asian Financial Crisis in 1997 had virtually no significant impact on their strong economic growth.

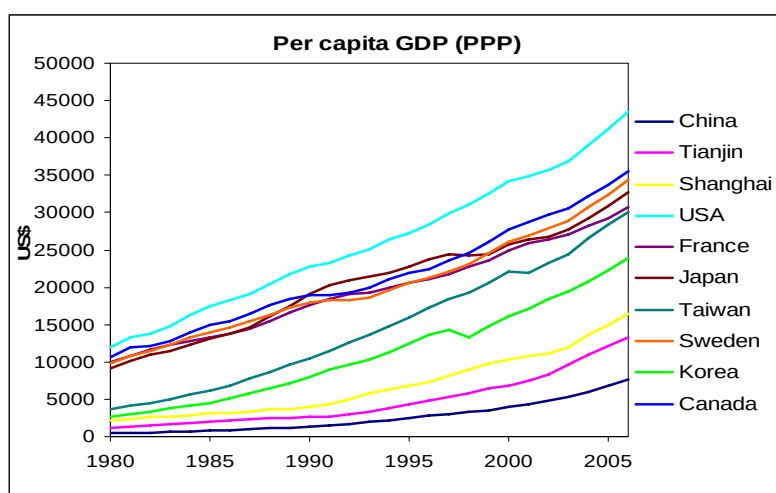


Figure 5-9 Per capita GDP (in PPP) evolution in China and developed countries

Source: IMF, World Economic Outlook Databook, April 2007. State Administration of Foreign Exchange. Shanghai Bureau of Statistics; Tianjin Bureau of Statistics

Note: the current GDP of Tianjin and Shanghai have been converted to PPP terms based on the national data in the calculation.

Interestingly, we see also that the p.c. GDP of Taiwan and other developed economies converged at the end of this period. This justifies our hypothesis that people's comfort level will approach or even exceed the current level in developed world at the end of the modelling period, driven by the macroeconomic convergence.

Importantly, per capita GDP in Shanghai in 2006 had already caught up with that of developed countries (Japan, France and Sweden) in early 1990s. However, residential energy demand in Shanghai is still much lower than the latter. This is partly because that the term of per capita GDP (PPP) may disguise some important information in terms of people's livelihood and must be interpreted with care. Moreover, the PPP calculation of the IMF only takes into account of the prices of a basket of comparable commodities. The PPP GDP may not necessarily capture sufficient information content of demand for thermal comfort in buildings sector as far as our study object is concerned, in particular in developing countries.

5.5.7 Econometric approach

Econometric analyses can provide insightful information about the price effect and income effect we mentioned above. The price and or income elasticity can be quantified through appropriately specified econometric models which capture in particular the so-called rebound effect, saying that household demand for energy services, say space heating is likely to increase when the house is more insulated than before since the actual price of energy service falls.

Some studies explored the causality between residential energy consumption and household income level based on econometric method, including the cointegration analysis approach to explain the causality based on historical time series variables. However, these analyses are not quite robust to predict the long-term dynamics between energy demand and household income due to lack of the long-term cointegrated equilibrium. Because in general, the average per capita income is derived simply by dividing the total national income of a country by the population, while in general, a country's wealth is not equally redistributed, in particular in a large economy like China with diverse situation in different parts of the country. Consequently, the measure with the end of the average per capita income does not include the effect of income at individual consumers.

This is confirmed by the results of Joyeux and Ripple(2007) in which a co-integration analysis approach is used to investigate the long-term relationship between PPP GDP and residential electricity consumption in different economic regions. Based on panel data covering Asian Pacific countries, USA and EU, they concluded that there is no cointegrating relationship between residential electricity consumption and GDP except for the USA, therefore the historical time series data-based econometric method will be incapable of predicting the long-run relationship between residential electricity consumption and GDP in China.

Indeed, the relationship between GDP growth and residential energy consumption is more subtle than that between GDP and the total electricity demand . For example, the cointegration approach leads Yuan *et al.*(2007) to conclude that real GDP and electricity consumption for China are cointegrated based on Time Series data covering 1978-2004. However, there is only unidirectional Granger causality running from electricity consumption to real GDP but not the vice versa. But their analysis is poor in terms of sectoral demand for energy. For example, their analyses do not allow us to identify the long-term relationship between per capita GDP and residential demand for space heating, let alone from a city-level perspective.

The review of previous literature leads us to not choose to build direct mathematical representation to link directly the residential demand for specific energy services with per capita GDP in the model, a qualitative approach is rather used . The indicator of per capita GDP is taken as a benchmark in the assumptions on demand growth in specific years (e.g. we assume that it is very probable that the thermal comfort in Tianjin's residential sector in 2030 and the current level in developed countries will converge). In contrast, GDP growth is major driver of increase in energy demand in commercial sector in terms of buildings area and progress of comfort level (office, hotel, hospital etc).

Indeed, the factors influencing the consumer's choice for a certain service (e.g. heating) are more complex than the variables assumed in our model. Generally speaking, any macroeconomic changes will cause eventually impact on decision of any final consumer in residential factor. To simplify our analysis, only household revenue is adopted to gauge the extent to which people's livelihood (per capita living floor space) is likely to ameliorate in terms of comfort requirement.

5.6 Description of Scenarios

Two distinct categories of scenarios are established, namely reference and alternatives.

5.6.1 Reference scenario

The first task of the long-term analysis is to build a likely prospect of energy demand in buildings, this scenario represents what could happen if current trends continue and is hence called the "Reference scenario", namely hereafter *TJ 2004 compliance* scenario. It is thus assumed in this case that no new

energy conservation policy will be introduced in Tianjin in the next decades and the current TJBEEDS 2004 will be maintained throughout the modelling period. It is also assumed that enforcement and implementation of TJBEEDS 2004 are ensured in all new construction. Certainly, assuming 100% of enforcement of building code in the new construction is far more optimistic than what will happen in practice. Instead, we will draw another storyline in which the difficulty in enforcement and implementation of building regulation will be addressed, the subsequent consequences will be quantified.

5.6.2 Alternative scenarios

Similarly to the modelling approach of Shorrocks and Dunster (1997), the alternative scenarios share many of the same assumptions as the Reference scenario (same population, household numbers, heat supply system, fuel type, internal temperature rise, thermal rehabilitation and modernisation in existing housing stock etc.), but the rate of uptake of energy efficiency measures is increased, in other words. Furthermore, the uptake of more stringent building code in reference scenario has not been considered. “Efficiency scenario” comprising seven policy variants in our model under the modelling framework in order to examine and compare the residential energy demand and the relevant environmental impact and economic implications.

In contrast to *TJ 2004 compliance* scenario, these scenarios represent what could happen if the rate of uptake of a number of buildings energy efficiency measures (but involving currently available technology only) were to increase, so they are called “efficiency scenarios”. However, as mentioned by Shorrocks and Dunster (1997), “the scenarios which built only based on current trends and current technology, should not be regarded as forecasts, particularly for the longer term, since new technologies are quite likely to emerge and become commonplace within the next 30 years”. The cost-effectiveness of uptake of future BEE standards is analysed in different scenarios to identify the most efficient ones.

Despite overly optimistic official numbers stating that all new constructions comply with the building code since 2006, we may always expect incompleteness and bias in the statistics, also, past experiences shows those energy efficiency policies have hardly been fully implemented due to technical, financial and institutional barriers. So it is meaningful to examine a scenario to capture the certain failure of regulations implementation in actual construction in the real estate market. This scenario is called “ParCom” in which we assume simply that each year, about 75 per cent³⁴ of new construction complies with TJBEEDS 2004 while the rest one-quarter fails to respect the regulation before 2015, and then all new construction will comply with the TJBEEDS-2004 from 2016 as a result of technical diffusion of efficient construction practice and endogenised technological learning, implying a continued reduction in costs associated with BEE enhancement measures. Table 5-3 summarises previous and current BEE regulations in Tianjin.

³⁴ In fact, this is the average of implementation of building codes in new housing construction in European countries.

Table 5-3 Cross-comparison of energy performance of buildings complying with relevant BEE standards

	heating index	consumption
	W/m ²	Kgce /m ²
1980	31.6	23.7
1 st (1990)	25.3	16.6
2 nd (1997)	20.5	11.8
3 rd (2004)	14.4	8.3

Energy efficiency improvement follows the objective of reducing heating intensity by 30% in every new regulation enacted, thus the new regulation follows a geometrical trend in energy saving in comparison the baseline case (inefficient buildings in 1980s) is determined by formula:

$$BP_n = 1 - (1 - 0.3)^n \quad (5.6)$$

BP_n is the energy performance of N^{th} generation of BEE regulation, n is the time period , 1, 2, 3...

Details on the thermal characteristics of buildings and relevant useful energy demand for space heating have been discussed in Chapter 4.

5.6.3 Policy scenarios in the model

5.6.3.1 Building efficiency performance scenarios

Table 5-4 summarises the respective assumptions concerning BEE implementation in each of seven policy scenarios that will be tested in the model to identify the optimum choice.

Table 5-4. Description of policy scenarios

scenario	BEE Policy in new buildings
« Canadian code »	All new buildings adopt the Canadian building efficiency throughout the period.
« RT 2005 »	French building code RT 2005 is applied in all new construction, and reduced by 15% every five years in line with the buildings efficiency objectives in France.

« Swedish code »	Thermal parametres specified in the Swedish building code are to be implemented in all new construction.
A1 Progressive	All new construction should comply with TJBEEES 2004 , and French building performance level as prescribed in RT 2005 from 2011, the Swedish building code will start to be enforced from 2021. .
A2 Rapid Progress	TJBEEES is enforced until 2010, replaced then by French code RT 2005 until 2015, and substituted in turn by Minergie standard (equivalent to the German Passivhaus standard)
A3 High willingness to intervene	all construction applies Swedish code from 2006 until 2015, then passivhaus regulations will be fully implemented
Low-carbon (LC) scenario	This scenario aims at low-carbon emission in building sector; new construction adopts the Swedish building code until 2010. And the relevant heating index in the Swedish building code will need to be divided by a factor of 2 and 4 in 2011 and 2021, respectively.

Because the scenario analysis is concerned with the intertemporal comparison of different BEE measures that will be adopted in each of the scenarios that are formulated prior to modelling. Timing of policy options, it means when and how fast to implement the actual building codes or tighten them is of extreme importance, it is straightforward that adoption of a new generation of BEE in different time during the modelling process will not yield the same output.

In A2 , a progressive advancement scenario, upgraded building codes based on TJ2004 are envisaged to be introduced in 2011 and 2021, both building insulation and of heated air recovery efficiency would be improved significantly in these new building codes, equivalent to the French RT-2005 and Passivhaus requirements, respectively.

The different timetable of options of implementation of the different standards of building codes and degree of actual enforcement in the scenarios are reported in Table 5-5.

Table 5-5 . Summary of degree of enforcement and timing of upgrading building codes in new construction

Scenario	2006-2010	2011-2015	2016-2020	2021-2025	2026-2030
TJ2004	TJBEEDS2004				
CAN	Canadian building code				
RT2005	Equivalent to The latest French Building codes				
SWE	Swedish building code				
A1	TJBEEDS2004	RT 2005		Swedish building code	
A2	TJBEEDS2004	RT 2005		passivhaus	
A3	Swedish building code	Swedish building code		Passivhaus	
LC	Swedish building code	passivhaus			High efficient house
ParCom	The City fails to implement building codes fully by 2020 (75% of houses comply with the building codes)			TJ 2004 is 100% enforced and implemented	
REF NR	TJBEEDS2004 without retrofit programme				
Temp	Indoor temperature is maintained at initial level throughout modelling period				
Applmp	Household electric appliances efficiency should be improved more rapidly as in the reference case				

Note: Building energy performance of relevant standards in each of the scenarios in the table is identical to the standards described in Chapter 4 in which a techno-economic analysis has been undertaken in a prototype of residential zone in northern China.

In the case of inefficient buildings constructed after 2005 in the “ParCom with retrofit” scenario, housing retrofit programme is assumed to be carried out during the operation to make up the past errors in order to curb the sharply increasing demand for space heating. However, due to the long lifetime and slow turnover characteristics and financing and operational difficulties, large-scale retrofitting programme in this part of buildings will not be carried out immediately but rather intervene in the future. We assume that housing retrofit will only take effect fifteen years onward from the date of completion (e.g. non-compliance low efficient housing constructed in year 2005 may be retrofitted gradually no earlier than 2020³⁵) in order to capture the impact of retard in “BEE policy uptake” compared to quick compliance commitments scenarios.

On the other hand, one may wonder whether the low-C scenario is far unrealistic due to its excessively stringent requirements, from pure technical aspect, zero energy even negative energy building technologies are hitherto available in some pilot projects to date in Western and Northern Europe. This technology could substitute to a less extent a part of traditional technique in housing stock in the long run.

³⁵ It is assumed that the cost related to the housing retrofit will keep rising over the modelling period.

Indeed, the exorbitant cost constitutes a major barrier to large-scale deployment. Of course, carbon dioxide mitigation objective should be taken as a motive to constrain the growing demand for better energy services in buildings in Tianjin. In fact, low-C scenario can be served as a reference with regard to cost-effectiveness of ultra-efficiency measures.

Moreover, in “App-IMP” scenario, we constructed a variant of reference scenario in which buildings thermal efficiency is identical to baseline scenario’s, market transformation is assumed to favour more rapid efficient household electric appliances uptake by consumers through price signals (extra cost becomes less significant due to more rapid technological improvement and scaled economies of energy efficient products). It is assumed that all inefficient appliances will be phased out by 2015 in household durables market. Thus residential consumers are encouraged to buy more efficient appliances than in other scenarios. This scenario is established to quantify the effect of appliance’s efficiency in contributing to lowering electricity demand as well as primary energy resources, in comparison with the effectiveness of BEE amelioration in buildings *per se*.

Besides the reference and efficiency scenarios, a *temperature* scenario is elaborated to be served as a benchmark to assess the impact of requirements for higher dwelling indoor temperature during heating period. The *Temp* scenario is distinct from all other scenarios in the sense that the heating space of all houses, whether they are new or old, are always heated at the same temperature as in the base year, this implies that there is no comfort improvement in heating services. This scenario reflects to some extent Chinese official projection in which compliance with the building code does not imply necessarily progressive increase in thermal comfort of households, as we assume in all other scenarios to capture the effect of rise in indoor temperature.

From technical perspective, as demonstrated in previous chapter, trade-off between improvements in buildings envelope and ventilation system depend on the weighing factors in the heat loss equation, a threshold beyond which increased indoor temperature in heated space implies more energy loss through ventilation than buildings envelope (exterior wall and/or roof) need to be identified to allocate more efficiently financial resources in BEE investment.

5.6.3.2 Supply-side technological change

Carbon capture and storage (CCS), renewable heating (e.g. biomass-based co-firing) and fuel-switching are the most promising alternative energy supply options that allow mitigating significantly energy-related carbon emissions. Costs and technical difficulty are the major barriers to large-scale deployment of these technologies in the near term.

However, as mentioned in the introductory section, supply-side technological advancement can be considered in modelling a dynamically changing building stock for the longer term since the costs

associated with new technologies is likely to decline over the period. Furthermore, these options need to be put in place sooner or later in the context of increasing urgency of addressing the global climate challenge by diversifying energy supply technology over the next decades. Therefore, we introduced three technical variants in the key scenarios, namely CCS, fuel-switching and REN variants, respectively. In the coal-dominating supply scenario, it is assumed that CCS technology will commence to penetrate gradually in new constructed coal-fired power and heat generation plants (it is a good occasion when the old capacity will need to be retired and replaced by new generation technology) and partly in retrofitting the existing capacities from 2020. The geological condition in Tianjin is favourable to implement CCS technology, as shown in Fig. 5-10, Tianjin is situated in the North China Plain (green area in the graphic) where large potential for CO₂ storage exists. Alternatively, the city of Tianjin will make radical clean energy policy by switching from coal to natural gas or promoting massively the biomass district heating from the year 2020.

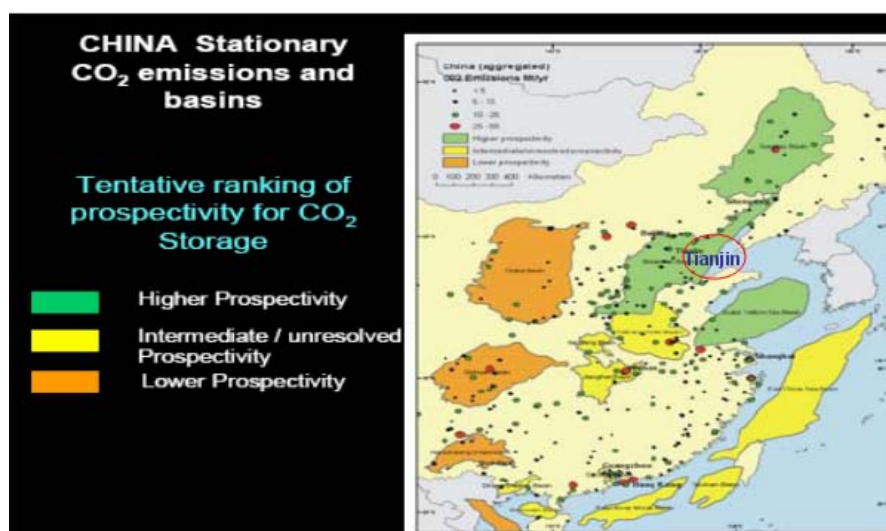


Figure 5-10 Geological potentials for carbon storage in China

Source: IEA, CO₂ CAPTURE & STORAGE *international progress & future prospects*

5.6.4 Household energy consumption

In the model, energy use in all residential buildings is disaggregated into space heating, water heating, lighting, cooking and other electrical appliances. BEE measures per se don't affect the energy use related to electrical appliance and cook, water heating is affected only in case of centralised hot water delivery system. Space cooling is included in electric appliance in the model. From economic development perspective, household energy demand for electrical appliances and water heating will become increasingly important as lifestyle changes in the coming years. To give an example, the average of per capita residential electricity consumption is only one-third of the world average and one-fifth of that in the OECD countries.

Household appliance consumption comprises air conditioning (cooling), cooking, lighting, and electric appliances (TV, Washing machine, Refrigerator). The largest electricity consumption appliances (TV, Washing machine, Refrigerator, AC, and PC etc) are considered in the model, improvement in the thermal performance of buildings will not have direct influence on this kind of energy consumption apart from air-conditioning³⁶, and instead the energy demand is determined mainly by appliance efficiency and operation frequency which in turn is related to life style change. Centralised cooling has not been considered in residential buildings where cooling demand is primarily met by reversible heat pump-driven air conditioner.

5.6.4.1 Space heating

Like most of northern cities, space heating represents a major part of energy use in buildings in Tianjin, it is accounting for approximately 60% of residential final consumption. Hence, our modelling exercise focuses mainly on BEE measures that improve the heating consumption efficiency in residential buildings.

5.6.4.2 Water heating

Hot water consumption (cooking not included), especially bathing consumption is still fairly low compared with the level in developed countries. Average water heating consumption is only one-fifth of that in developed countries. Currently, water heating consumption for bathing in China's ordinary urban household is approximately 5 kWh per square metre of floor space (Jiang *et al.*, 2007), Zhou *et al.* (2007) estimate that the average Chinese household water heating consumption is about 3600 MJ per household per year in which a significant part is related to cooking purpose in residential sector. No specific data for the city of Tianjin is available. Assumption on future demand for water heating in residential sector is based on cross-comparison with current levels in developed countries to date. For example, an US household consume on average 2552 kWh of electricity for water heating (US RECS 2001), and 1935 kWh per household³⁷ in France in 2000 (Observatoire de l'énergie, INSEE), and 3680 kWh per household in Japan (Zhou *et al.*, 2007). We assume that household in Tianjin is 30% above the average of their projection, i.e. 3100 MJ per household in the base year, equivalent to more than one-third of current US household consumption level roughly, it is expected to reach 6000 MJ per household by 2030, or two-third of current level of the US households and 85% of French households.

Renewable energy is considered in water heating in our model since China is both the largest producer and consumer of solar water heater in the world. Roof-mounted solar heater is the most very common in most of Chinese cities, however, the increase in penetration is limited by the solar availability and space constraints (most of residential buildings is the multi-family and medium and high rise apartment buildings, solar heater cannot be installed for most households).

³⁶ Strictly speaking, the enhanced insulation of buildings envelope can only play a limited role in reducing effectively space cooling consumption which is mainly driven by solar insolation through window and indoor heat gain.

³⁷ Only the permanently accommodated houses (résidence principale) are taken into account in the estimation.

5.6.4.3 Household electricity consumption

International benchmark

In 2004, residential electricity end-use is about 1830 kWh per capita and 4520 kWh per household per year on average in EU-15³⁸ (Eurostat, Atanasiu and Bertoldi, 2007) in which 30% for water heating. And consumption differs significantly among individual countries due to difference of buildings type, climate condition and energy supply mix. Fig 5-11 illustrates the residential electricity consumption in EU-15 (Sweden and Ireland are not included due to unavailability of data) in 2004, , ranging from 3005 kWh/household in Italy to 8560 kWh/household in Finland.

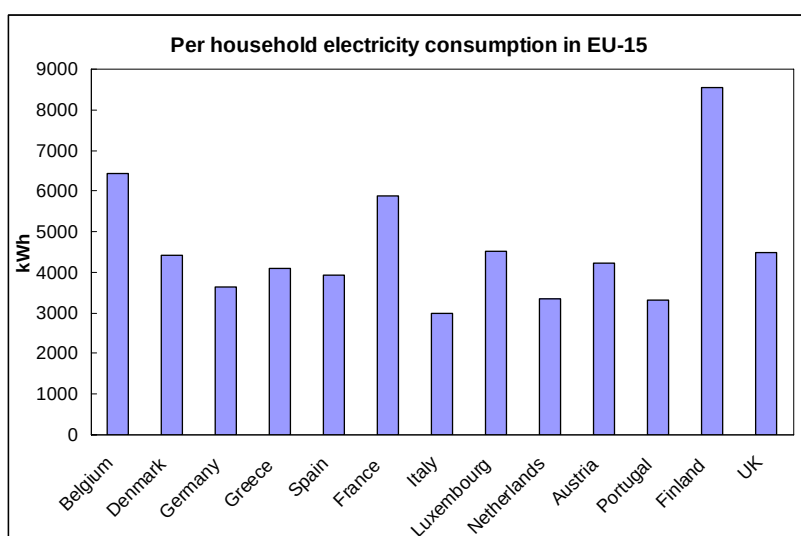


Figure 5-11. Residential electricity consumption in EU-15 (per household)

Source: adapted from Eurostat online database³⁹

The average electricity consumption in the EU (heating excluded) is about 2700 kWh/yr per household in the EU 15 in 1999, in which 1200 kWh for the six largest appliances and lighting (TV, washing machine, dishwasher, refrigerator, and freezer, dryer). The US residential electricity consumption is 6812 kWh (space and water heating is excluded) for dwellings conditioned by the RACs and 8658 kWh for households with centralised air conditioning according to US 2001 residential survey.

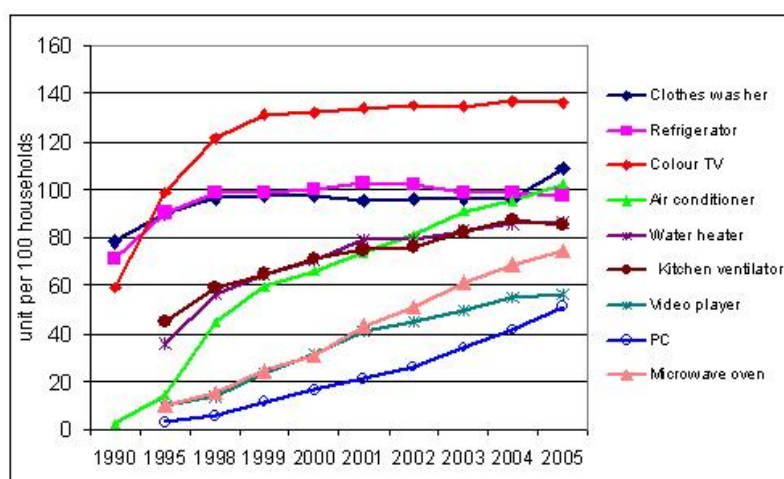
Household electricity consumption comprises all household durables: TV, Refrigerator, microwave oven, clothes washer, DVD, air-conditioner, PC, water heater etc. Appliance ownership has been growing steadily since 1990s. However, ownership will not grow infinitely because of saturation effect. We assume that all electric appliances ownership will approximate 100 per cent in 2020, while the energy use will continue to increase as a result of lifestyle changes. Historical data on urban household electric appliances

³⁸ All EU-15 countries aggregated

³⁹ Figures are calculated simply by dividing total residential electricity by number of households in the country.

ownership in Tianjin is plotted in Figure 5-12. Not surprisingly, there has been steady growth in ownership of all of the electric appliances during the past decade. Air-conditioner (AC) penetration augmented sharply between 1990 and 2005, from 2 to 102.1 units per 100 households, this phenomenon reflects perfectly the tendency of continuously appealing demand for housing thermal comfort, albeit extremely hot summer days in Tianjin is relatively short compared to the central and southern provinces. Also, it can be seen that TV, refrigerator, clothes washer penetration have likely approximated the saturation point whose ownership curves stagnate since 2000. The slight downturn trend in washing machine ownership curve between 2000 and 2005 may partly be explained by the sharp increase in number of urban households and to a lesser extent as resulting from statistical discrepancy.

In contrast to these indispensable electrical appliances, the curves of PC, microwave and video player illustrate a common strong trend of increase as a result of lifestyle change and growing propensity to interests in household cultural goods consumption and entertainments. Both ownership development and demand for energy services will be considered in the model.



Note: in units per 100 households

Figure 5-12. Ownership of consumer durables in Tianjin 1990-2005 (Tianjin Statistical Yearbook, various years).

However, the numbers in the figure above is to some extent misleading, the actual ownership of consumer durables should be lower since the residence registration-based household number is adopted in the statistical authority's calculation. A factor of 1.1⁴⁰ should be applied to obtain the actual ownership figures. Our assumptions on household durables ownership trend is plotted in Fig 5-13.

⁴⁰ It refers to the ratio of actual urban household's number to registered households number with *Hukou*.

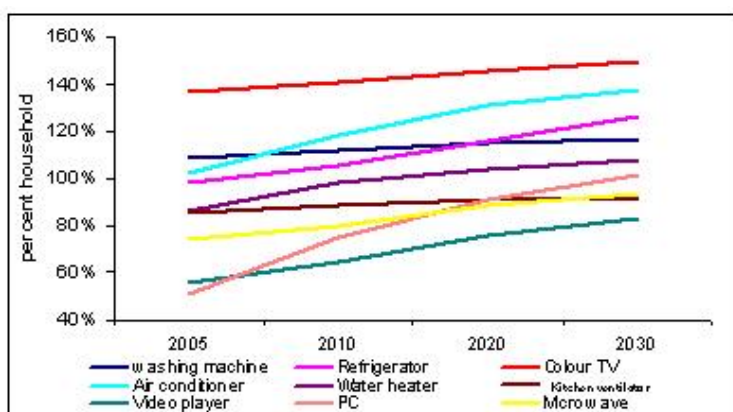


Figure 5-13. Assumption on residential electrical appliances ownership

Ownership of washing machine in Chinese urban residential has approached the saturation rate (Zhou *et al.*, 2007), we assume an insignificant growth in penetration from 109% in 2005 to 120% in 2030, whereas the penetration of AC, TV and refrigerator will continue to rise over the next two decades. Table summarises the assumptions on the penetration rates of durables in different years over the modelling period. In order to model the appliance energy demand, data of foreign countries are intensively referred because of absence of relevant data in China's statistical yearbook. We mainly consulted the US Residential Survey (DOE,2001) , UE Stat , European Environmental Agency and Japan Statistics.

Note that our model does not include all household appliances with exhaustive list since some of them only represent a very small part in total residential appliance consumption such as hair drier, cordless telephone, rechargeable tools, ceiling fans, coffee makers etc, however, we expect that the dish washer penetration will increase substantially in the coming years, especially among the young professional couples who follow closely the western lifestyle. Table 5-6 shows the major assumptions on the evolution of electrical appliance penetration ownership (%).

Table 5-6. Household durables penetration assumption

	2005	2010	2020	2030
Washing machine	109.1	111.9	115.3	117.5
Refrigerator	97.8	105.4	116.4	126.0
Colour TV	136.3	140.4	146.2	150.0
Air conditioner	102.1	118.4	130.7	137.4
Kitchen ventilator	85.1	88.6	91.3	92.2
Microwave oven	74.3	80.0	88.4	92.9
Entertainment				
DVDs	56.1	65.0	75.5	83.4
PC	51.1	75.1	91.5	101.1
Dish washer	3 ⁴¹	10	20	30

⁴¹ Estimated by author.

Source: figures in 2005 are from Tianjin Statistical Yearbook 2006. Data for other years are based on estimate of author.

5.6.4.4 Heating and Household appliance efficiency improvement

Household energy consumption will be dependent mainly upon two factors in the model: the heating appliance efficiency and lifestyle change. For example, it has been observed that all energy efficiency gains has been significantly offset by the lifestyle change in the EU-15 over the period 1990 and 2004, 12% of energy efficiency progress in the final consumption sector only allowed for a 3% reduction in energy consumption per household (Bosseboeuf, 2007). Future values of consumption other than space heating are based on the variable hypotheses in Zhou *et al.* (2007), Table 5-6 reports the assumptions regarding the values for major end-use in residential sector in Tianjin used in our model. Stock analysis is applied for TV, refrigerator, washing machine, air-conditioner for taking into account the improvement in appliance efficiency over the next two decades. The assumptions on variable of residential appliance consumption are provided in detail by usage in Appendix I. Electrical appliance consumption in Japan, US and EU -15 are taken as benchmark to the future appliance consumption in Tianjin's household. The constant increase in appliance energy efficiency will partly be offset by the intensified frequency of use and extended time period such as PC use. Up to now, no empirical data has been published on personal computer use in China's residential sector. We assume that consumption intensity is half of that in the US in 2001, or 318 kWh per household.

At present the Chinese white residential appliance energy efficiency labels (similar to the US Energy Star and European Efficiency Label) apply to refrigerator, air conditioner and washing machine. Yet, no compulsory efficiency label is required to microwave and TV manufacturers.

For microwave consumption, it is assumed that the average Power is 600W and 15 minutes of use per day per household, the actual efficiency of microwave/electricity conversion is approximately 50-60% varying with the product energy performance for conventional products. This gives an average consumption of 133 kWh per household per year, which is approximately two-thirds of the US consumption level in 2001(209 kWh per household). This difference mainly reflects the difference in cooking habitude between China and western countries. Further, the BAT product is assumed to perform 20% more efficiently than conventional ones.

Household dish washer ownership is assumed to increase from 3% to 30% in 2030. Energy intensity of dish washer is estimated at 307 kWh per household which is 60% of US household average. 10% efficiency gap exists between conventional technology and efficient equipment. For example efficient gains can be attained by reducing stand-by power consumption of PC, TV and other entertainment appliances.

5.6.4.5 Residential lighting consumption

It is assumed that more rapid technological progress in appliance energy efficiency in *App-Imp* scenario compared with other scenarios. It is assumed that household lighting intensity will grow at 2% slower than in the baseline scenario, generally through improvement in lighting appliances. Green lighting programme is likely to be generalised in the *Low-C* scenario with combinatory instruments (appliance improvement+ DSM measures), intensity grows at 3% below the *baseline* scenario.

5.6.5 Energy consumption in commercial sector

5.6.5.1 Estimate of floor space and energy intensity in commercial buildings

Unlike the residential sector, the principal driver of commercial buildings construction and relevant energy consumption is the economic development in the service sector, GDP growth is used as a proxy of sectoral increase in commercial buildings. Previous studies show that floor space in commercial buildings is strongly correlated to the GDP growth in tertiary sector in developed countries, based on this observation, Zhou *et al.*(2007) regressed the commercial floor space area on China's service GDP and found that the elasticity of the increase in floor space area of commercial buildings with respect to the average GDP growth rate in China was 0.8 over the period 1985 to 2002. This elasticity is applied into our model and is extended to 0.5 between 2020 and 2030. Large commercial buildings are distinct from ordinary buildings for the energy intensity, in particular cooling intensity is significantly higher than small buildings.

According to Wang *et al.*(2006) and Yang *et al.*,(2002), average primary energy demand in large commercial buildings in Tianjin is about 2.86 GJ/m²/y. In addition, (Jiang *et al.*, 2007) revealed that in China's major cities, unit energy intensity(UEI) in large commercial buildings is 5-10 times of that in residential sector, most of which is related to space heating and cooling consumption. This is due to the fact that space cooling period in some commercial buildings is much longer than in residential sector, covering nearly seven months a year, from the beginning of April to the end of October.

5.6.5.2 Cooling technology in commercial buildings

Electric cooling is predominant in commercial sector(Zhou, 2003; Zhou *et al.*, 2007; Jiang *et al.*, 2007). Cooling electricity consumption in commercial buildings represents more than 30% of total electricity consumption in summers. In most scenarios, air conditioning in commercial buildings use conventional technologies:

- Room Air conditioner (RAC) , mostly in office buildings
- Electric city-driven centralised cooling (reciprocating compressor, screw compressor)
- chilled water(lithium-bromide absorption-type)
- Gas-fuelled centralised heating (gas boiler coupled with steam absorption chillers; direct combustion)

- heat-pump cooling

In theory, different technologies exist in centralised cooling distribution, however, each of them presents some advantages and shortcomings, as discussed in Jiang *et al.*(2007).

1. The rejected waste heat from CHP plants can be recovered with absorption cooling machine to produce chilled water (5-7°C) for centralised space cooling in commercial sector, which is thermodynamically efficient, the chilled water is then transported to buildings by distribution networks, but the electric consumption in pumping for long distance distribution make this technology less attractive than one generally believes.

2. Contrary to the method 1, waste heat rejected from CHP plants is distributed to end-use buildings, then the potential energy is extracted through absorption procedure to produce chilled water for cooling use with a COP of 1.2. But a major difficulty arises on the approach to recovering the return condensed water through long-distance distribution network, considerable potential energy may be wasted if the condensed water is discharged on the site;

3 similar to heat production in winter, hot water is produced in CHP plant and then delivered to buildings side, then the same approach of absorption applies to extract heat and produce chilled water, the difficulty in method 2 can be avoided, however, thermodynamic efficient of this technology is rather low, only 0.6-0.7.

The buildings- based trigeneration technology(BCHP) is only considered for centralised cooling in commercial buildings in the LC scenario, assuming energy policy will facilitate the sale of electricity generated by this technology. Note that BCHP is only thermodynamically efficient if and only if there exists stable heat load (hot water in particular since space heating is only for winter) in the buildings (hospital, hotels, etc). Otherwise BCHP is operated only to deliver cooling and electricity, considerable heat will be waste to the detriment of system's overall efficiency.

In the ParCom scenario, heating and cooling load are estimated to stabilise over the period, while in the alternative scenarios, heating and cooling load are assumed to decrease 15-30%⁴² in 2030 compared to 2005, to be consistent with the energy savings obligations prescribed in the national public buildings energy efficiency standard which came into force in 2006. Lighting and water heating in commercial sector are both projected to increase at 1% per year in all scenarios to reflect the increasing service quality and living standard.

⁴² In fact, part of decrease in heating and cooling load will be offset by increase in thermal comfort in the commercial buildings, i.e. the heating and cooling hours will be extended longer than in the base year.

5.6.6 BEE in commercial buildings

Three types of buildings fall into the public buildings category: office buildings, commercial buildings and hotels or recreational buildings. Currently, buildings designed in compliance with national standard necessitate an average heat load of 60 watts per square metre constructed. In the baseline scenario, we assume that all new buildings will comply with the current standard. However, it is not unreasonable to predict that this figure should keep declining in alternative scenarios, it is assumed the heat load will decrease to 50 W/m² in 2020 in LC scenario. Assumptions on further improvement in energy performance in public buildings will be discussed in the LC scenario which aims at reducing dramatically heating demand and associated CO₂ emission.

Although our analysis centres on how BEE measures uptake will affect residential buildings energy consumption, it is necessary to consider the public buildings for two reasons:

1. our analysis is comprised of both energy demand and supply-side measures, it would be difficult to estimate the required newly added heating capacity if public buildings were completely excluded from the model;
2. Previous literature reveals that electricity consumption, in particular the air-conditioning and lighting intensity is much higher than in residential sector, excluding public buildings may also faces the trouble of consistency of electrical power installation.

Energy use in public buildings includes heating, cooling, mechanical ventilation, lighting, water heating and other electricity consumption such as elevator. Hot water consumption in commercial buildings can be excessively high in the case of starred hotels.

To simply our analysis as well as to concentrate the analysis on residential areas, energy consumption use in public buildings are estimated based on a yearly average intensity indices, in other words, we will not test the hypothesis how the BEE regarding commercial buildings will evolve over the modelling period.

Currently, the tertiary sector accounts for approximately 30% of heating consumption in buildings, while electricity consumption in public and commercial buildings is significantly higher than in residential buildings. Due to lack of sufficiently detailed energy consumption data on decomposed level, we interpret the recent literature on China as whole and also rely on results of previous empirical studies (Yang et al., 2002; Jiang *et al.*, 2007; Zhou *et al.*, 2007).

Our model centralises on BEE in residential sector and is designed to identify the optimal BEE regulation development for new urban dwellings construction in the Chinese cities, the BEE analysis of public buildings in tertiary sector is out of the scope of the modelling. However, commercial sector is incorporated into the model such that the heat generating capacity will be estimated more properly otherwise heat sources estimates would be less convincing. However, unlike residential sector, lighting,

water heating and specific appliance consumption account for a much more significant part in commercial building's energy end use. In fact, energy performance of commercial buildings is heavily relying on integrated energy management including both demand and supply-side techniques optimisation, improved buildings envelope or double glazing can only partly contribute to energy conservation. In a survey conducted by Yang *et al.* (2002), energy consumption in commercial buildings in Tianjin is significantly lower than that in Japanese city (Kobe) with similar climate condition, not because buildings in Tianjin are more efficient than in Kobe, but rather the heating and cooling period is much shorter and thermal comfort level is lower than Japanese commercial buildings. Similar to what is projected in the residential, demand for energy services is also assumed to increase in commercial sector by taking the Japanese level as benchmark. To capture the technological advancement, the effect of continuous reduction in average cooling and heat load of new constructed commercial buildings is considered while final energy uses will keep increasing for the sake of improved comfort standard. This assumption is consistent with the economic catch-up and technical improvement perspective.

In contrast to residential sector, no strong actions will be adopted in commercial buildings to improve dramatically buildings thermal performance. Yet energy efficiency improvement, especially energy savings in lighting and appliance consumption can be attained by implementing DSM programme such as substituting CFLs and LEDs to conventional inefficient lighting in office buildings and large commercial centres, or public procurement of high-efficiency office appliances. Energy savings in space heating and cooling requires an integrated approach to optimising architectural design and energy use in buildings, so more complex rather than single measures are required to reduce the relevant energy demand effectively. In addition, ventilation optimisation in air conditioning can reduce significantly cooling demand in commercial buildings, also the renewable can play an important role in energy-related greenhouse gas emission. Nevertheless, appliance consumption in office buildings is assumed to increase by 1% per year to take into consideration of more frequently use of new equipment as a result of stylistic change in office work.

In short, BEE measures in commercial sector involve usually the efficiency package apart from installing double-glazed fenestration or enhanced exterior wall insulation. And the cost associated with the BEE improvement is rather difficult to estimate and there exists no linear relationship between the efficiency standard and required additional up-front investment. No energy demand has been simulated in conjunction with BEE standard variation, as done in the case of residential buildings. A simplified approach is applied by predicting a regular decline in energy intensity in all of commercial energy end uses throughout the modelling process. Cost estimation of efficiency improvement is based on previous literature and empirical studies.

5.6.7 Thermal retrofitting in existing housing stock

According to Qiu (2006), 25% of inefficient building stock is required to be retrofitted in large cities by 2010. This is a fairly ambitious political goal for achieving this objective may encounter difficulties of magnitude in terms of financial and social implications.

In the reference scenario, thermal retrofits in the existing buildings should be taken into consideration if the government is committed to reducing drastically the buildings-related heating consumption in a more or less fast pace. The total housing stock is 152 million square metres in 2005, of which approximately 50% do not comply with the specifications of efficiency measures. A preliminary retrofit scheme is adopted by the local housing administration authority to implement thermal retrofitting or retrofits in existing housing stock constructed prior to 2005 that is not in compliance with building efficiency standards. Yet the municipality has not issued clear timetable and has quantitative retrofit objective only for the time span 2006-2010, during the remaining period in our model, we may face some uncertainty in terms of capital investment and political will. For the existing buildings stock prior to 2005, it is assumed that 50% of inefficient houses built before 2005 houses will be retrofitted by 2030⁴³. This means that around 1.5-2 million square metres existing inefficient houses will need to be retrofitted per year. The reference building energy performance standards of all retrofitted house is the current building code in Tianjin(TJBEEDS-2004).

In addition, it is assumed in the model that only the old-style low-rise buildings are concerned by housing demolition. About 25% of housing stock existing in the base year (2005) will be demolished eventually by 2030, representing 63% of existing old-style (brick-laid low-rise building) housing stock.

In the low-carbon (LC) scenario, progressive upgrade in retrofit standard is assumed, retrofitted houses will comply with TJ2004 until 2010, and Swedish code after 2011, while Minergie label standard applies from year 2021. For the non efficient houses constructed after 2005, LC scenario assumes that they will be retrofitted to comply with current Swedish building code. In others scenarios, TJ2004 performance mandatory provisions will be the benchmark for all non inefficient residential buildings subject to retrofit programme.

As far as commercial sector is concerned, it is assumed that no thermal retrofit will be undertaken in commercial sector in our model. Under the Low Carbon scenario, it is assumed that 80% of existing inefficient houses will eventually be retrofitted by 2030.

⁴³ This is indeed a relatively ambitious retrofit programme since a significant part of housing stock existing prior to 2005 will be demolished at the end of modelling period.

A Ref— NF scenario is designed to simulate the outcome of demand for energy is the case of no political intervention on retrofit programme during the modelling period, it aims to capture the potential contribution to reducing fuel consumption by means of retrofitting existing houses that are constructed by 2005. Also, this scenario will illustrate how important it is to focus on new construction given the significantly dominant role that new houses play throughout the development path. Similarly, every alternative scenario presented below has a non-retrofit variant.

We also simulate the scenarios in which the building codes are only partly enforced and implemented by 2020 (scenario of ParCom), it is assumed that one-quarter of new house construction fails to implement the BEE standards. To align with the base scenario, 30%-50% of non efficient houses constructed after 2005 in the model are expected to be rehabilitated before the end year of simulation⁴⁴, the share of rehabilitated house varies depending upon year of construction.

Past experience also shows that retrofitting can allow for a better inner thermal comfort for households. For example, several housing thermal retrofitting projects carried out in northern cities (e.g. Tangshan⁴⁵, Harbin⁴⁶) gives a very promising result in terms of reduced energy consumption and CO₂ savings.

Table 5-7 summarises the technical interventions and major results of these two housing retrofitting project. Extra costs related to thermal retrofitting stand at 173 yuan/m² (365 yuan/m²)⁴⁷ for the project in Tangshan and, it can be seen that retrofitting is more costly than implementation of BEE at the stage of new construction, let alone the institutional difficulty that the project planner may confront in situ, it is quite common that the stakeholders dispute about the sharing of financing.

In the “PartCom-RF” scenario where all new construction does not necessarily comply with the building code over the period 2005-2015, it is assumed that fifty per cent of non inefficient houses constructed after 2005 will be retrofitted to comply with TJ 2004 building code.

⁴⁴ Retrofitting in this stock is assumed to be undertaken every five years in this housing stock.

⁴⁵ This is a Sino-German BEE collaboration project aiming at reducing heating loss and improving local environmental quality in the northern China. The German technology company GTZ financed in part the project.

⁴⁶ The housing retrofitting project in Harbin was designed and financed by the French FFEM project; the major objective was to test new financing mechanism in energy efficiency improvement in existing buildings in northern China. The mostly remarkable point in this project is that an additional storey has been erected on the top of original roof, the property owner (a state-owned firm specialised in measurement metre manufacturing) use eventually the sales of the accrued housing to cover in part the investment cost in retrofit project. It is generally recognised that housing retrofitting can contribute to revaluing of property and relevant land premium.

⁴⁷ Housing façade renovation, heat supply system upgrading and other engineering works were also included in the housing rehabilitation project.

Table 5-7 Technical intervention in Tangshan housing retrofit programme (courtesy of Dr. Xu Zhiyong of GTZ, 2007)

	Insulation compound	Window	Roof	Techniques
Building 515	10cm EPS	Isolation-glazing	14cm PU	Mono-tube system with bypass, thermostatic valve and heat distributors
Building 512	10cm EPS	Isolation-glazing	14cm EPS	Horizontal distribution; thermostatic valve and heat metre
Building 509	10cm EPS	Isolation-glazing+low E	14cm PU	Perpendicular twin-tube system; thermostatic valve and heat distributors

5.6.8 Technological progress

Technology learning and proficiency by experience imply that even under the business-as-usual scenario, technical and financial barriers to efficiency implementations will be eased gradually due to endogenous technological innovation , represented by the learning curve and economies of scale. Nevertheless, the construction engineering costs are very likely to increase further in the next decades due to sharp increase in upstream raw materials. Consequently, a one-per cent annual increase in cost of housing construction engineering and 0.5% decrease in BEE measures resulting from learning curve are assumed in all of scenarios.

5.6.8.1 Economic modelling of technological advances

There are two main factors influencing the costs related to capital costs of investment in buildings and energy supply systems. The price escalation of raw material and human capital may drive the costs higher on one hand; and learning effect and technological change will lower gradually the costs of new technologies due to economies of scale and experiences gained through the learning by doing mechanism on the other hand.

Models that assess the costs of climate change mitigation policy, and energy policy in general, rely heavily on learning curves to include technology dynamics (Nemet, 2006), therefore the assumption on cost decrease trend is of extreme importance in the energy modelling exercises. Previous literatures (Arrow, 1962; Messner, 1997 ; IEA, 2000; Nemet, 2006; Wene , 2003) suggest that the cost of energy efficiency and emerging technologies ⁴⁸. Therefore, in the long run, these combined effects will lower the costs in new

⁴⁸ Renewable energy for example: the most famous example is the PV development over the last 20 years in the world. The average capital cost was reduced 20% every doubling of installed capacity (IEA, 2007b).

efficient technologies such as building efficiency reinforcement measures(insulation, heat recovery and IGCC , NGCC and CCS . The expected reduction in cost of new technology of the experience curve is mainly driven by both learning-by-doing and economies of scale. In 1936, a seminal paper by Wright (1936) introduced a quantitative model of “learning by doing” to describe the time savings (and associated cost reductions) achieved in manufacturing aircraft. He found that the time required assembling an aircraft decreased with increasing production levels. The relationship is predicted by an equation of the form:

$$y=ax^{-b}$$

Where a equals the costs (hours) to manufacture the first unit, x depicts the cumulative number of units produced, y is the costs (hours) required to produce unit number x , and $-b$ gives the slope for the improvement in costs (hours) in producing the units.

On a log–log scale, this equation plots as a straight line with slope $-b$. Wright coined the term “progress ratio” to describe the ratio of current cost to initial cost after a doubling of production. Thus, a progress ratio of 0.80 meant that costs decreased by 20% for each doubling of cumulative production. Some authors therefore prefer the term “learning rate” for the latter quantity.

Wright's “learning curve” equation was subsequently found to describe the decline in production costs for a wide range of manufacturing activities remarkably well (e.g. Dutton and Thomas, 1984). The concept of learning-by-doing was further extended to model the anticipated capital cost reductions in new generations of a technology, including a variety of advanced energy and climate change mitigation technologies (Nakicenovic *et al.*, 1998 and McDonald and Schrattenholzer, 2001; van der Zwaan *et al.*, 2002; Riahi *et al.*, 2004) . Riahi *et al.* (2004) investigated the technological learning for CCS technology based on a review of previous literature. In this paper, we measure the overall rate of progress or learning from its two principal components: new and improved generations of the technology and learning how to operate existing equipment more efficiently. These two components contribute to what is often referred to as “experience curves” that represent the change in technology cost as a function of its cumulative installed capacity (IEA, 2000).

This phenomenon of constant diminishing cost of new technology with gradual penetration in the market can be modelled by a simplified mathematical function, namely learning curve. Empirical studies on reduction in costs of Photovoltaic (PV) technology using the regression curve give good estimate of the relationship between cost and market penetration, the resultant is plotted in Fig 5-14.

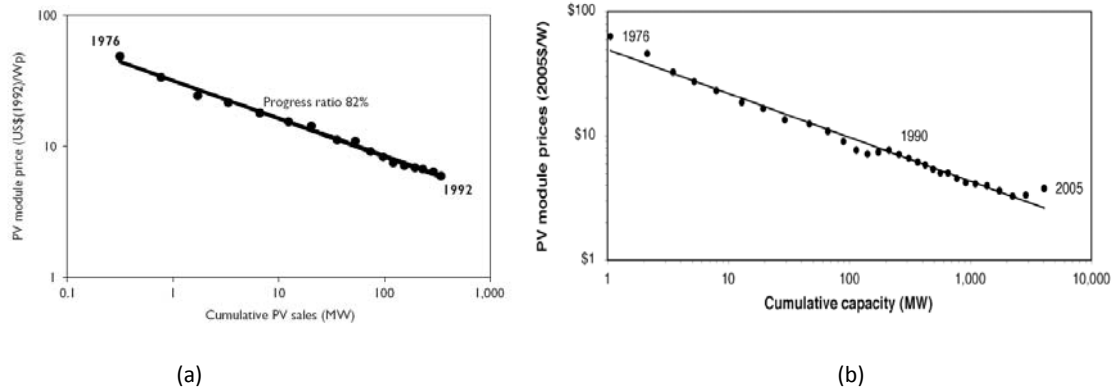


Figure 5-14. PV installation cost versus the cumulative capacity in the World(up left-hand side) and in the US(right-hand side)

Source: Nemet (2006)

Similarly, Arrow(1962) explains that the “learning by doing” provides opportunities for cost reductions and quality improvements. The learning curve model operationalises the explanatory variable experience using a cumulative measure of production or use. Changes in cost typically provide a measure of learning and technological improvement, and represent the dependence variable. The log-linear function is the most common tool in fitting experience curve with historical observation data. The curve can be described by equation 5.7

$$C_t = C_0(Q_t/Q_0)^{-E} \quad (5.7)$$

$$PR = 2^{-E} \quad (5.8)$$

$$LR = 1 - PR \quad (5.9)$$

- C_t is the cost in time t
- C_0 is the initial cost of technology in time 0
- Q_t is the cumulative production of technology in time t
- Q_0 is the initial cumulative production
- LR is the learning rate
- PR is progression rate of technology

The key parametre in the learning curve model is the exponent E which characterises the slope of the curve, which appears as a linear function when plotted on a log-log scale. Large values of E indicate a steep curve with a high learning rate (IEA, 2000; Nemet, 2005). The progress ration (PR) describes the extent to which the technology improves with associated cost decreasing over the time. For instance, Fig. 5-14(a) has a progress ratio of 82%, meaning that price is reduced to 0.82 of its previous level after a doubling of cumulative sales, in other world ,the learning rate was 18% over the period 1972-1992, meaning that each doubling of sales reduced the price by 18%.

Based on the assessment of PV development in the US market, Nemet (2006) argues that the lbd, the theoretical mechanism used to explain learning curves, only weakly explains change while the most important factors are plant size, module efficiency, and the cost of raw materials (silicon). In other words, Economies of scale play essential role in learning curves of energy technology such as buildings efficiency measures and renewable energy supply technologies. In addition, a broader set of influences such as technical barriers, industry structure, and characteristics of demand should be considered for the energy technology policy analysis.

5.6.8.2 Application of technological advancement in the model

The experience and learning curve is applied to efficient energy supply, clean coal and carbon management technologies such as IGCC, NGCC and CCS are considered in the model. There is no empirical study so far on the learning curve of CCS technology in coal or gas-fired power plants in China. Our model assumes that each doubling of installed capacity will allow for a decrease of 5% of construction cost, implying that E equals to 0.74. Likewise, we project that the cost of NGCC and co-fire of biomass with coal in the heat plants are to follow the identical dwindling trend over the modelling period.

Likewise, incremental cost associated with building energy efficiency improvement (especially the buildings shell performance enhancement) in high efficiency buildings is assumed to decline more fast than less-performing technologies, driven by endogenous technological learning and economies of scale, average decrease by 0.4% per year on average through out the modelling period, consistent with the assumption in van der Zwaan *et al.* (2002) who modelled climate change technology change. Fig 5-15 plots the costs of enhanced buildings envelop complying with different building performance standards in the model. Indeed, the influences on learning of technology should be ideally country and region- and sector-specific since their capacity of learning differ one from another. Assuming all the builders had the same learning rate of new technology may pose some methodological problems, but since our model is focused on one city in China, the difference amid different builders and property developers could be considered insignificant. Also, according to the model of Jaffe and Stavins (1994), the new technology can be diffused like an epidemic disease, i.e. the more the new technology is adopted, the more it spreads rapidly.

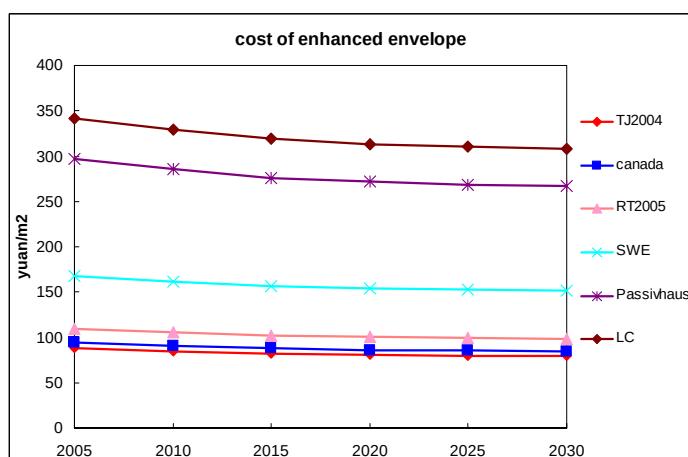


Figure 5-15. Incremental cost of buildings efficiency complying with different standards

5.7 Energy supply system

5.7.1 Heat supply

In reference scenario, heat supply infrastructure development will follow the official objective specified in the official government documents: 1. Tianjin city general heat supply planning; 2. city CHP heat supply scheme, and 3. Tianjin Binhai New Area heat supply plan.

Currently, about 90% of existing residential houses in Tianjin⁴⁹, or 120 million square metres of floor space are supplied by district heating, i.e., city-scale CHP or distributed or centralised coal-fired boilers. The rest refers mainly to the old houses in the downtown area where heat supply networks are not available for technical reason. Heating consumption in buildings (commercial buildings included) amounted to 3 million ton of coal equivalent.

Out of the houses connected to heat supply networks, about 70% are supplied by local district boilers, while the rest are heated by CHP, a small part of residential buildings are delivered heat by geothermal (water-source heat pump or ground-source heat pump). Gas-fired heating is virtually non-existing in the current heat supply picture.

According to the municipal heating administration, distributed small-scale district boiler will be progressively substituted by more efficient and sustainable supply system with relying more on renewable sources, vigorous development of large CHP will be favoured to tackling the local atmosphere pollution problem. CHP will cover at least 50% of city's heated floor area in 2015, while gas-fired and renewable energies-fuelled heating system will account for 25% of total heat supply capacity if the city heating plan 2003 is to be implemented thoroughly.

⁴⁹ In 2005, total existing floor area of housing stock in Tianjin is 140.4 million square metres.

It is assumed in LC scenario that the local government will foster vigorously the low carbon content fuel and renewable energies in district heating system such as natural gas-fuelled and municipal waste solid-fuelled heat and electricity combined (CHP) to decarbonise heat generation of the district heating suppliers, shown in Fig 5-16.

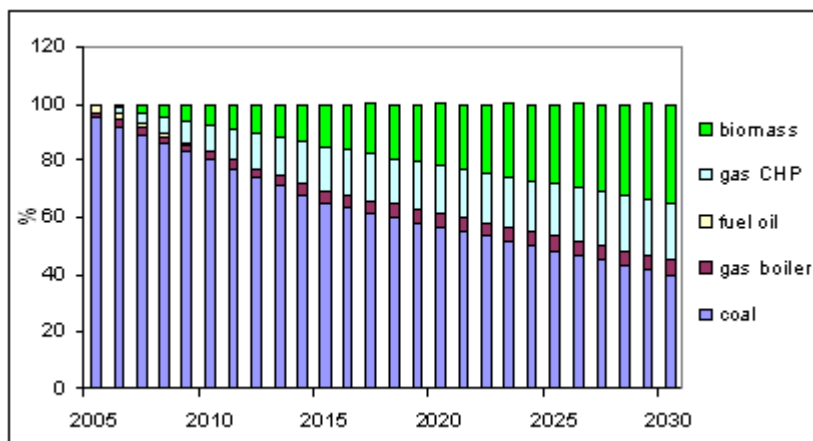


Figure 5-16. Breakdown of district heating supply system by technology under LC scenario

In LC scenario, renewables will be promoted vigorously to replace in part the coal-fired heat generation capacity, albeit the up-front cost is significantly higher than conventional technology. Heat values are referred to previous studies relating to biomass heating survey both in Europe and China(European Commission 2004; Li et al.,2005; IEA 2007), in which authors conducted comprehensive surveys into the renewables use in urban district and electricity generation. It is assumed that biomass energy and municipal solid wastes(MSW) will be used both in large CHP power plant and local heating boiler stations in this scenario.

5.7.2 Forecast of increase in heat load and cost of new capacity addition

The rising heat load due to increase in buildings floor area and thermal comfort will result in requirement of heating generation capacity addition. Investment in new added heating capacity constitutes the major upfront cost in energy system as large amount of financial resources need to be mobilised, opportunity cost of capital should also be taken into account in the technical and economic analysis.

The extent of heat load sizing is characterised by an irreversible processes. A corresponding load must be added when a building is constructed and occupied effectively by dwellers. For instance, addition of a new apartment building complying with TJ-2004 standard leads to 29.4 W/m² and 33.6 W/m² increase in low- and high-rise buildings, but 61W/m² and 72W/m² in the case of non compliance in these buildings. This

shows again the why it is so important that building energy efficiency needs to be included in new construction programme so as to avoid the lock-in dilemma.

For heat and electricity generation, if excess capacity exists, additional energy can be supplied at close to short-run marginal cost, as there is sufficient capacity to supply the additional demand. When there is no excess capacity, the marginal cost of producing additional energy includes the full costs of capacity and operations (Intelligent Energy System). The new generating capacity addition is calibrated to be consistent with the heating and electricity development plan of the local authority, which aims at replacing a substantial part of current generating capacity of distributed small boilers by large scale and more efficient city-wide CHP plants by 2015. Table 5-8 and Table 5-9 summarise the current situation of centralised CHP plants in the central city and Binhai (New satellite city of Tianjin, respectively. Therefore, the capital cost is accounted for whenever the generating capacity is added in the area during the modelling period.

Table 5-8.Current situation of district heat supply capacity in central city of Tianjin

Central city

CHP	Supply capacity		Distributed area
	Steam(t/h)	Hot water (MW)	(1000 m ²)
Yire (First thermal power plant)	475	151	7629
Chentangzhuang	250	391	6900
Yangliuqing		532	11000
Total	725	886	25529

In 2005, about 2.55 million square metres in the central city is supplied with heat produced by the CHP companies, which represented about 20% of centralised district heating area in the city of Tianjin.

Table 5-9 Current situation of heat supply in BNA zone

Jurisdiction	district heating penetration (%)	Floor area of Residential buildings supplied by DH (10000 m ²)	Heat sources
Tanggu	82	1239	Centralised boiler stations, CHP , geothermal
Hangu	38.44	170.76	Centralised boiler stations
Dagang	100	142	Centralised boiler stations; industry heat recovery
Downstream of Haihe river		20	Industry heat recovery
Jinnan	52.1	71.2	Centralised boiler stations
Dongli		120	Centralised boiler stations; geothermal
Total		1545.56	

Inner city heating plan

Geographical distribution of projected heat load

Division	2007		2010		2015	
	1000 m ²	Heat load (MW)	1000 m ²	Heat load (MW)	1000 m ²	Heat load (MW)
Zone 1	13820	760.1	14560	800.8	15030	826.7
Zone 2	31090	1710	36300	1996.5	43450	2389.8
Zone 3	11080	609.4	12940	711.7	15480	851.4
Zone 4	12900	709.5	14390	791.5	21500	1182.5
Zone 5	21550	1185.3	25830	1420.7	35800	1969
Zone 6	21060	1158.3	24590	1352.5	31700	1743.5
Zone 7	31190	1715.5	36420	2003.1	37770	2077.4
Zone 8	8890	489	10380	570.9	16230	892.7
Total	151580	8337.1	175410	9647.7	216960	11933

Outer city and Binhai zone

Zone	2007		2010		2015	
	1000 m ²	Heat load (MW)	1000 m ²	Heat load (MW)	1000 m ²	Heat load
Aeronaut industry	1390	76.5	5830	320.7	1711	941.1
Binhai High-Tech industrial zone	0	0	1370	75.4	4550	250.3
West TEDA	800	44	2740	150.7	7280	400.4
Hua Ming Zhen	1000	55	3000	165	5000	275
Yangliuqing Zhen	1500	82.5	3000	165	5000	275
Zhongbei Zhen	500	27.5	3000	165	5000	275
Huayuan High-Tech Development Zone	3000	165	4000	220	5000	275
Third higher Education District	700	38.5	1200	66	2580	141.9
Total	8890	489	24140	1327.8	51520	2833.7

Source: Tianjin District Heating Development Plan, 2007 update (courtesy of Song, P and Ing. Xiao) .

5.7.3 Projection of new generating capacity addition

Based on review of international electric power and CHP generation (IEA, 2005), in particular in developed countries and given the context of prevailing thermal power supply technology in China, the following generation technologies will be considered in the new generation capacity in our model.

- Coal-fired pulverised-fuel steam plant with supercritical conditions with net thermal efficiency of 43%
- Coal-fired integrated gasification combined cycle(IGCC) of 400 MW_e capacity and a net thermal efficiency of 50%
- Combined cycle gas turbine (CCGT) plant a net capacity of 600 MW_e and thermal capacity of 72% (52% of electric efficiency and 20% of thermal efficiency)
- Coal-fired pulverised-fuel steam plant with ultra supercritical conditions with net capacity of 2 X 400 MW_e

- Coal-fired pulverised-fuel CHP steam plant with a back-pressure turbine (CHP BST), new generating capacity ranging between 200 and 600 MW_e ; steam boilers will be sized accordingly with a maximal supply capacity of 320 -680t/h
- Coal-fired pulverised-fuel CHP steam plant with an extraction-condensing turbine (CHP ST, extraction), the net capacity of the electric power units ranges between 300 and 600 MW_e.
- biomass and waste-fuel CHP with net capacity of 50 MW_{th} and 20MW_e, with an overall efficiency of 89% (reference of Finnish Kokkola town CHP),

Note: steam production in the above-mentioned CHP is to meet industrial heat process demand.

Yire : all existing capacity will be retired by 2010 and replace by Junliangcheng CHP plants .

5.7.4 Electricity supply technology

Technological advancement in electric sector is reflected by the increasingly improved thermal efficiency in power generation resulting in reduction in both fuel consumption and greenhouse gas emission in the power plants. Currently, it is estimated that 1% improvement in energy efficiency in power generating plant will lead to 2% reduction in CO₂ emission (Dantang Power, 2005). Based on the current situation and future development trend of electricity supply, the model identified potential new entry generator technologies and their respective costs, and used an exogenously planned capacity add-on approach to simulating new capacity addition and dispatching based on cost merit order, i.e. the rule of dispatching electricity pursues the ascending costs of generating technology.

Most of recently commissioned coal-fired power plants of high-efficiency in the world use pulverised coal combustion(PCC) with supercritical (beyond critical point of water : 22.1 Mpa, 374°C) steam turbine cycles, those using the highest steam temperatures (around 580°C and above) can be referred to as ultra-supercritical (IEA,2007a). The new entry technologies assumed for the mix of generators to supply accordingly depending on the heating and electricity load profile in buildings are reported Table 5-10. Relevant efficiency of power generation technologies is shown in Table 5-14.

Table 5-10. Assumptions on new power generating capacity

Technology	Capacity addition
Conventional Coal thermal power stations (sub-critical)	1000MW decommissioned by 2015; and 1500 MW decommissioned by 2030
Supercritical	2 × 500 MW
Ultra supercritical	2 × 400 MW
IGCC	2 × 500 MW
Combined cycle gas turbines (CCGT)	2 × 300 MW

Conventional Subcritical units will peak in around 2015-20 and then start to decline as several old units need to be decommissioned at that time, the subsequent retired capacity will be replaced by more efficient electricity generation technologies such as IGCC⁵⁰, Supercritical(SC) and Ultra-Supercritical (USC) units. Also, the gas-fired CCGT will be added to the generating capacity. Assumptions on generating capacity additions vary depending upon the scenarios and are presented in Table 5-11 through Table 5-13.

While IGCC is not yet commercially proven for it is generally perceived as riskier by the financial community and by utility companies around the world (Rubien *et al.*, 2007). The model assumes that ICGG power will not be dispatched as first merit order until 2015 under baseline scenario. According to Tianjin Electric Power Development Plan, a unit of 2000 MW IGCC will be available by 2015, another unit of 2000 MW of USC (i.e. Tianjin Beijing Power Plant using sea water as cooling media) could be commissioned in Binhai New Zone in by 2010⁵¹. This is will be largest commercial-scale IGCC plants in China.

Electric power generated in the power plant is dispatched by production process (conventional, IGCC, CCGT, supercritical, ultra-supercritical etc) share and the extra capacity will be “exported”. In fact, the current electricity generation, distribution system does not allow the direct sale of electricity from a generator to end user. Electric power distribution market is monopolised by the subsidiaries of National Grid Company, the city of Tianjin is supplied by North China Electric Grid (NCEG) which is in charge of distribution networks in northern China. To simply the calculation, the surplus electric power in the large electricity generators and the municipal CHP heat supply companies is assumed to be purchased by NCEG at wholesale price, considered as benefit of energy supply system in the cost-benefit analysis.

Table 5-11. Assumptions on technology penetration in new coal-fired units capacity addition in heat plants in baseline scenarios

	per cent				
Supercritical	2005	2010	2015	2020	2025
Conventional	100	60	40	30	10
Supercritical	0	40	45	50	60
IGCC	0	0	15	20	30
IGCC With CCS	0	0	0	0	0
Co-firing	0	0	0	0	0

⁵⁰ IGCC can be configured to be readily adaptable for CO2 capture and storage through removal of carbon from the system before the fuel gas is fired. The carbon monoxide in the gasifier product gas would be converted to additional hydrogen plus CO2 using a shift reaction. The CO2 would be separated for storage, then the hydrogen would be burnt in the gas turbine with nitrogen as a diluent (IEA, 2007a; p.129).

⁵¹ This project consists of five sub-projects: power generation, desalination of seawater, salt production, land development and waste recycling .press Release of Binhai New Area. http://www.bh.gov.cn/misc/2007-05/17/content_10349945.htm

Table 5-12. assumptions on technology penetration in new coal-fired units capacity addition in heat plants in LC-R1 scenario and its variants

	In percentage				
	2005	2010	2015	2020	2025
Supercritical					
Conventional	100	30	15	0	
Supercritical	0	50	60	50	50
IGCC and USC	0	15	20	40	40
IGCC With CCS	0	0	0	0	0
Co-firing	0	5	5	10	10

Table 5-13. assumptions on technology penetration in new coal-fired units capacity addition in heat plants in LC-CCS scenario and its variants

	per cent					
	2005	2010	2015	2020	2025	2030
conventional	100	30	0	0	0	0
supercritical	0	50	45	40	30	20
IGCC	0	15	40	30	30	30
IGCC with CCS	0	0	10	20	30	40
Co-firing	0	5	5	10	10	10

Assumptions on costs of generating electricity were based on review of recently published papers on both international and Chinese power plants (Li *et al.*, 2004; IEA, 2005; 2007a) and field study (North China Electric Power Design Institute). However, it is rather difficult to model exactly the electricity demand and supply load curve since industry sector is not included in our model, at present buildings, in particular the residential sector represent a relatively small share in total electricity consumption, industry represents about 75% of final electricity consumption according to official statistics⁵², as shown in Fig 5-17.

⁵² as mentioned before, Chinese statistical system is devised to compile the data by sector by NOT by usage, it results in the fact that significant buildings consumption are accounted for in industry sector otherwise they would be classified as part of energy feedstock in the commercial sector

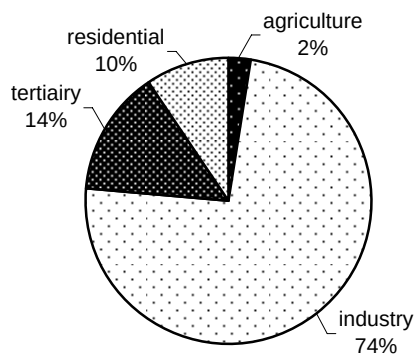


Figure 5-17. Final electricity consumption breakdown by sector in 2005(Tianjin Statistical Yearbook 2006)

Assumptions on generator net efficiencies (in %)

Table 5-14. Thermal efficiency in power generating technologies

	2005	2010	2015	2020	2025	2030
Conventional	35	35.8	36.6	37.4	38.2	39
IGCC CCGT	43	44.4	45.8	47.2	48.6	50
super critical	45	45.8	46.6	47.4	48.2	49
ultra supercritical	48	49.4	50.8	52.2	53.6	55
fuel oil unit	37	38	39	40	41	42
CCGT	52	52.6	53.2	53.8	54.4	55

Technical parametres of coal-fired power plants in the model

Type	steam pressure	steam temperature	heat efficiency	Net coal consumption
	Mpa	°C	%	Gce/kWh
Subcritical	17	540/540	38	324
Supercritical	25.5	567/567	41	300
HT supercritical	25	600/600	44	278
USC	30	600/600/600	48	256
high-temperature USC	30	700	57	214
IGCC *	Thermal efficiency is identical to ultra-supercritical			

*IGCC has the best environmental performance by minimising negative impact among all clean coal technologies

Source: , Li *et al.*, 2004.

5.7.5 Assumption on penetration of heat supply technology

District coal-fired boiler will be substituted gradually by large CHP, gas boiler, geothermal and to a lesser extent by individual electrical heating appliance⁵³ in the model. Assumptions on their respective penetration during the modelling period in the reference scenario are plotted in Figure 5-18. Note that vast majority of existing generating capacity of small district boilers will retire by 2025 within the economic lifetime (20 years).

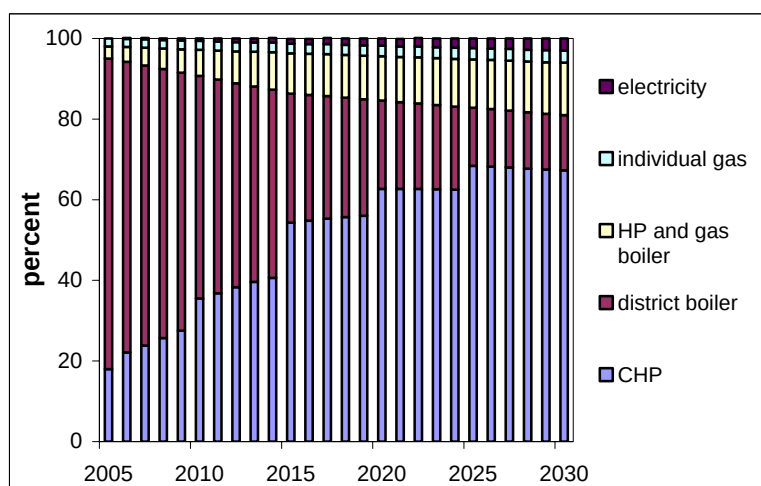


Figure 5-18. Residential heat supply technology penetration(reference scenario)

The financial and institutional perspective of district heating development in Tianjin will be discussed in detail in Chapter 6 which deals in particular with the institutional structure of property market and energy supply regime in the city.

Table 5-15. Technical parametres of municipal heat distribution

	Pressure (Mpa)	Temperature (°C)
Water pipeline	1.3	130/70
Stem pipeline	1.6	300

Parametres in the upstream energy supply system in our model use Tianjin heating plan as major reference. Table 5-16 summarises the general technical parametres for heat supply projection, in the Binhai Zone Heat Planning that has been drafted by local authority.

⁵³ Actually, according to building energy efficiency experts in China, individual electrical heating appliances must be strongly discouraged if the upstream electric power generation efficiency and fuel consumed should be taken into account.

Table 5-16. General parametres in Binhai Heat Supply Planning⁵⁴

	Component	Current situation	Planned	Improvement	Comments
1	District heating penetration (%)	75	100	+25%	Covering city centre, built-up zone, new rural area and urbanised towns
2	Percentage of Renewables and clean energy ⁵⁵ in heat generation (%)	8	20	+12%	Gas, geothermal, heat pump, solar energy
3	Pollutant concentration (mg/m ³) SO ₂ (mg/m ³) NO _x (mg/m ³)	≤80 ≤200 ≤450	≤30 ≤100 ≤400		Local standard 《 regulation on atmospheric pollutant emission from boilers》 DB12/151—2003
4	Buildings heat load (W/m ²) Residential Commercial Industrial	55 70 70	40 60 65	-27.3% -14.3% -7.1%	Mandatory BEE design in all new buildings
5	Thermal efficiency (%)	77.25	91.28	+ 18.2 %	Large CHP: 92 % , District boiler station: 83 % , Small boiler: 60 %
6	Distribution system: Heat loss in hot water networks (%) Heat loss in steam network (%)	5 15	2 5	-3% -10%	
7	Recovery of condensing water (%)	/	100	/	
8	Water recycling		Sea water , gray water		Sea water is used as cooling water in CHPs; while gray water is used as cooling water for both district boilers and CHPs

⁵⁴ Heat source and capacity projection may have significant changes in this revision plan since the urban general planning in Binhai New Zone is likely to be modified by the new government.

⁵⁵ Essentially this refers to natural gas

9	Recycling of combustion dust (%)		100		

Source: Binhai Heat Supply Planning revision 2007 (courtesy of Meng Tao).

Pollution control in power and heat supply

The up-to-date electric technologies are considered in the model by specifying that they should be penetrated into the power and heat generation in the coming years. Pollution control system is considered in the power plants, sulphur dioxide is assumed to be controlled tightly in all power generators, in particular the equipment with the wet scrubber, composed of reaction vessel in which the flue sulphur dioxide is absorbed and form flue gas by slurry of limestone or other reagent, sulphur removal efficiency is considered 95% or more (IEA, 2005 update).

5.7.6 Alternative or low –carbon energy supply technology options

A variety of array of low-carbon energy supply technologies exist regarding carbon emission mitigation in power and heat generation plants. Some are expected to be promising to cut significantly the carbon emission in the fossil fuel-based power and heat generation plants. However, many of them will not be commercialised in the short run due to expensive costs and lack of regulatory framework of large scale deployment such as CCS. Yet it is foreseeable that these emerging technologies will increase more rapidly in the coming decades and relevant costs are likely to decline gradually due to learning experiences and economies of scale. District heating from urban waste recycling and biomass reutilisation seem to be promising supplement to fossil fuel-fired heat generation in the municipal heat companies. Thus we simulated the different scenarios in which supply-side technology evolution are combined with the demand side management (DSM) measures such as the BEE improvement.

Industrial and household wastes can be recycled to extract heat to meet space heating and industry process heat. In some European countries, waste and biomass energy represent a significant part in urban district heating supply by using the up-to-date combined power and heat technology, this environmentally friendly technology can contribute effectively to improving energy efficiency and lowering carbon emission from fossil fuel combustion, hence protecting local environment. Fast development of renewable heating can allow the development of the whole industrial supply chain of renewable energy (logistic of biomass energy transport and distribution) and also create the new employment in the renewables sector. Many European large cities have been developing waste fuelled city-level CHPs. For example, in the Danish capital Greater Copenhagen area, around half a million people are distributed by the CTR heat networks, fuelled essentially by waste heat and refuse incineration plants and CHPs (Metropolitan Copenhagen

Heating Transmission Company). In the Parisian district heating system, nearly 50% of heat is produced from household waste in the cogeneration plants, the waste-fuelled DH capacity in the municipal CHP plants reached 430 MW in 2007 and represents around 35% of total consumed energy in the heat plants, and accounts for 44% of steam generated on average during 2002-2005⁵⁶. Moreover, the European Union is aiming at recycling 70% of household waste by 2020 (*les Echos* 17/06/2008; p.33,), a significant part of the waste can be used in the waste incineration plant to produce heat energy. This model can serve as a good example for Tianjin municipality in the diversification of energy production resources. In fact, the city has been promoting circular and low-carbon economy, for example, the *Guohuan Shale Production Plant* uses the natural shale resources to fabricate energy efficient buildings insulation materials (see chapter 6 for detailed explanation).

5.7.6.1 Biomass co-firing option

One of the most promising technical solutions of carbon emission mitigation in power sector is the biomass co-firing in coal-fired boilers for power and heat generation. The coal-fired boiler can be retrofitted to burn both coal and bio-fuels simultaneously. Biomass is a well suited resource for co-firing with coal. This technology is extremely interesting when seasonal agricultural wastes are available with an economical transportation diameter from the surroundings of the city, currently it is found that the transport distance of less than 500 km be the most viable option. Beyond 300km transportation distance, pelletisation, fast pyrolysis, and methanol synthesis become increasingly cost competitive for different ranges of thinning yield and duration (Polagye *et al.*, 2003).

Since biomass is the “flexible” fuel, a 5-day stockpile should be sufficient and will allow avoidance of problems with long-term storage of biomass such as mold development, decomposition, moisture pick-up, freezing etc (US DOE, 1996). Unlike coal, most of biomass contains very small amounts of sulphur (0.2%) , partly substitution of biomass for coal in the CFB can result in significant reductions in sulphur dioxide (SO₂) emissions. Furthermore, the use of biomass to produce electricity and heat in the CHP plants in a dedicated feedstock supply system , where biomass is grown specifically for the purpose of providing a fuel feedstock will provide new revenue sources to local agriculture industry by providing a new market for farm production . Firing biomass in boilers with pollution control can reduce burning of agricultural and wood residues in uncontrolled furnaces or in open fields, as is mostly the case in China’s rural area, and hence provides another means of reducing air emissions.

However, there exist also several negative points that need additional R&D in biomass co-firing system; 1. slagging and fouling on boiler surfaces caused by high alkali herbaceous biomass feedstocks, and 2. The potential for reduced fly ash marketability. In addition, due to high transportation costs, sufficiently

⁵⁶ CPCU (Compagnie Parisienne du Chauffage Urbain) PowerPoint presentation, 2008.

inexpensive biomass residues and energy crops must exist within an 80 to 120 Km radius to economically justify a biomass co-firing operation (Turnbull, 1993).

In our model, the heat plants characterised in the model are generally pulverised coal plants, which co-fire from 10% to 15% biomass on a heat input basis. The co-firing is not projected to exceed 20% due to biomass resources seasonal limitations and the necessity to maintain the unit efficiency.

The development of biomass co-firing in power and heat plant requires an integrated industrial chain be established from biomass farming, collection, transportation, stock, distribution and convey. The slow development of biomass use in power and heat generation plants is due to lack of well-established vertical industrial relationship. As pointed by Osterkorn (2007), *“the relationship between farmers and power station managers in China is yet polarised, they are not used to working together. As in other countries, it has been hard to make a new horizontal incision into a vertically integrated industrial infrastructure – yet that is essential for a well-functioning biomass-to-energy industry.”* In fact, straw is plentiful across the country. According to ESD’s study, carried out in conjunction with China’s Centre for Renewable Energy Development (CRED), at least 70,000,000 tonnes of unused surplus straw is burned each year. In addition, large amounts currently used for fertilising, paper-making or other purposes are potentially available as feedstock for power stations (Osterkorn, 2007)⁵⁷.

5.7.6.2 Recycled urban waste for the use of district heating fuel

Currently, most of urban residential waste is disposed in city’s peripheral landfill, waste incineration can be scaled up to recuperate the waste heat to generate electricity and heat for district heating in urban area. In the “LC” model, the consideration of residential waste incineration is taken into account in the heat and power generation technology.

5.7.6.3 Carbon capture and storage perspective

Carbon capture and storage (CCS) technology which consists of carbon dioxide capture⁵⁸, transport and storage processes in the large emission point sources in the lieu of releasing it to atmosphere (stocking in the geological formations or in Deep Ocean mass)⁵⁹. CCS technology applications are found to date mainly in petroleum and petrochemical industries (such as natural gas processing and ammonia production). Capture of CO₂ from combustion-generated flue gases has also been demonstrated commercially at small scale. Geological sequestration of captured CO₂ also has been demonstrated at three large scale projects in Norway, Canada and Algeria (each storing over one million tonnes of CO₂ per annum). However, there have been few applications of CO₂ capture at the electric power plant at a large scale (Rubin *et al.*, 2007).

⁵⁷ Biomass co-firing potential in China. <http://www.reeep.org/9863.2669/biomass-co-firing-potential-in-china.htm>

⁵⁸ Currently the post-combustion capture is mostly used in around the world.

⁵⁹ CCS is already applied or will be in operation in several sites (Weyburn in the US, Sleipner in Norway, Shell-Statoil Halten Project) around the world for various purposes, e.g. enhanced oil recovery. Many international cooperative research programmes in CCS are also under way (CASTOR in Europe, IEA GHG gas R&D programme etc.). Shenhua Energy Group and Petro China are also conducting CCS research programme. However, the current expensive cost and lack of reliable geological formations in Chinese major emission point sources hinder the large-scale deployment of this technology in the short run. In addition, energy penalty is also to be addressed in the technological breakthrough.

In the model, CCS are considered in three types of electricity and heat generation plants, PC, SC, IGCC plants in relevant scenarios. CCS is not considered in the fuel-switching supply option in which new capacity CCGT and part of existing coal-fired plants will be retrofitted to switch to gas from 2020. Rubin et al. (2007) investigate the cost and performance of fossil fuel power plants with CCS technology in the US. The costs of CCS in terms of US\$ per tonne CO₂ avoided may vary significantly depending on fuel, plant size, capacity factors etc. The review by Rubin *et al.* (2007) in recent literature shows that the cost of captured CO₂ ranges generally between 37 and 74 US\$/t CO₂, 29-51 US\$/t CO₂ and 13-37 US\$/t CO₂ in the CCGT, PC and IGCC plant respectively. To this should also add the cost of transport and storage, approximately 15-20 US\$ per tonne of CO₂ captured.

It is also found that the cost of electricity generated in terms of \$/MWh with CCS is the lowest in the IGCC power plants, and highest in the CCGT plants. In addition, impacts of CCS energy requirement on plant-level resources requirements is found significant with increases of 15-30% of energy resource requirements, known as energy penalty. This conclusion is consistent with the findings of CASTOR pilot project in Europe. The thermal efficiency with CCS is reduced by 15-30% in the pilot plants fuelled by bituminous coal, CCGT and lignite respectively(CASTOR project presentation). Furthermore, the CASTOR project aims to limit the CCS cost below 20-30€ per tonne CO₂ captured in the future, compared with 50-60€/tonne today⁶⁰.

To simplify our analysis, the economic implications will be addressed by comparing two distinct energy supply development strategies: coal and gas respectively as a response to the international debate on whether China should continue to use coal or switch to gas to reduce dramatically GHG emissions. The combinatory matrix of building codes standards and energy supply options and timing of adoption are represented as follows

CCS option	CCGT option
TJ-2004, Coal with CCS from 2020	TJ-2004 with CCGT in all new installation from 2020
A2, Coal with CCS from 2020	A2 with CCGT in all new installation from 2020
LC, Coal with CCS from 2020	LC with CCGT in all new installation from 2020
ParCom, No Retrofit Coal with CCS from 2020	ParCom No Retrofit with CCGT in all new installation from 2020

⁶⁰ EU CASTOR project presentation, Pierre Le Thiez, CCS Project Manager – IFP.

5.7.7 Energy flows

Fuel designated to final consumption in buildings sector is distinguished from upstream primary fuel used in producing the secondary fuel for end users.

Electricity, LPG, Heat, Natural gas, District heat, Heat generated from Heat pump, boilers and municipal heat plants and other oil product, such as coal gas are considered the final energy consumed directly by end users both in residential and commercial sector.

Coal, natural gas, crude oil, MSW, solar and biomass (straw stalk, agriculture residue, wood) are considered primary energy resources. Some oil products are considered intermediate energy fuel such as residual fuel which is a refinery product of crude oil and is consumed in turn in power and heat generation. In fact, oil-fired boilers are also in operation in some commercial buildings; nevertheless, our assumptions ignore their production given their relatively small share compared with district heating and electricity-fuelled space cooling in both residential and commercial sectors.

In fact, natural gas is considered simultaneously primary and secondary energy since it is either consumed directly by end use primarily for space heating/ cooling and cooking use and also for heat and power generation in energy transformation plants. The diagram in Fig.5-19 illustrates the energy flows in the model from primary fuel production to end use.

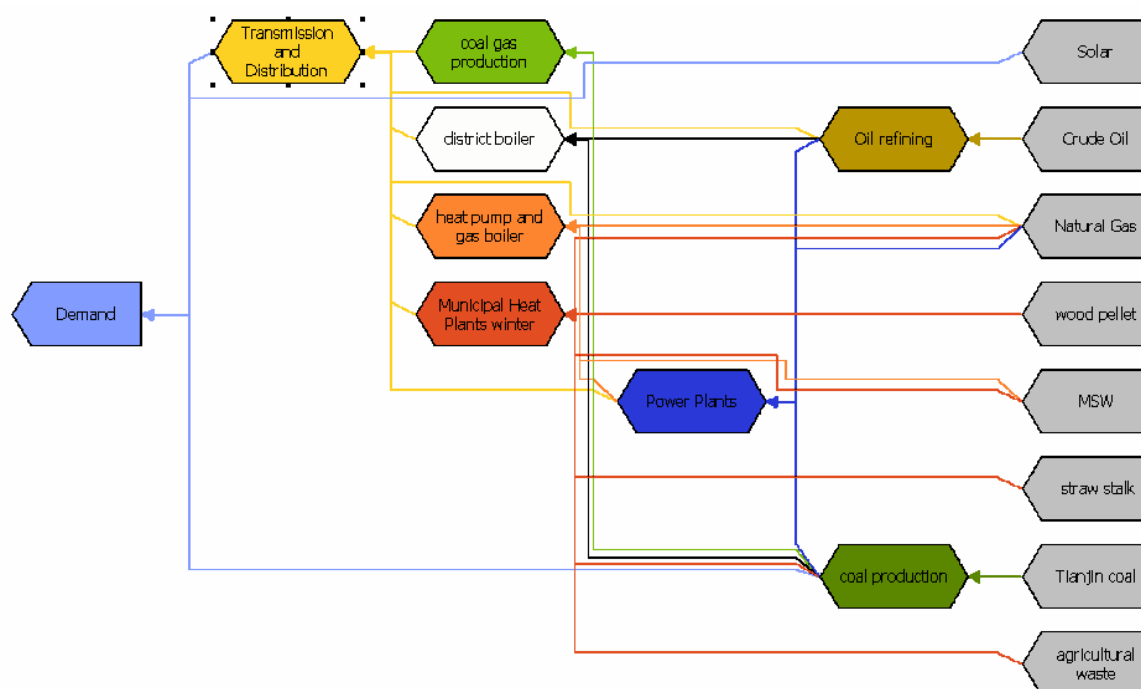


Figure 5-19. Energy flow chart in the model framework

Note: MSW stands for Municipal Solid Waste

In fact, different types of coal have its own physical characteristics, in this model all the coal consumed in power and heat, coal gas generation is normalised to a universal term “Tianjin Coal” which is assumed to represent the general physical characteristics of all the coals shipped from two principal coal supply regions (Shanxi and Tangshan) near Tianjin, “Tianjin coal” is assumed to have the average characteristics of anthracite, bituminous and lignite coal.

5.8 Estimation of cost

The social cost rather than narrow-sighted and single-minded consumer-side fuel price and appliance price is considered in our cost-benefit analysis. The total social cost comprises the cost of buildings construction, cost of appliance efficiency improvement, development of heat supply system (cost of heat sources installation and network development).

Costs in the modelling are decomposed into three fragments ,

1. buildings construction costs which includes all upfront costs associated with buildings engineering’s and investment in building energy efficiency, the on-site heating supply network (within the limitation of buildings zone) cost is also included in the buildings construction as a part of urban infrastructure development
2. energy supply costs including capital cost in new capacity addition, main network development cost, fuel resources cost, O&M costs falling on the utility that would influence the choice of generation options⁶¹
3. Cost of externality which is related to the shadow price of emitted greenhouse gas, desulphurisation process is considered in all the scenarios for the air pollution control purpose.

Apart from the fact that the costs associated with the demand side energy efficiency technologies (buildings shell insulation, electric appliances efficiency, heating and cooling distribution system performance, lighting appliance efficiency etc), the overall costs in the different scenarios are heavily dependent upon the new generating capacity addition, determined in turn by the BEE and end-use technologies.

5.8.1 Capital cost of energy supply system

This cost mainly covers the capital cost, operation and maintenance costs, variable and fix costs in heat and power generation plants and interest costs of investment loans. Capital cost is annualised over the lifetime

⁶¹ The choice of generation options can be modelled by setting the merit order of commissioning new capacity, or by specifying exogenously the technology options of installed generation.

(generally 30 -40 years) by taking the conventional interest rate. Capital cost consists of generation capacity and distribution networks investment. Capital in the investment in new generating capacity is annualised based on the lifetime of each process, with an interest rate charged on the capital cost. The total capital cost is annualised into a stream of equal annual real payments, starting in the year when any new capacity (either exogenously specified or endogenously specified) comes on line and lasting for the lifetime you enter for the process. Capital costs in the thermal power plants are annualised (spread-out over the plant lifetime) using a standard mortgage formula as follows:

$$\text{Annualised cost } AC = \text{Total Cost} \times CRF \quad (5.10)$$

$$\text{where } CRF = i * N / (N - 1) \\ N = (1 + i)^n$$

i = interest rate (8%)

n= plant lifetime

CRF is the capital recovery factor

In fact, the overall efficiencies specified in the CHP plants are lower in practice given the load factor of heat supply. Heat load in the buildings varies depending on actual weather condition, thus load factor crumbles in summer and part of CHPs will either stop producing electricity and heat or only be running as the purely condensing units whose energy efficiency is much lower than cogeneration period. It is assumed that the surplus of electricity produced in the CHPs is “stored” in the electric grid (it is rather sold to distributor) in summer time when capacity is exceeding the demand and can be recuperated in winter time.

- Capital cost in power and heat plants in 2005 price

Type of plant		Cost
Conventional		
coal-fired	4000	Yuan/KW _e
thermal plant		
Coal steam	5500	Yuan/KW _e
power plant		
Oil fired	5800	Yuan/ KW _e
gas CCGT	4700	Yuan/ KW _e
CCGT with CCS	5600	Yuan/ KW _e
Supercritical	8500	Yuan/ KW _e
Ultra-		
supercritical	10000	Yuan/KW _e
IGCC	1300	US\$/ KW _e

IGCC with CCS	1430	US\$/ KW _e
Co-firing	4200	Yuan/KW _{th}
Biomass and waste	5400	Yuan/KW _{th}

- Distribution Network infrastructure
 - o Heat substation: 5 -12 MW /unit; distribution floor area: 100-200 thousand square metres.
 - o pipeline quality: DN≥250mm : Q235B steel (Spirally Sewed High Frequency Weld Steel)
 - o DN≤200mm, seamless steel

Cost of development of heat supply infrastructure (distribution networks) is estimated by multiplying the fix-cost factor (per square metre cost) by the developed distributed floor area. A typical estimation of unit-cost is around 45 yuan per square metre of floor space.

5.8.2 Cost of electricity generating capacity addition

The factors considered in the development of new power generating capacities included fixed capital costs; variable operating costs (fuels and operation & maintenance) and financial costs (interest rate⁶²). Electricity generating capacity is discomposed into two parts: 1) power generating capacity in the large CHP plants and; 2) large coal-fired power generation plants. Capacity in the CHP plants depends in fact upon the heat load calculated based on buildings energy performance in the demand-side. We assume that all electricity generated in the CHPs will supply the requirements in the buildings, surplus will simply be sold to the North China Grid ⁶³(*Huabei Dianwang*) and exported to other regions, resulting in benefits in the economic analysis. It is commonplace that during the first years power generated in CHP plants will not meet the projected increasing demand in the buildings sector, the unmet electricity demand in the CHP module is then supplied by upstream power plants whose capacity expansion is calculated endogenously depending on following elements

- how quickly electricity requirements increase
- The initial reserve margin (if it is much higher than the planning reserve margin then LEAP may not add extra capacity for many years), if its starting value is less than the planning reserve margin, LEAP will start adding capacity in the year after the base year.
- and whether any capacity is added exogenously

⁶² Assuming that capacity-adding capital is raised essentially by banking loans and needs to be paid back by financial flows yielded by sales of electricity in the power plants.

⁶³ The subsidiary entity of State Grid in charge of power distribution and transmission in the northern China.

To simplify the cost estimation, cost of installed MW for the same technology is identical in CHP and power plants.

More specifically, within the boundary of cost analysis in the model, overnight construction cost (capital cost) of upstream power plants should not be included in the general cost –benefit analysis for two reasons:

- Accurate load curve data is necessary to estimate exactly the upstream electricity generating capacity expansion attributable to the increased electricity demand in buildings in Tianjin, implying the analysis of the whole North China Electricity Grid which is far out of the scope of our analysis focusing on heating consumption in Tianjin. This hypothesis implies that no capacity expansion is accounted for in upstream power plants;
- By testing the different scenarios, it is found that electricity supply shortfall in the CHP plants exists only during the first five to seven years of modelling period, in other words, the electricity supply in buildings can be auto-sufficient by CHP plants during the most part of the timeframe. It is not sound to account for the whole capital cost of upstream power generation for this relatively short-term electricity supply shortfall.

However, the variable costs such as O&M and fuel consumption are taken into account into the model.

5.8.3 Cost of fuel resources

In the model, fuel cost is not directly considered in the transformation module, instead the cost of upstream primary energy resources (coal, gas, crude oil etc) are accounted for. In principle, economic theory suggests that shadow costs reflecting the full opportunity costs, not market costs, should be used in specifying resource costs. In practice, market prices are often used as a proxy to estimate the resources cost, however, the problem of price bias arises when end use fuel prices are subsidised by the government (Heap, 2007), in particular in the case of residential energy consumption price in China (see Box 5-1). Therefore, international energy resources supply costs are considered as the opportunity costs of fuel consumed in the model to minimise the cost deviation effect. Coal is the dominant energy fuel in power and heat generation in all the basecase scenarios (without significant change in new supply technology investment in 2020). In practice, different kinds of coal are consumed to produce the steam and or electricity (anthracite, bituminous and lignite, lean etc). As said above, all these coals are harmonised to the Tianjin Coal (representing the general physical behaviour of the commonly used coal in district heating and power generation) in the model to make the assumption consistent, albeit their physical characteristics may differ to some extent.

Box 5-1. Energy price subsidy and perspective

Hitherto the delivered energy resources prices have been subsidised heavily by the national government, hence the market price of commercial energy do not reflect the actual opportunity cost of the depletable fossil energy. Although local energy market has been deregulated (Coal, electricity for example), energy transportation and distribution prices are always tightly regulated by the government (Chinese Ministry of Railway for coal transport). Low price level hinders the LNG pipelines development. Domestic energy price subsidy in China is estimated at 11 billion US \$ in 2006 (IEA,2007b)⁶⁴.

Residential consumers are the most subsidised among all end users. Although the government has ended the transport fuels price subsidies, the household still benefit from price subsidies for energy use in cooking and heating, in particular the natural gas, it is estimated that the end users only pay the half of its actual economic value. Thus current energy price structure is not consistent with the national energy efficiency objectives.

Very recently, China has raised the domestic energy price, NDRC announced a rise of 18% and 5% in fuel and electricity prices respectively (Financial Times, June 20, 2008) under both international energy market pressure and domestic refineries complain about low price of delivered oil products. NDRC, the national energy regulator, has pointed out that domestic energy prices and international market prices will eventually converge in the coming years, by adjusting the tax rates imposed on fuels consumption (tax on natural resources consumption, environmental tax in energy sector).It is thus plausible to project a continuous energy price increase in the model.

Coal price has been surging since 2004 following the coal market reform and the all-out economic boom stimulating the demand for coal, in particular the price of steam coal used for electricity generation whereof the increasing buildings electric appliance penetration is a major driver together with industry sector.

It is reported that the pit-mouth steam coal price (with 5800 Kcal per tonne LHV) has increased more than 20% in the first half year of 2008 to reach 585 RMB (US\$83)per tonne in the Shanxi province (major coal mining area in China), and nearly 100% compared with 2007 average price . Thus we believe that the increase trend of coal price will pursue in the baseline model driven by market forces. It is assumed in the baseline scenario that coal price will increase 2% per year over the modelling period. Table 5-17 shows the rapid increase in coal supply price in China during 2007-2008.

⁶⁴ The method of estimating the energy price subsidy is to compare the difference between the benchmark energy prices and end user paid energy prices.

Table 5-17 Coal price variation during May –July in 2007

	Coal brand	8 May	14 May	21 May	28 May	4 Jun	11 Jun	17 Jun	25 Jun	2 Jul	9 Jul	16 Jul	23 Jul
Pre-train unloading	Datong premium blend	450-460	450-460	450-460	455-465	455-465	455-465	455-465	455-465	460-470	460-470	460-470	460-470
	Shanxi premium blend	415-425	415-425	415-425	420-430	420-430	420-430	420-430	420-430	425-435	425-435	425-435	425-435
	Shanxi blend	370-380	370-380	370-380	375-385	375-385	375-385	375-385	375-385	380-390	380-390	380-390	385-395
	General blend coal 1	330-340	330-340	330-340	330-340	330-340	330-340	330-340	330-340	335-345	335-345	335-345	335-345
	General blend coal 2	295-305	295-305	295-305	295-305	295-305	295-305	295-305	295-305	295-305	295-305	295-305	295-305
Reference price (FOB)	Datong premium blend	475-485	475-485	475-485	480-490	485-495	485-495	485-495	485-495	490-500	490-500	490-500	490-500
	Shanxi premium blend	438-445	438-445	438-447	440-450	443-452	443-452	443-452	443-452	445-455	448-458	448-458	450-458
	Shanxi blend	390-400	390-400	395-405	400-410	400-410	400-410	400-410	400-410	405-415	410-418	410-418	410-418
	General blend coal 1	350-360	350-360	350-360	355-365	355-365	355-365	355-365	355-365	355-365	360-370	360-370	360-370
	General blend coal 2	315-323	315-323	315-323	315-323	315-323	315-323	315-323	315-323	315-323	315-323	315-323	315-323

Source: China Coal Report, July 2007.

International energy market price will have more and more repercussion on China's domestic energy prices. In 2006, nearly 60% of oil consumption in China were dependent on foreign import, IEA (2007b) projected that China should participate more actively in international energy trade in the next decades. International oil benchmark prices and considered as reference of Tianjin's oil supply cost. Oil supply price is dependent upon the international oil trade price and the exchange rate between Chinese Yuan Renminbi (CYR) and US dollars. Under the baseline scenario, we projected that oil price will reach 130, 200 and 300 US dollars/bbl in 2010, 2020 and 2030, respectively. CYR is expected to appreciate against US\$. Exchange rate between USD and CNY is assumed to decrease from 7.8 : 1 in 2005 to 6:1 at the end of this period. The nominal price of oil in Chinese Yuan will increase 70% over the period, increasing from 4500 Yuan/ Toe to 8000 Yuan/toe.

Increasing trend is also likely to maintain for the natural gas price in China. Average growth rate of NG demand was nearly 10% per year over the period 1998-2005, gas consumption is about 48 billion metric cubic metres in 2005. Gas supply and demand will hardly equilibrate over the next 20 years if current demand trend continues, the Chinese Academy of Engineering (CAE, 2004)⁶⁵ projected that domestic natural gas demand will increase at 10.8% per year over the period 2000-2020, while supply will grow only 7.5% per year. Gas demand would reach 200 billion metric cubic metres in 2020 under the business as usual scenario, of which 45% will then depend on imported gas since the maximum domestic production is projected to reach 110 billion cubic metres in the same year. The main NG exporter to China, Russia, has been pricing the NG exported to China at the same level as that supplied to European Union. Also, natural gas supply intermittence occurs regularly in China, in 2006, 6000 MW of natural gas-fuelled power generation units were forced to shut the production of electricity due to serious supply shortfall. Moreover, gas price is under pressure of foreseeable increase as oil supply tension intensifies in the future. All these factors make sense that the strong pent-up demand for natural gas will drive the price much higher over the modelling period. From international natural gas price perspective, Figure 5-20 illustrates the US

⁶⁵ 中国可持续发展油气资源战略研究(Sustainable development strategies of oil and gas resources in China) is a research report undertaken by the Chinese Academy of Engineering for the end of policy recommendation to the central government regarding oil gas resources prospect in China.

natural gas prices evolution over the last century. The graphic also shows a sharp increase trend in the past years in the US gas futures market. The current natural gas spot price is about 13 US \$ per Mbtu in the NYMEX market, or 0.42 US \$ per cubic metre (*Les Echos*, 24 June 2008). By comparison, current gas supply price in China's major cities is around 0.25-0.27 US \$ per cubic metre in foreign exchange rate term. Gas supply price is assumed to increase at 1.5% per year over the modelling period.

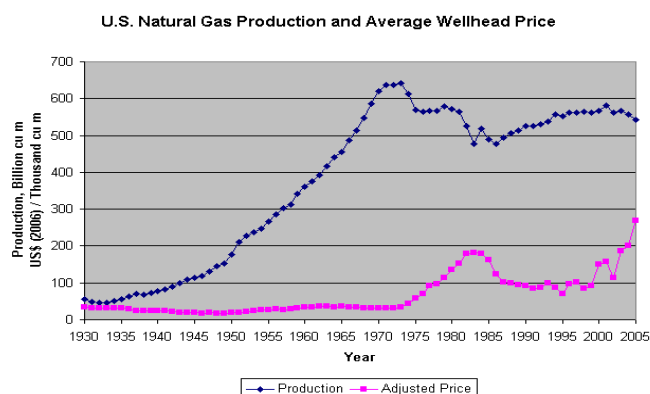


Figure 5-20 Natural gas price historical development

Source http://en.wikipedia.org/wiki/Natural_gas_prices

5.8.4 Oil products price

Crude oil price is not used as the proxy of energy fuel costs, instead the oil product prices are used due to the price gap between the internal oil supply and imported crude oil, while it is difficult to distinguish the imported oil from the locally produced oil in the power plants and refineries supplying the city of Tianjin. The prices of oil products consumed in buildings and heat and power production plants are expected to be closely correlated with the crude oil price charged to upstream refineries.

Residual fuel oil and diesel are consumed in energy transformation module for the end of heat and electricity generation. LPG is consumed directly by residential consumers. The price of oil products are assumed to follow the same trend as the crude oil since it is predictable that internal supply price and international benchmark price are likely to converge eventually. Furthermore, the Chinese major oil refinery companies (PetroChina and Sinopec) are also very keen on lobbying the central government in order to raise the oil products end use prices. The price of oil products in 2005 is as follows

	RMB per metric tonne
Residual fuel oil	1800
Diesel	4700

Biomass fuels and waste costs

Currently, no explicit market price is available on biomass energy and urban households and agricultural waste. Price revealed in some biofuel power generation in Shandong and Jiangsu provinces are taken as proxy to approximate the biomass supply gas. Since we are uncertain about price difference between the wet and dry straws, a universal price is assumed. All the biomass and waste costs include the collect and transport costs from rural area to the heat plants. Biomass costs are assumed to increase at 1% per year, more slowly than the fossil fuels. Heating value and price are based on the previous literature (Li *et al.*, 2005; Chen *et al.*, 2006; Liu, 2006). Average biomass and recycled wastes prices in 2005 are as follows

	RMB per metric tonne
Wood-pellet	250
Straw stalk	150-180
Rural agriculture waste	70
MSW	45

Note : Cost of transport is included

5.8.5 Costs related to building shell thermal performance and ventilation recovery system

The enhanced envelope insulation and heat recovery in ventilation system (thermal exchange) is considered in BEE measures. Cost of installation of ventilation technology (mechanical ventilation) is included into the total cost of construction in the efficient house construction scenarios. The cost of learning of new technology is also taken into account. The extra cost associated with the enhanced buildings energy efficiency is presented in Tables 5-18 and 5-19.

Table 5-18 Incremental cost of enhanced BEE in high-rise residential buildings

Options	Extra cost (yuan/m ²)
Non insulated buildings	0
RT 97 code	62,3
RT97(ref)	63,8
Tianjin RT2004	75,1
Tianjin WB	86,5

Canada	96,8
France RT2005	115,5
Sweden	151,4
Minergie	181,3
Low carbon house	252,5

Table 5-19 Incremental cost of enhanced BEE in low-rise residential buildings

Options	Extra cost (yuan/m ²)
Non insulated buildings	0
RT 97 code	46,5
RT97(ref)	57,8
Tianjin RT2004	73,6
Tianjin WB	84,3
Canada	78,3
France RT2005	91,2
Sweden	135,6
Minergie	247,1
Low carbon house	285,0

5.8.6 Cost of externalities

Only carbon dioxide cost associated with energy consumption and energy conversion in transformation sector in the model is included in the co-benefit analysis. Other GHG gases are all accounted for in terms of equivalent CO₂ by their relevant GWPs. Apart from SO₂, all other pollutant gases are out of the scope of our study objective. Consequently, cost of externalities only refers to CO_{2eq} and SO₂ emissions cost systematically hereinafter.

Environmental externality associated with CO₂ and SO₂ emission is internalised by pricing the relevant emission. Different prices of CO₂ are applied to test the responsiveness of CO₂ emission reduction resulting from implementing more stringent building regulations, to the extent the emission constraints get more and more clear, reflected by rising CO₂ price throughout the modelling period. CO₂ price uncertainty exists depending upon the demand and supply of CO₂ on international carbon trade market. They are in turn determined by the international carbon regime and global mitigation policy. In fact, different mitigation technology options are highly dependent on carbon prices for a rational investor who will choose to invest in low carbon technology now if the cost of delaying in investment is larger than the value of delaying, and will hold the option if value of holding an option exceeds the value of revenue, and vice versa(Blyth and Yang, PowerPoint presentation, IEA 2006).

Two approaches are used to take into account the CO₂ emission costs.

1. no explicit CO₂ price is given in the model, we calculate the levelised value of average abatement cost (AC) of CO₂ in the alternative scenarios with respect to the high-emission scenarios (ParCom and NR), the AMAC can either be positive or negative depending on relevant cost profile in alternative scenarios compared to the No policy or high-emission scenarios. The levelised cost discounts the time series of expenditures associated with CO₂ abatement to their present value in a specified base year by applying a discount rate. The levelised cost per tonne CO₂ abated in different scenarios is the ratio of cumulative lifetime expenses in the alternative scenarios to the total expected CO₂ emissions in terms of present value. By definition, this is calculated by the equation 5.11,

$$AC = \frac{\sum_{i=2005}^{2030} \frac{C_{ms_i} - C_{ref_i}}{(1+a)^{i-2005}}}{\sum_{i=2005}^{2030} \frac{Em_{ref_i} - Em_{alt_i}}{(1+a)^{i-2005}}} \quad (5.11)$$

where

- C_{ref_i} is the cost of reference scenario in year i
 C_{ms_i} is the cost of mitigation scenario in year i
 Em_{ref_i} is the CO₂ emission in the reference scenario in year i
 Em_{Alt_i} is the CO₂ emission in alternative scenarios in year i
 a is the discount rate selected, here 6%

2. An explicit CO₂ price is given exogenously in the model. Price assumptions may vary depending on future global carbon emission constraints and Chinese government's environmental policy, resulting in a price range between 10 and 50 US dollars per metric tonne CO₂ emitted. The global social cost of CO₂ averages around US\$12 per tonne on in 2005 (IPCC, 2007) but differs significantly depending on estimation assumptions (-3 US\$-100US\$/tonne). We model the sensitivity of carbon emission cost implementation with respect to the time frame of implementation and increase rate of carbon price. In most of scenarios , carbon price is assumed to come into effect to tax fossil fuel energy use from 2010.

Exhibits of carbon price and time of implementation (US\$/t CO₂ eq)

Assumptions		2010	2020	2030
Low price perspective	Slow convergence with international carbon market price	5	12.5	20

Medium carbon price perspective	Slow convergence with international carbon market price	5	27.5	50
High carbon price perspective	radical mitigation scheme	12	56	80

Sensitivity of impact of CO₂ price on global system cost is tested in the model, end year CO₂ price may range between 20 US\$ and 80 US\$ / t CO₂ eq⁶⁶.

In contrast to CO₂ pricing, the cost of desulphurisation is taken into account from a technical point of view, sulphur dioxide (SO₂) emission in power plants is strictly regulated by the Chinese environmental agencies. We assume that all coal-fired heat generation plants should be equipped with appropriate device to control the emission below the mandatory threshold prescribed in environmental regulations. SO₂ emission is priced at 3 CNY per tonne which is the benchmark desulphurisation in most modern thermal power plant.

5.9 Result of simulations

This section discusses the result of simulations of change in buildings stock and heat load demand and the social cost implication of each scenario will be presented, recall our principal goal consists of identifying the optimal BEE development scenario which is selected from the seven scenarios mentioned earlier.

5.9.1 Estimation of current fuel consumption of DH in Tianjin

A clarification on reference consumption information is needed to determine the efforts that should be put in place to improve the current situation. It is thus necessary to estimate the average of current final and primary energy demand in building sector. Two methods are compared as follows.

5.9.1.1 Top-down method

As said above, district heating covers 90% of space heating services in the city, hereinafter we deal only with DH⁶⁷. The average final and primary energy demand of district can be derived from Tianjin's statistical Yearbook and the data supplied by the Tianjin Heating Office.

⁶⁶ The presumed carbon emission cost lies within the lower range of projected carbon prices in the previous literature on climate change economy modelling. For example, in IPCC (2007), lower carbon price ranges (\$5 to \$65 per ton CO₂-eq in 2030, and \$15 to \$130 per ton CO₂-eq in 2050) may achieve the stabilization levels if policies that induce technological advances are implemented.

⁶⁷ In fact, among the rest 10% of floor space not included in DH, a significant part uses centralized geothermal energy, it is also a kind of district heating except that does not burn coal to supply heat to end users.

Table 5-20 DH supply situation in Tianjin

	Unit	2004	2005
Supply capacity			
Heat network	t/h	3407	3294
Hot-water network	MW/h	10111	10563
Heat supply			
Steam	1000 Gj	17640	19660
Hot water	1000 Gj	65300	75720
Length of networks	Km	8038	8705
Coverage zone	Million square metre	114.4	140.4
In which residential	Million square metre	89.7	109.7

Source : Tianjin Bureau of Statistics

This table gives the information about total supplied heat and consumption area. Based on our interview with the local energy experts, around 20% of steam are supplied to space heating in buildings, of which residential buildings account for 80%. The average heat loss in the distribution network is 15%, then it can be calculated easily that the average per square metre final demand in residential heating (AFD) in 2005 is

$$\text{AFD} = \frac{19660 \times 20\% \times 75\% + 75720 \times 109.7 / 140.4 \times 100\%}{1000 \times 109.7} \times (1 - 15\%) = 0.48 \text{ Gj / m}^2$$

$$= 134 \text{ kWh / m}^2$$

Then, we calculate the primary coal consumption in coal-fired boiler and large CHP since none of the existing CHP use gas boiler in Tianjin. The data in Tianjin Jinneng DH office shows that the average primary fuel consumption in Tianjin's medium and large CHP is about 36-37 kgce per GJ, and 45-53 kgce per GJ in case of distributed boilers. Then average fuel consumption of 1 Gj (UPFC) heat is can be calculated by

$$\text{UPFC} = (36.5 \times 30\% + 49 \times 70\%) = 45.25 \text{ Kgce primary coal / Gj heat generated}$$

Thus, the primary energy demand of residential building space heating is then

$$\text{APD} = \frac{45.25 \times 0.48}{(1 - 15\%)} = 25.62 \text{ kgce/m}^2 = 208.6 \text{ kWh / m}^2$$

5.9.1.2 Bottom-up method

The BM estimation of buildings average demand for energy in DH can be done using the weighted consumption level across all the existing buildings in the city. The breakdown of building stock by energy performance is as follows

Type of building	%
Non efficient (built before 1990s)	60
First generation of Efficient buildings (-30%)	20
Second generation of efficient buildings (-50%)	20
Third generation of efficiency (-65%)	0

Situation of buildings energy performance in 2005⁶⁸. The municipality's official number related to the percentage of buildings in compliance with building codes (1-3 versions) is roughly 50%. To simplify the calculation, we only take two types of model buildings (high-rise and low-rise houses) to simulate the final consumption for space heating with value in parenthesis indicating the energy savings compared to a common design in 1980-81.

86 code	20%
97 code	20%
2004 code	0%
non efficient	60%

Specific per square metre energy consumption for space heating is dependant on the type of buildings and energy efficiency of buildings. We use the values results explained in Chapter 4 to estimate the average specific energy demand in the existing buildings in 2005.

Table 5-21 Final heating demand of buildings complying with different BEE standards

Building EE level	final consumption of heating kWh /m ²
High-rise non efficient	160
High-rise compliance with 86 code	74.8
High-rise compliance with 97 code	52

⁶⁸ The last building code is implemented in the city since 2005. Therefore we believe that virtually no buildings in that year comply with it.

Low-rise non efficient	167.7
Low-rise compliance with 86 code	117
Low-rise compliance with 97 code	81

Associating these values with the corresponding percentage of buildings types shown above, we estimate that the average heating intensity (final demand) in residential buildings in Tianjin in 2005 is

$$AFD=133 \text{ kWh/m}^2$$

This estimate is almost identical to the result obtained with the macro approach, this confirms the pertinence of method we use in estimating the building's energy intensity.

5.9.2 Change in buildings stock

Buildings stock consists of residential and commercial buildings. Total buildings stock is projected to increase 130% of total area in 2005 to reach nearly 480 million square metres in 2030. Of which housing and commercial buildings represent 70% and 30%. Figure 5-21 represents the total buildings stock development in the model up to 2030.

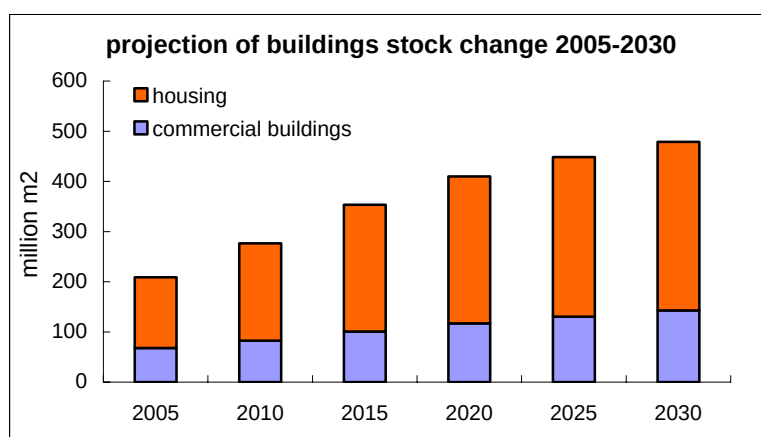


Figure 5-21. Projected increase in buildings stock in Tianjin

Housing

The change of energy performance in existing housing stock is influenced by both new construction addition and evolution in housing stock existing in 2005 (dynamics of demolition and retrofitting of inefficient houses). Figure 5-21 illustrates the change of housing stock during 2005 and 2030.

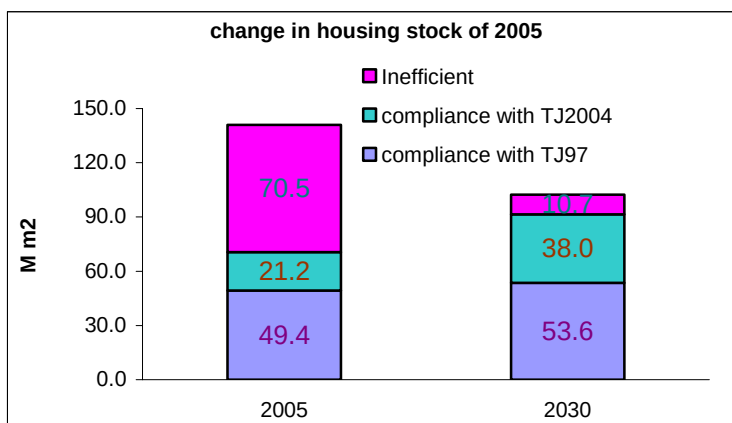


Figure 5-22. Evolution of energy efficiency of housing stock existing in 2005

The decrease in quantity of inefficient house shown in Fig 5-22 is due to demolition and retrofitting programme that will have been carried out during this period.

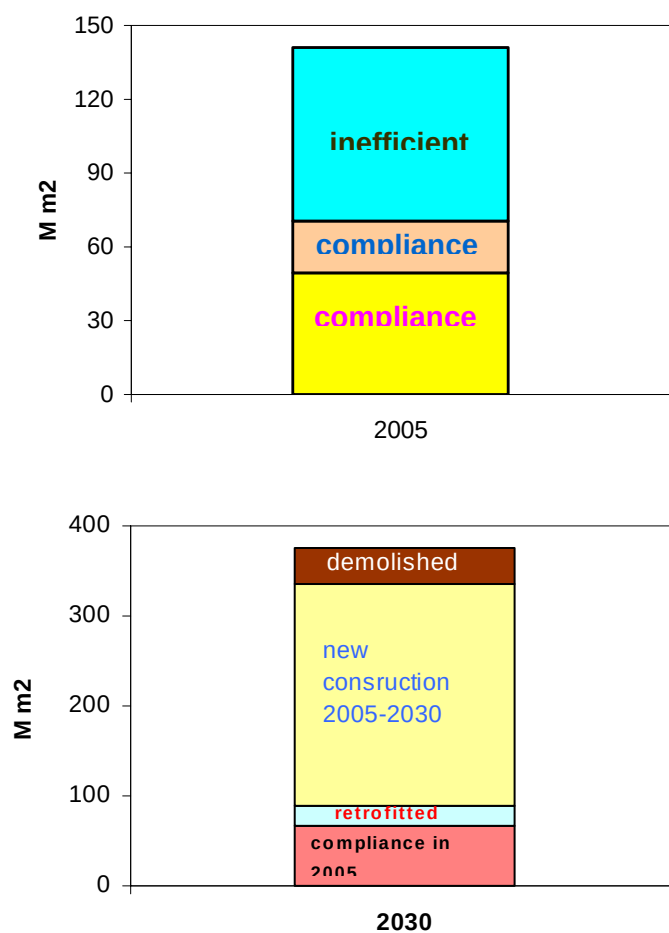


Figure 5-23. Breakdown of housing stock in 2005 and 2030

Figure 5-23 illustrates the change of composition of total residential buildings stock during 2005 and 2030. Total residential buildings floor area is expected to reach 336 million square metre in 2030, of which 247 million m² (73.5% of total housing stock in 2030) are constructed after 2005. Thus, houses constructed after 2005 will play dominating role in the housing stock in 2030 in terms of both absolute area, implying that energy efficiency in these buildings is extremely important as they will shape the energy future in buildings stock over the next decades, and great attention of public policies must be attached to this part of buildings in the next years.

5.9.3 Average final consumption of space heating

Intuitively, the dynamics of change in breakdown of housing stock will result in change in average energy performance of the total buildings stock. Table 5-22 compares the average heating consumption in the housing stock by housing age in 2005 and 2030. Table summarises the average space heating consumption in 2005 and 2030 of different types of buildings.

Table 5-22. Comparison of heating intensity in 2005 and 2030 in different type of residential buildings (kWh per square metre floor space) in the baseline case

final consumption of space heating		
	2005 (16°C-18°C) ⁶⁹	2030 (22°C)
Total average	132	117
Inefficient house low-rise	147	265
Inefficient house high-rise	172	293
Compliance with TJ97 low-rise	79	143
Compliance with TJ97 high-rise	52	96
Compliance with TJ2004 low-rise	46	85
Compliance with TJ2004 high-rise	43	79

As explained earlier, the increase in energy consumption in buildings complying with each of above mentioned performance standards is due to increased demand for thermal comfort as a result of improvement in people's living standard. However, this shows again that increase in energy demand in non-efficient buildings (+around 120 kWh/m²) will be much higher than efficient ones (+37-65 kWh/m²).

⁶⁹ It is assumed that indoor temperature will be maintained to 18°C in efficient houses whereas in inefficient houses, indoor temperature will be 16°C to reflect the performance difference.

5.10 Model calibration of reference scenario

Since LEAP requires highly disaggregated energy consumption data to run scenario simulation, the first task of modelling is to calibrate the base year energy demand in order to ensure that the assumptions on model variables have been defined properly and consistently, we use the Tianjin Statistical yearbook as the reference for benchmarking. Model calibration is concerned with defining the model parameters relating to final energy demand and energy supply technology to guarantee the consistency of variables assumptions in the model. The result also allows testing the robustness of model compared to historical data. After all the variables are calibrated accordingly, future energy demand scenarios can be simulated consequently. The table shows two ranges of final energy demand, representing the model estimate and statistical data in 2005, respectively. Final consumption by fuel is only available in residential sector in the statistical yearbook, no detailed information is given to commercial buildings consumption.

Table 5-23 shows the statistical data and the results of modelling regarding the residential final energy consumption in the base year⁷⁰, suggesting that our model is rather consistent with historical data derived from statistics, especially for electricity and gas (natural gas and coal gas) consumption, although heat and LPG consumption deviate slightly from actual data.

Table 5-23. Comparison of statistical and modelling results of residential final energy consumption in 2005

	Statistics	Model calibration
Electricity (GWh)	3226.6	3221 (3443)
Natural gas and coal gas (million Mega joule)	7029	7010
Coal (tonnes)	667350	654960
Heat (million Mega joule)	38097	37892
LPG (toe)	80940	82047
Renewable (million Mega joule)	N.A	600

Source: Tianjin Statistical Yearbook 2006; calculation of author

Note: figures appearing in statistics have been adjusted based on original data in the statistical yearbook which compiles only the aggregate energy consumption in the whole municipality (our study models the urban housing and commercial buildings consumption), quantity of urban consumption is derived from

⁷⁰ Only electricity data is available for commercial sector in the statistical yearbook. In addition, our study focuses on modelling the residential building energy efficiency, based on the results of comparison between statistics and modelling output for residential buildings, we assume that modelled results for commercial buildings are also in consistency with actual consumption level.

aggregate statistics by assuming that urban households represents around 85% of total final commodity energy demand for electricity, gas and LPG ; and 75% for coal end-use of residential as a whole (biomass consumption is not supplied explicitly in the statistical yearbook, used primarily by rural households). Note that heat is consumed only in urban residential where district heating networks are available. Biomass and coal are widely consumed to meet heating requirement of rural households.

5.10.1 Simulated heat load

The increase in heat load due to added new construction requires gradual installation of new generating capacity during the modelling period. In most of actual situation, new capacity will be added with certain time span between the construction and service date (e.g. A new unit will necessitate several years before being commissioned), the model assumes that time is infinitely dividable thus the installation cost could be accounted for by dividing it into several neighbour years. To simplify the analysis, the marginal addition of new capacity is assumed to be equal to the increase in heat load at the end of each year for the district heating, while electric power generating capacity is calculated endogenously by the model, new generating capacity will be added when demand exceeds the existing capacity plus the planning reserve margin (30% in our model). Table 5-24 reports the simulated heat load during 2005-2030 by heat supply type.

Table 5-24. Heat load projection

	Projected heat load by supply technology in MW					
	2005	2010	2015	2020	2025	2030
Municipal CHP	2070	3730.9	5856	7615.4	9280.1	10995.3
district boiler and heat pump	6925.5	8675.6	8721	8602.1	7979.1	7146.9
total	8995.5	12406.5	14577	16217.5	17259.2	18142.2

According to the model projection, total heat load of buildings is likely to reach 14.6 GW in 2015 under the baseline scenario, in comparison, according the city's heating plan, total heat load of the seven heating subdivisions covering substantially the city core will be around 12 GW and 2.8 GW in the inner and outer city respectively, total heat load would be 14.8GW according to the city's municipal district heating plan. This implies that the underlying assumption on variables in our model is quite consistent with the official projection. The projected total supply capacity will be 16.9 GW according to the municipality's district heating plan, this implies a 15% reserve margin, in which municipal CHP's supply capacity represent 63%, or total installed capacity of municipal heat plants would be 10647 MW.

5.10.2 Final energy consumption

The simulated result of total final energy demand in buildings sector in Tianjin 2005-2006 is plotted in Fig 5-24. Note that the reference *TJ-2004* scenario assumes that all new residential buildings will implement the TJ 2004 energy efficiency design standards and 50% of inefficient existing houses (before 2005) will be

retrofitted by 2030. No specific efficiency measures are considered in commercial sector except for improved cooling technology and lighting efficiency.

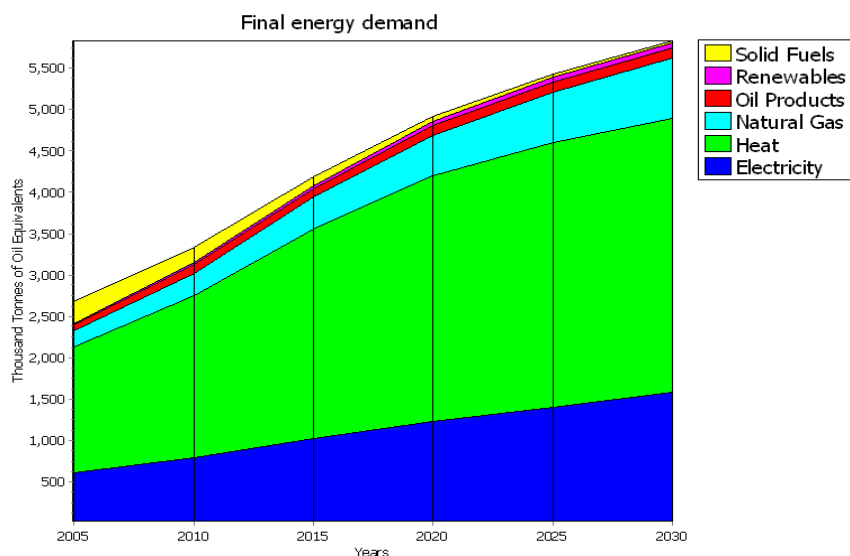


Figure 5-24. Total final energy consumption in buildings sector in Tianjin 2005

Energy demand in Tianjin's buildings sector will more than double over the period 2005-030, increasing from 2732 thousand tonnes of oil equivalents (TOE) in 2005 to 5807 thousand TOE in 2030 with an average growth rate of 3.06% per year, implying an elasticity of about 0.7 with respect to the real GDP growth. Heat constitutes the major part of final energy consumption, which reflects the climate characteristics of Tianjin. Demand for natural gas increases fastest among all the fossil fuel consumption with an average growth rate of 5.15% per year, followed by electricity and heat demand, growing at 4% and 3.5% per year, respectively. Fig 5-24 also demonstrates that heating is the dominant consumption sector in buildings.

District heating consumption dominates the final consumption throughout the modelling period, accounting for more than half of total final consumption in buildings sector. This confirms the thesis that improving buildings thermal performance will have significant impact on final energy demand. Solids fuels in Fig 5-24 refer to coal consumption which is scheduled to be eventually phased out by 2015 in residential sector.

5.10.3 Residential consumption

5.10.3.1 By energy carriers

Coal is assumed to be phased out completely for individual space heating by 2015 for the sake of health protection. A very small part of households continue to use coal for cooking purpose during the modelling period. Fig 5-25 illustrates the current situation of energy carriers breakdown in residential sector in Tianjin.

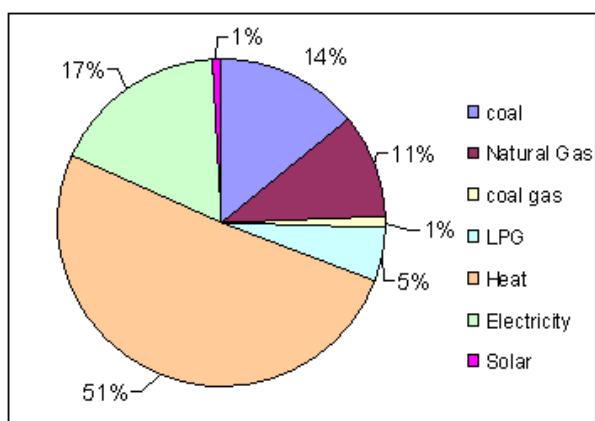


Figure 5-25. Energy carriers distribution in residential sector in 2005

Fig 5-26 shows the projected fuel mix in residential sector over the next 25 years. Heat will dominate the fuel mix, accounting for more than 58% of final energy carriers.

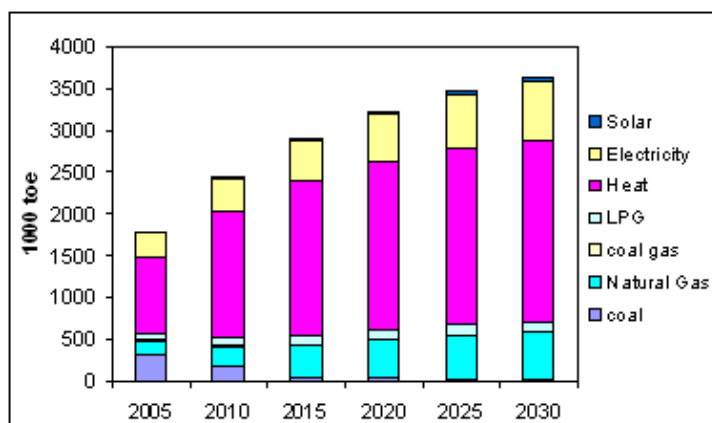


Figure 5-26. Fuel mix of residential final consumption

5.10.3.2 By energy use

Fig 2-27 illustrates the breakdown of final energy use in residential sector in 2005. The largest sector of energy use in the residential buildings is space heating which accounts for 64% of household final energy demand which is similar to previous literature (Jiang *et al.*, 2007, Zhou *et al.*, 2007, IPCC, 2007) the national average level calculated by that considers the space heating in northern Chinese cities represents about 63%⁷¹ of residential consumption. Represents approximately 50% of buildings energy consumption in urban China. Appliances consume around 14% of final energy consumption, implying that appliance efficiency improvement would have rather limited effect in reducing household consumption.

⁷¹ According to Jiang *et al* (2007), average primary consumption of space heating is 20 kg of coal equivalent per square metre in northern cities and all other household consumption is 27 kWh/m² in 2004. Applying the conventional district heating efficiency to the household end use would give the percentage mentioned above.

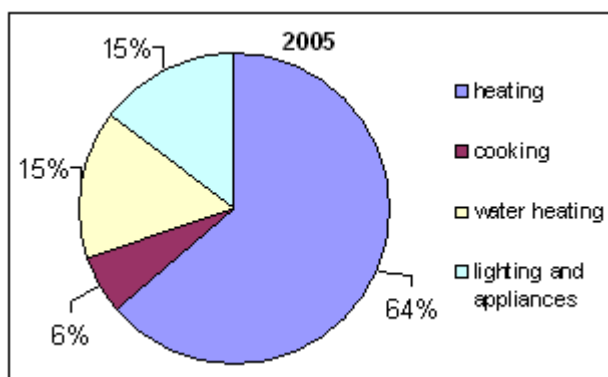


Figure 5-27. Breakdown of residential final consumption by energy use in the base year

With assumptions taken in reference scenario, heating consumption will be more than double from 1112 Mtoe in 2005 to 2434 thousand TOE in 2030.

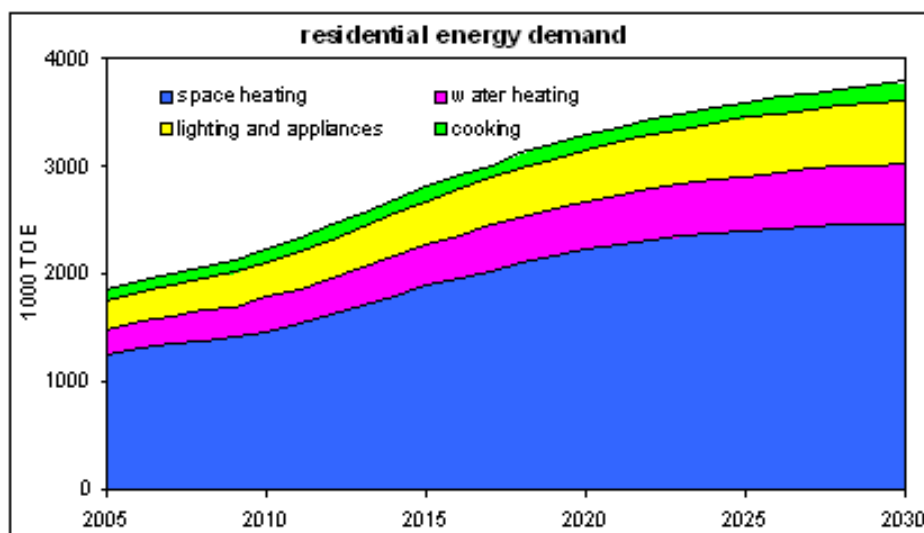


Figure 5-28. Projected residential final energy demand in TJ2004 scenario

Final consumption in residential buildings is broken out into energy use, as shown in Figure 5-27 and 5-28, it can be seen that the shares of each major energy use in residential sector remains quite stable, except that there is a slight decrease in water heating's share and insignificant increase in household appliance's share in total final fuel consumption, respectively, whereas space heating keeps dominating final energy use mix.

5.10.4 Electric appliances consumption

Currently, appliance's share in total household energy consumption is small compared to district heating and water heating consumption, in 2005, it is estimated by the model that appliances consumption is nearly 287 Ktoe per year, accounting for 17% of total final consumption in residential buildings. This

number is slightly higher in 2030 by reaching 18%. Fig 5-29 delineates the future increase in electricity consumption by appliances. Currently, refrigerator is the most energy consuming appliances accounting for more than one-third of residential appliance consumption, followed by air-conditioning (13.7%), washing machine (8.4%) and lighting (14.7%). In 2030, this situation will remain virtually unchanged in the baseline scenario, Washing machines and cooling's respective share will both have slight decrease compared to the base year.

Residential lighting and appliances consumption could more than double to reach 6587 GWh in 2030 compared to 3218 GWh in 2005. Cooling and lighting increase rapidly that they together will account for nearly 42% of appliance electricity consumption, approaching 2740 GWh in 2030. Refrigerator accounts for the largest share in appliance consumption but its weight keeps falling from 32.5% to 28.5 % in 2030; lighting and dish washer's shares increase substantially, from 14.7% to 22.4% and 1.3% to 2.4% respectively. The share of TV in the appliance consumption remains quite stable up to 2030, or around 9-10% of total consumption. Dish washer's increases the most fast (more than 700%) compared to all the other appliances for its low penetration level in initial stage, albeit its share will still remain marginal , accounting for only 3% of total appliance consumption.

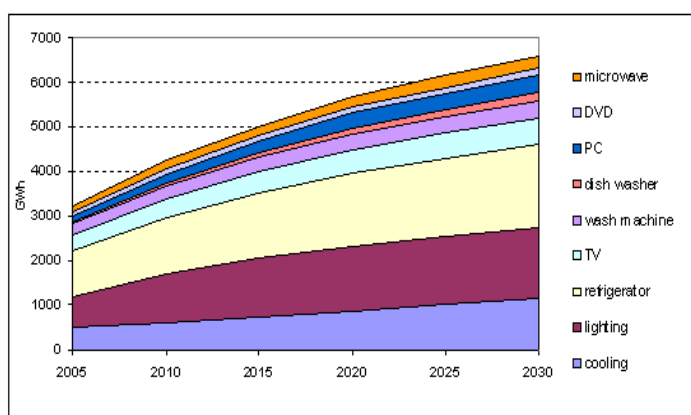


Figure 5-29 Lighting and electric appliances electricity consumption in residential sector 2005-2030

5.10.5 Existing VS new construction in space heating consumption

It is interesting to compare the evolution trend of respective share of new and existing buildings (constructed before 2005). Fig 5-30 depicts the change in their respective shares in total heating consumption⁷². Existing buildings' share drops steadily due to the demolition mechanism and retrofit programme in the old stock. Buildings constructed after 2005 will outpace existing buildings in terms of share of total heating consumption in 2019. In 2030, new buildings will account for more than 68% in total heat consumption. We may expect, however, results of other scenarios will differ more or less significantly,

⁷² Here the residential appliances consumption is excluded since the model uses a stock turnover analysis thus appliance consumption between old and new housing stock is not distinct, aggregate energy consumption is stimulated instead.

depending upon the rhythm of uptake of new buildings codes and the implementation of retrofit programme in old houses in the next decades. We will present the other tree scenarios.

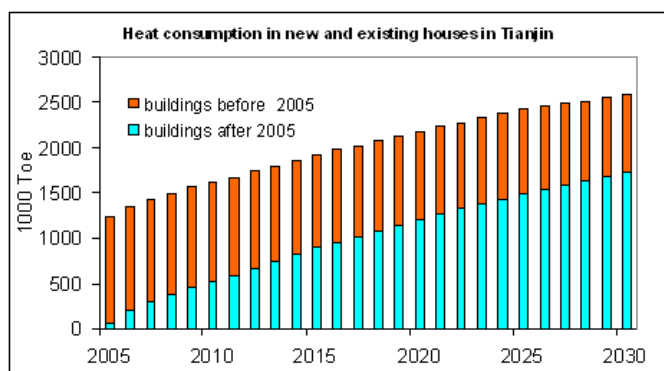


Figure 5-30. New and old houses' share in total district heating consumption

5.10.6 Residential versus commercial sector

Final consumption in commercial buildings is 858 thousand Toe in 2005 and could reach 2,154 thousand Toe with an average growth rate of 3.75% per year. Natural gas grows fastest although its share is quite small, it grows more than 6% per year. Demand is broken out by fuel and sector, as shown in Fig 5-31 and 5-32.

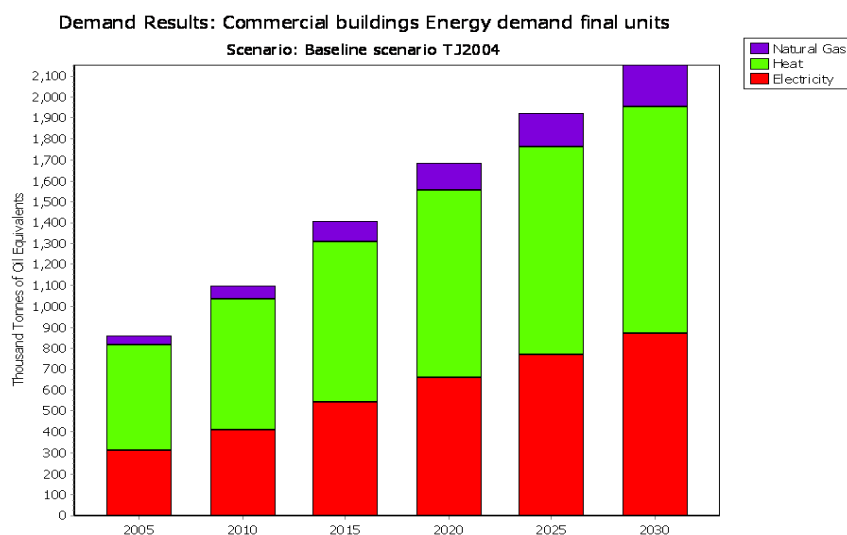


Figure 5-31. Energy consumption in commercial buildings sector by fuel.

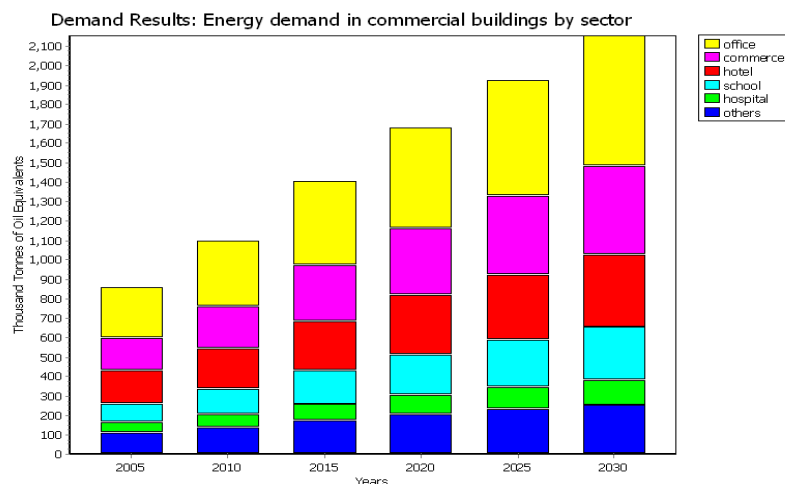


Figure 5-32. Final energy consumption in commercial buildings by sector

The question of whether action priority in BEE improvement should be give to residential or commercial buildings remains unsettled in most of debates. Fig 5-33 depicts the final energy consumption development trend in residential and commercial sectors, indicating a predominance of residential sector in total buildings energy consumption. Obviously, residential buildings account for larger share in total fuel consumption throughout the modelling period; however, commercial building's share keeps growing since due to the fact no specific energy efficiency measures are to be implemented in commercial sector, contrarily to what is assumed in the residential buildings.

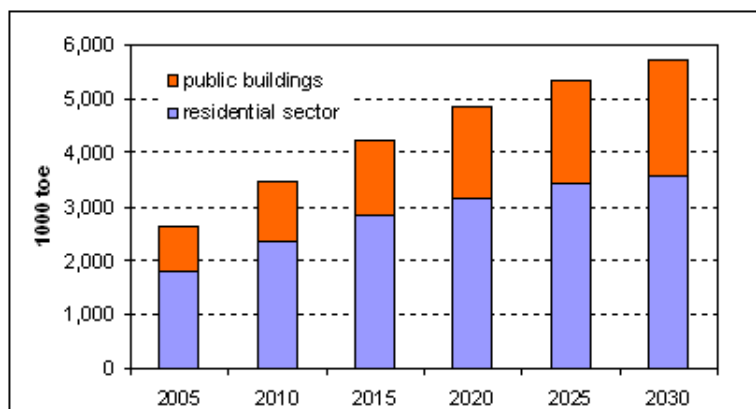


Figure 5-33 shares of residential and commercial buildings in final energy demand

5.10.7 District heating

Similarly, heating consumption in residential sector also outpaces commercial sector over the modelling period, as shown in Fig 5-34. In 2030, residential buildings will account for nearly two-thirds of district heating consumption, approaching 2.16 Mtoe.

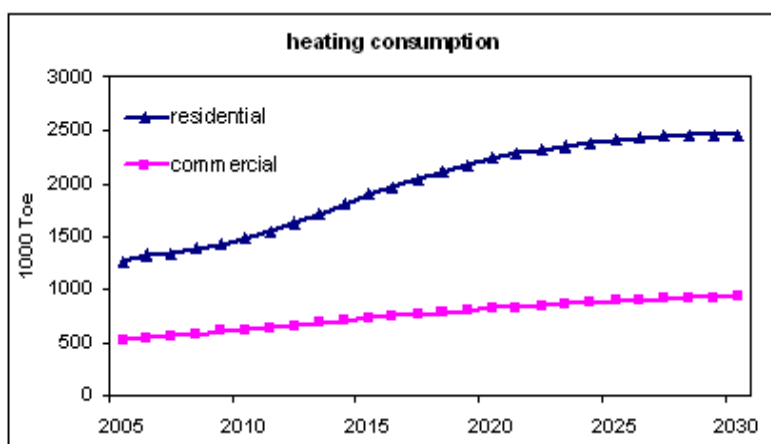


Figure 5-34. District heating consumption in residential and commercial sectors

5.10.7.1 Natural gas

Gas is consumed for space and water heating, cooking uses in residential sector, while commercial buildings use gas for heating, cooling and water heating purposes. Our modelling suggests that demand for natural gas in residential increases sharply until 2015, after it will pursue a linear increase trend as well as in commercial sector by 2030. Their respective increase trends are plotted in Fig 5-35.

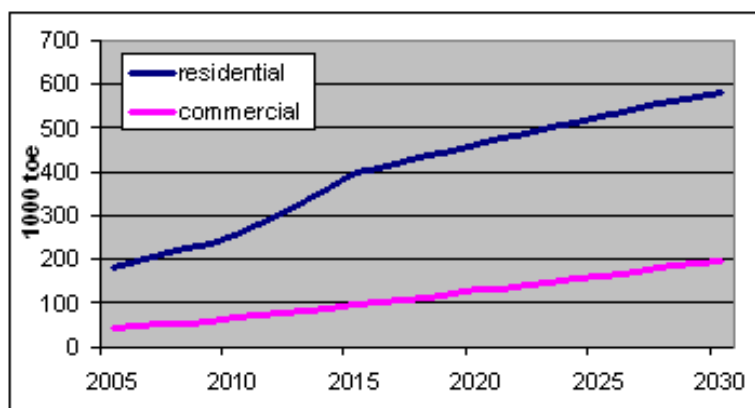


Figure 5-35. Demand for natural gas in commercial and residential sectors

5.10.7.2 Electricity consumption

Electricity demand in the baseline scenario will increase 4% per year, more rapidly than total fuel consumption acceleration due to fuel switch and higher household ownership of electric appliances, total electricity consumption in buildings sector will increase from 7014 GWh in 2005 to 18 853 GWh in 2030 under baseline scenario. Contrary to total final consumption trend, public buildings play an increasingly important role in electricity consumption in buildings under baseline scenario, as shown in Fig 5-36. In commercial buildings constantly dominates residential sector in terms of electricity demand during the modelling period. Electricity demand increases 4.2% and 3.7% per year in commercial and residential

buildings, respectively. In 2030, commercial electricity consumption will be 17% higher than in residential sector.

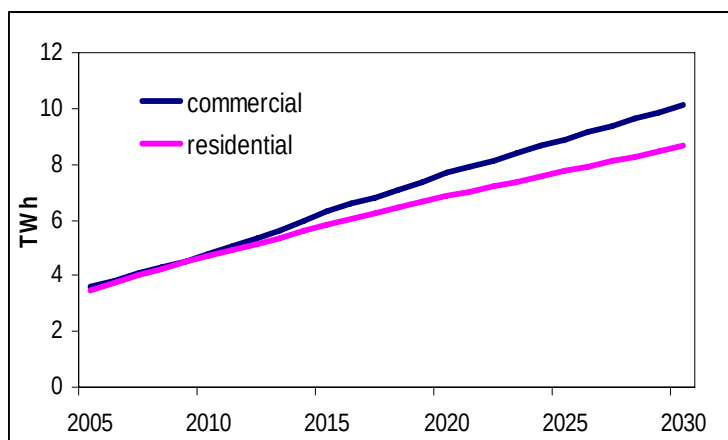


Figure 5-36. Electricity consumption in residential and commercial buildings

5.10.8 Residential Electricity consumption by use

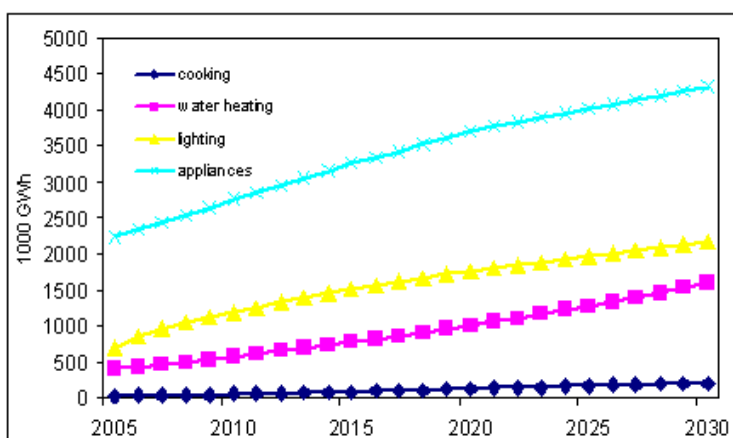


Figure 5-37. Residential electricity consumption

As can be seen in Fig 5-37, there would be a substantial increase in residential electricity consumption over the modelling period, in particular for household durable appliances, water heating and lighting due to improved living standard of inhabitants. Their respective consumption would increase by 100%, 200% and 300% during this period.

5.11 Commercial electricity consumption by energy use

5.11.1 Test of sensibility of residential appliance efficiency

We simulated the App-Imp scenario to examine the electricity savings potential offered by improvement in residential appliances energy efficiency. It is found that the effect is rather limited and costly to implement

compared to thermal efficiency upgrade such as assumed in alternative scenarios which will be discussed in detail in sections below. Electricity consumption could be reduced by approximately 7% in 2030 in App-Imp scenario compared to baseline scenario, as shown in Fig 5-38, this result accepts the presumption in chapter one that appliance efficiency improvement would only play a marginal role in reducing buildings final consumption and carbon emission.

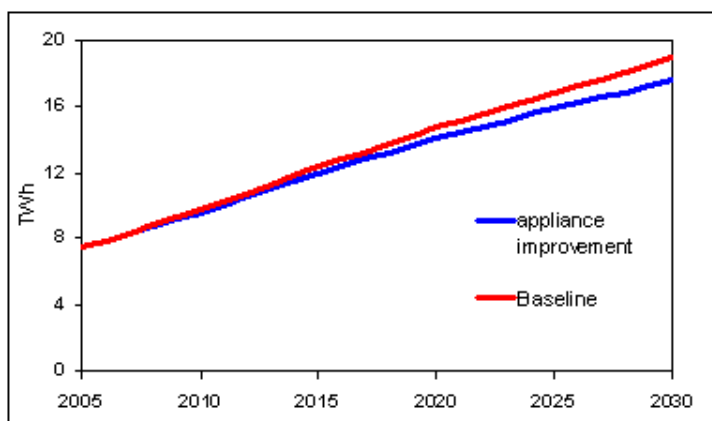


Figure 5-38. Two scenarios of electricity demand in buildings

5.11.2 Final demand by fuel mix

In commercial sector, only secondary fuel such as electricity, natural gas and heat are accounted for in the model, solid fuel such as hard coal is hardly used in commercial sector. As mentioned above, space cooling and heating and water heating are major energy consumers in this sector, most of these services are met by modern the three aforementioned energy carriers. The breakdown of the final energy in the base year is shown in Fig 5-39 and the forecast of increase is plotted in Fig 5-40. In addition, office buildings represents the largest share in commercial buildings in terms of final energy consumption, this confirms the thesis that economic structure evolution will also play a significant role in the coming years as more and more added value will be created in tertiary sector in which office workers' share will be gradually increasing as a result of industry chain promotion.

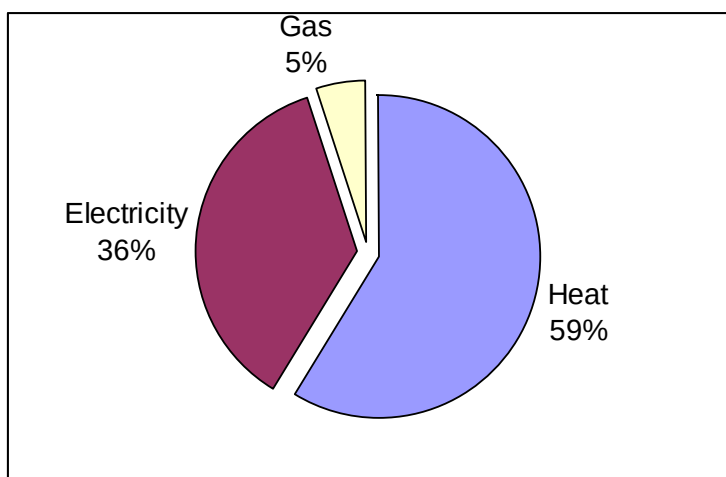


Figure 5-39. Fuel mix in commercial buildings in 2005

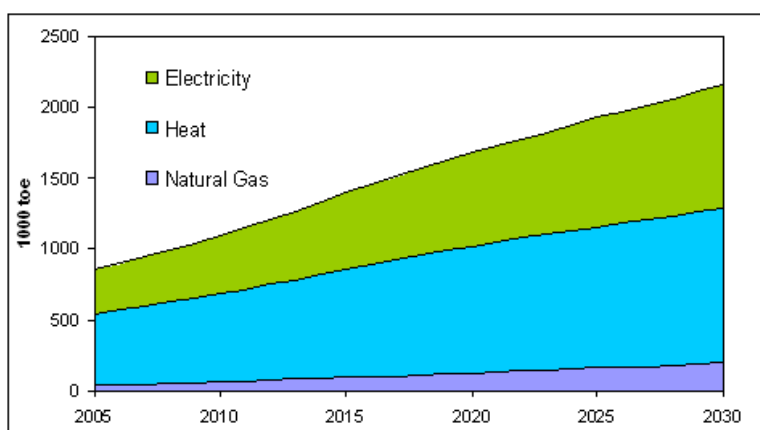


Figure 5-40. Projected energy demand in commercial buildings by fuel use

5.11.2.1 Demand by building type in commercial sector

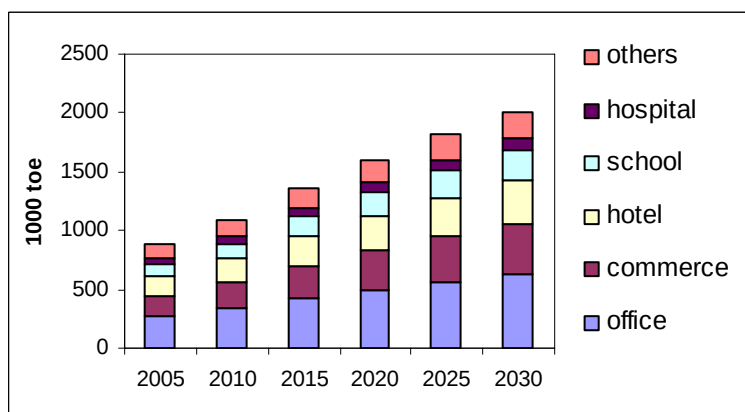


Figure 5-41 energy demand in different types of commercial buildings

Office and large commercial centre buildings account for the majority of final energy demand in commercial sector throughout the modelling period due to their dominating floor area and relatively higher HVAC comfort requirement compared to other buildings.

5.11.2.2 Demand by energy services

As in residential sector, districting heat consumption represent about 60% of final energy use in commercial buildings, by contrast, the shares of lighting and cooling demand in commercial buildings are much higher than in residential buildings, especially in large shopping malls and retail shops, plotted in Fig 5-42.

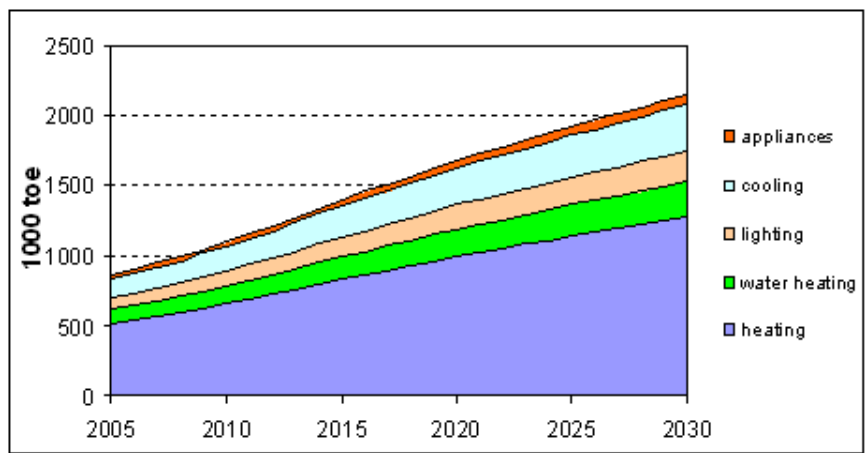


Figure 5-42 Energy demand in commercial buildings by energy use

5.11.2.3 Energy use breakdown in commercial sector

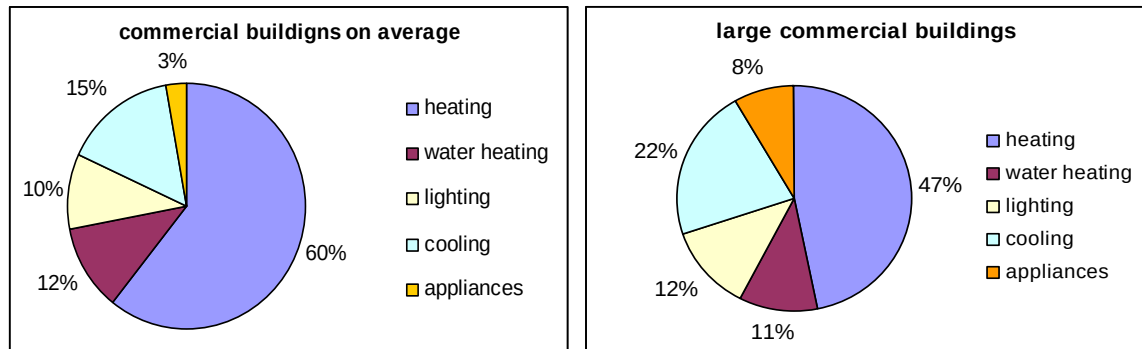


Figure 5-43 energy use in commercial sector

5.12 Primary energy demand and emissions

The model allocates the primary energy demand of end-use by assuming that each final fuel gets a proportion of the average mix of supply side processes in each year. It does not distinguish between

demand side technologies that operate at on- and off-peak, perhaps with a different mix of supply side technologies. The peak load analysis of electricity is out of scope of the modelling for our main objective is focused on district heating consumption, albeit electricity technology mix (fuel mix) has strong implication of CO₂ emission.

As mentioned at the beginning of this chapter, our modelling framework covers both BEE and energy supply options. District heating and electricity generation capacities are considered in the transformation module in the model. In fact, three distinct scenarios are examined to compare relevant cost, denoted by SYS3, SYS2 respectively:

SYS3 : New heating capacity is added exogenously by following the explicit DH planning of the municipality covering both the inner city and Tianjin Binhai New Zone. The estimation of required capacity is based primarily on the actual building energy efficiency standards and the derived values in relation to heat load, varying with building types; this case is most likely to occur in mid run since the majority of new generation installation programme have been validated by the municipal heating plan and are expected to be commissioned by 2015. Heat and power supply will be kept align with the municipality planning. This supply scenario describes the primary energy demand outlook from local heating planner's perspective, since all new capacity addition is based on the municipal DH development planning. City's heating plan, DH heating plan (2005) and BNA's DH Plan(2007) are taken as reference of heating planning. Technical parametres in these plans are also regarded as benchmarks in terms of and supply technology and relevant energy efficiency.

SYS2: alternatively, heating capacity will be added continuously⁷³ based on the variation of actual heat load, simulated by the model with the specified technical parametres regarding heating services in buildings; i.e. more efficient buildings new construction and continuing retrofit programme in existing housing stock will defer building new capacities in heat supply, consequently, the discounted capital costs associated with capacity addition can be substantially lower. Compared to Sys1, Sys2 models the responsiveness of supply capacity addition in line with final demand energy and assumptions on fuel mix in supply technologies portfolio. Marginal cost of supply addition is continuous.

The two approaches to estimating the required heat capacity will result in different projection of timing of system addition and supply technology options, consequently, the primary sources supply and GHG emission will differ from one another.

⁷³ This is only theoretically correct if the time of analysis is considered infinitesimally dividable, however, in practice, all power plants or heat plants are commissioned with a specific capacity in a given year.

5.12.1 Sys2 simulation results

Primary energy supply by fuels

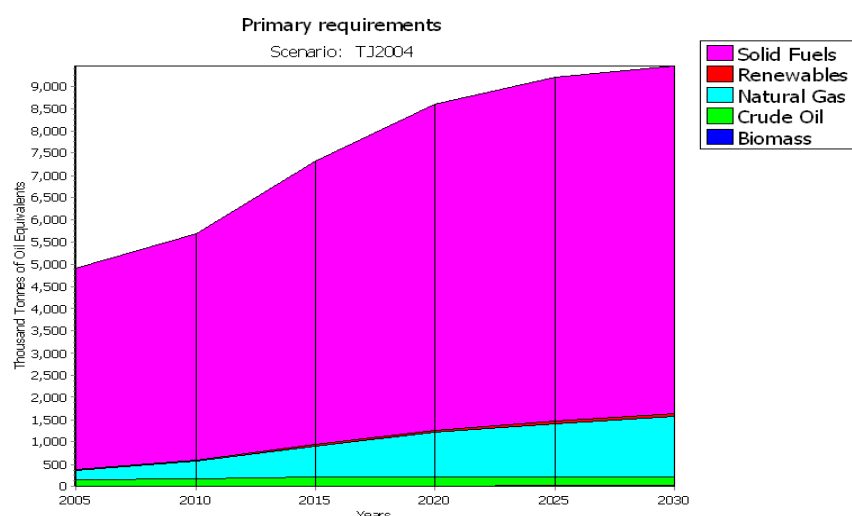


Figure 5-44. Total primary energy supply 2005-2030

Figure 5-44 depicts the primary energy supply in buildings sector in Tianjin. Total primary energy demand increased from 4.74 Mtoe in 2005 to 10.12 Mtoe in 2030 in the reference scenario, increasing at 3% per year on average. The diminishing marginal increase in the primary energy supply implies the assumptions on energy efficiency improvement in supply technologies. Overall energy conversion efficiency, expressed as the ratio of final demand to primary energy resource, improves steadily, increasing from 56.8% to 63.2%. Coal is expected to dominate primary energy supply throughout the modelling period. The share of coal in total primary energy will decrease 12% during this period, while natural gas increase the fastest among fossils which will meet approximately 16% of total primary supply in 2030, with an average growth rate of 7.7% per year. Renewable' share will remain tiny despite a high growth rate of more than 10% per year, accounting for only 2% of total primary energy supply at the end of modelling period, renewable source refers to wood, straw, municipal solid waste (MSW) incineration that are considered to be CHP fuels, and solar for residential water heating. Landfill gas used for waste incineration can also be included in local CHP plants in the category of waste.

Figure 5-45 delineates the accumulated primary energy supply during the modelling period, approximately 188 Mtoe of primary sources will be consumed to meet final energy services requirement between 2005 and 2030.

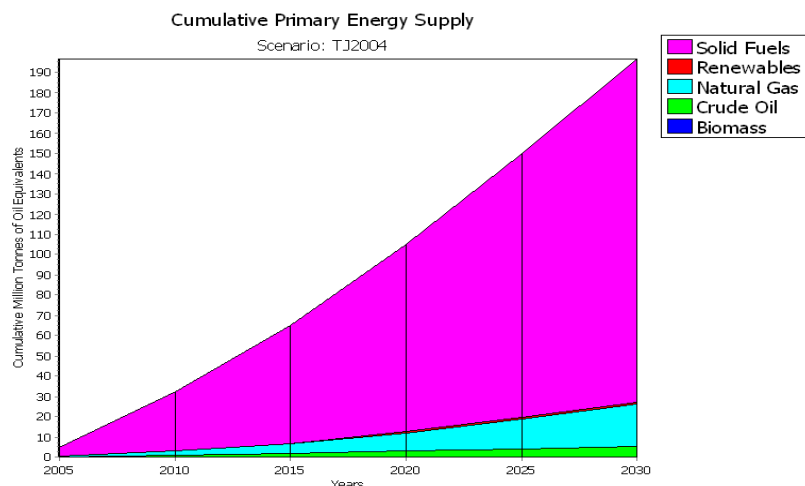


Figure 5-45. Accumulated primary energy supply

Note: solar is included but its share is very small, accumulated demand is roughly 1 Mtoe up to 2030.

5.12.2 Primary energy supply by sector

5.12.2.1 Residential sector

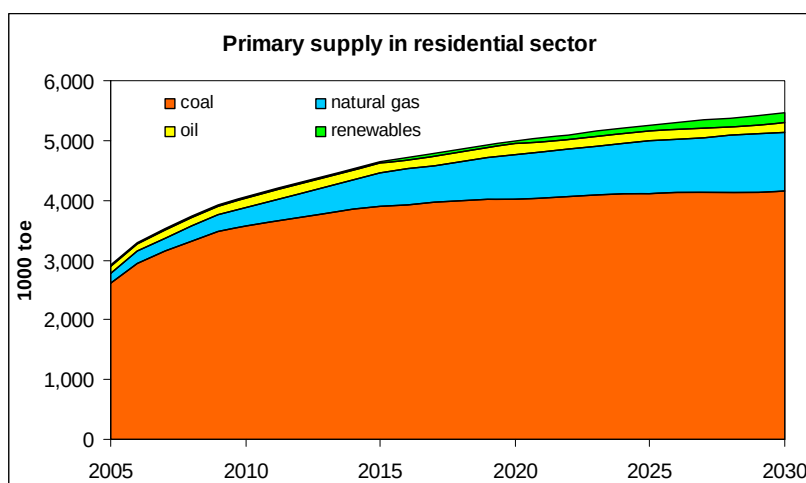


Figure 5-46. Primary energy supply in residential sector

Primary energy supply in residential buildings increase at 2.4% per year on average over the modelling period. Natural gas supply in 2030 will be 5.5 times that in initial year with an average increase rate of 7% per year. Primary coal supply would need to increase 60% to meet the rising residential energy demand in this scenario, from 2.6 to 4.1 Mtoe. In fact, the policy of phase-out of coal consumption in final consumption for water heating and cooking, as assumed in the model, has a very limited contribution to reducing primary coal consumption by otherwise the primary supply would be in absence of this policy, because primary coal consumption for cooking and water heating is relatively small compared to heating.

Solar will increase the fastest at more than 10% per year, although its share will remain very low, primary supply will increase from 14 to 170 Mtoe per year in residential buildings.

5.12.2.2 Commercial sector

Primary energy supply in commercial buildings increases more rapidly than in residential buildings with a growth rate of 2.55% per year. Natural gas increases nearly at 9% per year during the period, compared to 2% of growth per year of primary coal supply. Overall oil consumption decrease as we assumed that no oil products are consumed in commercial buildings the oil supply derives solely from upstream power generation. The model stops dispatching the electricity generation from residual fuel-based generator for supercritical and IGCC are more favoured according to the merit order of electricity dispatch rule.

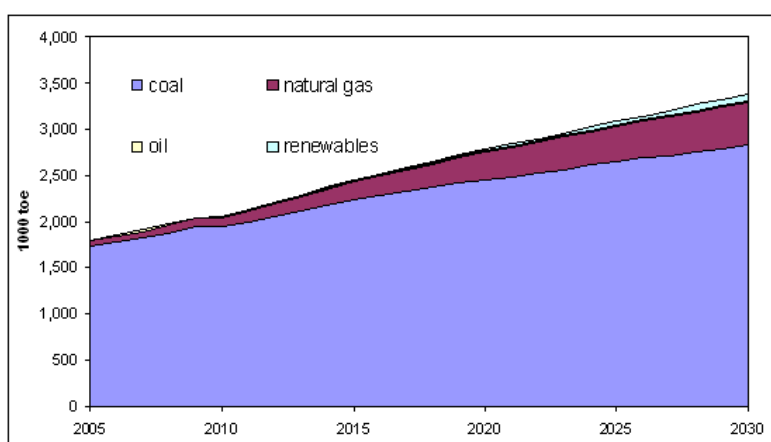


Figure 5-47. Primary energy supply in commercial buildings

5.12.3 Carbon emission

Carbon emission from buildings is divided into two categories according to the emission source, the demand-side direct combustion of fossil fuels in buildings; and upstream emission in heat and electricity production from fossil energy sources. The first type of emission is mainly concerned with cooking, water heating and space heating, while the second is related to electric heating, electric water heating and cooking, all residential and commercial appliances, cooling and lighting in both residential and commercial sectors. Note that coal is still being burned with inefficient small coal oven for cooking and water heating purposes among the low-income urban households. This not only generates greenhouse gases like carbon dioxide or NO_x, but also and more importantly the pollutant gas such as SO₂, causing environmental hazard and risk to public health. All energy-related greenhouse gases emissions are accounted for in terms of CO₂ equivalent (CO_{2eq}) in the model.

5.12.3.1 Emission accounting

Total GHG emission will increase 2% per year over the modelling period. Coal is the dominating source of emission among all the fuels. It accounts for more than 90% of GHG emission throughout the modelling period.

a. Total emission in CO₂eq (1000 tonne)

	2005	2010	2015	2020	2025	2030
coal	17249	22215	24468	25665	26563	27057
natural gas	616	874	1304	1562	1807	2054
oil	636	723	797	839	829	797
Total	18500	23812	26569	28066	29199	29907

Note: total may not match due to rounding

b. Emission by sector

The sectoral projection of GHG emission is plotted in Fig. 5-48. Before 2012, district boiler will be the biggest emission source, after municipal heat production plants will outpace the small boilers to become the first emitter as a result of heating production shift in the district heating policy. It is interesting to note that emission from power generation keeps decreasing , this is caused by the fact that the model gives priority of dispatch implicitly to the power generated from city's CHP generators, resulting in the fact that the share of power from dispatched from large power generator will diminish as new capacities are to be installed in the CHP plants. CHP plants are likely to outpace the other sectors in CO₂ emission as early as 2012. Emission from final energy consumption starts to decline slowly in 2025 as a result of fuel switch in the residential sector in cooking and water heating use(coal is to be substituted by gas eventually).

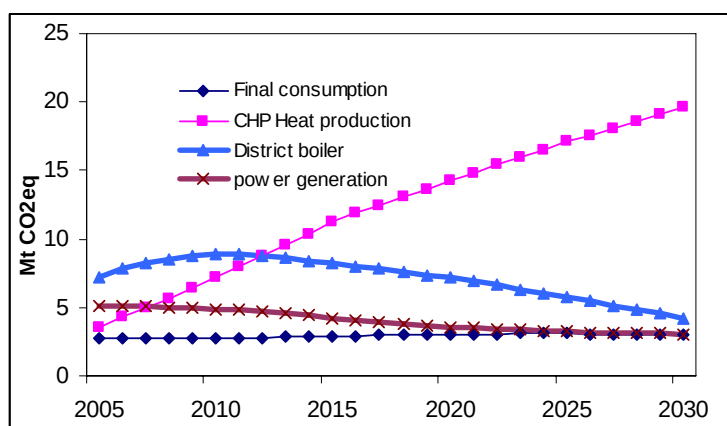


Figure 5-48. Emission by sector

c. Emission by energy use

1. Emission in residential and commercial buildings

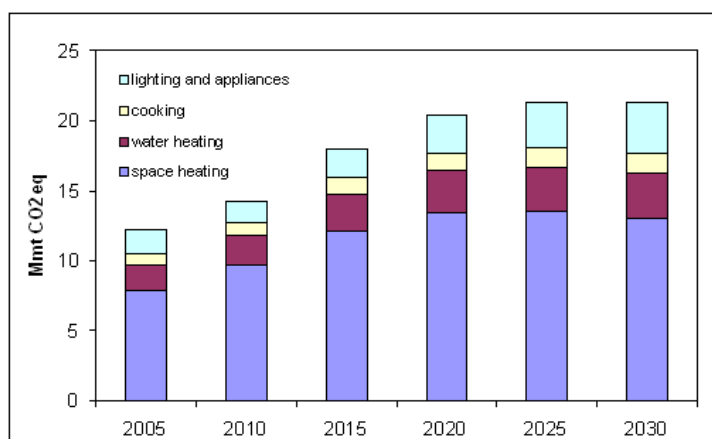


Figure 5-49. Emission from residential buildings by energy use

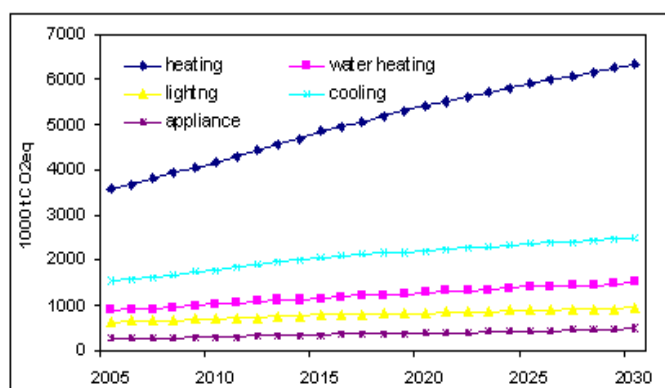


Figure 5-50 emission from commercial buildings by energy use

As shown in Fig 5-49 and Fig 5-50, residential buildings will contribute to the majority part of CO₂ emissions, this is intuitive since the emission is associated with energy demand. In the reference case, emissions from buildings would roughly double in 2030 compared to 2005 level, increasing from 11.6 to 23 Mt CO₂eq in residential sector, growing at 3% per year. A 70% growth in emission from commercial buildings is expected. Heating is the most important emission source in both residential and commercial sector and increases the fastest compared to other energy uses in residential buildings with an average growth rate of 3.6% per year. Thus, enhancing the buildings energy efficiency would be the most effective and efficient way of mitigating and reducing CO₂ emission from buildings sector.

5.12.3.2 Emissions in new and existing houses in Tianjin

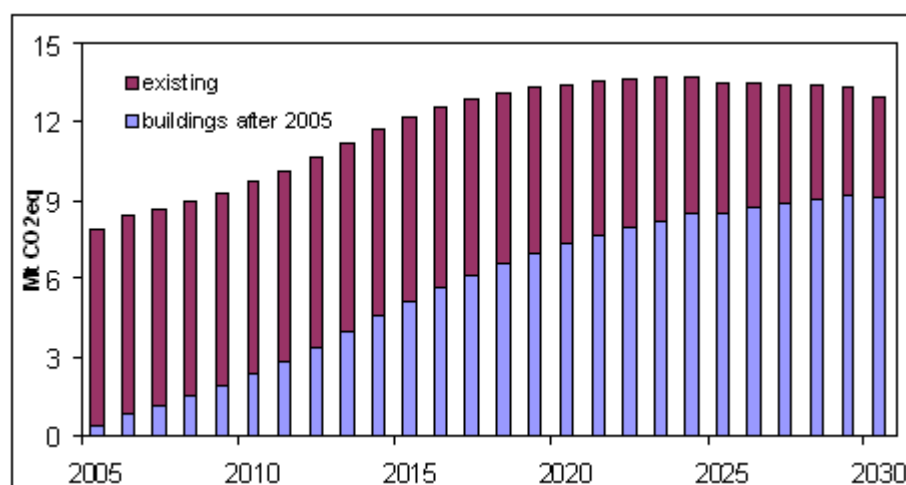


Figure 5-51. Emission from residential heating consumption by buildings vintage

Similar to energy demand trend, buildings constructed after 2005 will be dominating CO₂ emissions from 2015, total emission associated with residential heating will reach 17.2 Mt in 2030, or 140% growth compared to 2005 level. Buildings constructed after 2005 will be responsible for 57.2% of accumulated emissions during this period, represented by the integral blue area in Fig 5-51.

5.13 SYS2 primary energy supply and emission

This scenario of primary energy supply reflects the case of endogenous capacity addition meeting actual demand based on capacity dispatch rules (merit order), settled in the model.

5.13.1 Primary energy supply by fuel

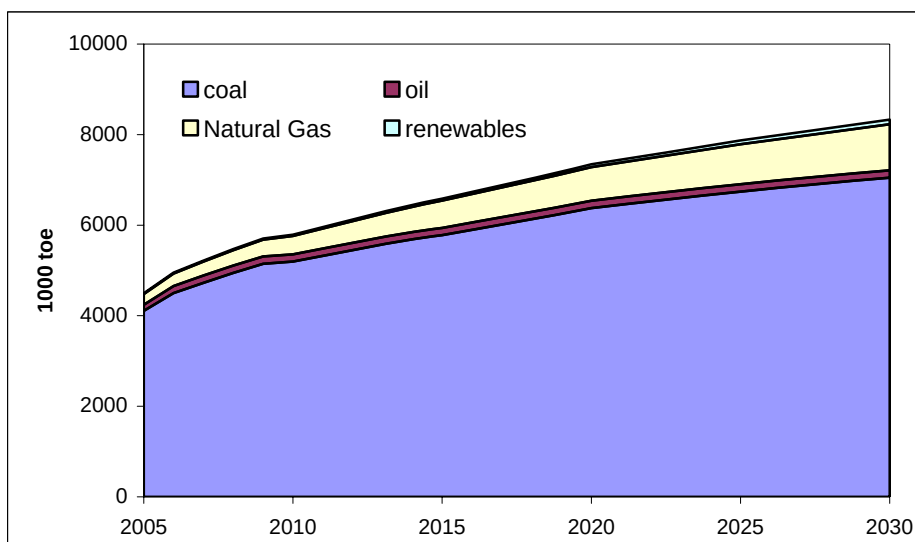
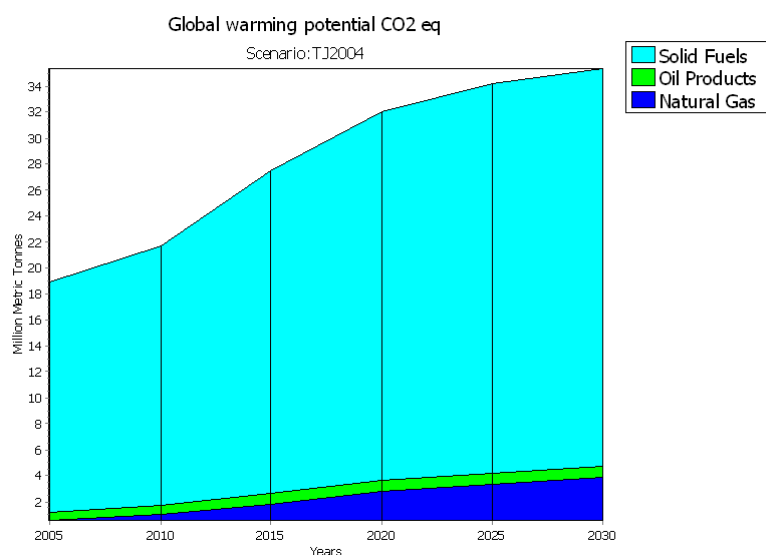


Figure 5-52. Total primary energy supply 2005-2030 by energy

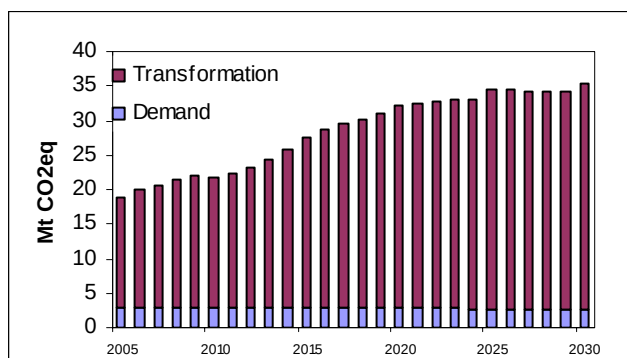
Figure 5-52 depicts the primary energy supply in buildings sector in Tianjin. Total primary energy demand would increase from 4.8 Mtoe in 2005 to 8.3 Mtoe in 2030 in the reference scenario, growing at 2.5% per year on average. Coal is the major source of CO₂ emission.

5.13.2 Emission from final consumption and primary supply

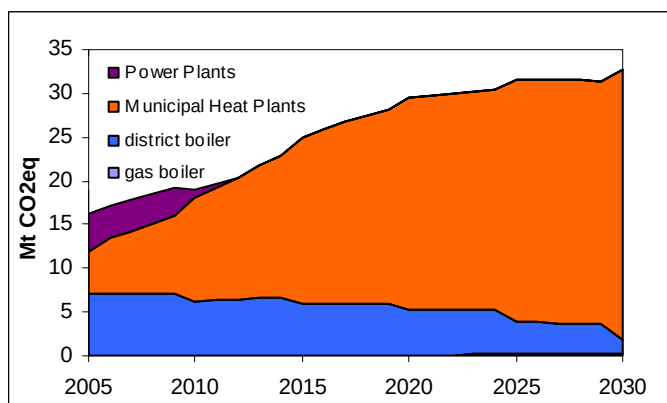
5.13.2.1 Emission by fuel



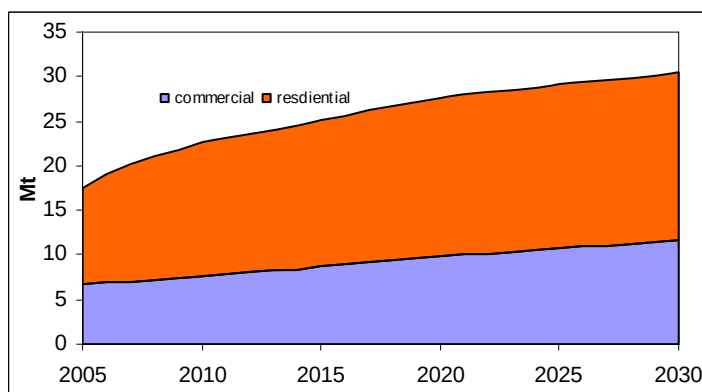
5.13.2.2 Emission in demand-side versus supply side



5.13.2.3 Emission associated with energy transformation

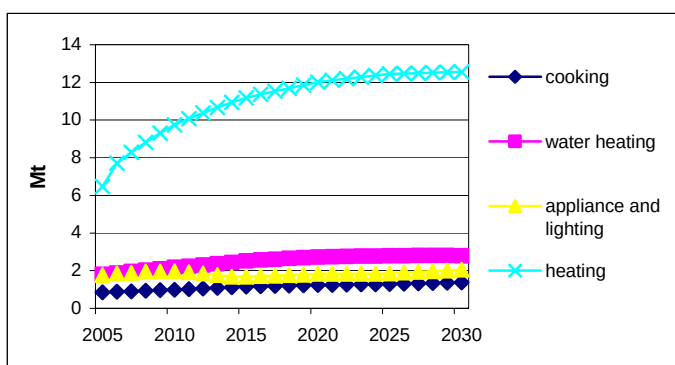


5.13.2.4 Emission by sector in end-use

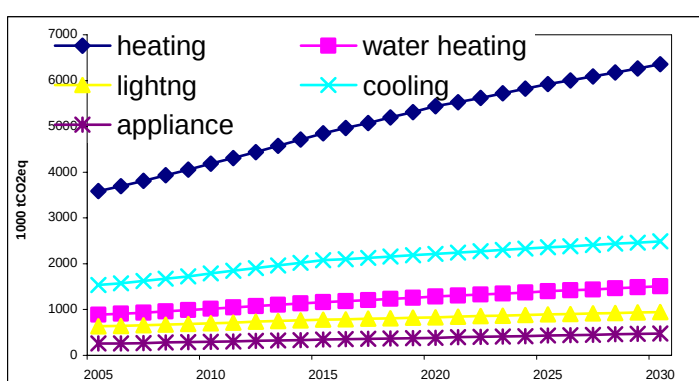


The distribution of CO₂ emission in residential and commercial sector remains quite stable over the modelling period, 62-63% from residential buildings and 37-38% from commercial buildings.

-Sectoral breakdown of emission from residential



-breakdown of emission in commercial buildings by energy use



5.14 Results of alternative scenarios

5.14.1 Assumptions on thermal retrofit

It must be emphasised again that the variants of non-retrofitting and temperature-fix scenario is little probable from BEE regulation and urban-social development point of view, since the least cost alone cannot justify the fact that inhabitants living in the old inefficient houses should always be prevented from having access to better thermal comfort and living condition as ones in the new houses, it is unacceptable from both public perception (ethic dimension) and inhabitant's living standard perspective. Also, the municipality has issued housing retrofit plan up to 2010 in the 11th five year plan. Here we eliminated all the socially not acceptable and unrealistic variants in which thermal retrofit are not carried out at all. Only the most representative scenarios are selected hereinafter.

5.14.2 Final demand development trend

- Trend of average housing heating consumption

In order to assess the impact of implementing different BEE standards on the general performance of the entire housing stock, it is necessary to illustrate the trend of average heating intensity⁷⁴ in the housing stock. Fig 5-53 illustrates the trend of heating consumption in total housing stock in Tianjin by adopting different BEE standards over the entire modelling period. Interestingly, average heating consumptions keeps decreasing during 2000 and 2020 in all scenarios due to the improvement in energy efficiency in both new construction and retrofitting in non efficient houses. However, in the cases of TJ2004 and CAN, decline trend of average final demand for heating will be inverted after 2020 as a result of increased demand for heating thermal comfort of inhabitant in all types of buildings and all categories of people. In other words, the improvement in energy efficiency is completely offset by the increase in demand for thermal comfort. In comparison, the other scenarios (SWE, LC, and A2) will see the average heating consumption decrease steadily thanks to more aggressive improvement in buildings energy performance. Average heating consumption of housing stock will range between 62.4 kWh/m² (LC scenario) and 122 kWh/m² (ParCom RF) in 2030, nearly a factor of 2!

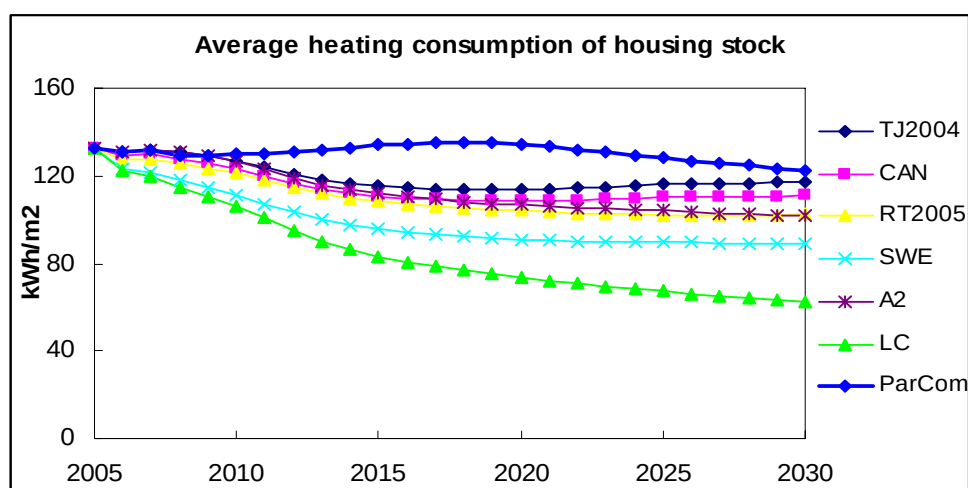


Figure 5-53. Average heating consumption of total housing stock in different BEE standards implementation scenarios.

In addition, it is necessary to demonstrate the heating consumption of a household in 2030 living in a house complying with different BEE standards constructed and or existing in 2005. Fig 5-54 shows the heating consumption in 2030 for a typical household living in a residential building that was constructed in 2005 by applying different building energy performance standards.

⁷⁴ As mentioned earlier, other residential or commercial energy consumption such as lighting or electric appliance is not directly influenced by buildings thermal performance except for cooling consumption. In the model, it is assumed that only the EER of air conditioner will have direct impact on cooling consumption.

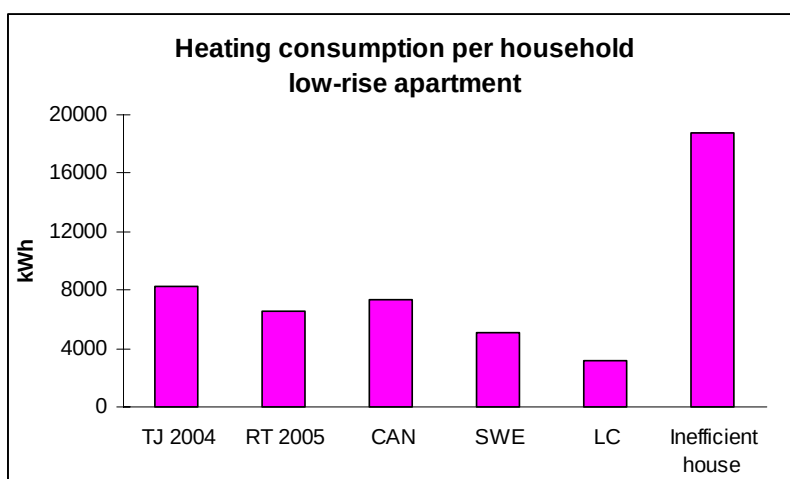


Figure 5-54. Comparison of heating consumption per household in 2030 in different BEE scenarios (case of low-rise buildings)

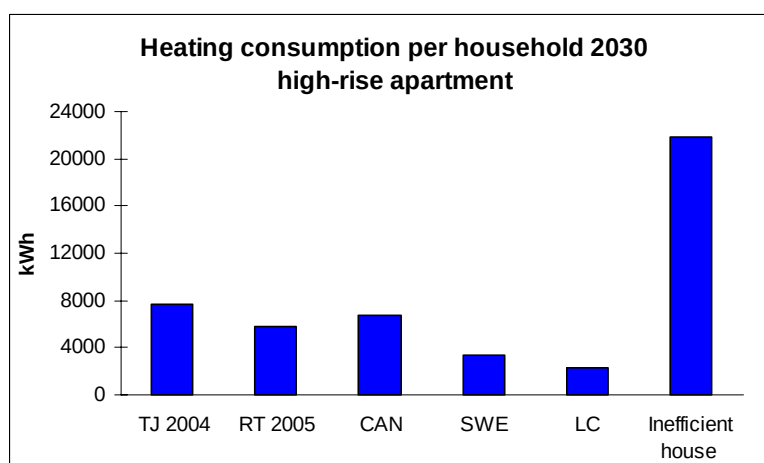


Figure 5-55 Final heating consumption in for a house constructed in 2030 (high-rise apartment).

5.14.3 Comparison of scenarios of total final energy demand

The results of six central scenarios, namely TJ2004, RT2005, A2, SWE, LC and ParCom and their non-retrofit variants are presented hereafter. Complete scenario outcome is provided in Annex II. Note that the technical intervention in existing housing stock (houses constructed before 2005) remain identical in all of the scenarios discussed below in order to quantify the impact of BEE implementation in new construction in terms of energy demand and costs (construction cost of buildings).

Case I No intervention in existing housing stock

This case assesses the extent to which the different levels of BEE standards implemented in new construction may have impact on final energy demand through the period. The results of all 6 scenarios are plotted in Fig 5-56.

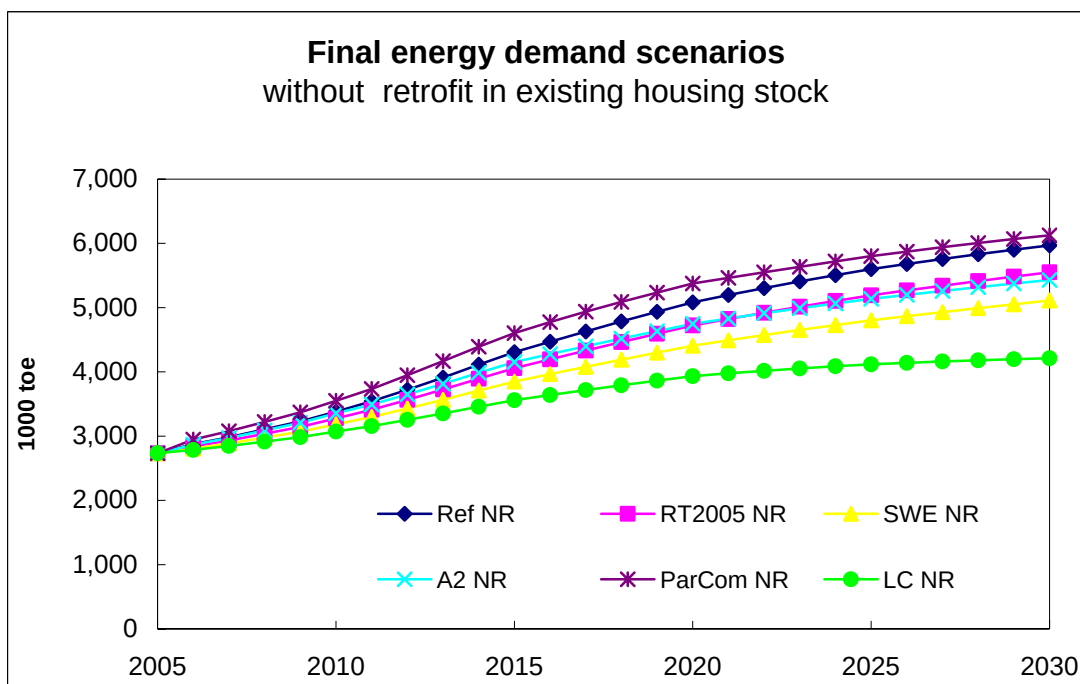


Figure 5-56 Final energy demand when no retrofitting programme in existing houses will be carried out

Final energy demand in Tianjin in 2030 may vary between 4212 Ktoe and 6127 ktoe in two extreme scenarios, LC and ParCom, respectively. Interestingly, A2 has a quite close trajectory with RT2005 throughout the period, and the final point in 2030 of A2 is slightly lower than that of RT 2005, meaning that the catch-up of less-performing scenario may take quite long time.

Case II with retrofitting programme

This case assesses how the actions taken in existing housing stock by retrofitting non-compliance houses may influence the result of final demand. Scenarios' outcome is presented by Fig 5-57.

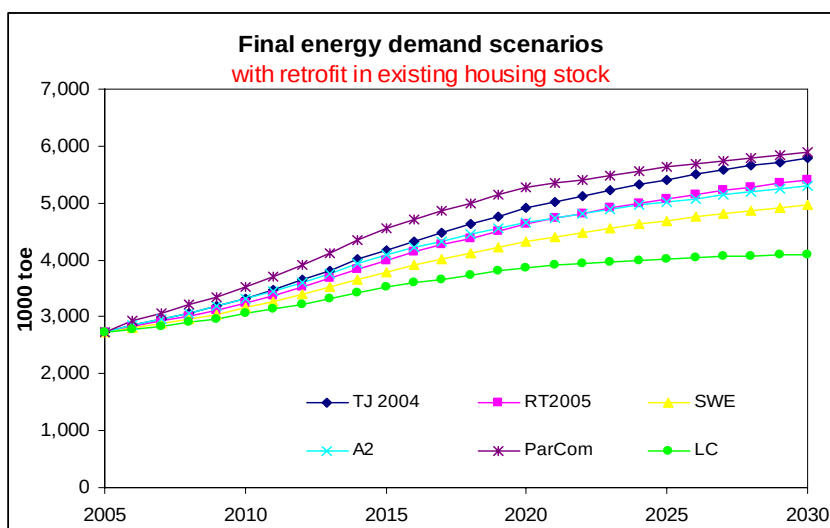


Figure 5-57. Final energy demand with retrofitting programme in existing houses

In this case, final demand in buildings in 2030 range between 4102 and 5900 Ktoe. We see immediately that actions taken in retrofitting inefficient houses in existing stock of 2005 have marginal effect on the building's final demand for energy in 2030, demand could be reduced by a quite small rate, between 2.4% and 3.7% per year at the end of modelling period. The graphics below illustrate the small difference between the base scenarios and their non-retrofit variants.

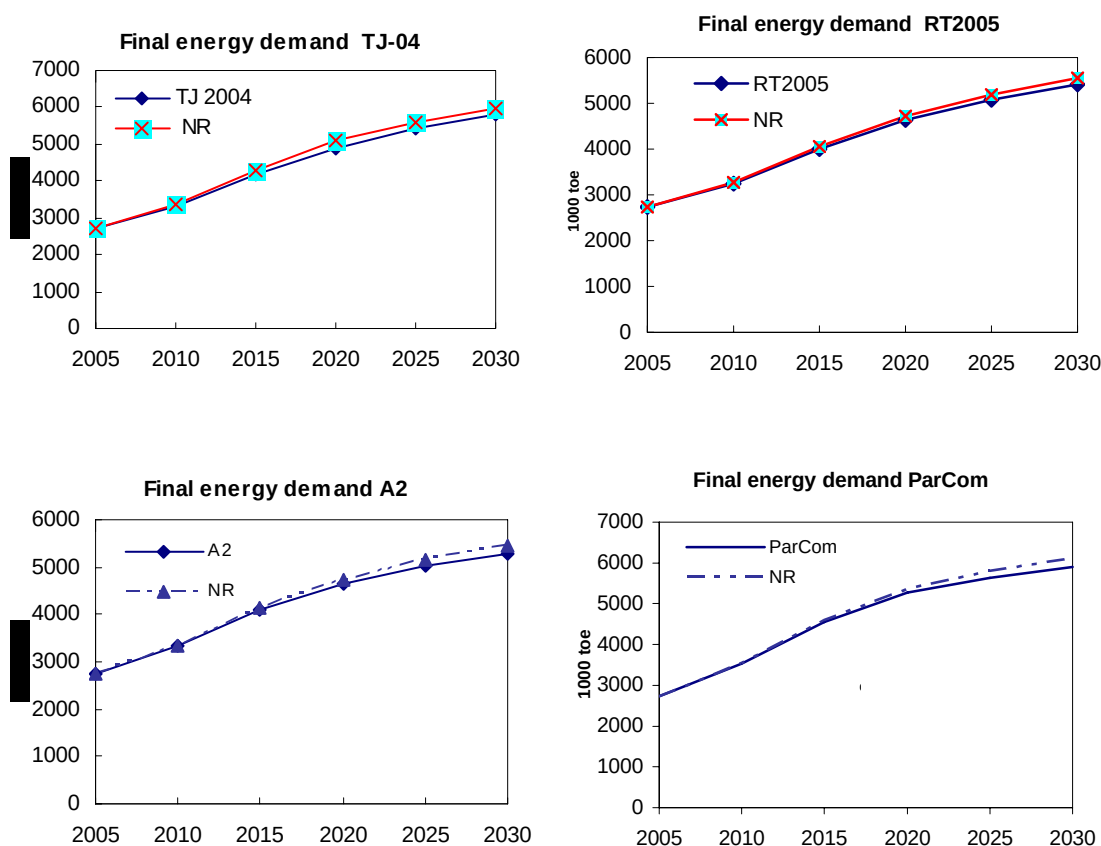


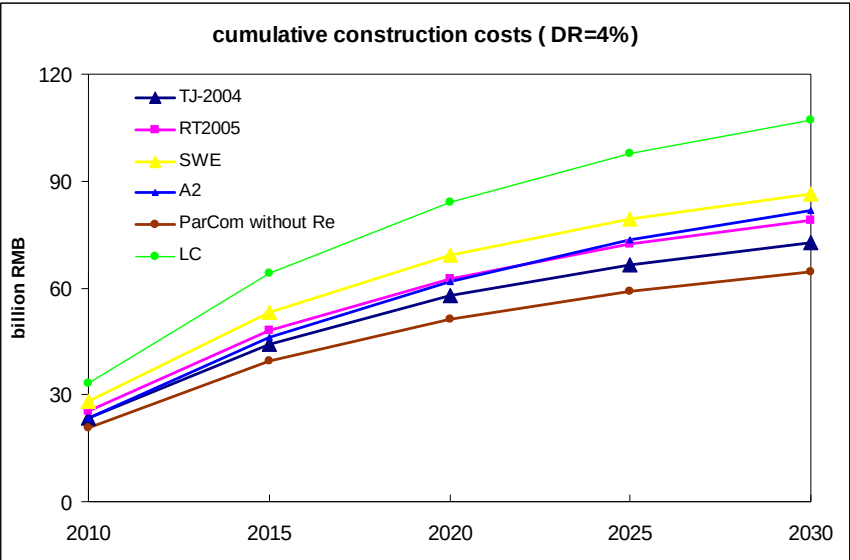
Figure 5-58. Comparison of base scenarios with their non-retrofit variants

5.14.4 Comparison of final costs

At this stage, it is possible to compare the costs associated with buildings construction from demand-side perspective. As discussed in chapter 4, costs associated with the improvement of building energy efficiency pursue a non-linear relationship with target building performance standards. In general, investment in BEE measures seems to have diminishing marginal gain of efficiency, or in other words, there is increasing marginal costs of BEE improvement. We compare below the cumulative buildings-side cost scenarios of implementing six different BEE standards, similarly to final consumption comparison in the previous subsection.

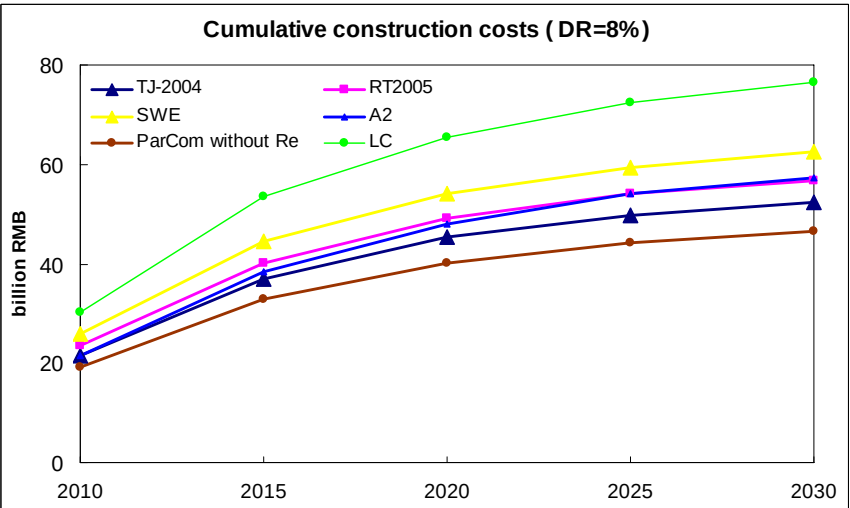
Certainly, the choice of discount rate is critical to defining the cost-effectiveness of BEE improvement in investment. Scenarios with low, medium and high discount are given in the figures below.

1) DR=4%

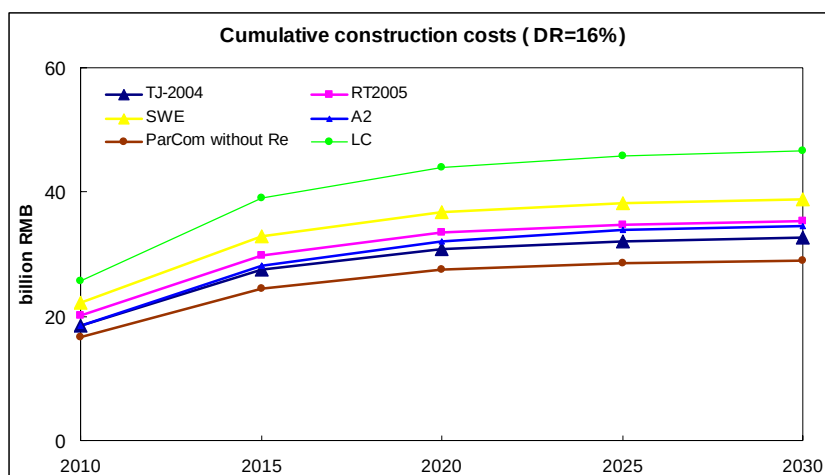


When low discount rate is applied, the cumulative buildings costs during the whole period vary significantly depending on BEE standards adopted. Increase in cumulative costs of buildings (ParCom as baseline) range between 13% (TJ2004 case) and 65% (LC case).

2) DR=8%



3) DR=16%



Not surprisingly, difference of the total present cumulative costs between different BEE standard implementation scenarios narrows as the chosen discount rate increases. In general, we found that the costs increase ranges between 12% and 65%. When high discount rate is used, total costs will be below 40 billion RMB in most scenarios except for LC scenario.

5.14.5 End-user energy bill

Another way to assess the impact of BEE standards implemented on the final energy users is to compare the energy bill in 2030. As mentioned in chapter 1 and 4, under current circumstance, many residential households still pay the heating bill based on occupied area instead of real consumption. Comparison of energy bill in our analysis assumes that heating billing and pricing reform will undergo smoothly, that is to say that heating will be billed based on real consumption as well as electricity and gas consumption in residential sector. For this purpose, we need to disaggregate the final energy consumption in buildings by energy carrier. Energy consumption is assumed to be charged at prices equalling the marginal cost of energy production and supply to reflect the real economic costs.

5.14.6 Household energy bill burden

Final energy detail sale price is assumed to increase 0.5% per year. The metreed heat price is billed based on the two-par tariff, i.e. fix charge +variable charge (10 RMB per square + 0.089 RMB/kWh⁷⁵)

⁷⁵ This price is indicative value implemented in Tianjin's heat reform programme, for more detail see chapter 7.

Total final energy consumption in residential buildings is 18201 GWh in 2005(all use included), it can be derived that per household annual consumption is approximately 7410 kWh. Figure 5-59 and 5-60 show final energy demand by energy in different scenarios. Total consumption would reach 51358 GWh and 30697 GWh in ParCom and LC scenarios, respectively. Increase rate of total final energy demand in housing is expected to range between 170% (LC) and 280% (ParCom) in 2030 compared to the base year level. In comparison, the average per household consumption is expected to reach 14750 kWh in the ParCom scenario, which is 67% higher than LC case which has an average of around 8820 kWh in 2030.

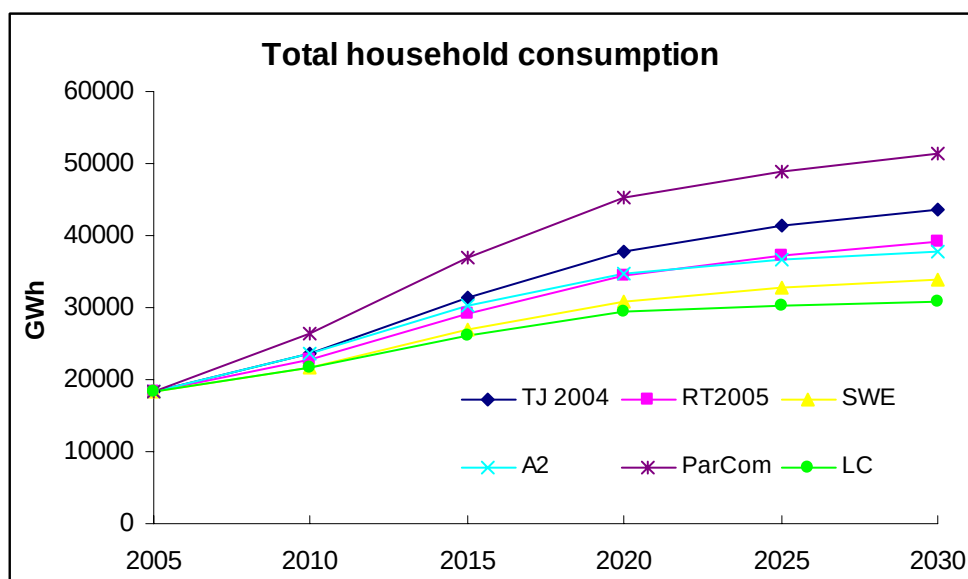


Figure 5-59 Total final energy demand in residential buildings

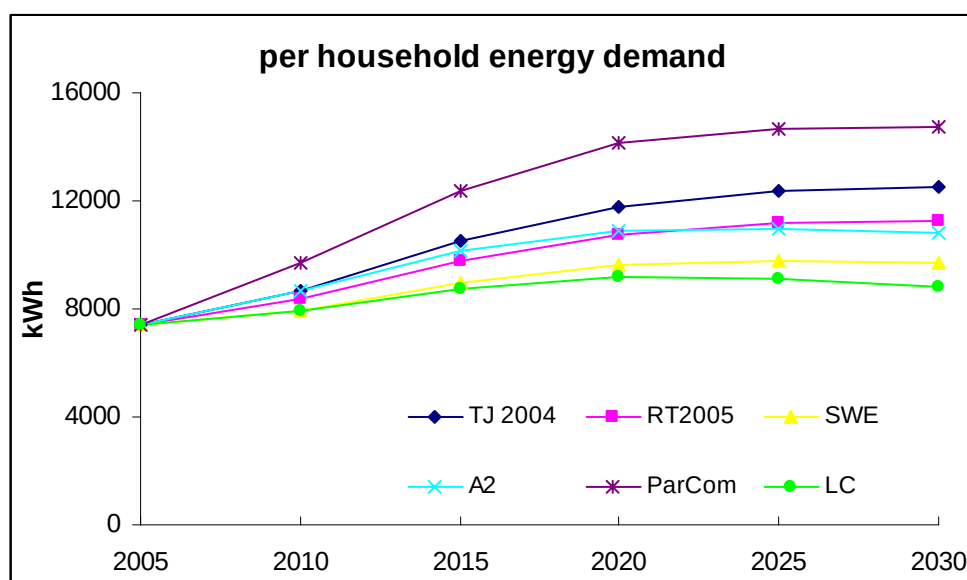


Figure 5-60. Per household final energy

In 2005, yearly annual energy bill for a household of Tianjin would be around 2053 RMB (around 260 US\$) per year if heat consumption in residential buildings was metered and billed by consumption.

Figure 5-61 summarises the average residential energy bills varying with BEE standards implementation scenarios in the total housing stock in different years.

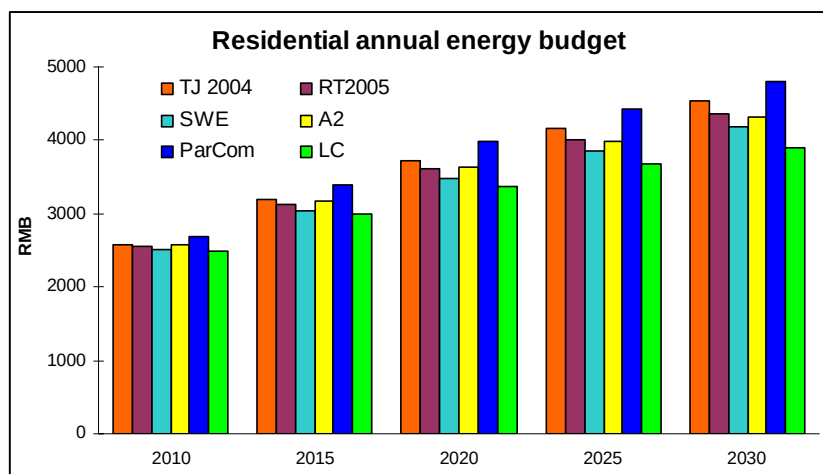


Figure 5-61 Annual energy bill in different scenarios

Household's energy bill in 2030 range between 3900 and 4800 RMB depending upon scenarios of BEE standards implementation. This means that energy bill would increase 90% (LC scenario) to 134% (ParCom scenario) compared with 2005 level, as shown in figure.

5.14.7 Energy burden

Another key indicator of buildings energy efficiency issues is the household energy burden which is defined as the ratio of annual energy bill to household annual disposable income. Use of this indicator is to evaluate how the energy efficiency in buildings would have impact on household's income, and the welfare eventually. Two sorts of energy burden are considered in the analysis, general household energy burden and low-income family energy burden, respectively, because household income in Tianjin's residential sector varies significantly among different income groups. In 2005, the lowest income group in the city has only 13% of the highest income group. Thus, it is necessary to calculate the energy burden of low-income family apart from the average figure.

In the starting year(2005), average per capita disposable income in Tianjin's urban area is around 12640 RMB Yuan (US\$ 1580) according to the Tianjin Statistical Communiqué 2005 (TJ Bureau of Statistics ⁷⁶). The 20 % lowest income group only has a per capita revenue of 6120 RMB Yuan (US\$ 764) while per capita disposable revenue in high-income family is almost three times higher with 17473 RMB (2200 \$US). Thus,

⁷⁶ The communiqué is available in Chinese at <http://www.stats-tj.gov.cn/Article/tjgb/stjgb/200612/5375.html>

energy bill would represent 5.2% of total household revenue on average while it may reach 10.8% of lower-income family's disposable income, but only 3.8% of high-income family in 2005. We assume that average household income will increase by 3% while lower-income family's revenue is expected to lag behind, with 2% of increase rate per year, implying the deepening social gap in the fast-growing economy.

Similarly to the comparison of final energy demand of a household in 2030 living in a house constructed in 2005, their energy budget may vary significantly depending on building energy performance and household income. We calculate both the space heating consumption and total energy consumption burden for a household who purchase a new house in 2030 for different income groups and different building energy performance levels.

Combining final heating intensity and household income trend, household's heating consumption burden can be calculated with ease. Figure 5-62 show that heating bill may represent more than 12%-14% of household revenue for the low-income families living in a typical low-rise or high-rise apartment building in 2030. Similarly,

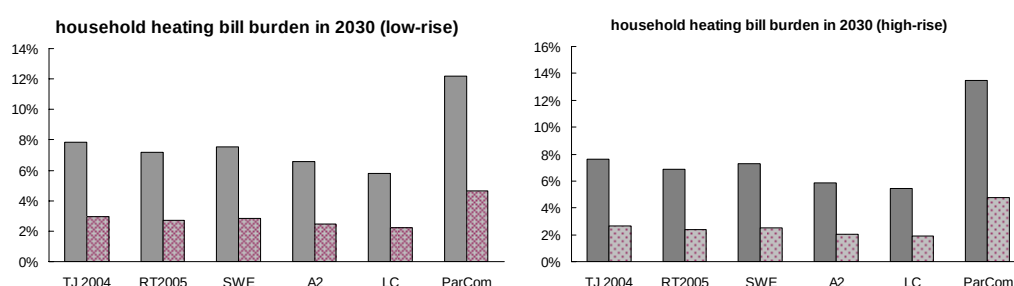


Figure 5-62 household heating bill burden in a new house constructed in 2030

In contrast, this percentage is less than 8% for the same category people if the building adopts the Swedish BEE equivalent standards. This shows again how energy efficiency may affect household's welfare to a large degree, in particular the less-affluent people who will get worse-off if the house purchased fails to respect the minimum standards of energy efficiency.

Also, the total energy bill burden for households in 2030 can be estimated with similar methodology. Figure 5-63 illustrate the contrast between different scenarios of BEE and income situations. It can be seen that energy burden for low-income family may be as much as more than 20% in case where the household lives in an inefficient house constructed in 2005. Also, the energy burden for household living in non-retrofitted house existing in 2005 will be significantly higher than efficient and or retrofitted houses for both average and low-income families. In this regard, the municipality needs to implement the thermal retrofitting programme in the existing non efficient housing stock during this period to reduce the energy burden of family with financial difficulty.

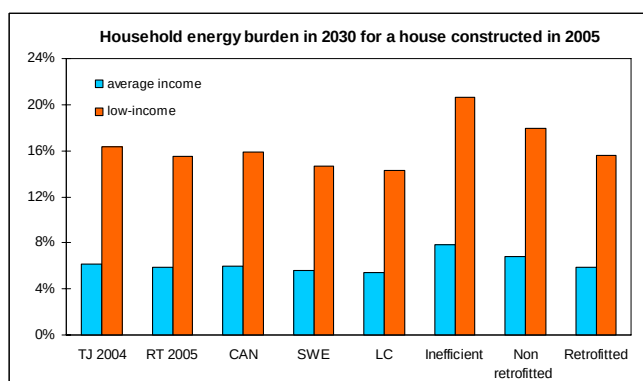


Figure 5-63: Energy burden of household living in different types of buildings in 2030

Table 5-25 and 5-26 compare the energy burden of different income groups of Tianjin throughout the modelling period.

Table 5-25 Average level in Tianjin

	2005	2010	2015	2020	2025	2030
TJ 2004	5.2%	5.8%	6.3%	6.5%	6.5%	6.2%
RT2005	5.2%	5.7%	6.2%	6.3%	6.2%	6.0%
SWE	5.2%	5.6%	6.0%	6.1%	6.0%	5.8%
A2	5.2%	5.8%	6.3%	6.4%	6.2%	5.9%
ParCom	5.2%	6.0%	6.7%	7.0%	6.9%	6.6%
LC	5.2%	5.6%	6.0%	5.9%	5.7%	5.4%

Table 5-26 low-income family

	2005	2010	s2015	2020	2025	2030
TJ 2004	10.8%	12.6%	14.4%	15.6%	16.2%	16.4%
RT2005	10.8%	12.4%	14.1%	15.2%	15.7%	15.8%
SWE	10.8%	12.2%	13.7%	14.6%	15.0%	15.2%
A2	10.8%	12.6%	14.3%	15.2%	15.6%	15.6%
ParCom	10.8%	13.0%	15.3%	16.7%	17.2%	17.4%
LC	10.8%	12.2%	13.6%	14.2%	14.3%	14.2%

We can see that energy burden will increase over the period in all scenarios due to assumed energy price rise and increased demand for residential energy services (heating, cooling, hot water, electrical appliance, cooking, entertainment etc). The trend clear shows that energy burden for the lower-income family will be much heavier in 2030 if they are living in an inefficient houses and city government will not carry out large-scale thermal retrofitting and rehabilitation in the existing inefficient houses. The burden (here defined as the ratio of average energy bill in the scenario to the low-income family's annual revenue) could reach as

much as 17.4% of low-income family in the ParCom scenario. It is clear that this social group will be worse-off as a result of energy price increase and energy service diversification if no government subsidy will be available. However, the energy subsidy may result in energy price distortion and will not give incentives to families to save energy or use energy in smart way. The complete comparison of final energy demand in all scenarios is provided in Annex II.

5.14.8 Lessons learned from the scenario outcomes

First, retrofitting old inefficient houses (constructed prior to 2005) can contribute to energy saving over the modelling period with a relatively limited effect, final consumption could be 3.5% higher in 2030 than otherwise it would be if no retrofit programme will be committed.

Second, total final energy demand in buildings may range between 4000 and 6200 thousand toe in 2030 among all the scenarios. The difference comes from divergence in building codes compliances and energy use appliance efficiency improvement rate. Energy demand could be reduced by 3% , 7.5% and 14.6% if all new construction will comply with Canadian, French and Swedish building code from 2006 up to 2030 compared to implementing the current TJ-2004 building code. Progressive approaches to upgrading building energy performance , represented A1, A2, A3 scenarios, respectively.

LC-R1 is the lowest scenario and ParCom-NR is the highest scenario of final energy consumption as expected from relevant assumptions. LC-RS is likely to save more than one-fifth of final energy consumption in 2030, compared to more than 12% increase in the PAR-NF scenario.

Moreover, the energy budget of households in 2030 may vary significantly depending upon BEE standards adopted and income group to which they belong. In the extreme cost (low income people living in an inefficient house), the energy bill could represent more than 20% of household's disposable income in 2030. Also, retrofitting the existing inefficient house may reduce the energy burden of income family in the longer term. Actually, many local income people live in the existing inefficient housing stock and cannot afford to buy new houses (more efficient in general) due to income constraints in the modelling period. In this regard, the *laissez-faire* (non-retrofitting)in existing houses is hardly justifiable from social and ethical point of view in housing efficiency policy-making. The next subsection discusses the primary energy demand scenarios and cost implications, the issues of environmental externalities will also be analysed.

5.15 Alternative scenarios of primary supply

As mentioned earlier, primary energy supply outcome is dependent on the assumptions on energy supply system. Two systems are tested in this subsection, namely SYS2 (supply capacity is added accordingly to the heat load simulated in the model) and SYS3 (new generating capacity is added according to the municipal plan up to 2015 and number afterwards are extrapolated from previous years' data) , respectively, to represent two different vision on energy supply. Scenarios comparison of primary energy demand, emissions and costs consists of two parts, SYS2 and SYS3, respectively.

Case SYS2

Investment strategy in 2020

2020 is considered as a critical year in our modelling framework for the following reasons

- From supply side, a large number of existing generating capacity will be retired and needs to be replaced, the choice of supply technology is determining for the energy and environmental pathways for another twenty to thirty years onwards.
- Some new carbon-free or low-carbon technologies will technically deployable and the capital costs are projected to decrease over the next fifteen years. However, adoption of these new technologies will still necessitate sufficient financial capacity
- From demand side , part of buildings constructed by 2005 will be demolished and retrofitted in case of low-efficiency. The city would face huge capital injection in retrofit programme if the historical buildings stock has been built without complying with energy performance requirements

Similarly to final energy analysis, this subsection concentrates on six base scenarios (TJ2004, RT2005, SWE, LC, A2 and ParCom) with variants of supply technology options (switch from coal to gas or CCS , REN etc). These scenarios represent the trend of current technology and practice, i.e. business-as-usual case (TJ04), option of new BEE standards and construction techniques (SWE and RT05), gradual sectoral transformation (A2), and retard in BEE implementation (ParCom). Their consequences in terms of demand for energy resources; environmental impact and social costs will be evaluated in order to find out the best path to BEE development. Our discussion will be structured into four categories from energy supply perspective:

1. basecase: current dominant energy system will pursue without any climate objective constraint;
2. Large-scale deployment of CCS in coal-fired power and heat plant from 2020;
3. Implement fuel switching policy (coal to natural gas) in majority part (60%) of new added capacity built after 2020 and retrofit gradually the existing coal-fired plants built before 2020 (assuming that 5% of existing capacity would be retrofitted per annum).
4. REN: Promotion of renewable (biomass in particular) in energy supply system from 2015.

5.15.1 Coal-based energy system (basecase)

A. Energy demand trend 2005-2030

The trend of primary energy supply in major scenarios

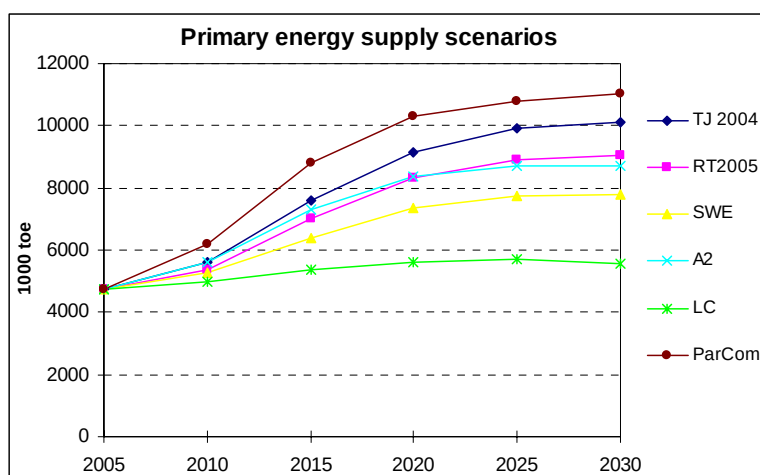


Figure 5-64 Primary energy supply trend in major scenarios (2005-2030)

Figure 5-64 illustrate different primary energy supply scenarios during the period 2005-2030. Average yby growth rate range between 0.63% and 3.53% , in the highest(ParCom) and lowest scenario(LC), respectively. The declining trend of PES in LC scenario after 2025 is mainly due to demolished inefficient old houses and thermal rehabilitation in the existing housing stock, as well as introduction of high efficient electrical appliance in both residential and commercial buildings.

B. Primary energy demand in 2030

Figure 5-65 shows the primary energy supply in Tianjin's building sector in 2030 in different scenarios. As expected, failed in full implementation of BEE in new buildings will result in significant rise in primary energy supply in the entire building stock in 2030. It is expected that coal will still play large role in primary energy supply in 2030 from energy supply security perspective in China. Coal will account for more than 80% of total primary energy supply in most scenarios except for the LC scenario in which coal will account for slightly more than 60% of total primary energy, while the share of oil and gas and RENs will be much higher compared to the other scenarios.

Energy supply in baseline scenario (TJ2004) will exceed 10 Mtoe in 2030, or more than double compared to 2005 level. In the extreme cases, it can be seen that primary energy supply in ParCom scenario will more

than double that of LC in 2030. From sustainable energy supply's perspective, the BEE standards should be improved further to mitigate the sharp increase in fossil-fuel in the future.

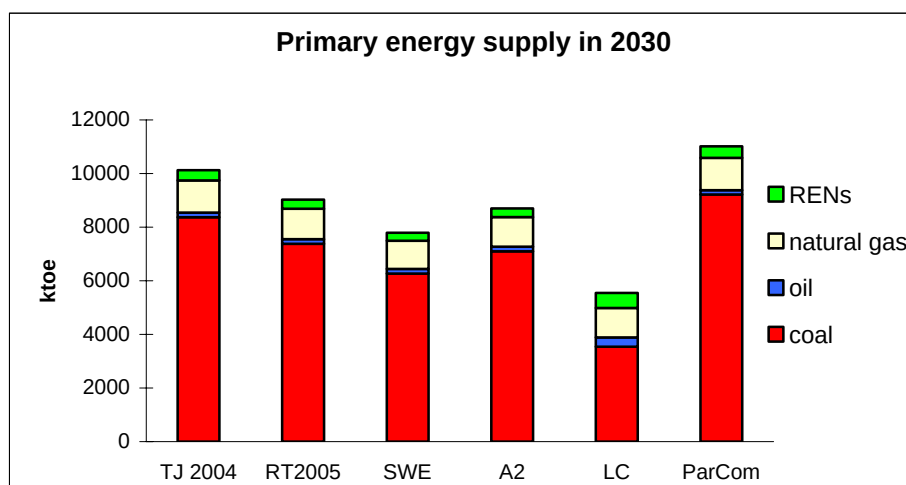


Figure 5-65. Primary energy supply in 2030 in six base scenarios

1. CCS

As mentioned above, CCS will only be commercially available after 2020 for large-scale deployment in coal-fired power and heat generation plants. It is assumed in our model that under all scenarios with CCS variant, CCS will be equipped in the new generating capacities built after 2020 including replacement of the retired capacity existing by 2005. About 2000 MW large CHP generating capacity will be retired from 2020, we estimate that 300 MW will be retired each year until 2025. In addition, we assume that 5% of existing CHP capacity (PC, Supercritical and IGCC power plants) added between 2005 and 2020 (around 320 MW in the reference scenario⁷⁷) will be equipped with CCS each year from 2020 onwards.

IEA(2008) clearly demonstrates that CCS is a necessary technology component which contributes to realising the global emissions mitigation objective (halve the 2000 emission level to keep the GHG concentration at 550 ppmv by 2050) in order to stabilise global temperature increase (+2-3°C) by the end of this century. IEA's forecast is somewhat more optimistic than our projection. Equipment of CCS in all the capture-ready plants will take both time and money; no magical stick is available to let CCS penetrate from the day to the next. Large deployment can only be envisaged when the costs and techniques are sufficiently managed by the engineers in the power sector. How fast the cost of CCS is going to decrease is a key determinant when considering large-deployment in the next decades.

⁷⁷ Added generating capacity differs in each scenario of BEE improvement. More efficient buildings construction will necessarily result in reduced capacity addition and subsequent CCS conversion.

Prospect of CCS cost

In our model, only pre-combustion capture technology is considered since post-combustion and oxyfuel have significant higher cost and more technical complexity. Figure 5-66 illustrates the assumption on CCS cost in different types of power and heat plants over the modelling period. The assumption is based on technological learning process using the experience curve equation as described in subsection 5.6.9, implying each doubling of CCS capacity will allow reducing the cost by 8%.

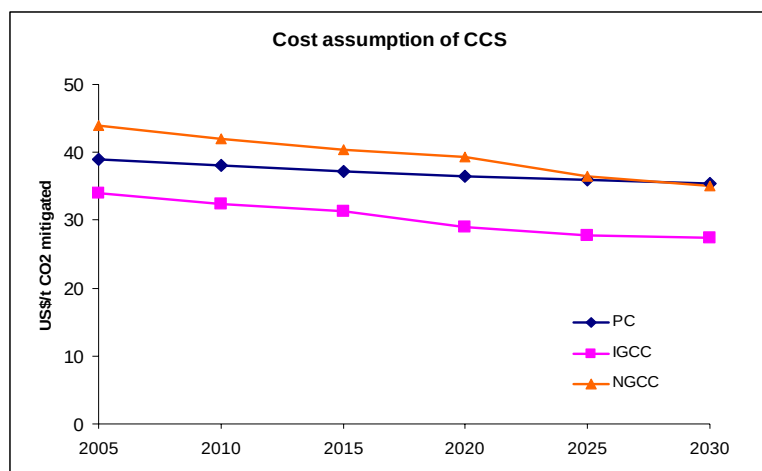


Figure 5-66. Assumption on CCS costs in different type of power plants

A. Energy demand trend 2005-2030

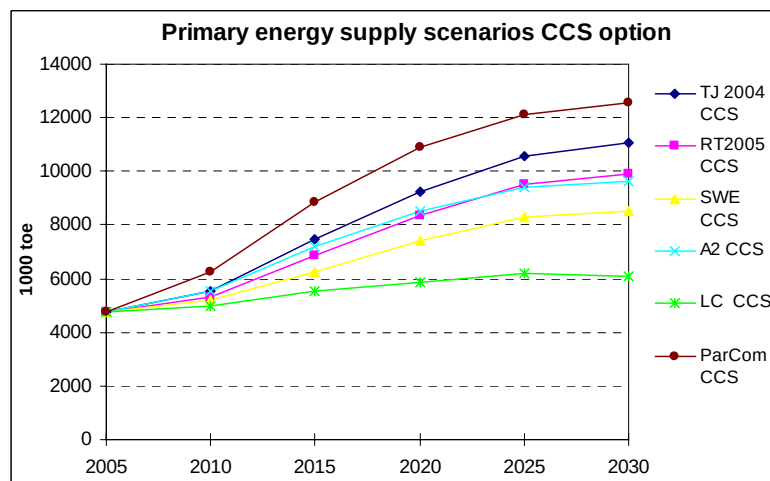


Figure 5-67 Primary energy supply scenarios in CCS option

Indeed, primary energy supply in CCS option will increase significantly compared to the basecase, more specifically, greater variance is observed between different scenarios in CCS energy supply option.

B. Primary energy supply in 2030

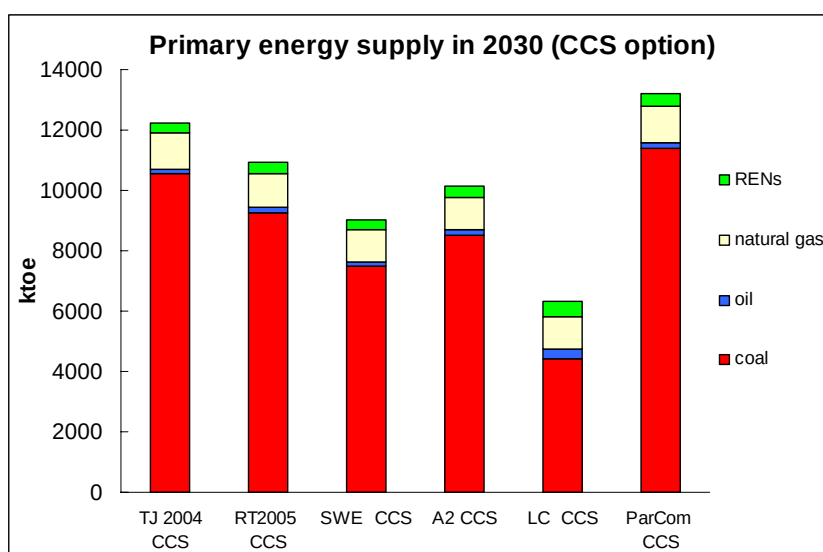


Figure 5-68. Primary energy supply scenarios in CCS option

Primary energy supply in this case is 14% to 20% higher than in the base case, as shown in Fig 5-68. Consequently, the share of coal in total energy supply is greater than in the base case due to the inherent energy penalty in coal-fired power and CHP plants. PES in ParCom would more than double that of LC ; implying that the role of better energy performance of buildings is even more important when the energy supply is constrained by explicit climate protection objective which requires large-scale deployment of clean coal and CCS technology.

2. Fuel switch option (coal to natural gas)

Likewise, the fuel switching policy perspective is quite similarly to CCS option, new generating capacity including that added replacing the retired coal-fired capacity will switch to natural gas from 2015, and part of existing power and heat plants in that year will be retrofitted and switch to gas (around 5% of existing capacity per year is assumed to switch to natural gas). The capital costs of retrofitting coal-fired to CCGT technology plants depends on the size of unit, ease of retrofit, control system upgrade requirements, and availability of natural gas at the plant (Miller, 2005; chapter 6 “Emissions control strategies for power plants”, p. 345). We estimate that the retrofit capital costs range between 30-40 US\$/kW_e in the Tianjin’s power plants including natural gas reburn system and pipeline infrastructure. Figure 5-68 shows the primary energy supply in the ParCom scenario, natural gas consumption increases gradually as the coal’s share keeps declining from 2020. Nevertheless, coal will still represent nearly 46% of primary energy supply under this scenario since all the coal-fired CHP and district boilers will be unable to switch to gas simultaneously.

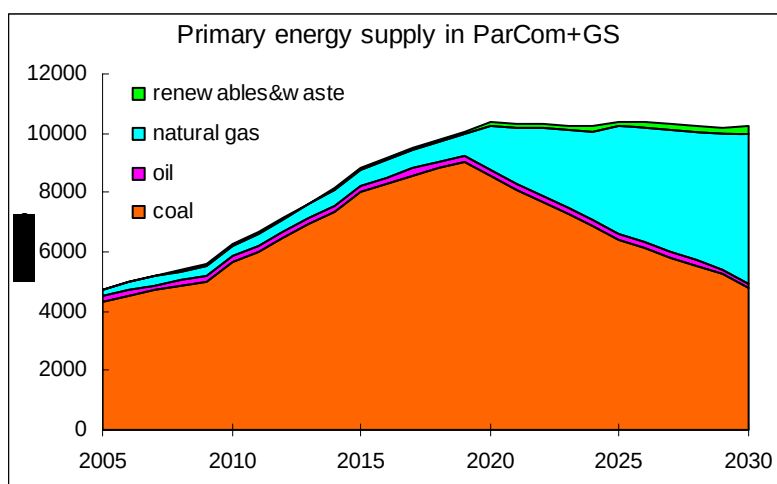


Figure 5-69. Primary energy supply trend in ParCom scenario

A. Energy demand trend 2005-2030 in key scenarios

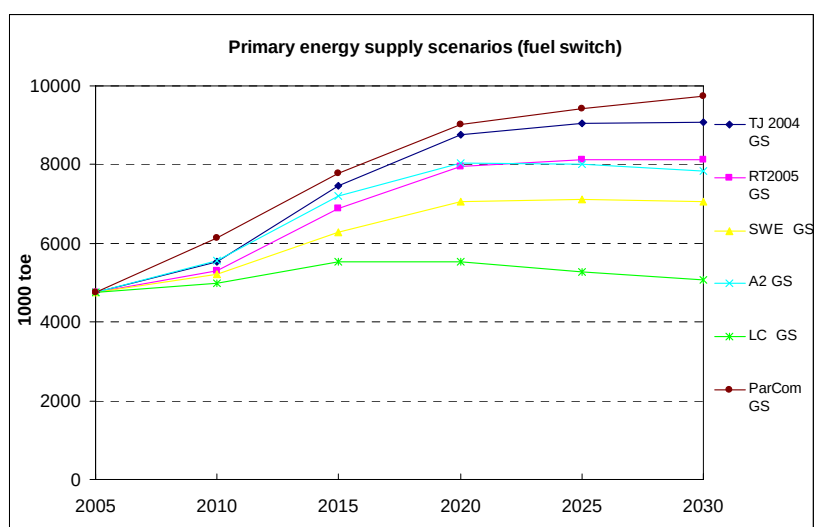


Figure 5-70. 2005-2030 PES scenarios of CCS option

Switching to natural gas in the large coal-fired power and CHP plants will result in PES reduction, total cumulative PES can be reduced by 5% to 10% compared to the base case and 20% to 29% in comparison with CCS option, depending on BEE scenarios.

B. Primary energy supply in 2030

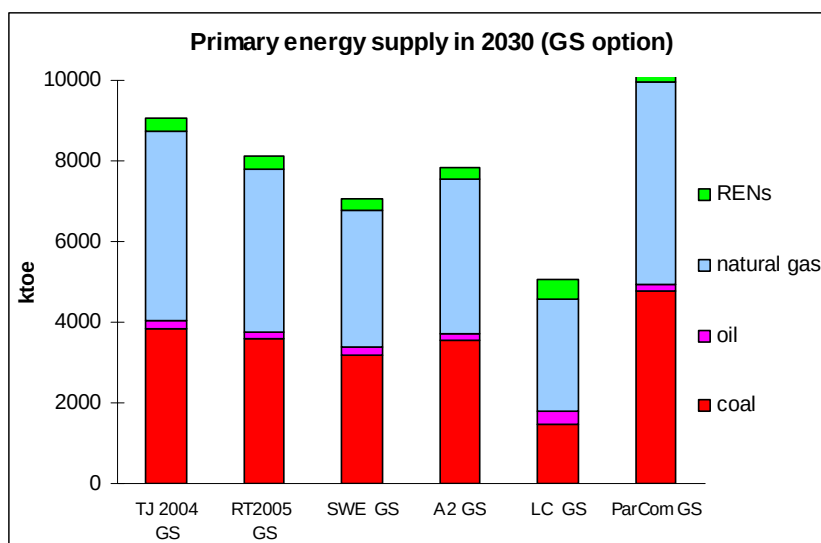


Figure 5-71. Primary energy supply scenarios in GS option in 2030.

As can be seen in Fig 5-71, natural gas and coal will be both dominating the primary energy supply in all scenarios as a result of fuel switch policy. PES in 2030 in this option could be reduced by 11-14% compared to the base case option ; and 22% to 28% compared with CCS option.

3. RENs promotion

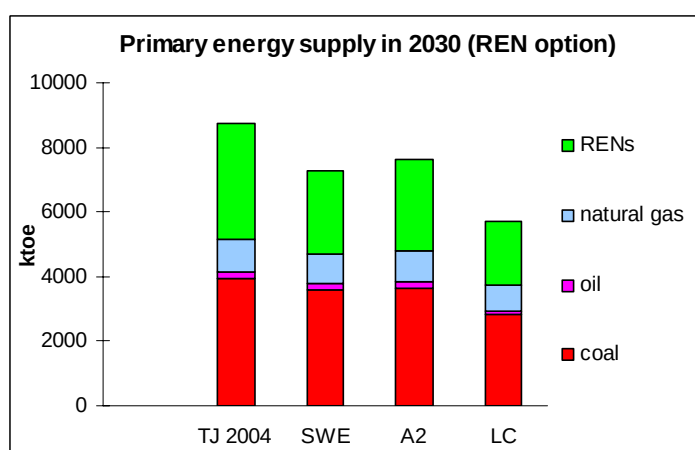


Figure 5-72 Primary energy supply scenarios in REN option

5.15.2 Primary energy supply scenario of basecase and variants

Since more than 35 variants have been simulated in each of energy supply system, we present here only the most representative scenarios with table and graph representation to keep description as brief and analytical as possible. Details are provided in Appendix II. The graphics below the most representative results of primary energy demand in all base scenarios and their main variants (BEE enforcement and energy supply option alternatives). Variants are classified into respective base scenarios, as shown in Fig 5-73 through 5-78.

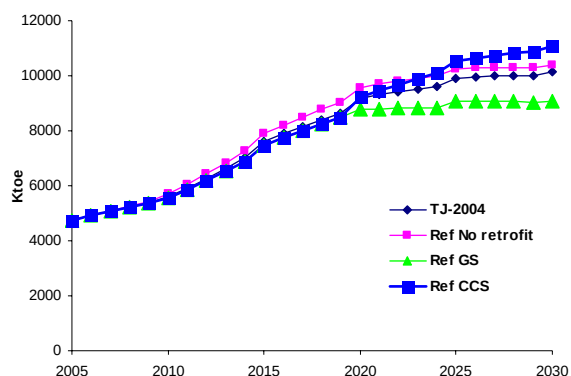


Figure 5-73 TJ2004 basecase and variants

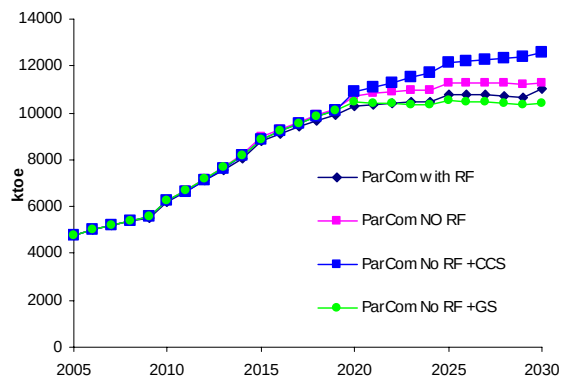


Figure 5-74 ParCom and variants

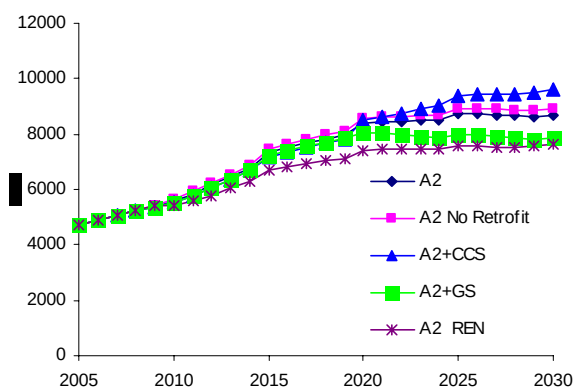


Figure 5-75 A2 scenario and variants

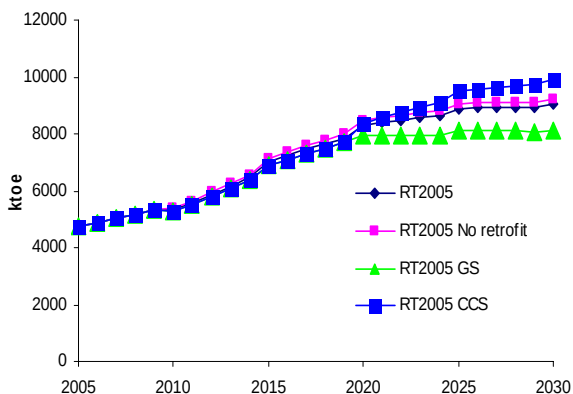


Figure 5-76 RT 2005 and variants

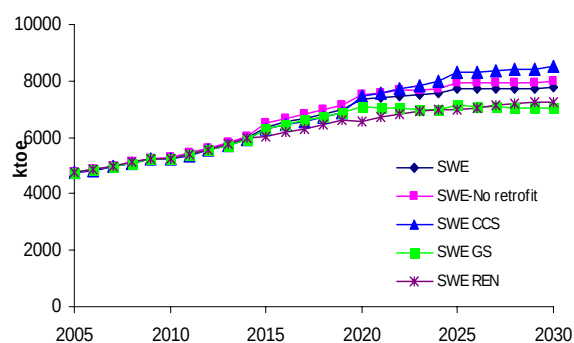


Figure 5-77 SWE and variants

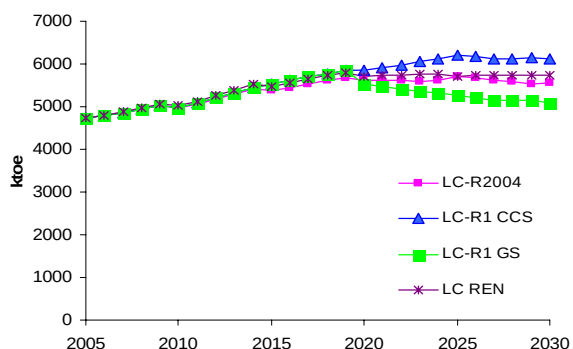


Figure 5-78 LC and variants

LC-R1 scenario given more ambitious goal, heat pump, biomass and natural gas-fired cogeneration will represent 30% of district heating supply by 2030, instead of 15% in other scenarios, similarly, large municipal CHP will only cover 50% of total heating supply instead of 70% in other scenarios. In addition, the capacity of renewables combustibles-fired city CHP will reach 400 and 800 MW in 2010 and 2020, respectively in the low carbon scenario.

Note of scenario

Renewable is assumed to reach 30% of large CHP heating supply by 2030, whereas it will only represent 5% of fuel mix in CHP in the baseline scenario. Gas cogeneration will represent 10% in the municipal heat plants by 2020. Coal's share will keep declining until 60% of total supply in CHP in 2030 whereas it will remain 90% in the baseline scenario. In all scenarios, supply efficiencies in different technology options are assumed to improve 0.5% per year over the modelling period.

The model allocates 20% margin of capacity reserve in alternative scenarios of energy performance improvement compared to inefficient buildings (TJ 2004,CAN, RT2005, SWE, A1, A2, and A3) for the sake of peak load , as in the other two scenarios. Unlike in the case of the final energy demand, primary energy supplies vary significantly in different scenarios and between the different variants in each scenario. Of all the scenarios simulated, CCS is the most energy intensity supply option due to the inherent energy penalty, leading in consequence to the highest primary energy supply. It is interesting to note that primary supply divergence in the less-efficient cases(ParCom) is significantly more remarkable than in higher efficient scenarios(SWE for example) under which all variants are more likely to converge eventually. In addition, increase trend of CCS variant is reasonably lower in efficient scenario than in ParCom, implying that CCS will be more affordable to deploy with a more efficient infrastructure since the city is under permanent constraints of limited energy resources.

5.15.3 Emission scenarios

Emissions scenarios are very much dependent on the primary energy supply. Thus alternative energy supply technologies such as fuel-switching, CCS and renewable will allow carbon emissions abatement from the business as usual scenario.

5.15.3.1 Trend of emissions in base scenarios

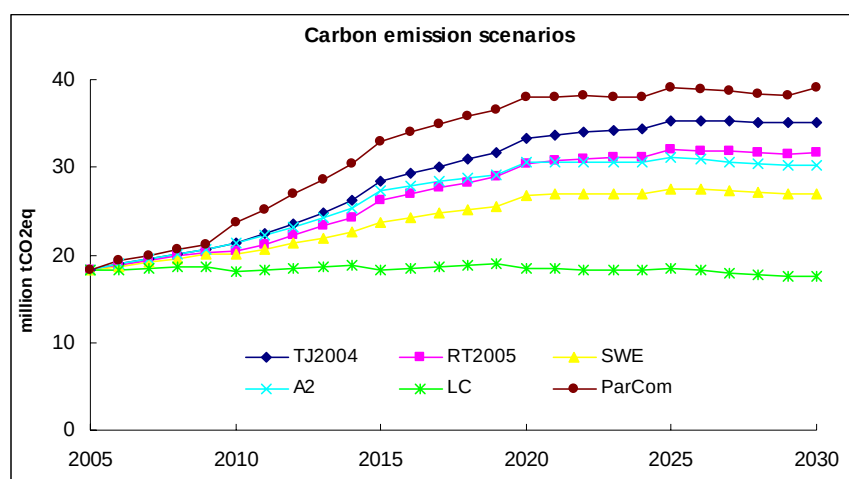


Figure 5-79 emission trend in key base scenarios

Figure 5-79 illustrates the trend of carbon emissions in all six base scenarios up to 2030. It shows that the emission in different scenarios begin diverging from 2010, this is because housing and commercial building construction rate is the foremost high during 2015-2010 period. From 2010, the increase is driven by both added new floor area and the rise in demand for thermal comfort. Emission in 2030 could more than double in the most pessimist scenario (ParCom) and could be reduced by 5% in the case of successful LC implementation. In contrast, increase in emissions could be limited to below 50% in the SWE scenario.

5.15.3.2 CO₂ emission projection in key scenarios

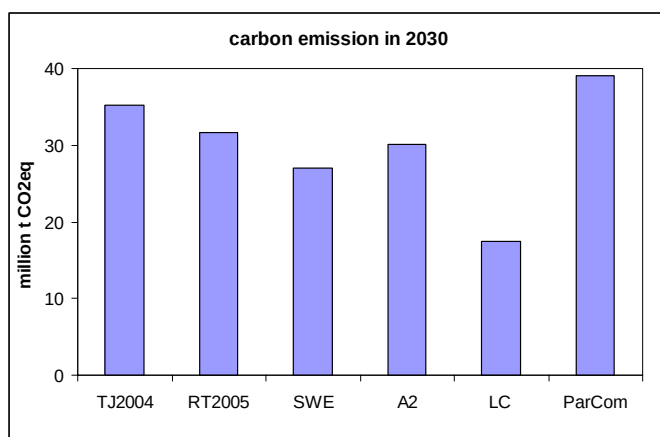


Figure 5-80 Carbon emissions from buildings in Tianjin in 2030

Carbon emissions in 2030 will range between 17.5 Mt and 39.1 Mt CO_{2-eq} in the base scenarios, as shown in figure 5-80, in other words, carbon emission in the case of ParCom would more than double that of LC at the end of the modelling period.

The cumulative emission is more important than the point emission in specific year since the likelihood of catastrophic scenarios of climate change will correlate to the accumulated greenhouse gases concentration in the longer term, thus the cumulative emissions should also be taken into account. Cumulative emissions vary significantly across different scenarios, ranging between 477 and 831 million tCO_{2-eq} over the next twenty-five years. It can be seen from Fig 5-81 and 5-82 that A2 and RT2005 scenarios are almost identical in terms of carbon emissions in 2030, implying that A2 may be preferred to RT 05 if carbon emission consequence in the final year is the only determinant since A2 favours a progressive transformation approach, and would be much easier to implement than radical change of technology and practice in the building sector.

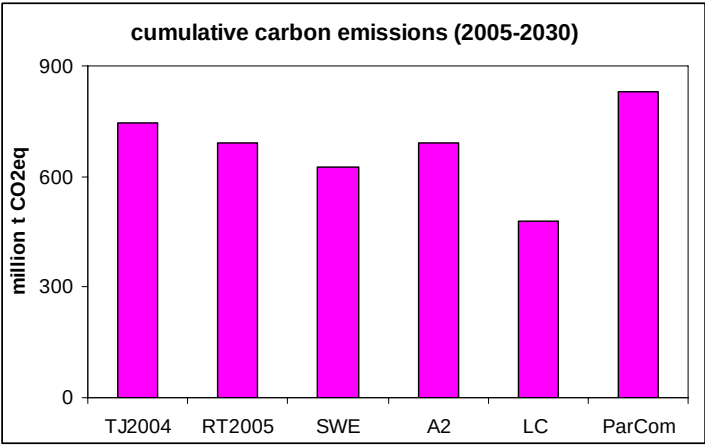


Figure 5-81 Cumulative carbon emissions from buildings in Tianjin in 2030

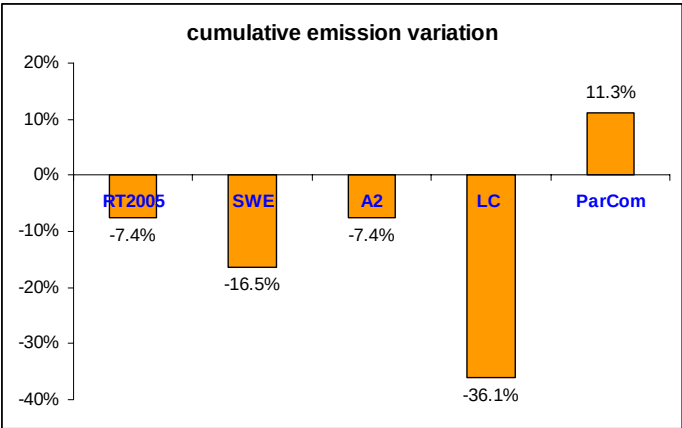


Figure 5-82. Variation of cumulative emissions in different scenarios compared with baseline (TJ2004)

1. Fuel switching option

Fig 5-83 delineates the trend of carbon emissions in GS option; emissions start to fall from 2020 due to the switching to natural gas in new built power and CHP plants and gradual retrofitting old coal-fired plants.

Compared to the baseline scenario, the fuel-switching policy will allow the energy production sector to reduce gradually carbon emissions in all scenarios. It can be seen that reduction of carbon emissions will be modest by 2025, contrarily to what may be expected by gas policy advocates.

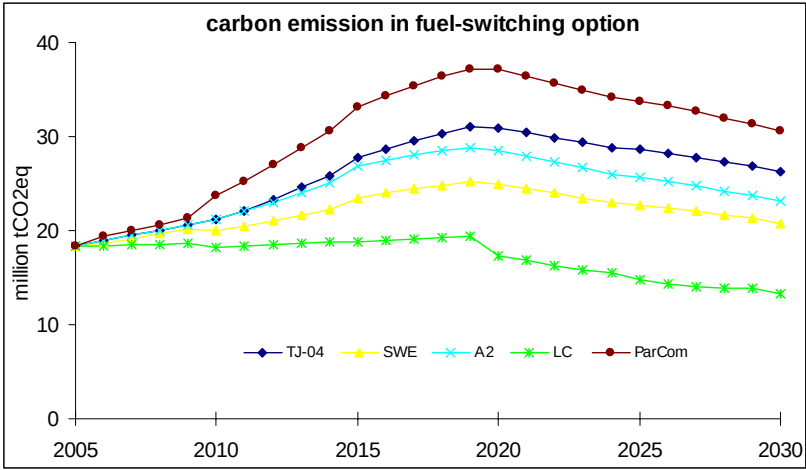


Figure 5-83 Emission trend scenarios in CCS option

5.15.3.3 Emission in 2030

Figure 5-84 compares carbon emission scenarios in 2030. Carbon emissions in 2030 range between 13.2 and 30 Mt CO_{2-eq}, allowing 21.7-25% reduction of carbon emissions compared with the base case in all the scenarios. ParCom emission is still nearly double that of LC scenario in this option.

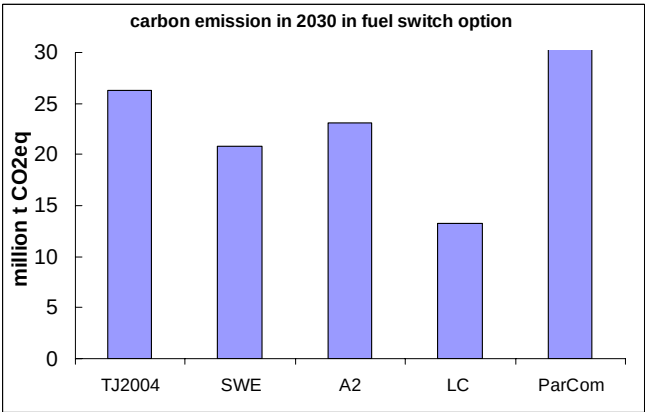


Figure 5-84 carbon emissions from buildings in Tianjin in 2030 with gas switch policy

5.15.3.4 Cumulative emission

Cumulative emissions range between 450 and 780 million t CO_{2-eq} during this period, or 5.8%-9.5% reduction compared to the base case discussed above. Fig 5-85 illustrates the cumulative carbon emissions in the five scenarios.

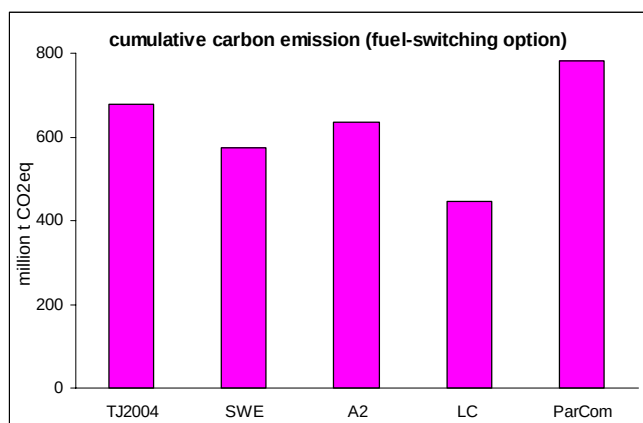


Figure 5-85 cumulative carbon emissions from buildings in Tianjin in 2030

The results show that fuel-switching will not allow reducing the cumulative carbon emission drastically, in particular in the ParCom scenario due to system inertia. The historical inefficiency debt will still have considerable impact on emission profile twenty years later.

2. CCS option

Emission trend in CCS option

CCS is the most promising technology to curb emissions while maintaining the coal as dominant energy supply resources. Emission in all scenarios will peak in 2020 and commence to decline when CCS commence to be deployed in the emission production points. Emission reduction in this option will be more drastic than “fuel-switching”. Emission in 2030 will be roughly halved compared to base case in most scenarios. However, it is counterintuitive that carbon emissions will not converge, as shown in Figure 5-86. The main reason is that like in fuel switching case, CCS will only penetrate in new power plants which are almost all capture ready from 2020. Deployment in existing power plants will take time and huge capital to invest. We see from Fig.5-87 that emissions in 2030 in the case of ParCom is still nearly 50% than SWE and more than double that in LC scenario. This confirms that the performance of low-carbon energy supply technology is also closely dependent on the quality of demand infrastructure.

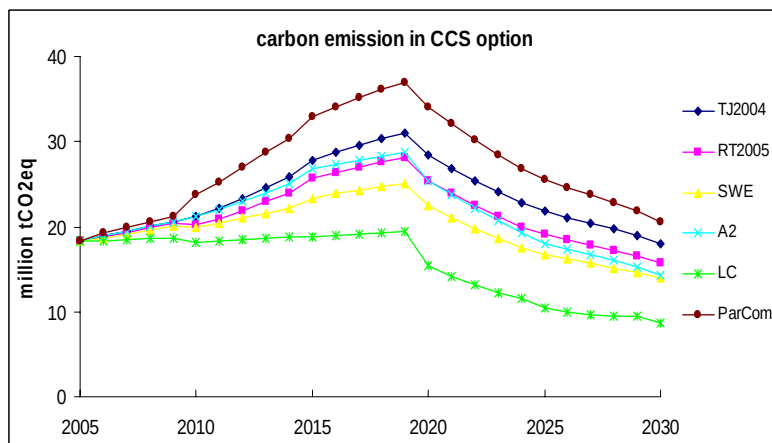


Figure 5-86 emission scenarios in CCS option

Comparison of carbon emissions in 2030

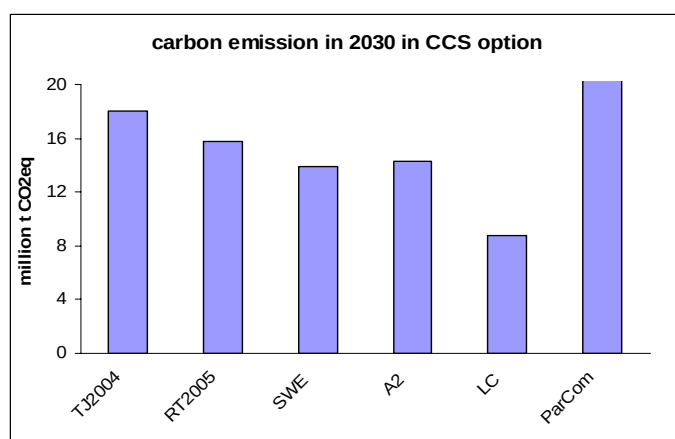


Figure 5-87. Carbon emissions from buildings in 2030 using CCS supply technology

Cumulative emissions 2005-2030

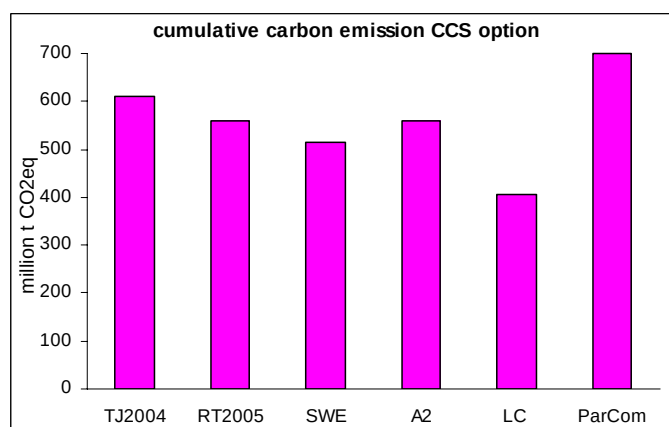


Figure 5-88 cumulative carbon emissions from buildings when CCS is deployed

Figure 5-88 shows different scenarios of cumulative carbon emissions if the CCS technology will be largely deployed from 2020. Cumulative emissions range between 400Mt and 700 Mt CO₂eq over the modelling period in all scenarios. In the reference scenario, deployment of CCS will allow reducing cumulative CO₂ emission by 18.4% in 2030. Carbon emissions reduction rate varies between 15.2 % (Low-carbon scenario) and 19% (RT2005) compare with the base case. Table 5-27 summarises the projected GHG emissions in selected scenarios and respective variants. Complete results are provided in Appendix II.

Table 5-27 Summary of Year-by-year emission (In million metric tonne CO₂-eq)

Base scenarios

Emission in Mt	2005	2010	2020	2030
<i>TJ-2004</i>	18.36	21.32	33.39	35.19
<i>RT2005</i>	18.36	20.38	30.50	31.71
<i>SWE</i>	18.36	20.13	26.82	26.98

A2	18.36	21.32	30.57	30.19
LC-R2004	18.36	18.15	18.49	17.49
ParCom without Re	18.36	24.02	40.05	40.87

CCS and Gas switching variants

emission in Mt	2005	2010	2020	2030
Ref CCS	18.36	21.13	28.46	18.03
Ref GS	18.36	21.13	30.92	26.31
A2+CCS	18.36	21.13	25.36	14.31
A2+Gas Switching	18.36	21.17	28.58	23.11
SWE CCS	18.36	19.90	22.49	13.92
SWE GS	18.36	19.93	24.98	20.80
LC CCS	18.36	18.16	15.37	8.74
LC GS	18.36	18.16	17.34	13.22
RT 2005 + CCS	18.36	20.19	25.46	15.75
RT2005+GS	18.36	20.19	28.10	23.78
ParCom No retro +CCS	18.36	23.73	34.11	20.61
ParCom No retro +GS	18.36	23.77	37.16	30.60
REN supply scenarios				
TJ2004	2005	2010	2020	2030
SWE REN	18.36	18.96	18.60	17.37
A2 REN	18.36	19.37	20.78	17.07
LC REN	18.36	17.75	15.55	14.08

5.16 Cost implications of scenarios

Cost is the determining criterion of optimal BEE trajectory in the building sector in this research. Modelling results show that the non-retrofitting variants may, in some cases, seem to be the least costly option. However, as noted in the previous subsection, the non-rehabilitation policy option in existing buildings may pose social problem since the energy burden would be very excessively high for the low-income households living in an inefficient house. Thus, the selection of best trajectory of BEE standards should exclude the non-retrofitting variants for the sake of equity and social concerns. In order to test the sensitivity of the cost ordering, different rate of discounting is to be used to investigate the extent to which the higher or lower DR can influence the policy-making.

From economist point of view, the optimal decision on BEE standards adoption will primarily depend on the results of discounted cumulative costs throughout the entire modelling period. However, one of the major objectives our study is to quantify the impact of today's investment decision on the financing capacity of the society tomorrow. In this regard, we present both cumulative discounted costs and the non-discount yearly

costs. The later will illustrates result of a series of sequential decision on the investment nature from future generation’s perspective. In other words, we project a society in which the finical resources availability is highly dependent on their preceding decision makers’ choice. The comparison of the six key scenarios of annual costs is focused on year 2020, and 2030. Finally , the cumulative costs will be the determining criterion in selecting the best BEE decision.

5.16.1 Yearly cost trajectory

As mentioned in introductory section, the illustration of sequence of annual costs in different BEE implementation costs will show how the current decision in buildings quality can influence the future investment capacity in supply infrastructure. We present first the annual costs change in the baseline (TJ-2004) scenario, which will be served as the reference of other scenarios.

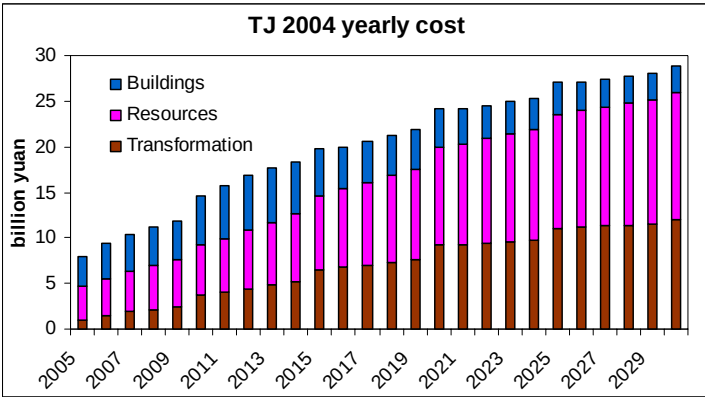
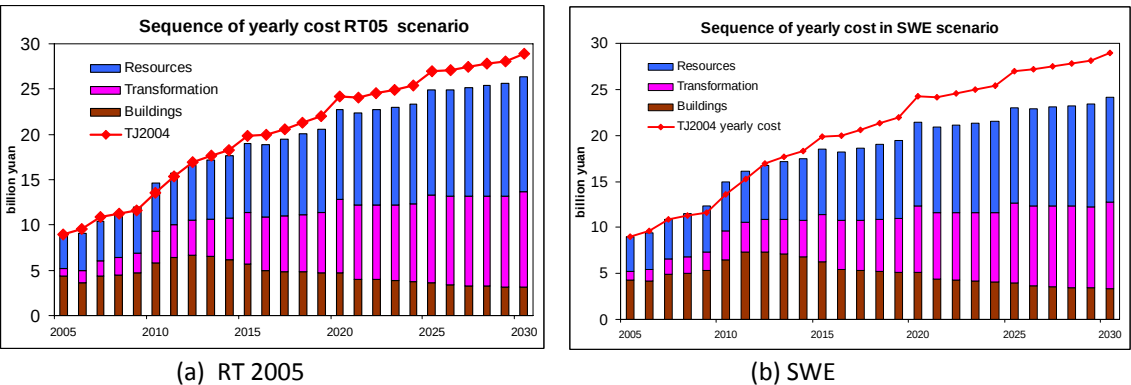


Figure 5-89. Annual cost sequence of TJ2004 scenario (in specific year value)

Under the baseline scenario, yearly cost will more than triple, increasing from 8.94 billion yuan per year to nearly 29 billion yuan in 2030. We see easily that costs of buildings would be dwindling throughout the period while the operation and energy supply investment costs will keep rising.

Consequently, we can compare alternative scenarios by taking TJ2004 as the reference, represented by the red curves in the following charts.



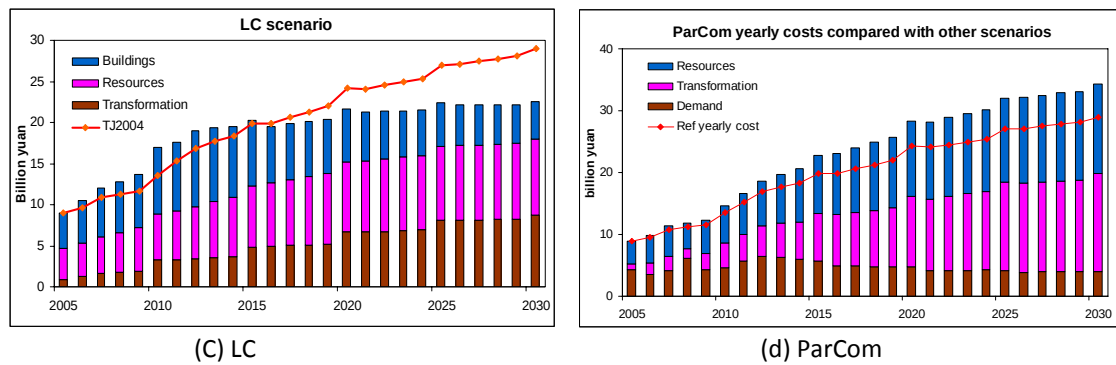


Figure 5-90. Yearly Cost in different BEE decision scenarios

It can be seen from Fig.5-89 that both RT05 and SWE are very interesting to be considered in terms of potential benefits compared with the reference line which represents current BEE standard (TJ2004). The annual cost in these two scenarios will lie below that of TJ2004 by 2012-2015. It means that if the local authority decides to upgrade the current TJ2004 to RT2005 or SWE, finance appears not to be a major barrier to implement the higher efficiency standard since considerable revenue can be created, the reduced costs will largely compensate the upfront extra costs associated with performing buildings construction. However, this implies that local authority will be capable to ensure the benefits creation and redistribution within an adapted institutional context. The question is then related to institutional organisation which will be discussed later in chapters 6 and 7.

In contrast, LC and ParCom represent two extreme scenarios. We observe that although the operation costs will also be significantly lower than baseline eventually, the city need to set up a mechanism to anticipate the finance in upfront buildings efficiency investment since the total costs in previous years of operation of LC scenario are significantly higher. Local authority could borrow the future “revenue” to finance the extra cost and recuperate the benefits in the future. The integral area between the bars and red curve represent the benefits or loss or alternative scenarios. Thus it is straightforward to find out that the upfront investment on BEE improvement in the early stage could be covered by the benefits generated in the future. The possibility of using arbitrage of investment in different period of time depends upon the local authority’s institutional efficiency. Policy instruments can be employed to achieve the non-lose investment strategy.

Lastly, the Parcom scenario outcome clearly shows that lack of efficiency in buildings that we construct today will result in huge loss in the future as the operation costs of such a building stock will be very costly for the society throughout almost the entire modelling period.

Now consider the circumstances under which the local decision makers will face the choice of energy supply infrastructure renewal in the future. This decision is likely to intervene by 2020 when a large part of old boilers will need to be retired. To achieve the global climate objective, China needs to reduce drastically the carbon

emission in the energy sector, in particular the power and heating sectors. The local authority can choose CCS or switching the coal-fired power plants to natural gas. Both solutions will contribute to lowering the emissions as shown in Fig.5-82 and 5-85 in previous subsection. The consequent costs scenarios in these technology options are plotted in Fig. 5-90 and Fig.91.

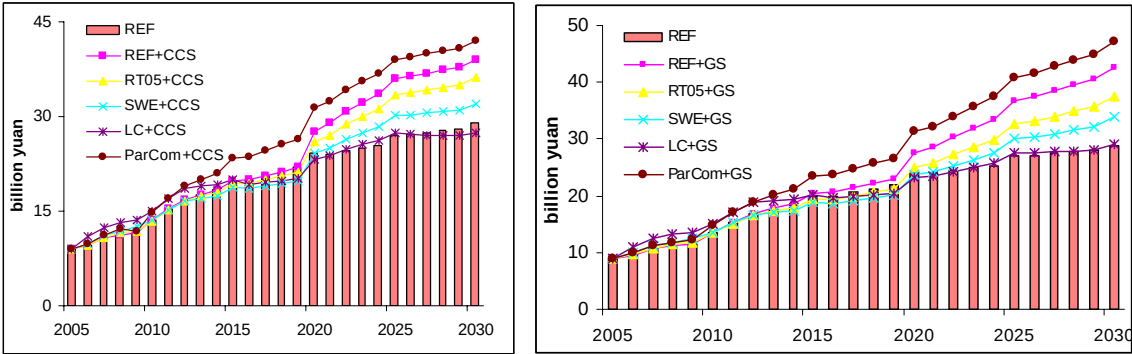


Figure 5-91. Cost with CCS option from 2020

From Fig. 5-90 it can be seen that there will be a sharp jump of annual cost in 2020 as CCS technology begins to be deployed in part of coal-fired power plants. However, it can be seen that the cost of SWE+CCS is almost identical to the reference cost, and more importantly, the cost of LC with CCS option in 2030 will still lie below the level of reference. However, the cost in reference+CCS and ParCom+CCS will see a 14% and 30% jump in annual costs compared with the reference line. This is totally unacceptable by the local authority since huge financial resources should be required to cover the big jump in operation cost of introducing the CCS. This implies that efficient buildings scenarios have more flexibility in facilitating the technological transition in energy supply, contrarily to the sharp increase in costs in the starting year of new technology penetration in the less efficient scenarios. It can also be seen that the difference between scenarios in 2030 would deepen compared with the situation in 2020 when new technology penetration just starts. In the long run, efficient buildings can help achieve the investment strategy which allows smooth sectoral transformation toward gradual decarbonisation of the city's coal-fired supply system without significant impact on financial resources allocation.

Likewise, the situation in fuel-switching option also favours the efficient buildings stock in terms of ease of implementation. It can be seen that the operation costs incurred when carrying out fuel-switching policy in the improved efficiency scenarios (RT05, SWE and LC) in 2020 can be minimised with an acceptable range. SWE+GS and RT05+GS are slightly higher than the reference costs without fuel-switching policy. Again, costs of LC+GS are lower than those in reference case.

Fig. 5-59 and Fig.5-60 show that the municipality can manage to deal with the extra costs associated with decarbonising energy supply infrastructure in 2020 if higher efficiency of buildings can be guaranteed, because the results show that higher buildings efficiency coupled with low-carbon supply technology will be less costly than the business-as-usual and far less expensive than in the case of failure in compliance in some parts of new construction from the starting year of this trajectory.

Combining the emission and annual costs of scenarios, the carbon emission abatement cost can be calculated with ease in each of the options. Table 5-28 and 5-29 summarises the costs of CO₂ abatement in specific year in the selected scenarios from 2020 onwards in CCS and GS technology option, respectively.

Table 5-28 CO₂ abatement costs in different scenarios of CCS options (US\$/t CO_{2-eq})

	2020	2025	2030
REF+CCS	100	95	84
RT+CCS	30	57	53
SWE+CCS	-1	25	20
A2+CCS	22	31	22
LC+CCS	-8	2	-8
ParCom+CCS	-	178	128

Table 5-29 CO₂ abatement costs in different scenarios with fuel-switching options (US\$/t CO_{2-eq})

	2020	2025	2030
REF+GS	191	278	319
RT+GS	22	133	180
SWE+GS	-9	68	102
A2+GS	50	97	108
LC+GS	-10	24	34
ParCom+GS		1654	773

Note: i) values are expressed in specific year and not discounted

ii) Exchange rate between US dollar and RMB is assumed to fall from 7 to 6.5

iii) TJ-2004 is taken as the baseline emission scenario

From Table 5-28 and 5-29 we can see that CCS option is generally much more cost-effective than fuel-switching option. This is somewhat intuitive, since in our model, no CCS will be deployed in the CCGT power plants in the case of fuel-switching scenarios albeit carbon emission in natural gas powered plants is far from negligible.

More importantly, we see that CO₂ abatement in buildings is more cost-effective in the high-efficiency scenario, the cost is even negative in the high-performing scenario (LC). However, CO₂ abatement costs will be very high in the Reference scenario, nearly 200 US\$/t CO_{2-eq} in 2020 in fuel-switching policy scenario; and it is excessively high in low efficiency scenario(Par Com) which may reach more than 1650 US\$/t CO_{2-eq} by 2025 with gas switching option. In comparison, abatement costs in SWE and RT scenarios can be maintained within affordable range.

The results in the Tables above have very strong economic implications with regard to global climate policy. The results tell explicitly that if the Chinese government can succeed to implement immediately the equivalent RT05 or SWE BEE standards, the required international financial aid for the CCS technology deployment in China would range between around US\$ 20-50 /t CO_{2-eq}, a carbon price totally competitive in the global carbon

market for from carbon emission management perspective. On the contrary, fuel-switching policy would be more costly to implement although the technology is already deployable.

The analysis of annual costs shows that although a remarkable jump of investment costs are perceived in all scenarios, the degree of change is considerably less significant in high efficiency case (LC)than in lower case (ParCom). To avoid painful sharp jump in current year operation costs such as in the ParCom scenario, upfront buildings energy performance and quality of construction are of critical importance and should never be ignored, otherwise the city would be trapped into a vicious circle: lower efficient buildings results in costly operation and thus less financial capacity could be formed to invest in low-carbon technologies to mitigate carbon emissions in the future.

5.16.1.1 Operation costs of energy infrastructure

Energy supply infrastructure development and operation are highly capital-intensive. Low-efficient buildings will result in high operation costs. Large amount of capital investment is due in all of the key scenarios. Figures 5-92 through 5-95 show the trend of necessary yearly investment in energy supply-side investment (transformation part in our model) with different technology options, figures expressed refer to specific yearly non-discounted value. Not surprisingly, CCS ,gas-switching and REN options will generate significantly higher cost in the energy supply system.

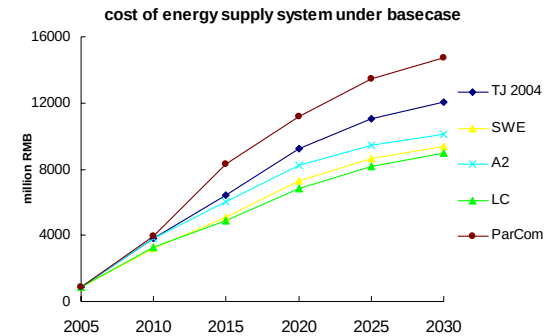


Figure 5-92. baseline case

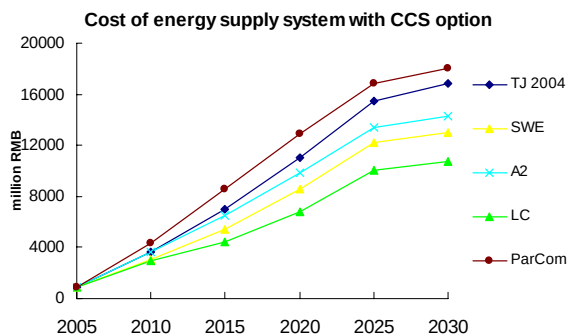


Figure 5-93. CCS option

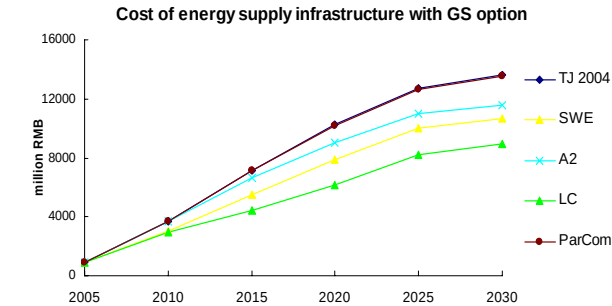


Figure 5-94. Fuel-switching

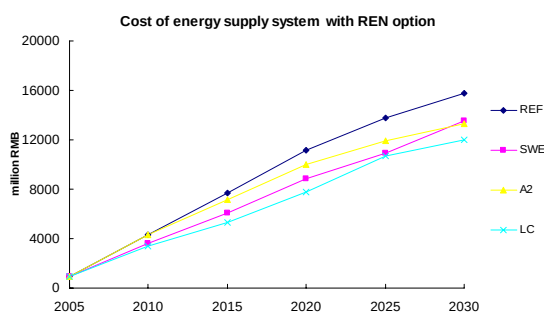


Figure 5-95. REN option

Figure 5-96 compares the cumulative investment costs in the scenarios and relevant variants over the modelling period. It can be seen that the less efficient the buildings average energy performance is, the higher costs of energy supply system will be incurred. For example, the cumulative costs in ParCom in the basecase supply technology would be more than 208 billion RMB (26 billion US\$ in 2005 price) , nearly 15% higher than reference case (TJ2004). And extra cost compared with the most efficient scenario (LC) is even bigger. When CCS technology is assumed to be adopted, ParCom’s total costs of energy supply system are nearly 90% higher than LC. These results show that orienting the investment solely in supply-side technology to decarbonise the building energy consumption will be very costly and is unsustainable technical solution. Instead a comprehensive approach to integrating the BEE into energy policy should be taken into account to minimise the avoidable costs.

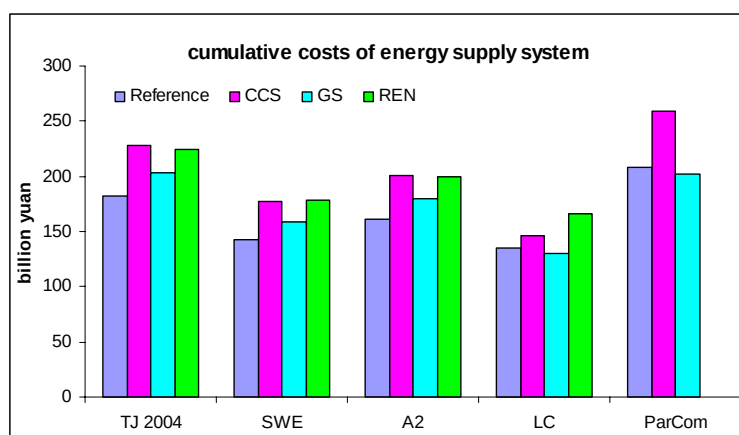


Figure 5-96 Cumulative costs in energy supply system 2005-2030

5.16.2 Assumptions on costs of alternative technologies

In fact, in almost all the scenarios, there will be surplus capacity of power generation in the large CHP plants, we consider that surplus electricity generated during the heating season will be purchased by distributors , i.e. the electric grid company which is beyond the cost analysis boundary since electricity can be dispatched to any parts of the regions by North China Grid. A question arises thus about whether or not the sale of electricity surplus to the network should be accounted for as benefits(negative costs). We will test the two hypotheses in the following calculation.

Case 1: surplus electricity is considered as waste

In this case, all surplus electricity of large CHP plants are simply wasted and is excluded from cost analysis, being out of the boundary of cost analysis.

Exclusion of CO₂ emission cost

Cost can be expressed as yearly cost and accumulated cost respectively, the optimal trajectory selection aims at identifying the scenario that minimises the present value of accumulated costs over the modelling period. First, we present the simulation results without the externality costs (CO₂ emission cost), then this environmental cost will be added with different pricing level.

1 .Cost breakdown in the case of non discounting in baseline scenario

When no explicit binding objective of carbon emission reduction is imposed by the authority, the emission cost will not be internalised in the overall cost analysis. Figure 5-97 illustrates the composition of yearly cost in different years over the modelling period when future costs are not discounted in the baseline scenario. It is shown that cost of energy supply (designated ad transformation cost in the model) will account for a large part of the total cost compared to the costs associated with buildings side investment (construction cost, appliances purchases and on site energy infrastructure development such as local substation and heat supply networks) . Note that costs associated with buildings efficiency only vary in residential buildings, building performance in commercial buildings is assumed identical between all scenarios.

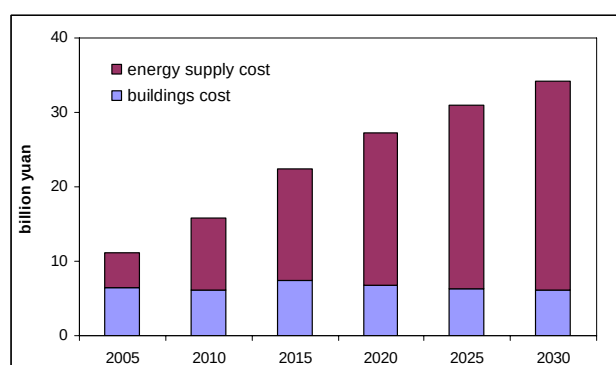


Figure 5-97. Non discounted Cost breakdown in baseline scenario

Nevertheless, the cost composition would give a different profile when the costs incurred in the future are discounted , Fig. 5-98 illustrates the cost breakdown when an 8% discount rate is applied.

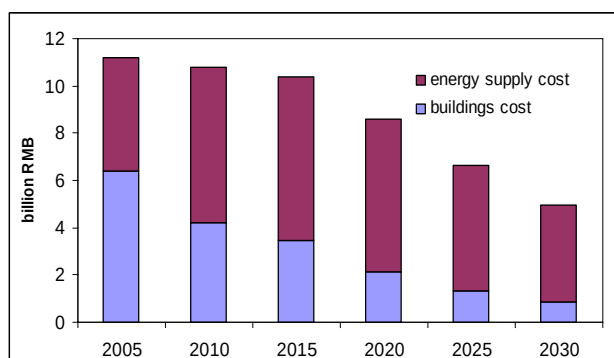


Figure 5-98. Levelised cost breakdown in baseline scenario

Energy supply will also represent the larger part of total cost of the system but to a much less extent in terms of absolute quantity, with detriment to energy cost saving measures in BEE policies.

5.16.3 Cost scenarios in different energy supply options

A) No consideration of electricity sale benefits

Similarly to the economic analysis on the end-user side, it is convenient to compare both the end year(2030) value and cumulative cost throughout the period of the major scenarios and their variants to illustrate the divergences in terms of cost to society. Varying discount rate will only change the order of magnitude of values but not the order of cost in a specific year, whereas it may impact order in the case of cumulative costs that will be discussed in parallel.

Choice of discount rate

As mentioned earlier, not discounting the future value can be hardly justified in the long-term economics analysis. Every investor will be confronting financial risk associated with uncertainty in the future. We adopted a reference discount rate of 8%, almost equal to the long term housing mortgage load interest rates indicated by the Chinese Central Bank. However, another rate can also be used such as the general IRR required by the large-scale urban infrastructure investment programme , specified in NDRC(2004). On the other hand, discount rate selection has been debated extensively in the climate change economic literature, some use extremely low discount rate , or nearly 0% for equalising the intergenerational equity (Stern, 2006; Steiner) , others argues a rate between 3-6% is more appropriate to take into account the integrated emission mitigation costs.

In the following section, we test the economic implications at different discount rates by increasing order: 0%, 4%, 8% , 10%, 12% and 16% . Intuitively, the choice of discount rate affects the present value in each scenario, high DR discourages the investment in BEE as the discounted future benefits tend to be less compared to low

DR cases. Figure 5-99 illustrates the degree of impact of different DR on yearly cost in the baseline scenario. It can be seen that values vary significantly depending on DR chosen, implying that political choice of perception of future impact and financial risk of capital investment is extremely determining in the optimal path investigation.

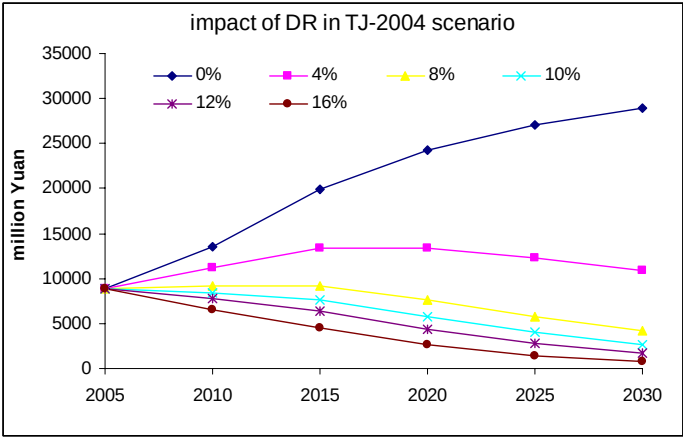


Figure 5-99 Simulated yearly costs of baseline scenario varying with DR

To keep the presentation brief and simple, we use three discount rate: 4%, 8% and 16% to represent low, medium and high discount rate respectively, along with a non-discount scenario (case of extreme concerns about future generation with DR=0%). Complete comparison with different discount rate between all scenarios under different DR assumptions is provided in Appendix II.

5.16.3.1 Base scenarios

Value in 2030

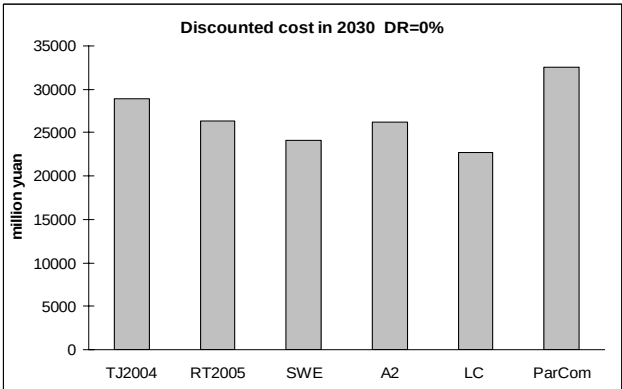


Figure 5-100. Comparison of scenarios of cost in 2030 in current year value with 8% discount rate

As shown in figure 5-100, the order of costs in 2030 in different scenarios remain unchanged when different DR is used regardless of differentiated magnitude order. LC is the costless scenario in 2030 while the ParCom is the most costly scenario. Cost differences compared to the baseline (TJ2004) vary between -21.3% and 12.5%.

Cumulative cost

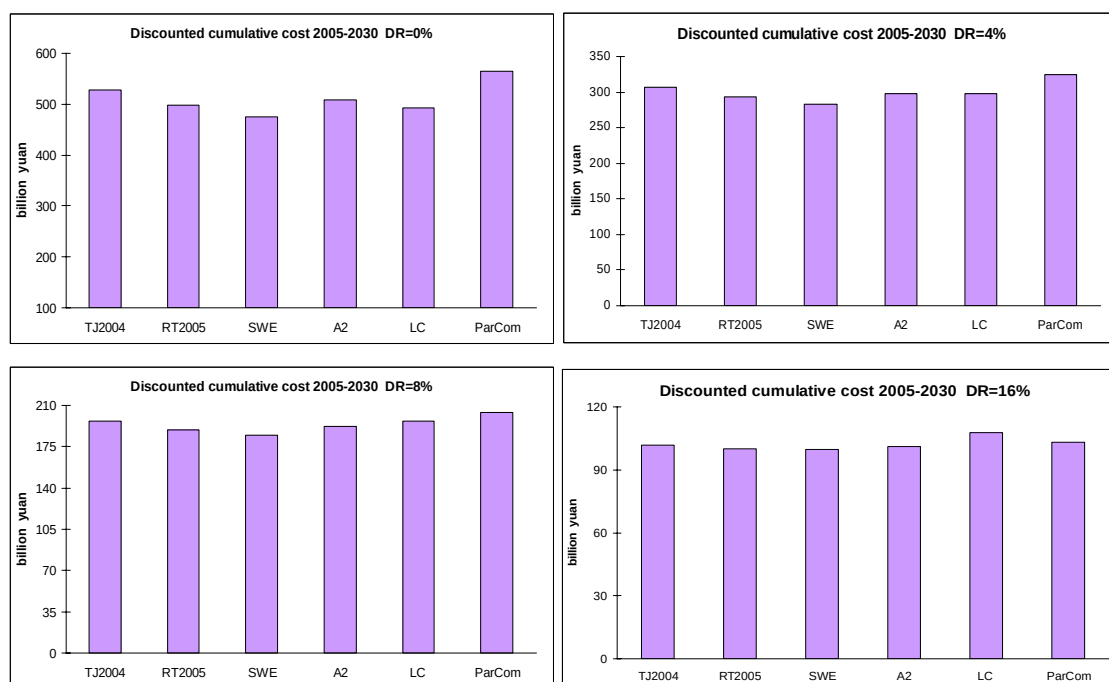


Figure 5-101 cumulative costs of base scenarios with different DR values

Comparison between value in 2030 and cumulative costs may give interesting different vision on the question of optimal BEE standards. For a social planner living in 2030, he certainly would like to adopt the LC scenario since the operation costs in this case is the lowest amongst all the scenarios. However, LC may lose its attractiveness if a decision living in today's society should select a best scenario. From economic analysis perspective, it is the SWE standard that should be adopted since it responses to the optimality objective (minimised discounted costs).

As shown in Fig.5-101, it is intuitive to see that variance of cumulative costs between the scenarios narrows as the chosen discount rate increases. SWE is the optimal BEE choice since the cumulative is minimised across all the scenarios regardless of discount rate chosen. Interestingly, we observe that ParCom is the most costly scenarios in the majority of cases. And LC overtakes ParCom to become the most costly scenario when DR is raised to very high(16%), this is intuitive since all the future energy savings potentials will be heavily disregarded compared with the case where low DR is used.

5.16.3.2 CCS option

Our modelling outcome suggests that CCS will generate significant increase in total costs over the whole period. Figures 5-102 compares the cost value in 2030 under different BEE scenarios when CCS is considered from 2020 .

Cost in 2030

The graphics below represent the cost of key scenarios in 2030 with different DR assumption. With 8% discount rate, the total cost of buildings and energy supply system with CCS will range between 27 and 42 billion RMB in 2030, significantly higher than base scenarios (22 to 32 billion RMB) due to the installation of carbon capture and storage facilities. The LC is still the least-cost option for the year 2030.

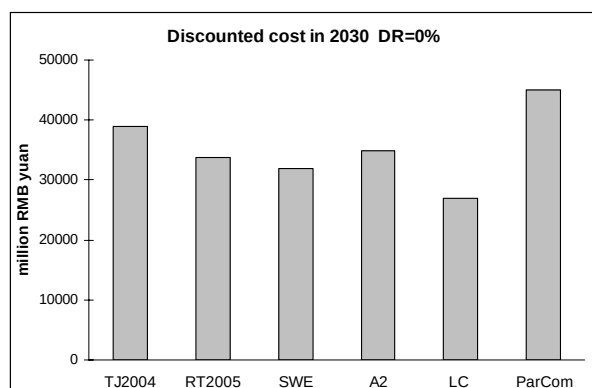


Figure 5-102. Comparison of scenarios of cost in 2030 with CCS option at different discount rate

Cumulative costs

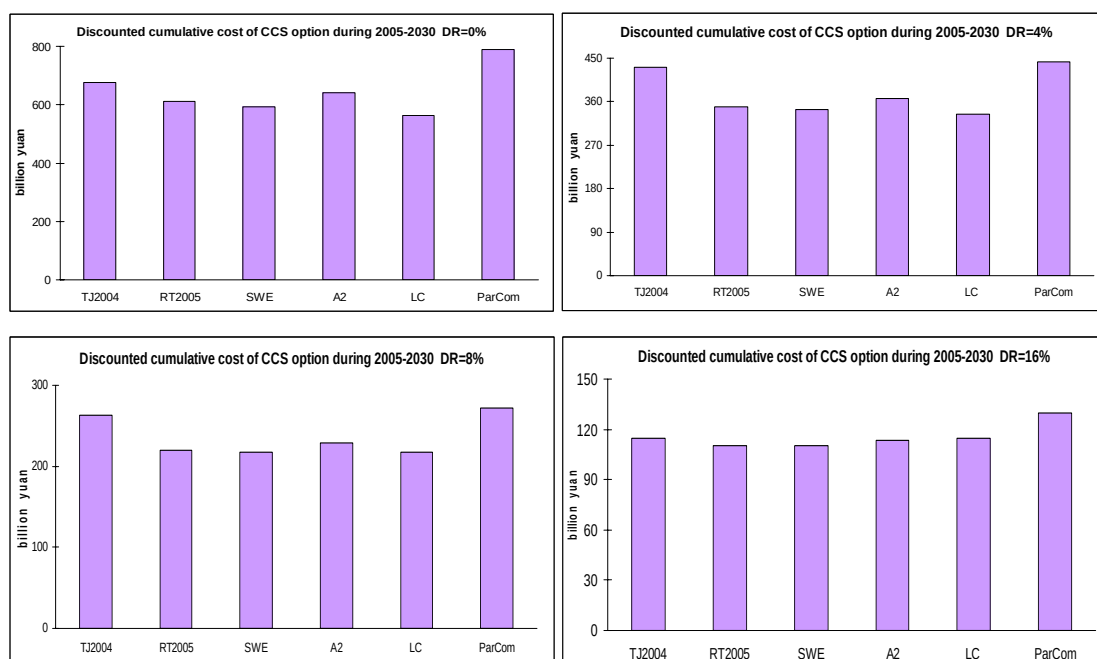


Figure 5-103 Cumulative costs of scenarios with CCS option

Several observations can be summed here. First, CCS is a very costly option and the total cumulative cost will see a considerable rise compared to the base scenarios, with total costs increasing by 6% to 40% compared to base case depending on BEE scenario and discount rate, increase in ParCom scenario is particularly significant. Second, contrary to the base case, the ParCom is always the most costly scenario, implying that

situation will even deteriorate with strong carbon emission constraints if the city will fail to implement effectively BEE standards in the new buildings, this is a typical example of the long-term carbon lock-in dilemma. In short, when carbon capture and storage technology is applied, the LC scenario becomes the most interesting BEE benchmark based on its low-emission advantages. This advantage tends to be reduced when the DR chosen is higher than 4%, when SWE will get very close to LC's cost value. RT2005 becomes the lowest-cost scenario when the highest DR(16%) is applied . The optimal scenario would be LC. Lastly, the choice of DR may be determining in some cases since the higher DR that we choose, the more the future benefits in terms of energy resources savings are discounted, investment in relevant technologies will be discouraged as a result.

5.16.4 Implement fuel-switching policy

Cost in 2030

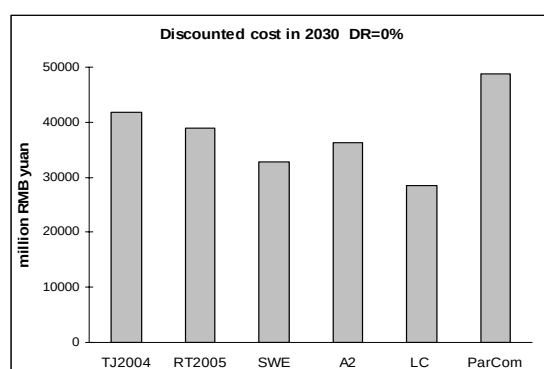


Figure 5-104. Comparison of scenarios of cost in 2030 with fuel switching option

Cumulative costs over period 2005-2030

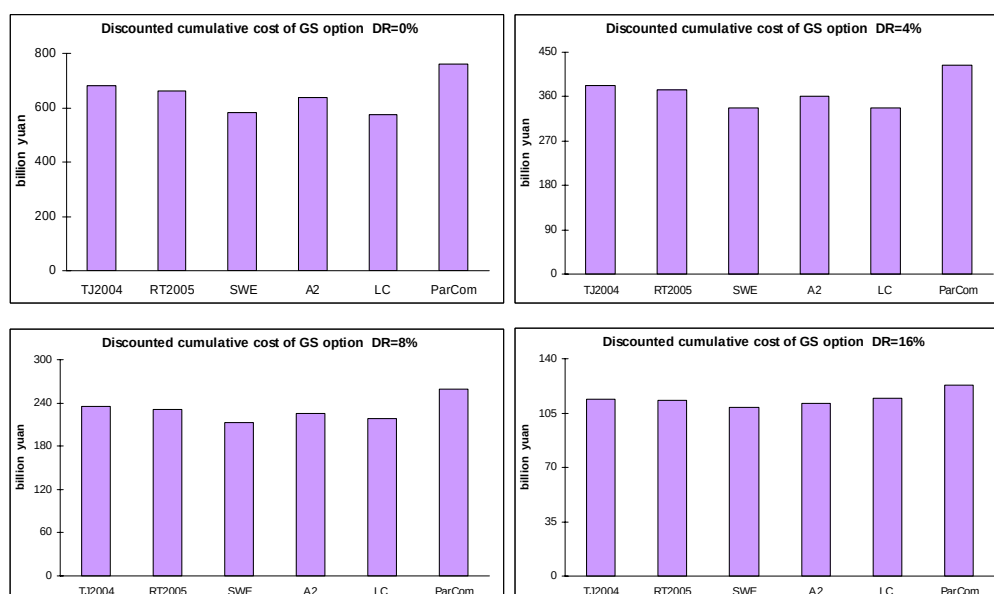


Figure 5-105. Cumulative costs of scenarios with CCS option

From Fig. 5-104 and 5-105, we can see that fuel-switch is also a very costly solution to decarbonise the buildings energy consumption and supply infrastructure. The yearly cost of all scenarios in 2030 will be even higher than the case of CCS option, cost in 2030 will increase by 28%-48% compared with the base scenario. Cumulative costs in fuel-switching scenarios are also significantly higher than base case, but are lower than CCS variants. SWE is unambiguously the optimal choice in the GS variant with minimised cost except for the Non-discounting case where LC is the best one.

5.16.5 Discounted CO₂ mitigation cost scenarios

Given the results of cumulative CO₂ emission and cumulative costs scenarios, the shadow price of CO₂ emission (average abatement cost) can be estimated using equation 5.11 described in subsection 5.9.6. Combining with the costs in different scenarios will produce the relevant CO₂ emission abatement cost. Two mitigation costs can be calculated depending on the inclusion boundary of costs.

a. Only the buildings costs are considered

In this case, only the discounted costs associated with the building-side investment (construction, retrofitting, heating equipment costs) are taken into account, in other words, this cost reflects the developer's viewpoint regarding the investment in building CO₂ mitigation programmes. Table 5-30 reports the average CO₂ mitigation costs varying with discount rates.

Table 5-30. Average CO₂ mitigation cost in buildings (building costs are considered only)

in US \$ /t CO₂-eq (2005 price)

		Discount rate				
		0%	4%	8%	10%	12%
ParCom without						
Re						
<i>TJ-2004</i>		3,8	6,0	8,5	9,9	11,4
<i>RT2005</i>		8,6	11,6	15,4	17,4	19,7
<i>SWE</i>		12,5	16,5	21,5	24,3	27,4
<i>A1</i>		10,1	12,1	14,4	15,7	17,1
<i>A2</i>		14,6	16,2	18,2	19,2	20,4
<i>A3</i>		19,3	23,7	29,2	32,3	35,6
ParCom with Re		6,6	8,0	10,0	11,3	12,8
<i>LC-R1</i>		19,0	23,4	28,9	31,9	35,2
<i>LC-R2004</i>		18,3	22,7	28,1	31,2	34,5
<i>Ref No retrofit</i>		0,8	3,4	6,2	7,7	9,2
<i>SWE-No retrofit</i>		11,8	15,8	20,8	23,6	26,7
<i>RT2005</i>	<i>No</i>	7,3	10,3	13,9	15,9	18,0

retrofit**Ref CCS****Ref GS**

A1 No Retrofit	8,8	10,6	12,7	13,8	15,0

A2 No Retrofit	14,0	15,4	17,0	17,9	18,8

LC-R1 CCS**LC-R1 CS**

CAN	6,5	9,1	12,2	14,0	15,8

CAN No retrofit	4,5	7,1	10,1	11,8	13,6

As expected, more the BEE requirements are higher, more mitigation costs will be incurred. The low-carbon scenario (A3, LC-R1, LC-R2004) are nearly three times higher than implementing TJ-2004 regulation. Mitigation costs increases with the discount rate, this is intuitive since the future benefits (here in terms of quantity of avoided CO₂ emission) shrink when discounted. This results shows that mitigation costs for a building programme developer can be much higher, or even double if a high discount rate is chosen compared to a virtual person who is extremely concerned about the interests of future generation and is ready to equalise the value of current dollar to that available in an indefinite future (DR=0). However, it is quite interesting to see that the gradual progress scenario (A2 among others) have relatively small variation of mitigation costs between the different selected discount rates, from a policy maker's perspective, it is easier to introduce the progressive advancement in energy regulatory standards since they are more likely to be accepted by the constructors. Policy instruments can be tailored accordingly to bridge the financing gap if this scenario is adopted.

5.16.6 Summary

Introduction of low-carbon technology such as CCS or implementing fuel-switching policy will entail significant rise in operation costs compared with the base case. However, by analysing the yearly and cumulative costs of the most representative scenarios, it is found that improvement in buildings in early stage of the modelling period will facilitate the financial resources formation to allow the local authority to make decision on new technology of energy supply. Moreover, better efficiency of buildings will also help reduce dramatically the costs of CO₂ abatement actions taken in fifteen years. A competitive carbon price originated from improved building performance is critical to look for international cooperation in climate change mitigation technology transfer and equitable burden sharing. A remarkable jump of investment costs are perceived in all scenarios, the degree of change is considerably less significant in high efficiency case (LC) than in lower case (ParCom). To avoid painful sharp jump in current year operation costs such as in the ParCom scenario, upfront buildings energy performance and quality of construction are of critical importance and should never be ignored, otherwise the city would be trapped into a vicious circle: lower efficient buildings results in costly operation

and thus less financial capacity could be formed to invest in low-carbon technologies to mitigate carbon emissions in the future. It is also found that fuel-switching policy would be more costly to implement than CCS despite of mature status of this technology.

Selecting the optimal BEE scenario is not trivial. Decision will be dependent on the perspective from which the decision will be made. If we are concerned with the fact how future generation will deal with the historical buildings heritage that we pass on to them, the most efficiency scenario (LC) should be taken immediately. However, due to the inherent uncertainty feature in all economic analysis dealing with future benefits and costs, the policy maker today will seeks to find out the least-cost scenario which minimises the discounted present costs. The modelling results suggest that choosing the best trajectory (with the lowest discounted costs) of BEE evolution seems to favour SWE if only cost issue is taken into account. Varying the discount rate will not change dramatically the order of decision on investment strategy. Alternatively, if a compulsory objective of sectoral CO₂ emission reduction is the primary policy priority, then the LC+ CCS would be considered as priority in BEE policy implementation. However, this implies a huge cost of learning and sectoral transformation of technology, practice and institutions that will be discussed further in the next chapter.

5.17 Cost scenarios with carbon constraints (Inclusion of CO₂ emission costs)

International carbon trading prices (EU- ETS, Chicago Mercantile Exchange and CDM project) are regarded as the benchmark of carbon emission costs. A tax-like carbon levy is assumed to be imposed on thermal power plants from 2010 in all scenarios. Carbon price is projected evolve under three scenarios, low, medium and high prospects respectively, the assumption on prices is represented in Fig. 5-106.

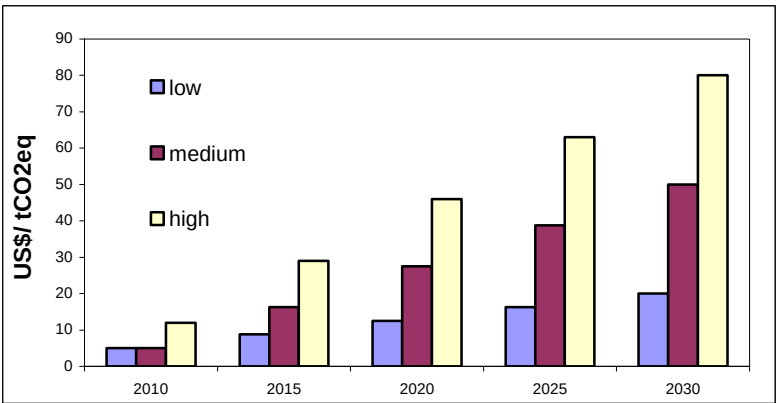


Figure 5-106. Assumptions on CO₂ emission costs

As mentioned earlier, China is likely to face the imposition of carbon emission reduction obligation in the next decades although the post-Kyoto regime is not totally clarified. It is reasonable to project the scenarios with internalisation of environmental cost. We simulated the scenarios with carbon emission costs varying at

different carbon price as follows. Uncertainty about CO₂ emission cost is resolved by placing differentiated price evolution outlook. However, it is quite clear that global CO₂ price will pursue an ascending trend. For example, EU-ETS CO₂ price stabilises at €25-27 per metric tonne CO₂ in the European Union, some models projects the price at 50-70 € PMC by 2030 (Imaclim-e, Pole 2007). The implementation of the second phase EU-NAP, more emission constraints will be placed onto the energy consuming industrials. Some arguments about if the utility companies may pass on CO₂ cost to the end users are still debated widely across the nations.

5.17.1 Outcome of simulated scenarios

A) When electricity sale benefits are excluded

Below only cumulative costs are discussed to identify directly the most cost-effective BEE implementation scenarios.

a. low carbon price

Figure 5-107 compares the cumulative costs of basecase, CCS and GS variants with different discount rate assumptions , similarly to the Non-carbon constraints scenarios, four different DR is tested , 4%; 8% and 16% to represent low , medium and high assumption respectively, with DR=0% to represent the extreme assumption on perception on future risk and benefit.

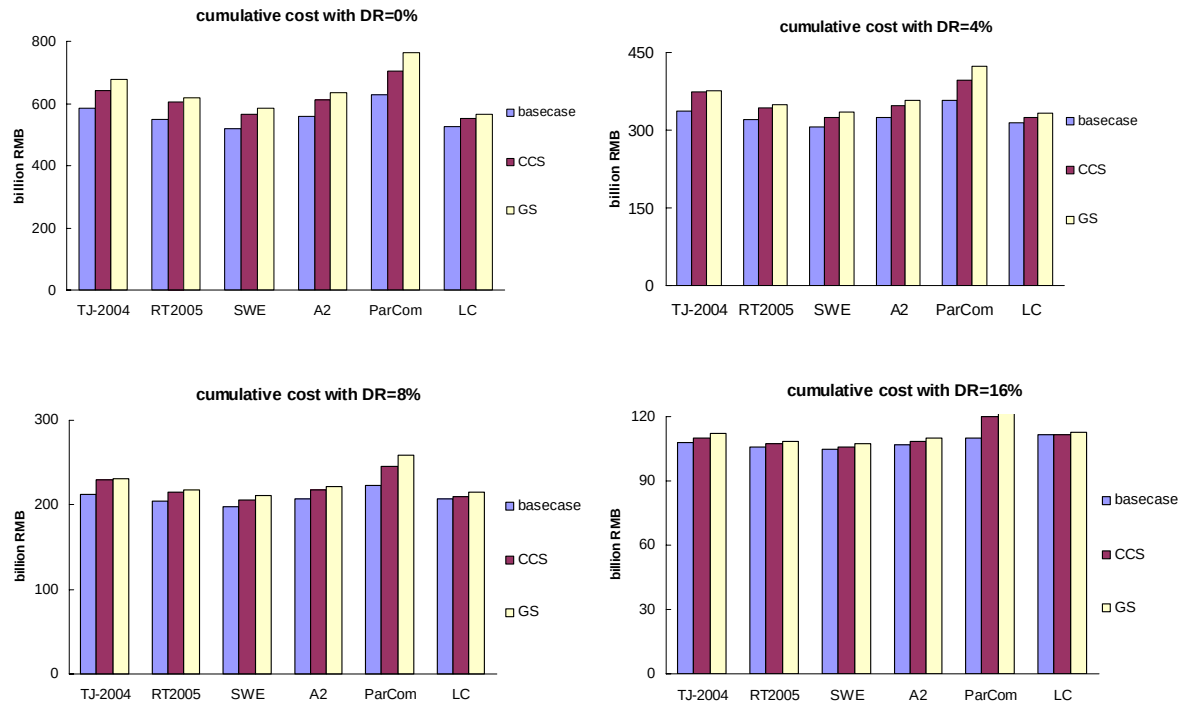


Figure 5-107. Cumulative costs of scenarios with low carbon price

Figure 5-107 shows the scenarios of cumulative costs with different supply technologies and different discount rates when low carbon price is imposed in buildings consumption-related greenhouse gases emissions. Not surprisingly, CCS and Gas-switching options will still be significantly higher than basecase, and more specifically, gas-switch option is costlier than CCS, and the costs of CCS and fuel-switching tend to converge as the discount

rate increases. In the basecase, SWE is unanimously the optimal choice regardless of discount rate. However, if the city opts for CCS and or GS policy from 2005 as assumed in the model, the LC would be the best choice to minimise the costs if the discount rate is lower than 8%. SWE become again the rational choice when the DR is greater than 8% even for CCS and GS options.

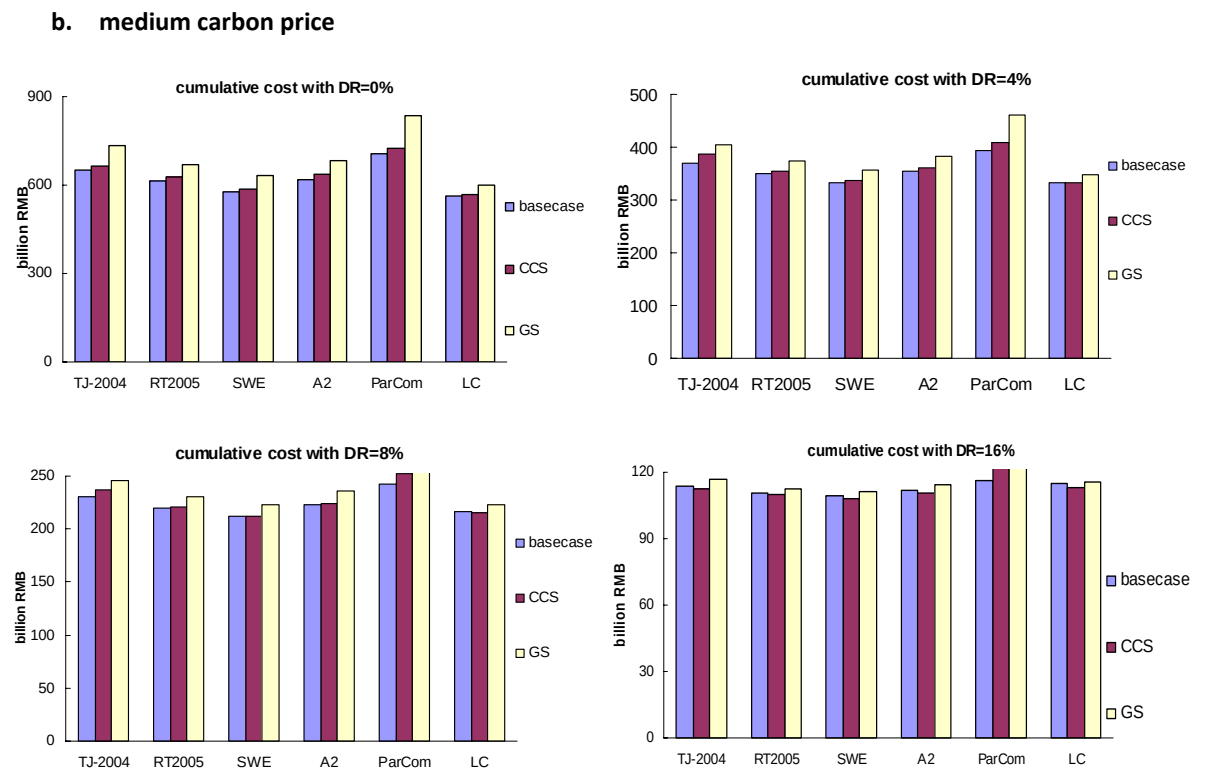


Figure 5-108. Cumulative costs of scenarios with medium carbon price

Under the medium carbon price constraint. LC is the best scenario for all energy supply options when the DR is below 8% except for base case. And SWE allows for the lowest discounted costs in all scenarios when the DR is higher than 8%, as shown in Fig 5-108.

c. high carbon price

Figure 5-109 compares different scenarios when high carbon price is included in the costs. Situation of this scenario is quite unique. The scenario ordering is highly sensitive to the discount rate chosen. LC is the optimal choice for all technology options when the DR is less than 10% , otherwise SWE is preferred on the basis of costs minimised.

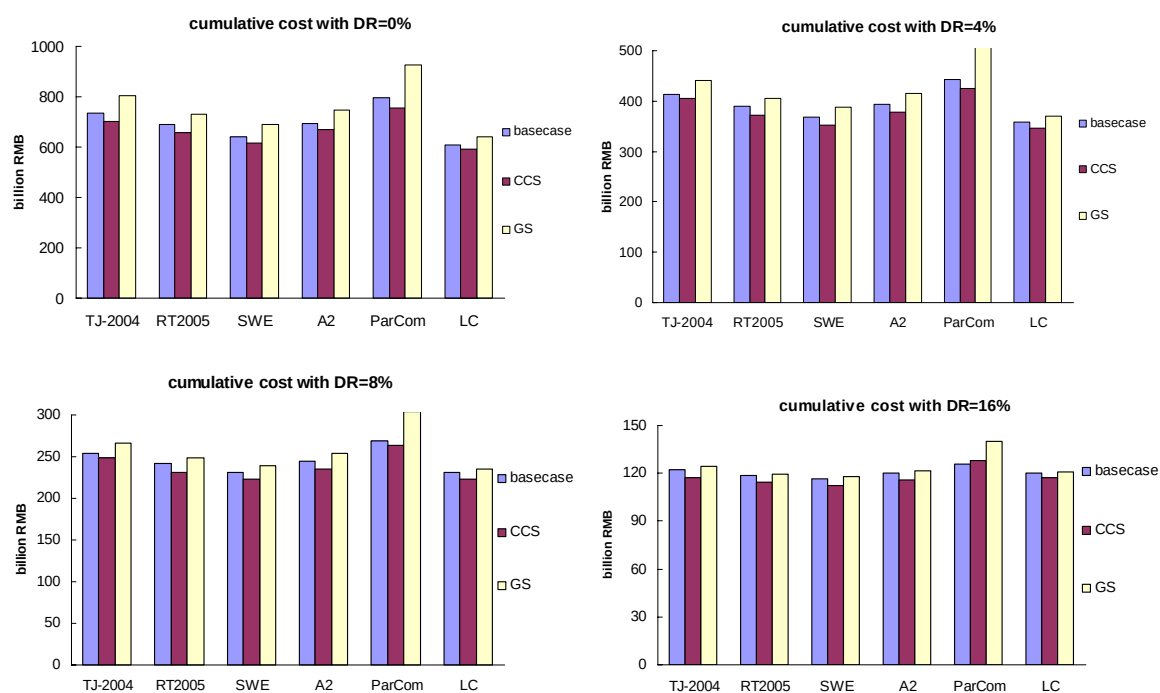
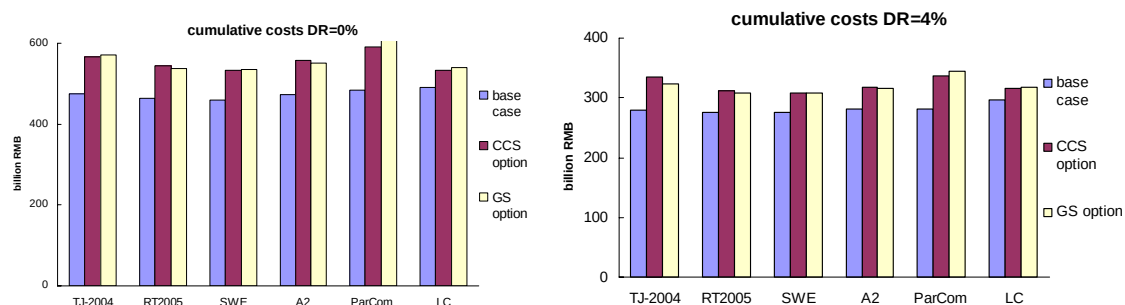


Figure 5-109 Cumulative costs of scenarios with high carbon price

B) When electricity sale benefits are taken into account

In all of scenarios presented below, it is assumed that electricity wholesale price increase 1% per year up to 2030. To make the results more illustrative, only cumulative costs are presented below. Complete results of yearly value are available in Appendix II.

I. Exclusion of carbon price



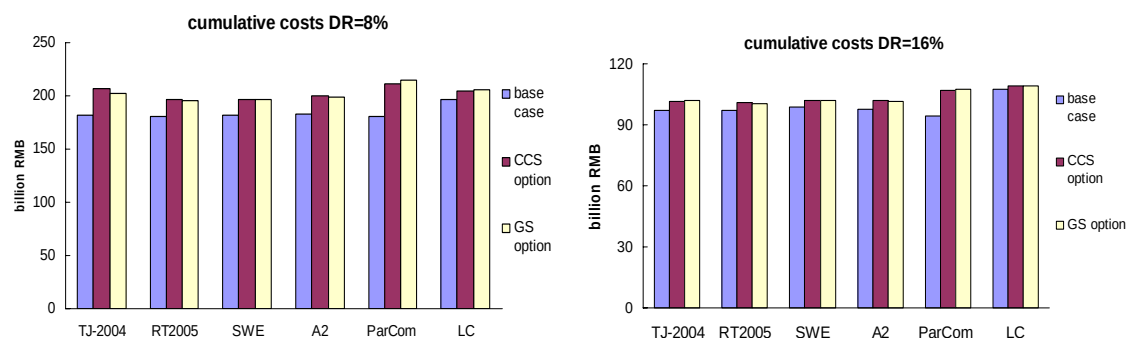


Figure 5-110 Scenarios of cumulative costs without carbon emission cost

When no carbon price is taken into account, SWE is the optimal choice when the DR is lower than 8% otherwise the ParCom will be the optimal choice. This result is very striking, it can be explained by the fact that the power generators have incentives to add new generating capacity to sell electricity.

II. With carbon price

Past experiences show that explicit carbon price and supportive public policy are needed to encourage the development of low-carbon and or carbon-free technology. Below we considered three alternative energy supply options: CCS, Fuel-switching (GS) and Renewable energy (RENs), recall that 40% of heating resources in RENs scenario is MSW, followed by agricultural waste (essentially the straws) and other biomass resources.

a. low carbon price

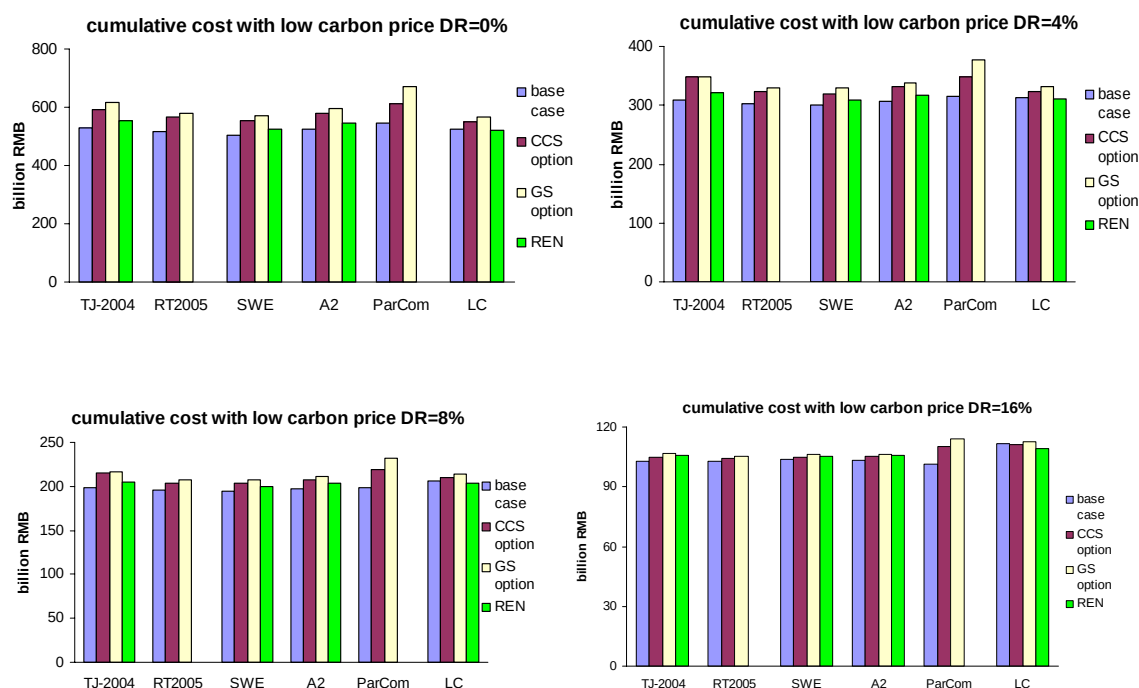


Figure 5-111 scenarios of cumulative costs with low carbon price

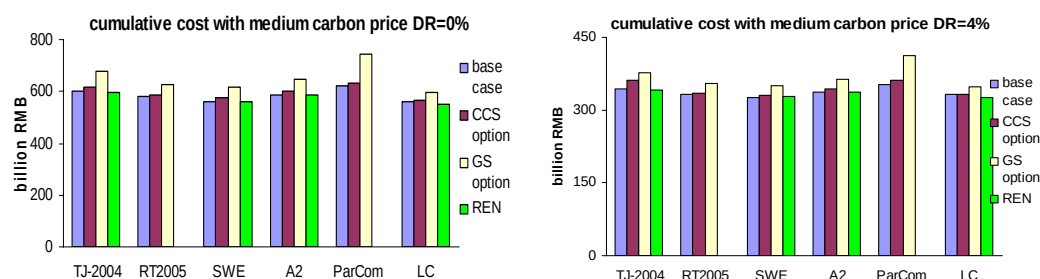
From Figure 5-111, we can see that under less stringent carbon emission constraints translated by implementation of low carbon price, the carbon-free or less carbon intensive supply technologies will favour the LC BEE if no future benefits will be discounted (DR= 0%). SWE is optimal choice for the basecase technology when DR is less than 10%, RT2005 will be the most interesting for basecase if chosen DR is larger than 10%, while SWE is still the optimal choice for CCS and GS options if DR is less than 12%. The choice can be summarised in the following matrix. RT2005 and SWE dominate the CCS and GS option, respectively.

Matrix of optimal scenario selection

DR	Baseline technology	CCS	GS	REN	REN
0%	SWE	LC	LC	LC	LC
4%		LC	SWE	LC	SWE
8%		RT2005	SWE	SWE	SWE
10%	RT2005	RT2005	SWE	SWE	SWE
12%	ParCom	RT2005	SWE		SWE
16%	ParCom	RT2005	SWE		SWE

Strikingly, ParCom would become optimal in the basecase supply technology when high DR is adopted, this result reveals the fact that electricity sale benefits could give incentives for energy supplier to increase supply capacity with detriment to the efficiency consideration in the buildings.

b. medium carbon price



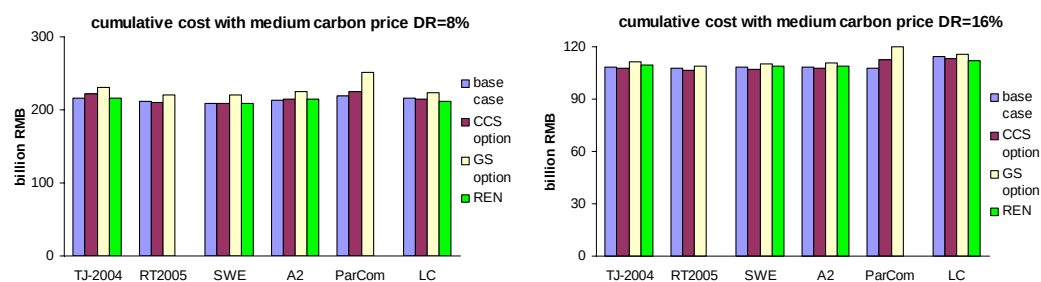
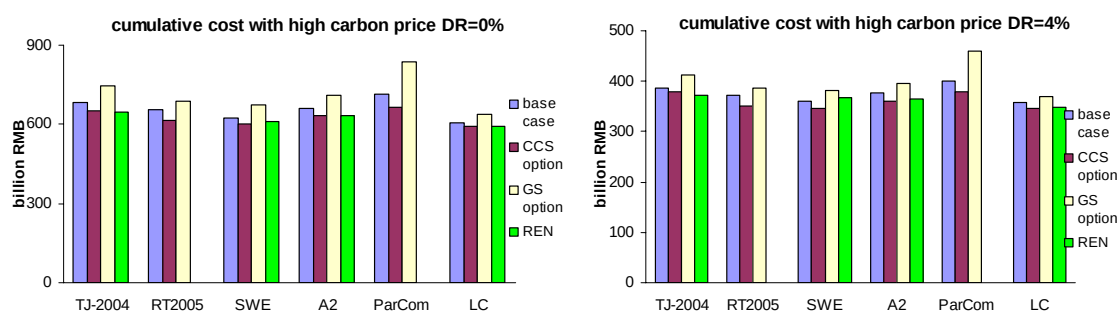


Figure 5-112 Cumulative costs with medium carbon price

Medium carbon price constraints give almost identical results as in the case of low carbon price, the optimal choice is summarised in the matrix below.

DR	Basecase	CCS	GS	REN
0%	SWE	LC	LC	LC
4%	SWE	LC	SWE	LC
8%	SWE	RT2005	SWE	SWE
10%	SWE	RT2005	SWE	SWE
12%	SWE	RT2005	SWE	SWE
16%	RT2005	RT2005	SWE	SWE

c. high carbon price



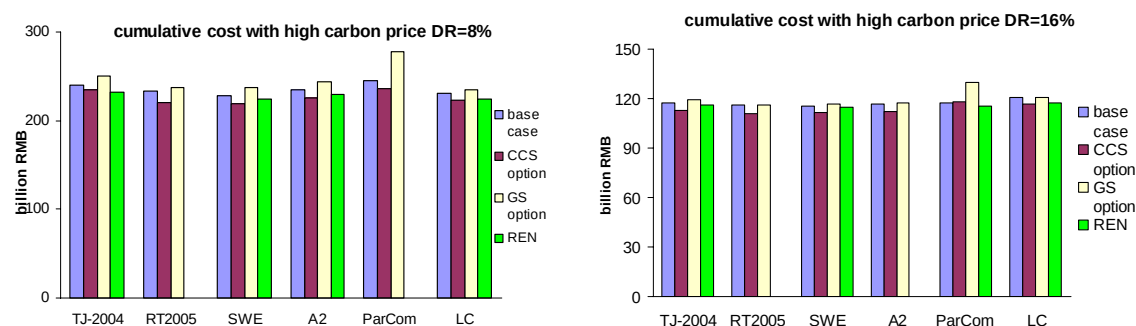


Figure 5-113. Scenarios of cumulative costs with high carbon price

Finally, high carbon price constraints scenario gives a different result from previous cases. REN option becomes dominant strategy which allows achieving the least costs regardless of DR chosen. LC is optimal when the DR is lower than 8%, otherwise SWE should be taken, the optimal choice matrix is as follows.

DR	Baseline technology	CCS	GS	REN
0%	LC	LC	LC	LC
4%	LC	LC	LC	LC
8%	SWE	RT2005	LC	LC
10%	SWE	RT2005	SWE	SWE
12%	SWE	RT2005	SWE	SWE
16%	SWE	RT2005	SWE	SWE

5.18 Decision on optimal BEE choice in SYS2 energy supply system

Since the low-carbon energy supply technologies are costlier than the basecase in most cases except for REN when high carbon constraints will be imposed, the optimal choice should be selected from basecase technology in the SYS2. Thus SWE is a dominant strategy for almost all assumptions. However, the low-carbon constraints coupled with high discount rate reflecting strong uncertainty of future energy price and energy savings potentials will impede the uptake of more efficient BEE standards, as in the case of lower left in the matrix of low carbon price.

5.18.1 Assessment of all scenarios and variants

In fact, differentiating the discount rate does not produce significant impact on the output order of total costs between the scenarios, while the difference between each other narrows as the DR increases. The yearly costs in all selected scenarios converge eventually as the discount rate rises. It can be seen that they costs are almost identical in all scenarios in 2030 when the DR is raised to above 10%, except the greenest scenario (Low-carbon).

The most important lesson from the output we can draw is that the current building code – TJ-2004 is NOT the best one in none of the simulated scenarios no matter what discount rate is applied. It is in some case very costly compared to other scenarios, consequently it must be upgraded as soon as possible in the following years.

On the other hand, similar to the annual cost scenarios, the cumulative costs will converge as the discount rate rises. However, discount rate has virtually no impact on the output the best scenario if the end year is fixed at 2030 , *SWE* is identified as the least cost option in all the scenarios. Selection of different time frame can give slightly different results. For example, *RT2005-No Retrofit* for a nearer term perspective 2005-2015.

Tables and figures above show that the *SWE* scenario is predominately the best trajectory for the BEE regulations in the absence of carbon emission cost, for this storyline minimises the accumulated cost defined as above up to 2030, except for the case when an extremely low (zero) discount is selected, by which the *LC-R2004* would be the optimal choice. It is demonstrated that the cumulative costs of most scenarios differ from one another insignificantly or even overlap. As expected, the variants *CCS* and *gas-switching* in the “Partly and no retrofit” scenario will be the most costly scenario, implying that the failure of immediate enforcement and implementation plus carbon constraints will result in huge loss in the future and could be the worst scenario even a high discount rate is applied; although the loss can be reduced to some extent by “retrofitting ”, incurring still a higher cost compared to all the compliance scenarios. Interestingly, the Low-carbon scenarios, such as *LC R1*, *LC 2004*, *A3* among others, will not be necessarily excessively more costly than other scenarios as one may imagine. They are even less costly than the baseline building codes when a low discount rate is chosen by the planner to favour future savings value. Certainly, much higher cost will be incurred if high discount rate is applied despite the obvious environmental benefits over the course of modelling period.

Case I . Without consideration of electricity surplus sale

When slow increase in CO₂ price is expected , the *SWE* still turns out to be the optimal scenario as the costs incurred can be minimised. Obviously, installing *CCS* and implement gas-switching policy in power plants will entail considerable increase in total costs , especially when the buildings are not in compliance with BEE standards.

Case II . Electricity surplus sale benefits are taken into account

Contrary to the case where electricity sale is not taken into account, the inclusion of electricity sale benefits gives different outcome of optimal BEE choice in some cases, in particular when low carbon price is coupled with high discount rate. This implies that increasing electricity sale price is likely to give incentives for the energy company to build new generating capacity instead of investing in energy efficiency or decarbonisation technology such as NGCC and CCS, renewable district heating and so on. Nevertheless, SWE is still the optimal BEE choice in most cases no matter what supply option is selected except for the high carbon price case where LC is the dominant choice.

5.18.2 Summary of scenario results

With the high carbon emission costs exhibits, the Low carbon BEE should be considered the best choice when the discounted rate is extremely low (less than 4%). However, the SWE is invariably the wise decision on BEE when using a normal discount rate (above 4%). However, RT-2005 is preferred in many cases when the time horizon is limited to 2020 and with a rapid increase in wholesale electricity price to the grid. We tested an extremely high electricity price escalation variant in the high-discount rate scenarios; RT-2005 appears again to be the least cost scenario. In addition, we found in some case the “RT2005 NonRF” (without rehabilitation in existing housing stock) will allow for the least cost , implying that the municipality could achieve an economic optimum without any intervention in the old housing. However, as discussed in the subsection of final demand side energy and household energy burden, this is unacceptable from social equality point of view, inhabitants living in the existing buildings should have the same possibility to improve the thermal comfort in their houses. Otherwise the people living in the existing buildings , in particular the low-income family will be worse-off and see their energy bill increasing dramatically if the municipality is committed to implementing market-based heat billing and pricing, this issue will be discussed in detail in next two chapters. This is the reason why our decision on choosing the optimal BEE standards will only be made among the scenarios in which retrofitting and rehabilitation will be undertaken.

5.19 System 3 energy supply scenario

This section briefly discusses the results of SYS3 energy supply system which does not take into account any ambitious renewable promoting variants since all upstream energy supply will follow the municipal district heating plan. General assumptions on model variables and the heat supply plan of the Municipality of Tianjin can be found in Appendix III. Note that REN variants are not applicable in all SYS3 scenarios since the municipal plan’s vision on renewable has not yet been defined clearly although the municipality is very keen on large-

scale deployment of natural gas-fuelled and geothermal heating in the future. To keep the discussion as brief as possible, only costs results are reported below.

5.19.1 Major assumptions in CCS and fuel-switching scenarios

5.19.1.1 CCS

CCS variants in “system 3” supply scenario is almost identical to “system 2” , all large CHP will be equipped with CCS including PC, NGCC and IGCC power & heat plants.

5.19.1.2 Gas switch variants

Of all “fuel-switching” variants of simulated scenarios , it is assumed that 80% of coal-fired district boilers will be retrofitted to use gas, the rest will be retired after 15 years service. On the other hand, all new built supply capacities (all of them are large municipal CHP according to Tianjin’s district heating plan) are assumed to opt for NGCC from the year 2015 under the “switch” variants, while the large municipal CHPs installed and operated before 2015 will continue to use coal until the end of modelling period. It is by no means that 100% of exiting generating capacity will switch to gas with no extra cost of retrofitting.

5.19.2 Cost assumption

Cost associated with CCS technology (capital cost and operational costs) is modelled with IEA(2000)’s experience curve model. We assume that the progress rate of CCS is 92%, the PR of US FD cost reduction is used as a reference. As CCS is quite distinct from FD techniques, we assume that the room for reduction is smaller than FD. Thus a learning rate of 8% is used in the LEAP model, implying that each doubling of installed CCS capacity allows reducing 8% of costs. Indeed, the modelling is focused on the demand-side measures (improvements in EE), assuming that the supply-side technological change is identical in all scenarios.

5.19.3 Main findings of SYS3 supply option

SYS2 supply options are generally more costly than SYS2 , this reflects the fact that the current district heating plan is not an optimised in the sense that the demand-side management (DSM) policies in building sector are not fully taken into account in the municipal energy supply planning. In other words, a synergy between energy supplier and BEE policy makers in the city needs to be created to attain the optimal technical option.

Contrary to SYS3 scenarios, the choice of DR has significant impact on the outcome order of BEE options. SWE remains the best solution when the DR is lower than 8%, RT 2005 would be optimal when RT lies between 8% and 12%; beyond which the CAN should be opted ; TJ-2004 has to be kept unchanged if we choose a high discount rate (greater than 16%). However, the difference of cumulative cost between narrows when DR increases, i.e. less than half billion between TJ2004 and RT 2005. If the local government reason in terms of

long term objective of energy supply security and environmental protection, the current BEE standard should be upgraded even without any external carbon constraints.

5.19.4 Cumulative cost internalising CO₂ emission cost

The results of cumulative costs in SYS3 are reported in Table 5-31 through 5-36 depending on DR chosen. All numbers are expressed in million Yuan (2005 price) with red colour indicating the optimal scenario.

-Low carbon price assumption

Table 5-31 cumulative costs with DR=4%

	2010	2015	2020	2025	2030
TJ-2004	58547	126068	201208	274441	341976
RT2005	60247	127893	200964	271066	335190
SWE	62568	131079	202056	268762	329086
CAN	59296	126683	200632	272062	337773
LC-R2004	68515	144791	219479	285851	342901

Table 5-32 cumulative costs with DR=8%

	2010	2015	2020	2025	2030
TJ-2004	53194	103024	149070	186279	214723
RT2005	54737	104691	149481	185104	212114
SWE	56841	107469	150990	184894	210307
CAN	53875	103621	148944	185239	212914
LC-R2004	62142	118541	164378	198139	222186

Table 5-33 cumulative costs with DR=16%

	2010	2015	2020	2025	2030
TJ-2004	44892	73149	91512	101918	107493
RT2005	46186	74548	92419	102384	107680
SWE	47948	76729	94104	103592	108576
CAN	45464	73690	91770	101921	107346
LC-R2004	52243	84338	102669	112130	116851

Under the low-carbon constraints, SWE still seems to be the optimal choice in most cases as long as the DR is below 12%. RT2005 and CAN would be preferred when the DR is greater than 12% and 16%, respectively.

-Medium carbon price assumption

Table 5-34 cumulative costs under medium carbon constraints with DR=0%

	2010	2015	2020	2025	2030
TJ-2004	65143	162336	300827	471344	666972
RT2005	67022	164034	297947	460056	644404
SWE	69599	167442	296468	449036	620183
CAN	65967	162732	298337	463380	652400
LC-R2004	76306	184088	316351	462510	617740

Table 5-35 DR=8%

	2010	2015	2020	2025	2030
TJ-2004	53306	105348	156137	198832	232254
RT2005	54843	106862	156002	196606	228108
SWE	56946	109495	156878	195112	224368
CAN	53983	105831	155583	196914	229204
LC-R2004	62237	120223	168907	205600	232169
A2+CCS	53298	108743	169352	216324	250559

Table 5-36 DR=16%

	2010	2015	2020	2025	2030
TJ-2004	44970	74427	94654	106584	113132
RT2005	46261	75743	95324	106673	112846
SWE	48022	77847	96742	107434	113168
CAN	45540	74906	94728	106278	112604
LC-R2004	52310	85272	104725	115003	120217

Observation of optimal choice

DR< 4%	LC
4%<DR<16%	SWE
DR>=16%	CAN

Under the medium carbon constraints assumption, LC standards turns out to be the best one when DR is extremely low(<4%), then SWE is optimal except for the case where the DR is greater than 16%, CAN becomes then optimal.

-High carbon price assumption

Table 5-37 DR=0%

	2010	2015	2020	2025	2030
TJ-2004	66126	173109	329244	524549	750168
RT2005	67961	174128	324219	508825	720233
SWE	70526	176935	320326	492438	686731
CAN	66919	173003	325080	512875	729714
LC-R2004	77142	192071	334909	494297	664703

Table 5-38 DR=8%

	2010	2015	2020	2025	2030
TJ-2004	53974	111210	168435	217323	255862
RT2005	55482	112362	167405	213630	249750
SWE	57578	114686	167316	210436	243644
CAN	54630	111426	167192	214205	251238
LC-R2004	62806	124615	177175	217177	246340

Table 5-39 DR=16%

	2010	2015	2020	2025	2030
TJ-2004	45438	77808	100585	114241	121790
RT2005	46708	78919	100840	113757	120833
SWE	48463	80855	101832	113886	120395
CAN	45993	78136	100343	113477	120730
LC-R2004	52708	87832	108827	120028	125750

Observation of optimal choice

DR< 8%	LC
DR>=8%	SWE

When high carbon constraints are to be placed, high efficient BEE scenarios are favoured. More specifically, LC standard need to be considered when the DR is lower than 8%; whereas SWE is optimal choice for all the rest of DR assumptions.

A. Electricity sale benefits are taken into account

To keep the analysis simple and brief, here only the cumulative costs are presented. The on-grid electricity price of North China Grid is revised by the NDRC, currently all thermal power electricity tariff is 360 yuan/MWh. We expected that the tariff increase 0.5% per year over the whole period. Recall that the non-retrofitting variants should not be considered as the best trajectory even the cost incurred is minimised amid all the scenarios since this economic “gain” can not justify the social equity. People living in existing houses should have the same right to decent condition and improved thermal comfort. Rehabilitation and retrofitting will be undertaken in part of existing buildings stock financed by the municipality, corporate and inhabitants. The Tangshan⁷⁸ model can be served as an example. As said before, optimal scenario is only selected from the compliance scenarios.

1. Without consideration of carbon price

DR=4%	2010	2015	2020	2025	2030
TJ-2004	57.87	118.96	181.82	240.15	293.36
RT2005	59.60	122.24	185.97	244.50	297.54
SWE	61.93	126.11	190.88	249.89	303.05
A2	57.87	120.67	185.82	246.51	300.85
ParCom	59.85	124.82	193.47	256.97	314.63
LC-R2004	67.94	140.59	210.90	272.69	325.42

DR=8%	2010	2015	2020	2025	2030
TJ-2004	52.64	97.78	136.34	165.99	188.40
RT2005	54.20	100.49	139.60	169.35	191.69
SWE	56.31	103.75	143.50	173.49	195.89
A2	52.63	99.06	139.03	169.88	192.78
ParCom	54.40	102.38	144.48	176.76	201.04

⁷⁸ See section 5.8 for full description of technical parametres in the project.

DR=16%	2010	2015	2020	2025	2030
TJ-2004	44.50	70.17	85.58	93.87	98.27
RT2005	45.81	72.14	87.76	96.09	100.47
SWE	47.58	74.56	90.45	98.85	103.24
A2	44.50	70.90	86.88	95.52	100.01
ParCom without Re	45.93	73.18	90.00	99.03	103.79
LC-R2004	51.91	82.49	99.76	108.57	112.94

When the sale of electricity is taken into account and without any carbon constraints, the choice of optimal BEE standard is quite delicate, the current building efficiency standard TJ-2004 is the optimal choice in the entire scenario regardless of discount rate. Also, we found that RT-No RF would be less costly than TJ-2004 if the DR is relatively high, in other words, the municipality has the incentive to upgrade BEE standard in new buildings while ignoring retrofitting in existing building, this in fact reflects again the fact that BEE should be enforced and implemented during construction stage as rehabilitation and retrofitting will entail additional costs.

2. Inclusion of carbon price

Table 5-40 summarises the results of optimal BEE under different carbon price and discount rate assumptions as well as timing.

Table 5-40. Summary of scenarios output with carbon price

	2020	2025	2030
Low carbon price			
4%	TJ-2004	TJ-2004	CAN
8%	TJ-2004	TJ-2004	TJ-2004
16%	TJ-2004	TJ-2004	TJ-2004
Medium carbon price			
4%	TJ-2004	TJ-2004	SWE
8%	TJ-2004	CAN	CAN
16%	TJ-2004	TJ-2004	TJ-2004
High carbon price			
4%	CAN	SWE	SWE
8%	CAN	CAN	SWE
16%	TJ-2004	CAN	CAN

In case where the electricity generated in the power and CHP plants can be exported to another region at competitive price, it can be seen that TJ-2004 would be dominant if the carbon price is low and discount rate is high. If carbon price is raised enough high, then the city should adopt SWE as the right choice. It can be understood that the local authority has incentives to keep the current BEE standards as indicative values if the price of electricity wholesale is sufficiently high. However, it should be borne in mind that China has already deregulated the power generation market, Tianjin's local CHP and power plants also face keen competition with other power generators located in other regions. Thus the assumption implied in this scenario (all surpluses will be purchased in electric power market). Furthermore, the fundamental hypothesis is that the city of Tianjin could buy the electricity from the grid with the same price that it sells to the grid during heating season, however, the marginal price in summer could be much higher than the DH season, this means that the perfect buy-in and sell-out policy is questionable in the current context. Thus the TJ-2004 should not be considered as the optimal choice despite the apparent lowest discount rate. If the purchase price of electricity is sufficient high, the advantage produced by its "surplus" capacity of electricity generation will be offset in part or entirely.

5.19.5 Discussion of scenarios

5.19.5.1 Costs of abatement in the key scenarios

Table 5-41. comparison of abatement costs

	Coal BAU	CCS	GS
RT2005	-56	32	39
A2	-38	43	67
SWE	-43	7	8
LC	1	11	14

Note: Reference is TJ-2004 coupled with coal-fired heating system

Table 5-41 compares the cost of abatement in different scenarios of BEE standards and energy supply systems. It is clearly shown that the City needs to tighten the BEE requirements immediately in the BAU scenario since the costs are negative. In contrast, the more stringent buildings performance are also necessary if the city will be required to decarbonise the energy supply infrastructure such as scaled deployment of installation of CCS or implementing fuel switching from 2020. The strategy matrix situated in the red circle refers to the rational choices since the costs of abatement will be significantly lower than otherwise.

5.19.5.2 Comparison between SYS2 and SYS3 supply options

Primary energy demand

In the long term, primary energy in SYS3 is generally higher than in SYS2. Figures compare the simulated primary energy demand of baseline and baseline+CCS scenarios in SYS2 and SYS3, respectively. Table 5-42 summarises the increase rate in energy demand of SYS3 relative to SYS2 in different scenarios and timing.

Table 5-42. Increase rate in energy demand of SYS3 relative to SYS2

	2010	2020	2025	2030
TJ-2004	0.56%	1.26%	2.16%	3.73%
RT2005	3.30%	1.22%	2.14%	3.67%
SWE	3.09%	1.18%	2.10%	3.58%
A1	0.56%	1.18%	2.04%	3.51%
A2	0.56%	1.13%	1.97%	3.39%
A2+CCS	0.65%	6.28%	6.49%	7.76%
A2+Gas Switching	2.11%	3.98%	5.35%	4.47%
A3	4.45%	9.00%	7.77%	11.81%
ParCom with Re	-1.53%	1.12%	2.19%	4.56%
ParCom without Re	-1.53%	1.31%	2.15%	3.73%
Applmp	0.33%	1.68%	2.54%	4.09%
LC-R1	4.45%	9.96%	9.42%	12.01%
LC-R2004	4.38%	8.65%	7.32%	11.16%
Ref No retrofit	-0.82%	1.27%	2.18%	3.78%
SWE-No retrofit	3.14%	1.20%	2.12%	3.63%
RT2005 No retrofit	3.18%	1.23%	2.16%	3.71%
Ref CCS	-0.34%	3.50%	4.35%	6.37%
Ref GS	2.11%	2.72%	3.91%	3.16%
A1 No Retrofit	-0.27%	1.19%	2.06%	3.56%
A2 No Retrofit	-0.27%	1.15%	1.99%	3.45%
LC-R1 CCS	3.80%	13.83%	13.99%	16.23%
LC-R1 GS	4.03%	8.87%	7.87%	10.40%
CAN	2.10%	1.24%	2.15%	3.70%

CAN No retrofit	1.52%	1.68%	2.55%	4.11%
SWE CCS	2.63%	6.45%	6.75%	7.99%
SWE GS	4.01%	1.54%	2.99%	2.51%
ParCom No retro +CCS	-2.81%	9.15%	9.51%	10.94%
ParCom No retro +GS	0.97%	-2.38%	-1.34%	-1.79%
Temperature	-0.15%	0.95%	1.71%	3.10%
RT2005+GS	4.23%	3.52%	5.17%	4.55%
RT 2005 + CCS	2.72%	2.63%	2.68%	4.04%

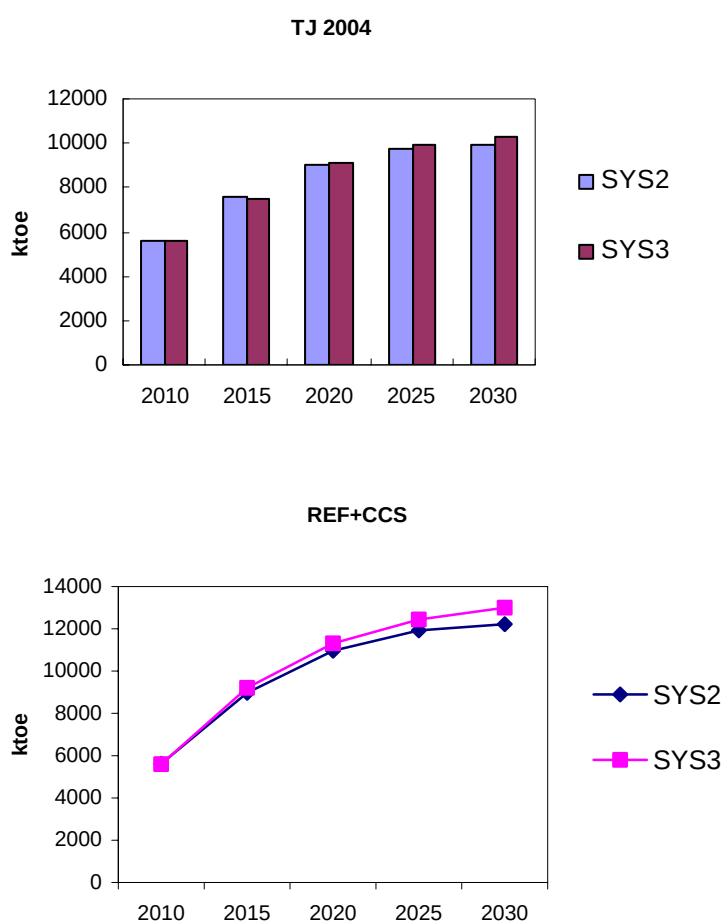


Figure 5-114 comparison of energy demand in SYS2 and SYS3 scenarios (Reference +CCS technology option)

5.19.5.3 Total costs

The foremost result shows that the SYS3 supply system is generally more costly than in SYS2. Cumulative cost in SYS3 is 1%-12% higher than in SYS2 in most scenarios. ParCom + GS scenario is especially much higher, around 25% more expensive. This means that if Tianjin seeks to implement gas-switching policy in the future, capacity addition should avoid oversizing mistake otherwise tremendous extra costs will be incurred. With low

carbon price constraints, most scenario outcomes still support the TJ-2004 standard except that the DR is less than 4%. Again, both uncertainty about new technology and benefits from sale of electricity does not result in improvement in BEE in a positive way. And low carbon price will not give incentive to upgrade the current BEE if the electricity generated from large CHP planned in the Tianjin district Plan will be purchased by North China Grid Company as bargained price in our model. This finding is consistent with the fact that many Chinese local authorities are keen on new power generating capacity addition instead of seeking to manage the electricity demand in smarter way. The sale of electricity gives strong incentive to invest massively in supply infrastructure.

Similarly to the outcome simulated in SYS2, DR choice affects the optimal choice under the medium and high carbon price scenarios, SWE becomes again the optimal choice when low DR is applied, less ambitious improvement in BEE (CAN) dominates the rest of scenarios of DR except for high DR when TJ-2004 outweighs the others. With high carbon price constraints, LC-2004 and SWE are favoured with low and medium discount rate, respectively. CAN will be the best one when adopting high DR. therefore, no consensus can be found with ease without trade-off between the costs and benefits that occur in different timing.

However, the assumption implied in the model is unlikely to be robust since heat and power generators will face risk relating to uncertainty about electricity purchase since no long term guarantee like feed-in tariff will be available over the time scale 2005-2030.

Cumulative cost in SYS3 is slightly lower than SYS2, nevertheless, in the long run, SYS2 is less costly compared to SYS3. For example, total cumulative cost increase in SYS2 relative to SYS2 in 2030 (although some cumulative cost in the nearer term is lower due to capacity addition assumption in SYS2) ranges between 1% and 11% when neither electricity sale benefits nor carbon constraint is taken into account, by using 8% as discount rate.

5.20 Conclusion of the chapter

We modelled different scenarios of energy demand, carbon emissions and total social costs relating to targeted BEE standards in the building stock in Tianjin over the period 2005-2030. We tested the sensitivity of discount rate and carbon price in terms of impacts on optimal BEE standard and supply option selection. Economic implications of two different energy supply systems, SYS2 and SYS3 was also investigated.

It is found that in most plausible scenarios which exclude the “Non-retrofit” variants since the “laissez-faire” policy in existing inefficient buildings may result in sharp increase in energy burden for lower-income households who will have difficulty in accessing to the new constructed houses in the future. Moreover, the difference of the total discounted costs between “retrofitting” and “no retrofitting” does not differ significantly.

Most importantly, the current building efficiency standard (TJ-2004) is not an optimal choice since the discounted cumulative cost could be reduced further by upgrading BEE standard. Decision on choosing the best scenario is dependent upon several criteria and objective, of which economic costs is one important factor. For example, LC will be the best choice if the primary objective is to reducing the long term buildings energy-related carbon emissions. Even with the objective to minimising the total discounted costs, LC turns out to be the best one if high carbon price will be imposed.

The choice of discount rate (low, medium or high) may have significant impact on the results of simulation. In general, low DR will favour the uptake of more efficient BEE standards and vice versa. SWE standard can be particularly interesting as the optimal choice since the costs associated with buildings and energy supply system and environmental impact can be minimised in many cases, in particular with assumptions of strong carbon constraints. However, the choice of discount rate can affect the preference of decision makers in several circumstances. High discount rate will systematically result in lower efficiency standard, also the low carbon price does not give enough incentive to allow the builders and property developers to adopt high performance building technologies. In this regard, the optimal choice of BEE standard is somehow subjective, as it depends on the vision on carbon friendly buildings and DH technologies of decision makers, various factors have significant impact on and thus would make big difference.

The analysis of annual costs shows that although a remarkable jump of investment costs are perceived in all scenarios, the degree of change is considerably less significant in high efficiency case (LC) than in lower case (ParCom). To avoid painful sharp jump in current year operation costs such as in the ParCom scenario, upfront buildings energy performance and quality of construction are of critical importance and should never be ignored, otherwise the city would be trapped into a vicious circle: lower efficient buildings results in costly operation and thus less financial capacity could be formed to invest in low-carbon technologies to mitigate carbon emissions in the future.

The supply technology options simulation shows that CCS option is generally much more cost-effective than fuel-switching option. This is somewhat intuitive, since in our model, no CCS will be deployed in the CCGT power plants in the case of fuel-switching scenarios albeit carbon emission in natural gas powered plants is far from negligible. In addition, fuel-switching policy has potential threat on China's long term security of energy supply since a significant part of natural gas will be supplied by Russia and Eurasian Countries⁷⁹. Recent disputes between Russia and Ukraine (and also the European Union) reveals considerable geopolitical risk and supply fragility of high dependence on imported natural gas. The Chinese energy policy makers must take energy supply security into account.

⁷⁹ Some framework agreements of gas and oil supply have been signed between China and Russia, Turkmenistan. The pipeline between Russia and China is estimated to supply 80 bn cube metres natural gas from Siberia to China annually from 2011.

More importantly, we found that CO₂ abatement in buildings is more cost-effective in the high-efficiency scenario, the cost is even negative in the high-performing scenario (LC). However, CO₂ abatement costs will be very high in the Reference scenario, nearly 200 US\$/tCO_{2-eq} in 2020 in fuel-switching policy scenario; and it is excessively high in low efficiency scenario(Par Com) which may reach more than 1650 US\$/tCO₂ by 2025 with gas switching option. In comparison, abatement costs in SWE and RT scenarios can be maintained within affordable range.

The results of simulation have very strong economic implications with regard to global climate policy. The results tell explicitly that if the Chinese government can succeed to implement immediately the equivalent RT05 or SWE BEE standards, the required international financial aid for the CCS technology deployment in China would range between around US\$ 20-50 /tCO_{2-eq}, a carbon price totally competitive in the global carbon market for from carbon emission management perspective. On the contrary, fuel-switching policy would be more costly to implement although the technology is already deployable.

In addition, the current Tianjin Municipal DH Plan is not optimal from long term analysis perspective. The modelling results suggest that SYS3, the supply option which follow up the municipal heating plan is generally more expensive than the SYS2 which establishes linkage between final demand efficiency and the upstream heat production accordingly in the model. Thus the current DH development plan needs to be amended by integrating demand side management technical solutions. A comprehensive approach will allow to allocate new generating capacity more efficiently and to avoid unnecessary capacity oversizing resulting in huge capital lost and inefficient allocation.

References

- Arrow, K. (1962), "The Economic Implications of Learning by Doing", *Review of Economic Studies*, p. 155.
- AtanasIU, B. and Bertoldi, P. 2007. Residential electricity consumption in New Member States and Candidate Countries. *Energy and Buildings*, Volume 40(2):112-125.
- Bernard, A., Jones, C.I., 1996. Comparing apples to oranges: productivity convergence and measurement across industries and countries. *American Economic Review* 86, 1216–1238.
- Bosseboeuf, D. (Eds.) 2007. Evaluation of energy efficiency in the EU-15: indicators and measures. 2007. Ademe.
- Capoor, K., and Ambrosi, P. 2008. State and Trends of the Carbon Market 2008. World Bank. Stockholm Environment Institute (SEI). LEAP Model User's Guide.
- Chen,X., Li,J., Wang,Y.,Tan,Y.,Yan,Y.,Li,J. 2006. 我国燃煤锅炉改用木质颗粒燃料效益分析(Benefit Analysis of Coal Boilers Being Replaced by Wood-pellet Burners in China). *Journal of Central China Institute of Sylviculture*. 2006.
- Ministry of Construction (MOC). Chinese Residential Building Code (中华人民共和国国家标准《住宅建筑规范》), 2003. GB 50368—2005. Enforcement 1st March 2006.
- Datang Power Group. 2005. Environmental benefits of installation of enhanced self-cleaning heat exchanger in power generation condenser. 凝汽器中加装自清洗强化换热装置的环保效益.

- Dietz, S., and Stern, N. 2008. Why Economic Analysis Supports Strong Action on Climate Change: A Response to the *Stern Review's* Critics. *Review of Environmental Economics and Policy* . 2008 2(1):94-113; doi:10.1093/reep/ren001
- Duan,Q., Wang,J., Zhuang,X. 2004. 生物质与煤共燃研究 (Research on Co-firing of Biomass and Coal) , *Power system engineering*. 2004(1).
- Echos(Les). « Vers un affichage des performances énergétiques des bâtiments ». 20 mai 2008. p.32.
- Gu, J. 垃圾发热值的实用测定方法. The Method of Measure Heating Value of Garbage in Garbage Incineration 节能环保 Energy Efficiency and Environmental protection. 2006(12).
- Intergovernmental Panel on Climate Change (IPCC), *Third Assessment Report. Climate Change 1995: Impacts, Adaptations, Mitigation of Climate Change: Scientific-Technical Analyses*. Cambridge, UK: Cambridge University Press.
- 2007. Climate Change 2007 Synthesis Report.
- International Energy Agency (IEA). 2000. Experience Curves for Energy Technology Policy. OECD/IEA, Paris.
- 2005. Projected costs of generating electricity 2005 update.
- 2006. World Energy Outlook. Paris.
- 2007a.Fossil fuel-fired power generation: case studies of recently constructed coal- and gas-fired power plants.
- 2007b. World Energy Outlook. China and India Insights. Paris.
- 2008. World Energy Outlook. Paris. OECD.
- Jiang Y. (2007). Energy Efficiency Ways in China. In 2007 Annual Report on China's Building Energy Efficiency. Tsinghua University. China Construction Industry Publishing House. 2007.
- Joyeux, R. and Ripple, R. 2007. Household energy consumption versus income and relative standard of living: A panel approach *Energy Policy* , Volume 35, Issue 1, January 2007, Pages 50-60.
- Keywan Riahi, Edward S. Rubin, Margaret R. Taylor, Leo Schrattenholzer and David Hounshell. 2004. Technological learning for carbon capture and sequestration technologies, *Energy Economics* , 26: 539-564.
- Kirjavainen,M., Sipilä., K., Alakangas, E., Savola, T., Salomón, M. 2004. Small-scale CHP technologies - situation in Finland, Denmark and Sweden. OPET Report 12.
- Li, J., Hu R., Song Y., Shi J., S.C. Bhattacharya and P. Abdul Salam. 2005. Assessment of sustainable energy potential of non-plantation biomass resources in China. *Biomass and Bioenergy* 29 (2005) 167–177.
- Li, J., Wu S., Li, Z. 2004. Supercritical--A Preferential Choice for China to Develop Clean Coal Technology. *Electricity*. Vol.15(4).
- Liu, T. 2006. 六安市裕安区发展户用沼气池的经济分析 Economic analysis on rural household methane gas pool construction in Yuan district of LiuAn city. http://www.carei.org.cn/hyxx/zq/t20060619_632571.htm.
- Maciejewska, A., Veringa, H., Sanders, J. Peteves, S. 2006. Co-Firing of Biomass With Coal: Constraints and Role of Biomass Pre-Treatment. DG JRC of European Commission, Institute for Energy.
- MAIZIA, M., (2007) *Pompe à chaleur et habitat. Prospective des consommations d'énergie et des émissions de CO₂ dans l'habitat : les gisements offerts par les pompes à chaleur* , Les cahiers du clip 18, 1-47.
- Mendelsohn,R.2008. Is the *Stern Review* an Economic Analysis? *Review of Environmental Economics and Policy Advance* Access published April 23, 2008.
- Messner, S. (1997). Endogenised technological learning in an energy systems model. *Journal of Evolutionary Economics*, Vol. 7, p. 291.
- Miller, B. 2005. Coal Energy Systems[M]. Academic Press. 544 p.

Natarajan, S. and Levermore, G. 2007. Predicting future UK housing stock and carbon emissions. *Energy Policy*. Volume 35, Issue 11, pp. 5719-5727.

National Bureau of Statistics(NBS) . 2000. Press Communiqué of National Population Census 2000.

Nemet, G. F. (2006). "Beyond the learning curve: factors influencing cost reductions in photovoltaic." *Energy Policy* 34(17): 3218-3232.

Nemet, G. Learning Curves for Photovoltaics. University of Wisconsin – Madison. IEA Workshop 2007.

Nicol, F. Standards for thermal comfort. Indoor air temperature standards for the 21st century.

Nordhaus, W. 1991. To slow or not to slow: The economics of the greenhouse effect. *Economic Journal* 101:920–37.

Olesen, B.(2004). International standards for the indoor environment. *Indoor Air*, Volume 14, Supplement 7, pp. 18-26(9).

Pearce, D., W. Cline, A. Achanta, S. Fankhauser, R. Pachauri, R. Tol, and P. Vellinga. 1996. The social cost of climate change: Greenhouse damage and the benefits of control. In Intergovernmental Panel on Climate Change, *Climate Change 1995: Economic and Social Dimensions of Climate Change*. Cambridge, UK: Cambridge University Press, pp. 179–224.

Plambeck, E. L., C. Hope, and J. Anderson. 1997. The PAGE95 model: Integrating the science and economics of global warming. *Energy Economics* 19:77–101.

Polagye, B., Hodgson, K., Malte, P. 2006. An economic analysis of bio-energy options using thinnings from overstocked forests. *Biomass and Bioenergy* 31 (2007) 105–125.

Qiu, B. (2006). Large-scale buildings thermal retrofitting projects will be undertaken in China. 我国将对现有建筑进行大规模节能改造. Ministry of Construction. Available at http://news.xinhuanet.com/house/2006-03/30/content_4362584.htm

Ren, G.; Chu, Z.; Zhou, Y.; Xu, M.; Wang, Y.; Tang, G.; Qu, P.; Shao, X.; Zhang, A.; Chen, Z.; Guo, J.; Liu, H.; Zhou, J.;

Review of Environmental Economics and Policy Advance. Access published April 23, 2008.

Sheng, C. 1999. 国动力用煤煤灰自身固硫特性的统计分析 Characteristics of sulphur retention in ashes of Chinese coals used . *环境科学学报 (Journal of Environmental Science)* . 1999 vol (01).

Shorrock, L., and Dunster, J. 1997, The physically-based model BREHOMES and its use in deriving scenarios for the energy use and carbon dioxide emissions of the UK housing stock, *Energy Policy* 25 (1997), pp. 1027–1037.

State Quality and Technique Monitoring Administration and Ministry of Construction .1999. Building Design Regulation (GB 50096—1999). 住宅设计规范, 2003 update.

Stern, N. 2007. *The Economics of Climate Change: The Stern Review*. Cambridge: Cambridge University Press.

Steve Dowrick, Duc-Tho Nguyen (1989). OECD Comparative Economic Growth 1950-85: Catch-Up and Convergence. OECD Comparative Economic Growth 1950-85: Catch-Up and Convergence. *The American Economic Review*, Vol. 79(5); pp. 1010-1030.

Tianjin Development and Reform Commission (TJDRC) , Tianjin Heating Office, North China Urban Engineering Design Institute, Tianjin Jinneng Energy Corporation. 2003. *Tianjin Urban heat supply Planning 2003-2015*. 《天津市城市供热规划 (2003 ~ 2015) 》 .

Tillman, D. 2000. Editorial . Cofiring benefits for coal and biomass. *Biomass and Bioenergy* 19 (2000) 363(36).

Traisnel J.P. "*Habitat et développement durable*", Les Cahiers du CLIP , 13 , avril 2001, p. 7-72 (publication du rapport de recherche Habitat et développement durable : étude rétrospective et prospective. Rapport, LTMU/IFU/Paris 8-CENERG/Ecole des mines de Paris/BE TRIBU, CNRS-ECODEV, janvier 2001, 105 p.

Turnbull, J., "Strategies for Achieving a Sustainable, Clean and Cost-Effective Biomass Resource," Proceedings: Strategic Benefits of Biomass and Waste Fuels, Electric Power Research Institute, December 1993, EPRI TR103146.

Utility Coal-Biomass Co-firing Plant Opportunities and Conceptual Assessments, Antares Group Inc., Landover, MD, and Parsons Power, Reading, PA, for the Northeast Regional Biomass Program, and the U.S. Department of Energy: November 1996.

- Van der Zwaan,B.,Gerlagh,R.,Klaassen,G. and Schrattenholzer,L.2002. Endogenous technological change in climate change modelling. *Energy Economics*, Volume 24, Issue 1, January 2002, Pages 1-19.
- Wang, Y., Wei, Q., Xue, Z. Jiang, Y. 2006. Energy consumption database and preliminary study on Beijing's large commercial buildings. In 2006 National HVAC Conference proceedings.
- Wang, W 2006. OECD convergence: A sectoral decomposition exercise. *Economics Letters* Volume 93, Issue 2, November 2006, Pages 210-214.
- Weyant, J. 2008. A Response to the *Stern Review's* Critics. *Review of Environmental Economics and Policy*. Review of Environmental Economics and Policy, 2008, vol. 2, issue 1, pages 77-93.
- WBSCD (2007). *Energy Efficiency in Buildings: Business Realities and Opportunities*.
- Weyant, J. 2008. A Critique of the *Stern Review's* Mitigation Cost Analyses and Integrated Assessment.
- Yang, J., Tu, G., Sun, Z., Chen,H., Song, X., Moriyama, M. and Takanishi,S. 2002. Energy consumption investigation and energy efficiency analyses of air-conditioning systems in public buildings in Tianjin and Kobe (in Chinese). *HV&AC*, Vol 32(1). pp 40-41, 66.
- Ye, M., Zyren, J., Shore, J.2002. Forecasting crude oil spot price using OECD petroleum inventory levels. *International Advances in Economic Research*. Volume 8(4), pp. 324-333.
- Yuan, J., Zhao, J., Yu, C., Hu, Z. 2007. Electricity consumption and economic growth in China: Cointegration and co-feature analysis. *Energy Economics* 29 (2007) 1179–1191.
- Zhang, H., Zhou, S. 2005. 城市垃圾焚烧及其余热利用Analyses of Municipal Garbage Incineration and Its Recuperation. *环境卫生工程 (Environmental Health Engineering)*, 2005(5).
- Zhao, Z.; Zhang, L.; Liu,X and Tang, H. 2005. 中国气温变化研究最新进展. The Latest Research Progress on Temperature Change in China. *气候与环境研究 (Climate and Environmental Research)*. Vol.10(4) , pp.701-716.

Website consulted

<http://www.treepower.org/cofiring/main.html>

Thermal power system cost analysis

http://www1.eere.energy.gov/hydrogenandfuelcells/pdfs/merit03/21_apci_todd_carlson.pdf

www.iea.org

World Resources Institute

http://earthtrends.wri.org/searchable_db/index.php?theme=6&variable_ID=634&action=select_countries

Chapter 6 Institutional analysis of energy planning and property market organisation

6.1 Introduction

In previous chapters, we investigated different scenarios of energy demand growth perspective in Tianjin as well as the subsequent economic and environmental implications. A significant part of energy and CO₂ emission in the high emission scenario can be avoided through enhanced BEE policy. Our modelling results suggest that the current BEE regulation is not the optimal choice from social costs viewpoint. The quantitative examinations of modelling confirm that it is judicious to update the current BEE mandatory requirements to minimise the latent demand rise and relevant social costs in the future. The option value of wait to see strategy to deal with the uncertainty is particularly risky in the sense that the whole infrastructure could be trapped in irreversible process of lock-in dilemma and would entail enormous difficulty to retrofit the historical energy-greedy urban heritage under a cost and institutional constraints even tougher than today. The city would find itself in extreme difficult situation about the capacity in financing by new supply technology with a large quantity of historical inefficient buildings stock in the future. In contrast, it will be much easier for local authority to find financial resources by allocating the “benefits” offered by cumulative reduction in operation costs with a high efficient building stock.

Thus the findings in previous chapter showed by the modelling suggest that buildings efficiency regulatory indicators should be upgraded to become more stringent as early as possible from social optimum perspective, and also to facilitate the transformation of energy infrastructure with new technological innovation. However, the relevance of institutions is a prerequisite to achieve the improved efficiency in buildings and the related energy savings explored by the quantitative analysis undertaken previously. Implementing the energy efficiency improvement requires appropriate institutional framework such that efficient technologies can be adopted by all the actors in a Pareto optimum condition. The objective of this chapter is to identify key actors including different institutions in property and energy markets in Tianjin and analyse their roles in order to facilitate the understanding the mechanism of market functioning. The diagnosis in this chapter will permit us to set up countermeasures addressing barriers to BEE implementation.

The major barriers to BEE upgrading stem from current organisational form of buildings and energy market. In the case of district heating in the northern Chinese cities, on the one hand, from demand-side, most customers don't pay the energy services at a cost-reflective price, rather a fixed charge proportional to the occupied premise's area is payable to the heat supply company each year. On the other hand, from supply-side perspective, building constructors are provided no incentive to improve the efficiency beyond the regulatory standards by the fact that he will not receive any benefits from improved energy efficiency, for the energy savings go to the end user and heat companies eventually.

The actual relationship between building energy efficiency and relevance of institution can be explained by microeconomic theory. The problems such as inertia of action in improving building energy efficiency are mainly rooted in failed markets and their resolution requires government taking some kind of action – to establish property rights, set standards of liability, apply pollution taxes such that emissions from fossil energy combustion will be discouraged, or regulate. All these measures together constitute the public policy instruments portfolio.

Economic theory provides a coherent framework for analysing the elements of growth and sustainable development. Appropriate policies and institutional structures are essential for achieving sustainable development. However, many environmental policies are based on a regulatory response without consideration first being given to the full range of options available (Sharp, 2002). From social and economic analysis point of view, the efficient functioning of an economic system depends on a whole set of institutional condition which consists of decision-making, mechanism for coordination, property rights and incentives (Gregory and Stuart, 1992; Zhu, 2002).

The main argument in this chapter is that improvements in building energy efficiency policies should be integrated into the urban energy planning in order to minimize the social cost incurred in the construction of new energy supply capacity. Investing in the efficiency measures such as buildings shell insulation may facilitate energy savings for end uses and also reduce the capital cost of capacity and infrastructure installation for the energy services suppliers. For this reason, we look at both the respects of energy supply infrastructure, in particular the district heating in Tianjin and of the property market organisation so as to have a comprehensive understanding the functioning of the energy-buildings couple. The diagnostic analyses in the rest of this chapter will lay the institutional foundation of policy instruments design in favour of efficiency measures implementation that will be studied in detail in Chapter 7.

Effective implementation of energy efficiency policies requires appropriate organisational framework, this is related to the institutional aspects of governance. Apart from a broad array of technical intervention in the course of design, construction, operation stage, an efficient institutional organisation is prerequisite of policy objective otherwise there would be no guarantee that initial objective can be attained effectively. Thus, investigation of policy instruments in this thesis implies beforehand unfolding the organisational form of energy and housing policies in the cities concerned, understanding the institutional organisation in both property and energy markets is of crucial importance relating to devising policy options.

This chapter is divided into five sections. Section 6.2 describes the urban development perspective and institutional and organisational structure of property market, in particular the housing programme development and land supply institutions in the city of Tianjin, financing and taxation issues in property market are analysed in detail. Section 6.3 focuses on the specific respects relating to district heating supply

organisation in Tianjin. Section 6.4 describes the major actors in the heating supply and energy pricing in Tianjin. Section 6.5 analyses the interaction of actors in the property and energy markets. Finally, an analysis on the relationship between property market and buildings energy consumption features summarises the chapter and gives some insights into the policy implications. Section 6.6. explains the efficiency gap and identifies the major institutional barriers to large-scale deployment of BEE technologies and state-of-the-art practices of construction.

6.2 Institutional analysis of property market in Tianjin

This section addresses the institutional organisation and functioning mechanism of property and energy markets to find out the hurdles of BEE implementation, results will allow us to design instruments accordingly in the next chapter in order to attain expected objective. It explains the property development procedure and the roles of different institutions.

6.2.1 Master plan of urban development

6.2.1.1 Spatial development

The Tianjin General Urban Planning 2005-2020 (hereinafter referred to as Master Plan⁸⁰) has drawn up the urban development blueprint of Tianjin which is characterized by the so-called “one axis two strips and three zones” spatial distribution structure. **One axis** refers to “Wuqing District—central city -- core of Binhai New Area (BNA) spindle”; **two strips** represent respectively “Ninghe--Hangu--- core area of BNA --eastern coastal area” development zone and “Baodi--Jixian – City Centre --western Jinghai” urban development zone. **Three districts** include 1) Jixian mountain ecological area on the north 2) Qilihai - Dahuangpu wetland ecological zone in the centre and 3). Tuanbowa water Reservoir – North Dagang wetland ecological zone on the south. This spatial development planning is shown in Fig 6-1.

⁸⁰ This master plan was elaborated by the Tianjin Municipal Bureau of Urban Planning in 2006 and endorsed by the State Council, yet some amendments on the Binhai New Area are still under way. In fact, the lack of consistence is one of major problems encountered during city planning elaboration and implementation since the zoning or detailed planning could be subject to arbitrary modification of succeeding city leaders and institutions in charge of planning. For example, the General Planning of BNA 2006 has received several substantial modifications after the new party leaders took office in 2007.

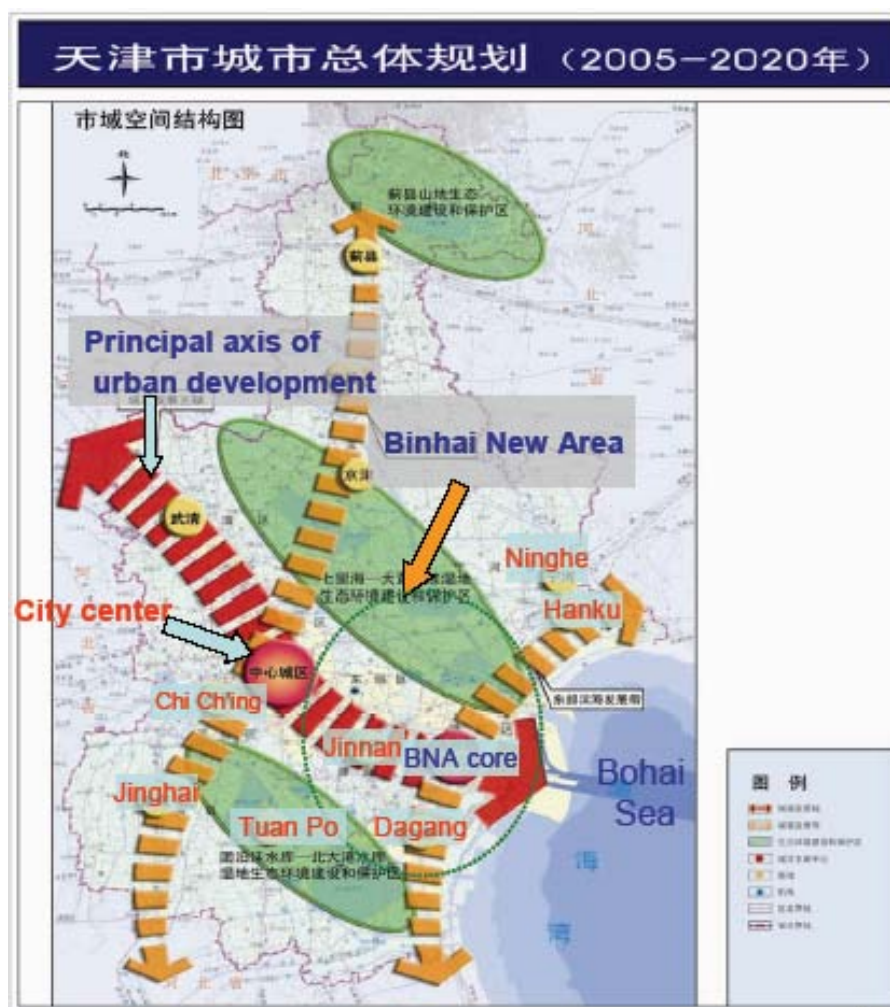


Figure 6-1. General Plan of Urban Development of Tianjin 2005-2020

Source: Tianjin Municipal Planning Bureau

According to the Master Plan, inner city area (City Centre and suburban districts) and BNA will be divided into 33 and 20 living zones, respectively. Each area consists of a population of 150,000 to 250,000, including 3 to 5 residential area or habitat community where amenities shops, supermarkets, community and cultural centres, sport ground, schools, community health service centres, and other service facilities will be built up. Eleven new cities will be developed in Jixian county, Baodi, Wuqing, Ninghe, Hangu, Xiqing, Jinnan, Dagang and Tuanbo by 2020. Over the next 5 to 10 years , population in the six central city districts will be reduced by 600,000, as a result of migration to the new developed residential communities around the central city. Land in central city will be mainly developed for commercial, service and public facilities development purposes. BNA will be the first destination to absorb the immigration from the centre city and other suburban and rural districts.

6.2.1.2 Population growth in Tianjin

It is projected in the Master Plan that population should be maintained no more than 13.5 million while the urbanisation rate is like to approach 90% in 2020, thus 12.1 million urban population. The current population in central city is around 4.2 million. In 2020, urban population living in the Central City and Binhai New Area's core area will amount to 6.3 million, in which 4.7 million in Central city and 1.6 million in BNA's core area. Total population in BNA will amount to 3 million. Like most Chinese mega cities, population in Tianjin is unevenly distributed, and urban density varies significantly depending on district. According to the Municipal Bureau of Statistics, the average population density in Tianjin is 840 persons /km² in 2000. Heping district (city core) is the most densely populated area, with 32230 persons/km²; while Ninghe county had only 254 persons per square kilometre in the same year. And the accelerated urbanisation and development of "satellite town" has reinforced the population concentration and centripetence effect. More and more rural residents in administrative counties move to the urbanised area.

6.2.1.3 Housing supply planning

The authority forecast of housing supply area up to 2010 is much higher than the projection in our model. The main reason is that per capita living area value in the base year(2005) is much lower than the official number published in the statistical yearbook in which all the city residents are not accounted for due to the Chinese *Hukou* system (residence permit registration system⁸¹). This results in the fact that annual increase in per capita housing floor space is significantly lower in the first years in our model compared with official numerical. The other reason is related to the uncertainty about the demolished area. We estimate that about 1.5 million square metres will be demolished each year in the model, whereas the actual number may be either much higher in the case of modified urban planning of infrastructure development and old houses replacement.

6.2.2 Land use planning control

The city-level "Master plan" determines the level of urban construction site development and strictly regulates the scale of urban construction land allocation which will be held at 1,250 kilometres in the city in 2010 and 1450 square kilometres in the whole city, in which 580 square kilometres are located in the City Centre and BNA core area (zone inside the circular in Fig. 6-1). The per capita urban built land area of the whole area is expected to reach 92 square metres; and 110 square metres in the new development city, 120 square metres per capita in other towns. Built area in central city will reach 371 km m² in 2020. Total area of land use for development in BNA will be 5.1 million square metres. The planned area for BNA's core area is 2.7 million square metres of which 166 million square metres are designated to urban development.

⁸¹ Although the Hukou system is mutating, most migrant population, in particular the holders of a rural resident permit living in urban area are still often considered temporary resident, it means that these people do not have the same right of abode as the permanent urban dwellers. The Chinese statistical system only takes part of the immigrants into account when compiling the data such as per capital living area and or per capital GDP production etc.

Each year, the municipal real estate and land administration bureau evaluates the property market situation based on a series of indicators and estimate the demand and supply of land and housing, and it will proceed to decide the quantity and locations of plot of land that will be supplied to the land market. The configuration of plots is generally already settled by the planning bureau in the GUP or Master Plan. However, some national macro adjustment policies can also have strong impact on land supply in terms of quantity and nature of land use. The national council issued a regulation which states that the land use right should be deprived if no effective construction take place during a maximum regulatory period after land acquisition for purpose of limit the speculation in land market transaction; which result in many idle land plots in central city.

6.2.3 Urban property and energy infrastructure development process

In China, the property (housing) development in the city follows a standardized process and different public institutions are involved successively. Different administrative formalities must be cleared at each stage before proceed to next step. The complete schema of the whole process of property development with specific formalities is provided in the diagram in Appendix. The flow chart illustrates in fact the **general** situation of property development process, we insist here on the word “general” since many actual housing development programs have more or less particular situations which are not always identical to each other, and the property market is rather heterogeneous in terms of financing and proceeding. The question raised here is who actually design the infrastructure and who will put it in place and through what kind of financing mechanism, and finally who will operate the network infrastructure and who will pay the service.

The property development is divided into three main stages. Before the development commences, the developer need to prepare a detailed project of land and property development and submit it to the urban planning authority. According to the Urban Planning Act 1989, prior permissions are required for land and property developments. Development applications are evaluated by the planning authority against the non-statutory Land Use Master Plan. A land use planning note will be issued with land use planning parametres attached such as land use, plot ratio, site coverage and building height etc (Zhu, 2004). When all the formalities for the land transmission are cleared and the land site details finalised, a Land Development Permit and a Buildings engineering planning permit are issued. With the permits, the developer can proceed to commission architects to design the building. After the examination of buildings design by the planning bureau and the commission of construction (for the review of building EE design by selected experts), a building permit is granted and the project can proceed to the construction stage. The commission of construction undertakes regular in situ inspection on the operating construction projects in collaboration with other municipal authorities (planning bureau, department of fire precaution, public works quality inspection committee) by sampling in the city. Guaranteeing the BEE design implementation is one of aims of this inspection. However, as indicated in the flow chart, the house developer in general plays no active role in the decision on heat supply infrastructure since heating planning has been undertaken prior to the land acquisition in the urban general planning.

6.2.4 Analysis of land market

6.2.4.1 Land market institutional structure in the property development program

The main aim to analyse the land market in Tianjin is to understand the land use right allocation and housing provision policy, such that relevant reflection on economic mechanism can be proposed in the next chapter. Like all their sister cities in China, built-area in Tianjin has been increasing steadily since the 1990s as a result of fast urbanisation and market-oriented land use reform and property development boom. Table 6-1 summarises the increased built-area in major Chinese cities over the last decade. Accordingly, built environment becomes an important issue for city planner and policymakers given the trend of strong increase in constructed floor space.

Table 6-1 The new built-up areas in the Chinese super-cities during 1990-2000 (in ha)

	farmland	forest	grassland	Water area	Rural settlement	Industrial-mineral land	Unused land	SUM
Beijing	25387.46	442.87	114.74	171.69	7782.88	1901.73		35801.37
Changchun	1730.07				113.66			1843.73
Chengdu	7664.97	14.31	18.03	1.86	251.26			7950.43
Dalian	4331.91	1770.41	933.96	8.94	990.2			8035.42
Guangzhou	6382.71	1033.75		95.97	3244.65	69.29		10826.37
Haerbin	561.69	349.68						911.37
Nanjing	6322.14	82.18	42.53	110.41	6.58			6563.84
Shanghai	17291.89	2.68			1113.03			18407.6
Shenyang	991.66							991.66
Tianjin	2390.73	102.39		273.11	627.28	1642.18	269.56	5305.25
Wuhan	1835.35	12.37		789.05				2636.77
Xi'an	2427.83	721.72			180.6			3330.15
Chongqing	2293.25	372.47		14.06	401.68			3081.46

source: Zhao *et al.*, 2004

Both urban land development policy and property market organisation have strong impact on decision on energy (DH) infrastructure in terms of performance quality and efficiency. At present energy infrastructure such as urban district heating in a city's new development zone is often planned based on the Master Plan prior to the formulation of the final plot and development program-based land use planning, energy efficiency design of buildings is decided on the plot of land by adopting *a posteriori* the indicative parametres specified in the Master Plan. In other words, energy infrastructure's supply capacity is already allocated in an area where future land and property development will take place, since the installed capacity is usually large-scale CHP or district-based boiler stations, the possibility of reducing the supply capacity has been extremely limited even the effective demand will be much lower by implementing high efficiency technology the future buildings. Hence, the actual planning model results in an irreversible dilemma. The urban DH engineers in general will not take the "risk" to lower the heat load allocation to buildings since they are unclear or uncertain about what will be the exact energy performance of buildings being constructed later, the common practice of allocating an

empirical value (usually a conservative design value is taken, it means a value much higher than actual requirement to meet the peaking heat load when outdoor temperature reaches the extreme design condition) will proceed in most of cases. For the sake of optimising size of the urban infrastructure, a synergy between urban land planner, DH engineers and future developer should be created to avoid huge capacity being left idle.

6.2.4.2 Emergence of land markets

Under the socialist system before the economic reform, the landownership was prohibited to be changed and there was virtually no land value, land was excluded from economic transaction in China. The reform and opening-up policy that resulted in radical changes in the Chinese cities are reflected in the land use pattern(Xu *et al.*,2007). Land Use Rights(LURs) were adopted in the late 1980s to promote land markets and to improve land management and land use efficiency(Ding, 2007). Since the 1988 amendment to the constitution, land leasing has been legalized so that urban land can be leased to developers or users for a fixed period after paying a rent in a lump sum to the State. Land leaseholds can be acquired through tender, auction or negotiation (Zhu 2004).

The economic reform and urban development policy in the Chinese cities are often accompanied by a *gradualism* doctrine which means a co-existence of new and old institutions. The present informal and insecure land development model induces hasty capitalisation of land rent, and the land use planning controls engaged with extensive bargaining which lead an inefficient and sub-optimal land uses (Zhu,2004). Fast-paced urbanisation and economic growth, motorisation, the, globalisation and the restructuring of urban economy, policy reforms in land allocation and housing provision, and government decentralisation are considered as the major forces behind the spatial trans-formation of cities in China.

Land acquisition (mainly land leasing and purchase of land use right) is the foremost issue when starting a property development program and is considered the priority for a housing developer before proceeding to submit the concrete construction feasibility plan to relevant planning and construction administration. Since no actual buildings construction project can take place without allocated land.

Deducing policies from the summarised mechanism of functioning of the land market in China should be applied with prudence since the land and property market in China is still in infant stage of development, the relevant laws and regulations are evolving rapidly and institutions often lag behind the effervescent economic development pace, facilitated by property boom across in the country. It is thus becoming increasingly difficult to treat the whole land market without a concrete case. Moreover, we should be prudent to analyse the general model of land regulation since a case by case analysis would be more pertinent under current institutional framework and practices in this hotly debated sector in China. Housing price hike has become the first concerns of urban households in China since 2003. A CASS survey shows the ratio between family debt and disposable income is 155 per cent in Shanghai and 122 per cent in Beijing in 2004, while five years ago very

few Chinese families had any debt at all⁸². In many cities, urban households have to undertake a 20-30-year loan to buy a 120-150 square metre apartment.

Hu *et al.* (2006) conduct an empirical study by using modelling approach to investigating the main driver of housing price rise; they find the rise is mainly due to market fundamentals despite of existence of bubble factor in the market. Zhang *et al.* (2007) model the fluctuation of housing prices in China to explore the mechanisms affecting house prices, their research shows that the equilibrium price influences significantly the fluctuation on actual housing prices which returns to equilibrium price through self-adjustments. Moreover, their model shows that the actual prices in China have the trend of continuing to rise in the future. These results imply that property market development will still be very attractive to the new entrants and households given their cultural reliance on property possession.

LUR acquisition of urban land occurs by the aforesaid means. Since the rise in real estate development in 1990s, more and more housing programs occurred on the outskirts and in the suburbs in the large cities following the fast-growing urbanisation characterised by spatial expansion in urban fringes; many rural lands have been converted to construction land designated to housing construction or industrial development. In China, agricultural land is owned by rural cooperative. According to the Chinese law, all development is prohibited on non-state-owned land; land acquisition in which landownership is converted from collective communes to the state shall take place prior to any land construction (Ding, 2007).

6.2.5 Property development pattern

A municipal and district-based land administrative body has been established to supervise the land market and undertake the LURs transaction in the land exchange market. Since 2003, land reserve centre has been established in all the large cities in China, primary land development is usually undertaken by local or district government or the government-owned land development public corporation. The primary development generally refers to installation of urban infrastructure such as water, electricity, heat, gas, telecom services and construction site land consolidation, namely *Santong Yiping* (i.e. three connections and one levelling (traffic, water, electricity and natural land consolidation), or *qitong yiping* (i.e. seven connection and one levelling (traffic, electricity, water, drainage, telecommunication, cable TV, gas, and natural land consolidation) has in general a much higher price than if the developer acquires a land with residents still living wherein. The developed plots of land are then put in the municipal or district land reserve centres to be supplied successively to the land exchange centre by land use nature and leasing rent.

There exist two urban land and property development patterns

⁸². China Daily. China's housing price hike reasonable? 2004-12-19
http://www.chinadaily.com.cn/english/doc/2004-12/19/content_401454.htm

1. local authority allocates the underlying land to the property developer based on compensatory transfer regulation; the property developer is in charge of paying the compensation and relocation to dwellers on the land; and also works related to all the necessary infrastructure development
2. Local authority develops the land to make it directly constructible and put the developed land into the land reservation centre for bidding and auction based on the annual land transfer plan. The property developer who acquires eventually the land through bidding or auction will not deal with the compensation to existing dwellers directly, they are instead compensated and accommodated by the local authority with the money raised by land use right transfer. In this case, the land is already for development upon the arrival of developer

Both methods of land development are practiced in all the Chinese cities. However, today, in most of the cases of urban land use transfer, the local authority is more likely to take the role of upfront investment in primary land development for implementing consistent urban planning policy and avoiding the potential social conflicts that may rise between the property developers and residents.

Usually a land reserve planning for next year is undertaken during the fourth quarter of the year by the municipal land reserve centre. All information related to area, location, compensation price, urban infrastructure and land use of the reserved land should be reported accordingly to the bureau of municipal real estate administration bureau. Local authority issues every year a certain number of land plots in the market to meet the demand from property development and urban development planning. Thus a housing program developer who acquires the underlying the land for future construction is called a secondary land developer. Developer who undertakes both primary and secondary land development is very rare in the current urban planning context. So the flow chart above should also be interpreted with care.

6.2.6 Financing and taxation of property market

Involving in the property development requires huge amount of initial capital-intensive investment. Most of property developers raise upfront development capital from financial institutions, in particular the commercial banks, for the land acquisition and preliminary development program. It is generally believed that property developer's equity only accounts for 10-20% of total mobilized financial resources in a large-scale housing construction program. Thus, the rate of return on capital is the foremost issue that a developer should take into account when carrying out a property development program.

Moreover, there are alternative financing instruments such as internal housing construction fund-raising mechanism in some public firms and institutions. It is generally undertaken when capital was not sufficient enough in a development program, the developer will turn back to its employee or stakeholder to ask them to make a contribution to housing construction resources. A person who invested in these funds was treated with priority and with advantageous tariff during the house selling period. To this should be added the allocation of

land administered directly by the local authority in the case of construction of low-income housing (social housing).

6.2.6.1 Taxation regulation in the property market

It can be misleading to talk about building energy efficiency without understanding the land market organisation, because from the municipality's perspective, the housing policy, including the building efficiency policy, is closely related to the development of land market, moreover, the property (real-estate) development program is one of the main tax bases of local authority in China. Since the tax reform (Box 6-1; see Toh and Lin 2005 for comprehensive explanation on 1994 tax reform), the central government and local authority have been in a constant game in regard to tax collection and distribution of tax revenue (Ma, 1995). In addition, empirical studies show that the fiscal decentralisation produced to some extent the interregional disparity and rising issue of central government deficit (Ma and Norregaard 1998; wang, 2002; Jin and Zou, 2005). After the reform 1994, the China's tax have been based a two-tile tax bases system, national taxation and local taxation⁸³. Real estate tax has become one of main government revenue for local authorities since this reform. Moreover, the land use right property transfer reform and consequent housing commodification have generated a market-driven property development industry (Zhu, 2004); this hence provided a powerful incentive for local governments to boost local land and property development so as to collect more locally tax based revenue. In such, local authority has incentives to seek rents by boosting local property market and is quite sensitive to central government's macro-adjustment measures related to the property market regulatory policies.

As a result of urban land use reform, local authorities realize very quickly that the lease of land and housing market allow them to generate substantial financial resources. In fact, the property-related tax and fee still represent a small part of local government's fiscal revenue. For example, tax of property development accounted for 4.62 per cent of local authority's total revenue, while the land use granting fees represented 26.21 per cent on average of local government's revenue in Chinese cities in 2005 (Yang and Li, 2008).

In some extreme cases, the profits from real estate development and land use transfer can cover up to 55% of government spending in some Chinese cities. They necessitate enormous capital investments to be injected in the property market, strongly encouraged by local policies with regard to the recovery of space. The

⁸³ Strictly speaking, there are three categories of tax after 1994 reform. taxes were divided into three distinct categories: central, local, and shared. Central taxes would go into the central coffer, and local taxes into local budgets. As for shared taxes, they were to be divided between the central and provincial governments according to some established formulas. For instance, 75% of the revenue from the value added tax (VAT) belonged to the central government and the remaining 25% to the provincial governments. The sharing ratios were fixed and applied to all the provinces, not subject to negotiation. The rule-based method was expected to reduce bargaining costs. There are two parallel systems of tax administration with separated chains of command: a national system to collect central taxes and a local system to collect local taxes. Shared taxes were collected by the national system first, but the proceeds from these taxes would be split between the central and subnational governments according to the specified formulas (Wang; 1997).

proportion of investment in real estate rose from 6.3% in 1991 to 18.8% of total investment in fixed capital in 2004 [Bank of China: the report of the real estate finance sector; 2004]. In contrast, personal revenue tax before 1992 in China was miniscule which represented only 1% of total tax revenue, while the bulk of government tax revenue comes from the corporate business and revenue tax (Toh and Lin 2005) .

Box 6-1. Major characteristics in the 1994 tax reform

1. move from turnover taxes to value-added taxes
2. the harmonisation of enterprise income tax rates for different types of enterprises
3. the change in some minor taxes including personal income tax , and selective taxes
4. the reform of fiscal relationship between central and local government; the reform's converge includes change in types of taxation, the quantitative yield and economic impact of new taxes

Source: Toh and Lin 2005.

Outlining the institutional organisation of land market in urban china requires differentiating the different market with an on-the-ground approach, since the Chinese real estate and business laws are still in an early stage of development and the legal and economic system are evolving rapidly also, there is a strong cultural tradition of reliance on personal relationship rather than rule-of-law principles in Chinese property market (stein, 2008). Although a number of national laws and regulation exist in regard to land and housing development program, each city has a specific institutional framework and taxation regulation.

As pointed by Stein (2008), all legal structures and institutions in the area of property are still evolving, and nothing is time-tested , developers and lawyers frequently operate by trial and error. No mature market rules have been established since the economic reform in most of Chinese cities are in the pursuit of Deng Xiaoping's theory of *mo zhe shi tou guo he* (Groping the stones to cross the river) with regard to economic development and institutional reform. However, this situation is extremely advantageous for policy innovation since there exists no *a priori* the most adapted institutional structure and policy instruments given the fast-evolving property market.

6.2.6.2 Category of China's property tax

The current real estate taxation framework in China was established after 1994 tax reform, there are currently thirteen different real estate-related statutory taxes, which in turn are classified into five general categories based on their properties and nature

- business tax (distribution tax)
- income tax (individual income tax, corporate income tax, foreign investment firms income tax)

- property tax (tax on house property, urban house property tax, stamp duty, contract tax)
- resource tax (urban land use tax) and
- specific tax (tax on improved land, tax on urban development, tax on arable land acquisition and tax on fixed assets investment orientation adjustment which is already abolished)

These taxes are levied during the whole cycle of property development –distribution- operation. The respective tax levies and rules of levy are presented in Table 6-2.

Table 6-2 Different categories of tax in property market in China

Category	Tax	Tax object	Tax base	Tax rate	Tax payment
Property Development stage	Deed tax	Private house purchase	Transaction price	6%	Tax payer is the purchaser , 50% tax deduction applicable to Housing purchase for self-accommodation since Aug.1999
		Foreign buyers	Sale price		
		Pawn	Price of pawn	3%	
		Overseas Chinese purchase with foreign currency	Sale price		
	Stamp duty	Sale contract formation		0.03%	applicable to all corporate and individual and two parties of contract
		Inspection of construction , property right transfer	Underlying value in contract	0.05%	
	Tax on arable land occupation	Occupied area		Fixed tax rate (1-10 Yuan/m2)	Foreign firms are exempted
Operating stage (sales and transfer of property)	Business tax	Buildings construction	Turnover, value of transfer, rent, commission	3%	
		Turnover of buildings sales , transfer of LURs,		5%	

		rent,			
	Stamp duty	Sales contract formation	Contract amount	0.03%	
		Contract of inspection and design, transfer of property		0.05%	
		Leasing		0.1%	
	Corporate income tax	Corporate income of business	earnings before tax	25% ⁸⁴	All corporate
	Individual income tax	income	all revenue; (property rent, lease, transfer) Property transfer, lease	20%	House sale after 5 years accommodation is exempted if the underlying property is the only premise of the owner
	Urban development tax		Turnover	Differential tax rates: 7%; 5%; 1% for urban, town and rural village respectively	Foreign firms are exempted
	Education contribution charge	All corporate		3%	
	land value increment tax	All corporate	Increased value of land	Progressive rate: 30%; 40%; 50%;60%	transfer, public acquisition of land is exempted, residential property can be exempted if the incremental value is below 20%
	Urban land use tax ⁸⁵	Actual land area	Large city	(1.5- 30 yuan/m ²)	

⁸⁴ Chinese and foreign corporate income tax is harmonized since Jan 1st 2008. Before this law, corporate income tax rate was 33% for Chinese corporation and 15% for foreign corporation.

			Medium and small	1.2-24 Yuan/ m ²	
				0.9 -18 Yuan/ m ²	
			Designated town	0.6-12 Yuan / m ²	
	Urban real estate tax	Tax on buildings	Reference house price	1%	Applicable to foreign corporate
		Tax on land	Reference land price	1.5%	
	Tax on urban house property	Self - Accommodation	Remaining amount taxable of buildings ⁸⁶	1.2%	
		Income of rent	House rent	12%	
tax on fixed assets investment orientation adjustment		residential house constructed by individuals	Capital investment	0	This taxed was suspended in 2000
		Non-individual development of housing		5%	
		Commercial and public buildings ⁸⁷		30%	

Source: Lin 2006

Following formulas are employed to calculate the relevant tax

Real estate tax p.a = [(1- deduction rate (10%-30%)] * original value of real estate

Urban real estate tax = property value * tax rate

Tax on house for rent = rent income* tax rate (12% -18%)

⁸⁵ 1988 Provisionary regulations on urban land use tax, 2006 update. State Council.

⁸⁶ This amount is in general computerized by deducting 10-30% of the building's initially assessed value.

⁸⁷ This refers to hotel; guest house, convalescent hospital (home), theatre, auditorium, conference hall, office building or exhibition building.

6.2.6.3 Drawbacks of current real estate taxes

It can be seen from Table 6-2 that taxes related to real estate market are quite complicated in China. Some regulations lag behind the market development. For instance, the regulation on urban real estate taxation was promulgated more than half century ago, in 1951, since then the property market has undergone fundamental changes. And the regulation on urban house property taxation was implemented in 1986. Obviously, these regulatory frameworks are no longer coherent with current economy in real estate market and should be updated immediately to take into account the reality.

In addition, tax base is still very narrow and overlapping in many circumstances. Only properties situated in urban area and designated town are subject to real estate tax. And residential buildings are exempted from any tax if the house is not used for commercial purpose. Some similar taxes are overlapped such as urban house property tax and urban real estate tax. Incoherence of tax rate design and tax calculation method lags behind market and lacks consistency. However, the urban real estate taxation system doesn't take into account the land rent differential and time value of land use. The tax on urban land use and arable land occupation is not proportional to the assessed land value, they are calculated based on a per square metre fixed charge, the levied tax regarding land use is too small compared to the incremental value of both improved and unimproved land.

Tax system in property market is extremely complex, besides the above mentioned tax categories, the property developers may be concerned with various administrative fees, charges imposed by local government as LUR transfer and real estate tax become the most important revenue for the local authorities, many locally specific charges are imposed on property developers during the programme of development. Property developers are complaining about the complicated and high levies. In some place, more than one hundred species of taxes and charges are collected by local governments, the under-regulated real estate tax levying system gives strong incentives to local government's rent-seeking and results in tremendous increase in transaction cost, thus the property market efficiency is being significantly compromised.

6.2.7 The functioning of land market

According to Chinese law, urban and rural land is owned by the State and the rural cooperative respectively. Private ownership of land is still strictly prohibited by the Chinese constitution. Through the period 1950-1980s, land had been distributed by the State and local governments according to industry production and social life planning, no monetary value had been ever accrued to land, in other words, there existed no land market during this period. However, this situation changed fundamentally with the land market reform at the end of 1980. The 1988 constitution amendment laid legal foundation of land use right compensatory transfer. Since then, local government is legitimized to transfer the land use right to corporate based on agreement and other means, the subsequent result is that the extensive development of real-estate market was triggered across

China, in particular in the eastern developed areas. Following the land reform and introduction of land transaction market, urban land use is no longer free of charge, the fees or indemnity of LUR acquisition should be paid prior to proceeding to land development although land developers can be exempted in some cases. The property boom was triggered as a result of national housing reform in 1998; property prices continue to raise constantly, in particular the commodity housing. In fact, the main purpose of land reform in the 1980s and at 1990s was to encourage efficient land use of urban land through economic incentives, speculation on land and property development increased substantially the premium of land leasing (LUR transfer) become an important source of local government (Wu, 2001).

6.2.7.1 Land use planning controls

In general, the land-use planning of urban land are specified from two different planning scope and level.

First, general urban land use nature and development perspective are specified by the General Urban Planning (Master Plan) in which land use such as housing, commercial services, industry, transport and others is specified based on the statutory planning regulation (MOC, 1990).

Secondly, the land use in each zone or district of the city is specified by regulatory detailed plan (RDP). RDP is a detailed planning document based on the zoning defined in the general urban planning; detailed land use nature and development intensity indicators, and also regulatory indicators on roads and pipelines location and distribution, space environmental are specified in it. Once the nature of land use is determined as residential land use (R category) by the planning authority, property developer who acquired this land aforementioned means will work in collaboration with a qualified planning organisation (in general, Research Institute of urban planning and Architecture Design) to prepare the detailed residential areas planning and design (MOC and STSB 1993), the extent to which the plan should be detailed depend on the scale and scope of development. The major indicators in this plan are listed in Table 6-3.

Table 6-3 indicators in land use and planning document

Parametres in the statutory planning document	Residential area	District	Neighbourhood Group
Number of households	10000-16000	3000-5000	300-1000
Number of residents	30000-50000	10000-15000	1000-3000
Type of buildings			
Building height			
Orientation			
Minimum space in-between			
Green scenery			
Fire precaution			
floor area constructed of house			

Commercial facility
 Educational infrastructure
 Vertical planning
 Infrastructure networks ,
 electricity, gas, heating, water
 networks etc)
 Other indicators associated with
 housing

Although a typical regulatory detailed residential area plan consists of various evolution indicator, no explicit indicator related to building energy efficiency is specified in the planning document, although the infrastructure like electricity and heating are taken into account in the planning phase, the technical specification refers essentially to network installation guideline (for example depth and in-between space of laying and construction of supply pipelines, construction of transformation and heat exchange substation in residential area). It means that energy suppliers (electricity and or heat company) will decide the electricity or heat load in this area based on the indicators specified in the regulatory plan. Energy infrastructure design and plan should of course comply with relevant national and local regulation.

6.2.7.2 Means of land use rights (LURs) acquisition

Land acquisition is the primary means used by governments to meet increasing land demand driven by rapid economic and urban growth in China (Ding, 2007). Stated-owned land is directly administrated by the institutions of the local administration of land and property. Each year, bureau of property and land will decide the quantity of land that will be supplied into the land market based on the construction plan (aim of construction of new house for example) of GUP as well as the estimate of demand on the market.

Different land use regulatory indicators are specified in the document of land use right transfer. Therefore, when a property developer, say a housing developer acquires a residential buildings construction land, he must comply with the detailed regulation on land use and other obligatory fulfilment.

This reform allows the local authority to make compensatory transfer of land use right to a third person (public or private entity) for a certain period with remuneration in return. The terms of land use right transfer determines in general the period of transfer based on the nature of land use, thus depending on what kinds of buildings being erected on the land. The time period of land-use right compensatory transfer is set by the land –use regulation as presented in Table 6-4.

Table 6-4: Period in the TOR of typical land use rights transfer contracts

Buildings	Year
Residential	70

Industry	50
Education, science, culture, public health, sport	50
Commercial, tourism , recreation	40
Others	50

The first national regulation related to land use right administration— the *Provisional Rules on Administration of Allocated Land Use Right* was promulgated in 1992 as to regulate the transfer, leasing and mortgage of allocated land use right, the legal issues related to state-owned land procured by land user through means other than land use right transfer were specified in this provisional regulation.

Before 2003, land in urban China could be allocated by local authority based on administrative planning or negotiation between local land administration authority and developer, there was then institutional change in some municipality such as Shanghai where some state-owned land occupied by the Danwei (de jure landowners) is intended to unlock the supply of land for redevelopment while accommodating the existing institution of the Danwei's land use right (Zhu, 2004). Currently, land use rights can be transferred through the following means.

1. tender
2. auction
3. quotation⁸⁸
4. negotiation

In 2006, Ministry of Land and Resources promulgated the regulation on land use right transfer by agreement which specifies that state-owned land can be acquired through agreement only for land use other than commodity residential buildings, commercial and tourist property development (land use for business purposes or operating land use), land use right of operating land can only be acquired through bidding, auction and quotation (MOLR 2006). Land designated for commodity housing development can no longer be acquired by means of agreement and should be compensated through bidding, auction and quotation procedures in a purpose of render the market transaction more transparent and all the land transfer should take place justly and legally. All LURs transfer/leasing occur in the government-led municipal centre of land transaction.

⁸⁸ In this LUR leasing mechanism, land administration authority issues a notice on transfer of LURs of the underlying land plot in the city land exchange market with terms of reference and transaction deadline, the would-be bidders offer can offer their applications and update their bidding price any times as they like before the date of deadline expires. The decision on transaction is made based on the offers received the deadline date. Compared to LUR auction , a much longer period is given to quotation transaction , thus the bidder are not obliged to make the final decision immediately as in the case of auction.

It should be pointed out the social housing category namely economically affordable housing (EAH) is not exempted from this mandatory LUR transfer procedure. Although land is still being allocated to the real estate developer free of charge, land use right transfer can only take place through the tender procedure based on land regulation policy, which results in the fact that most of EAH are located in the fringe area of the city.

6.2.8 Price of LURs acquisition

6.2.8.1 Reference land price

In Tianjin, local government settles reference prices of land leasing rent or the purchase of LURs according to the rent grade and land use nature. The land value is certainly dependent on various factors such as location (distance to city centre, accessibility to public transport etc), land use nature, and potentials for land appreciation. The price level in 2007 is listed as follows:

- Reference price for land leasing in central city (Yuan per square metre)

land rent			
differential	Commercial	Residential	Industrial
1	12300	5980	1250
2	9200	5200	1030
3	7250	4200	860
4	5350	3350	740
5	4000	2800	620
6	3150	2250	510
7	2600	1810	480
8	2150	1400	420
9	1670	1060	
10	1290	850	

- Reference prices for land leasing in suburb and rural districts (Yuan per square metre)

District	Land use	Differential rent						
		1	2	3	4	5	6	7
Tanggu	commercial	4004	2833	2005	1419	1004	711	503
	residential	1678	1339	1069	853	681	543	434
	industrial	635	544	466	424	384		
Hangu								
	Commercial	1260	825	540	355			

	residential	710	550	425	340			
	industrial	450	385	330	288			
Dagang	commercial	1475	1100	815	615			
	residential	930	795	685	585			
	industrial	490	420	365	315			
Xiqing	commercial	1350	960	720	480			
	residential	1310	930	650	360			
	industrial	440	380	336				
Beichen	commercial	1000	880	580				
	residential	980	520	400				
	industrial	350	320	288				
Jinnan	commercial	980	760	530				
	residential	770	530	400				
	industrial	350	343	336				
Dongli	commercial	1000	850	540				
	residential	980	720	530				
	industrial	430	320	288				
Jinghai county	commercial	1655	1255	1000	600	400		
	residential	885	755	580	330			
	industrial	425	280	204				
Ninghe County	commercial	1100	660	418	258			
	residential	560	410	280	211			
	industrial	345	256	182	168			
Ji County	commercial	2080	1170	655	370			
	residential	895	670	500	370			
	industrial	450	375	270	230			
Baodi	commercial	1435	983	673	461	318		
	residential	772	620	498	400	318		
	industrial	355	300	260	230			
Wuqing	commercial	1250	820	520	330			
	residential	665	565	390	290			
	industrial		275	264	252			
TEDA	commercial	2758	1750	1064	760			

	residential	1736	1310	994	662			

Source: Tianjin Real Estate and Land Resources Bureau

Table 6-5 Price of wholesale leasing of LUR in built-up urban districts

plot	Jinbeichenxiang(quotation) 2008-033
Location	Beichen district (inner city)
Area	3562
Land use	Residential
Means of acquisition	Quotation
PR	≤1.8
Transaction price	14800000
Lease holder	Baoshili real estate Co.
Period of lease	70 years
Price	4155

Source : <http://www.tjlandmarket.com>

The LUR price of this plot is excessively high, more than four times of that listed as 1st grade land in the reference price catalogue as shown in Table 6-5. Two rural district land plots LURs acquisition are listed below for purposes of comparing the actual transaction price with the aforesaid reference price, data are published by Tianjin Land exchange Centre.

Table 6-6 Price of wholesale leasing of LUR in rural districts

Plot	Jinwu (quotation) 2008-007
Location	Wuqing district (rural county)
Area	934298
Land use	Residential
Means of acquisition	Quotation
PR	1.0-1.2
Transaction price	420000000

Lease holder	Tianjiin Yinghui investment corporate
Period of lease	70 years
Per square metre floor area price	375- 450
Name of plot	Jinbao (auction) 2007-13
Location	Xinjin area in Baodi district
Area	277141
Land use	Residential
Means of acquisition	Auction
PR	1.0-1.35
Transaction price	84000000
Lease holder	Tianjin Hesheng Zhujiang real estate company
Period of lease	70 years
Per square metre price	303

Source: <http://www.tjlandmarket.com>

Is can be seen that the LURs price in the suburb and rural districts are generally quite close to the reference price indicated by the Land Resource Administration.

6.2.8.2 LURs acquisition in the case of EAH

Blow are presented some examples of announcement of result of tender for land use right transfer, planning parametres are specified with regard to land development such as total development area, land use, means of transfer (tender), period of leasing, ceiling of buildings floor space (according to plot ration allocated by planning bureau), ceiling of average price of apartment and of the most expensive house. Note that the transaction price of LUR is zero. The EAH sale price is regulated by the local government. Since the EAH enters into the secondary real estate market, the central government issued a regulation to curb speculations on EAH price, it states that the EAH can not be resold during first five years following the purchase date, and the land transfer price should be repaid a posteriori if the house owner resells the underlying EAH to a third person on the secondary real estate market according to indicative land transaction price in the corresponding area.

Case A and B are samples of public announcement of wholesale leasing of land designated for EAH construction in the city of Tianjin recently.

Case A.

Land piece 2007-06

Tender of land use right transfer for EAH development

Tianjin land resource administration bureau

Plot code: Tianjin PH (tender)2007-06

Location: South-side of Yangbei Rd. Dongli district (East inner city)

Area of transfer : 88500.00

Land use : Residential

Means of acquisition : Tender

Plot ratio: -

Transaction price: -

Leasehold of LUR: Beijing Taifuheng Investment Corporate

Period of transfer of LUR: 70 years

Date of commencement: October 9, 2007

Remarks : Total constructed floor area should be lower than 153600 square metre

Indicative average price of house: 3846 Yuan / m²

Ceiling of housing price: 4046 yuan/ m²

Case B

Land piece 2007-06 land use right transfer for EAH housings construction tender

Tianjin land resource administration bureau

Plot code: Tianjin EAH (tender) 2007-12

Location: West Tuanjie Rd, Hongqiao district (inner city)

Area of transfer (m²): 51480.40

Land use : residential

Means of acquisition : tender

Plot ratio: ≤ 3

Transaction price: -

Leasehold of LUR: Tianjin Housing Development Corporation

Period of transfer of LUR: 70 years

Date of commencement: October 22, 2007

Indicative average price of house: 4347 Yuan / m²

Ceiling of housing price: 4695 yuan/ m²

Source: <http://tj.focus.cn/>

6.2.8.3 Housing supply situation

In 1998, the Chinese State Council promulgated the “Notice on speeding up the urban housing system reform and housing construction”, which established the fundamental goal of market-oriented commodification of China's housing distribution system. It also specifies that urban low-income households should be provided low-rent housing; modest-income households to buy economically affordable housing (EAH) and normal commodity housing for the rest of urban residents. More specifically, land designated to EAH construction is allocated by local government through administrative means, in this case, the profit of housing developer is controlled and sale price is capped by the government. Developers may benefit in turn from tax reduction and or fiscal advantage. However, this welfare housing distribution system has been questioned by some Chinese scholar (Xu, D.2005; Xu,H. 2005),who argue that this policy has been deviated from government’s initial goal and violated in many cases.

Housing reform advocates propose to cancel this policy and put in place the monetary subsidy to low-income household’s housing purchase instead. Other empirical studies have analyzed EAH policy efficiency from government expenditure perspective (Song, 2001)and consumption behaviour theory (Huang, 2004), it is found that government’s direct subsidy is more efficient than administrative land allocation , also from equity point of view, both developer and low-income family aren’t really beneficial from EAH by default of relevant facilities. It is suggested that the current policy framework of EAH land distribution should be adjusted by give rise of housing subsidy to less affluent people in the city. Tian analyzed the EAH market with welfare benefits analytical framework.

Property prices has been rising sharply in all the major cities in China since 2003. One of the main drivers is the relatively low cost during the operation stage of a house. Unlike in the developed countries where the cost for

house ownership is relatively high since the property tax is levied in most of these countries, the majority of cost of house ownerships is made up of LUR acquisition and various development fees at the construction stage in China's property market. In other words, when someone buys a new house in China, he actually pays the in advance the implicit property tax of the house at the stage of purchase instead of paying year by year. And the taxes during the house operation stage are relatively low as explained earlier. Some Chinese property experts estimate that the tax and fees account for around 30-35% of house sale price in most of property markets in China to-date. They also argue that the property tax levy will not necessarily curb the current property speculation since the tax on property is based on surface calculation instead of assessed property and land value as in the US and other countries. Also, the tax on property transaction is not high enough to discourage the short-run property speculating. Although both central and local governments have already issued several directives aiming at curb the speculation⁸⁹, the house price hikes are still being observed in many cities since the upfront land supply is still being controlled tightly by administrative means, the supply-demand relationship in the property market can not be predicted precisely by economic theory.

6.3 Institutional aspect of district heating supply in Tianjin

6.3.1 General situation of district heating in Tianjin

District heating in Tianjin started in the 1980s and now covers about 80 per cent of the urban residential floor area. The heating sector is still very fragmented, with more than 200 heating companies operating independent networks, many of them supplied from small coal-fired boilers. The municipal government is now implementing a 2003 to 2015 heat supply development plan, including the interconnection of the local systems, elimination of the small boilers, and development of larger heat sources that can provide heat with suitable environmental controls. This would be in compliance with the Tianjin "Azur Sky Programme" which calls for the elimination of all coal-fired heating boilers of less than 7 MW and expanded use of DH and clean fuels within areas lying inside Tianjin's ring road(TJ Urban 2008, p.73).

Space heating in buildings in the inner city of Tianjin (urbanized area) is primarily distributed by centralized district heating system, individual heating is rare like most northern city in China. 80%-90% of buildings floor space is heated by centralized district heating system. Thus this chapter only deals with the district heating in Tianjin since household individual heating accounts for only a small part in the total heated space area.

Heat is mainly supplied by coal-fired district boilers and the combined heat and power (CHP) generation plants, namely the 1st thermal power plant, Chentangzhuang thermal power plant, Yangliuqing thermal power plant respectively(hereinafter referred to as Yire, Chengre and Yangdian 90 respectively). In addition, a part of outskirt of city is supplied by Junliangcheng CHP which is located in the eastern suburb of Tianjin. The total

⁸⁹ For example, since 2007, some local government issued new regulation which states that all EAH can not be exchanged on secondary market within five years after purchase to prevent the speculation on houses that are designated to be sold to urban low to modest-income households.

⁹⁰ The names of the CHP plants are literally First Thermal Power, Willow Green, Chentang Village respectively.

heated floor space is 120 million square metres in 2007, supplied essentially by medium and large-sized district boilers and municipal large CHPs. The distributed heat-only boilers⁹¹ and CHP account in total for 70% and 30% of district heating source, respectively.

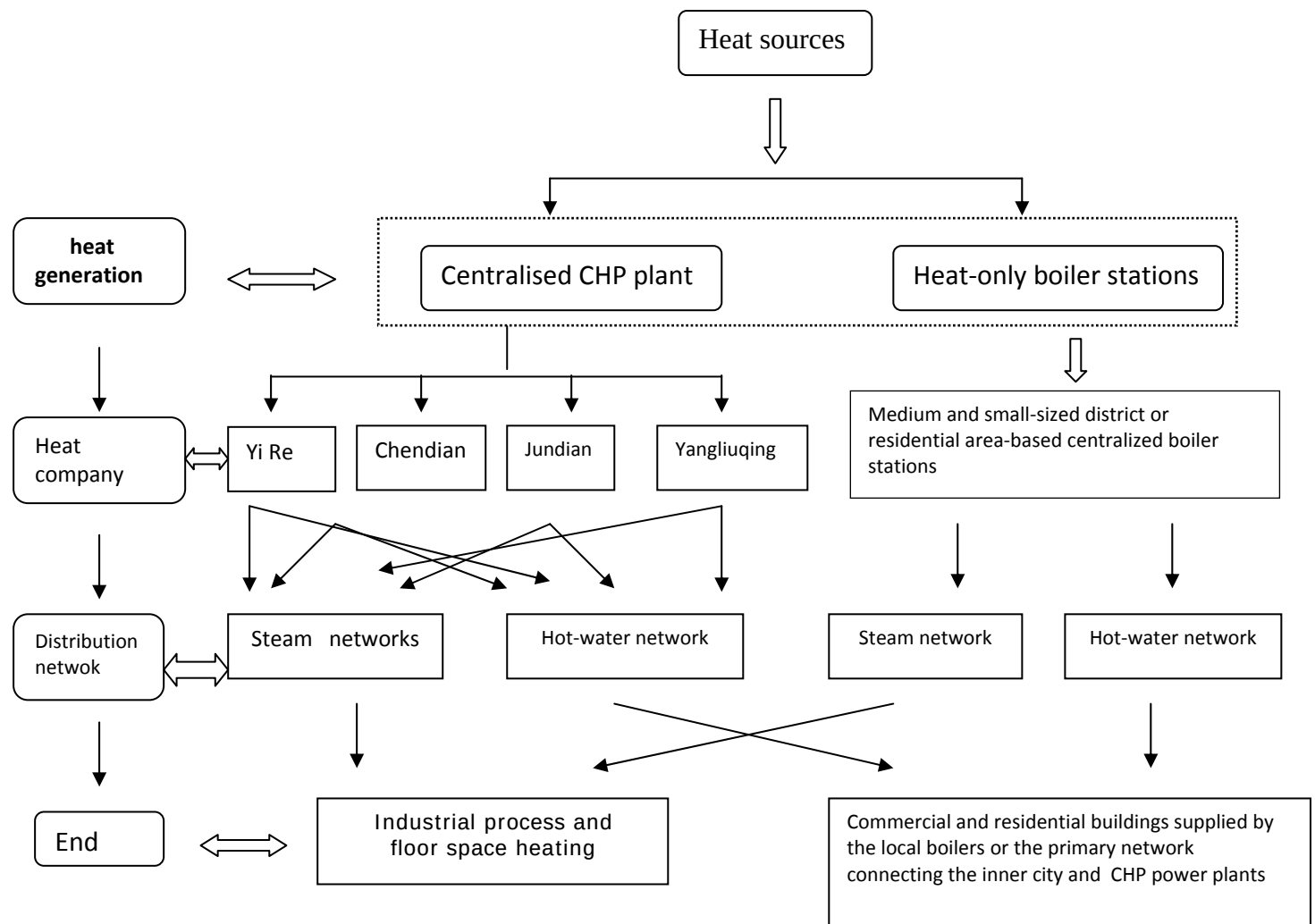
In accordance with the central government's directive relating to the improvement in power and heat generation efficiency, the local government in Tianjin is fostering vigorously the CHP promotion policy in order to substitute the small-sized boiler stations which raise enormous concerns about local environmental pollution during the winter heating season. The large CHP is likely to supply a significant part of the buildings floor space area currently distributed by medium and small-sized boilers, as to cover more than half of demand for space heating in buildings in the city-zone by 2015. alternative energies such as gas and geothermal are actually accounting for a very modest portion in DH in the city, their share is expected to reach 25% of total heating area in the long-run (2020) according to Tianjin Municipal Heating Energy Development Planning (Tian, Y. 2008, personal interview).

However, the policy of promoting large-size thermal power stations to eliminate eventually the small-size local coal fired boilers entails a potential financial difficulty, since the large power station necessitates more capital investment at the phase of installation and requires a stable and high load factor of end-user. For example, a 2X300 MW CHP can supply capacity can cover a 13 million square metres of floor space, whereas the full heat load might be only existing in 3-5 million square metres during the first years after the operation of the thermal power station, in other words, a large part of capacity is left idle and both the capital and O&M costs can hardly be repaid by the energy charges. Moreover, from technical point of view, although the large CHP is much more efficient than the district-based boiler stations, the wide-spread heat supply network poses a challenge of hydraulic equilibrium regulation. The heat loss resulted from inappropriate main network regulation may be significant, therefore the gain from production efficiency is effectively counterbalanced by the network energy loss, in particular for the steam supply networks.

6.3.2 Heat distribution network operators

The following charts explain the main structure of heat supply in Tianjin.

⁹¹ The word "Boiler" in the part below refers systematically to heat-only coal-fired boiler except special explanation.



Currently, in the built-up central city of Tianjin, heat supply networks are operated by 27 major central heating supply business companies⁹² (heat networks operator) in the city, including both public and private firms. All of these companies have business office in each service area to provide heating service related information and deal with the heating billing and pricing issues with their customers before and after the heat season. The way of functioning varies from each other between these companies. The thermal heat (produced in the CHPs) supply companies (in particular, Jinneng and Jing'an Energy Group⁹³ which are both public enterprises owned by the local government) run the thermal heat distribution networks by purchasing heat from CHP power plants and resell it to end users, the difference between the purchasing and sale prices may cover their depreciation and operation cost and yield economic profits⁹⁴. It should be borne in mind that the heat company is responsible for investing capital in the heat network infrastructure

⁹² They are referred to as heat companies in the following text except for specific note.

⁹³ Jinneng Energy Group is a wholly state-owned public investment corporation. Its main responsibilities are to invest in the electricity, heat, gas, energy conservation projects, such as energy infrastructure and high-tech industry development and investment management through equity participation, holding and commissioned loans in order to preserve and increase the value of state-owned assets within the provisions of relevant government's regulations

⁹⁴ In practice, this distinction between the CHP plants and heat supply company is less obvious since a large heat company like Jinneng Energy Group has stakes all of large CHPs and also participate to invest in heat source infrastructure development, again, Jinneng is involved in the IGCC project in the Lingang district of Binhai New Area. In addition, Jinneng holds the major part of Chentang's stake. Moreover, the future Beijing thermal power generation center is also partly financed by Jinneng Group.

renewal and maintenance, for example, Jinneng Group has been involved in two-thirds of infrastructure investment of the city's CHP's heat-supply networks.

Conversely, in the case of district boiler stations, many heat companies' deal with both heat generation (boiler stations unit) and heat supply (distribution) business simultaneously. Unlike the thermal power heat supply companies, they are both heat producer and supplier in practice⁹⁵. CHP plants themselves are not involved directly in the heat delivery, heat are sold to distribution companies at negotiated price.

Both boiler stations and CHPs produce both industrial process steam and hot-water for space heating. For residential and commercial buildings, heat is usually distributed by urban heat distribution main networks and different substations and exchangers before being delivered to the end-user (household, commercial customer etc) eventually. Currently, when a heat company purchases heat from the local CHPs, the following wholesale rates apply:

Steam	16.72	yuan /GJ
Hot water	18.65	yuan/ GJ

6.3.3 Heat Company

The general organisational framework is illustrated by diagrams 6-2. Jin An Thermal power utility and Tianjin Thermal Power Company are two major operators in supplying heat that generated from the four CHP plants of the city. Jin An is a wholly-owned subsidiary of Jinneng Energy Group, which in turn is a Tianjin government-affiliated public investment corporation, led directly by the municipal development and reform commission (DRC). Jinneng is also investing in the large-scale CHP units in the BNA in collaboration with the Chinese Hwaneng Energy Group.

The Thermal power plants had been administrated by the municipal bureau of electricity until 2004, when the Chinese reform of electricity came into force, since then the heat supply of thermal power plants is directly managed by the Jinneng Energy Group whereas electricity generation is under the leadership of the relevant group of the five national major power generation groups⁹⁶.

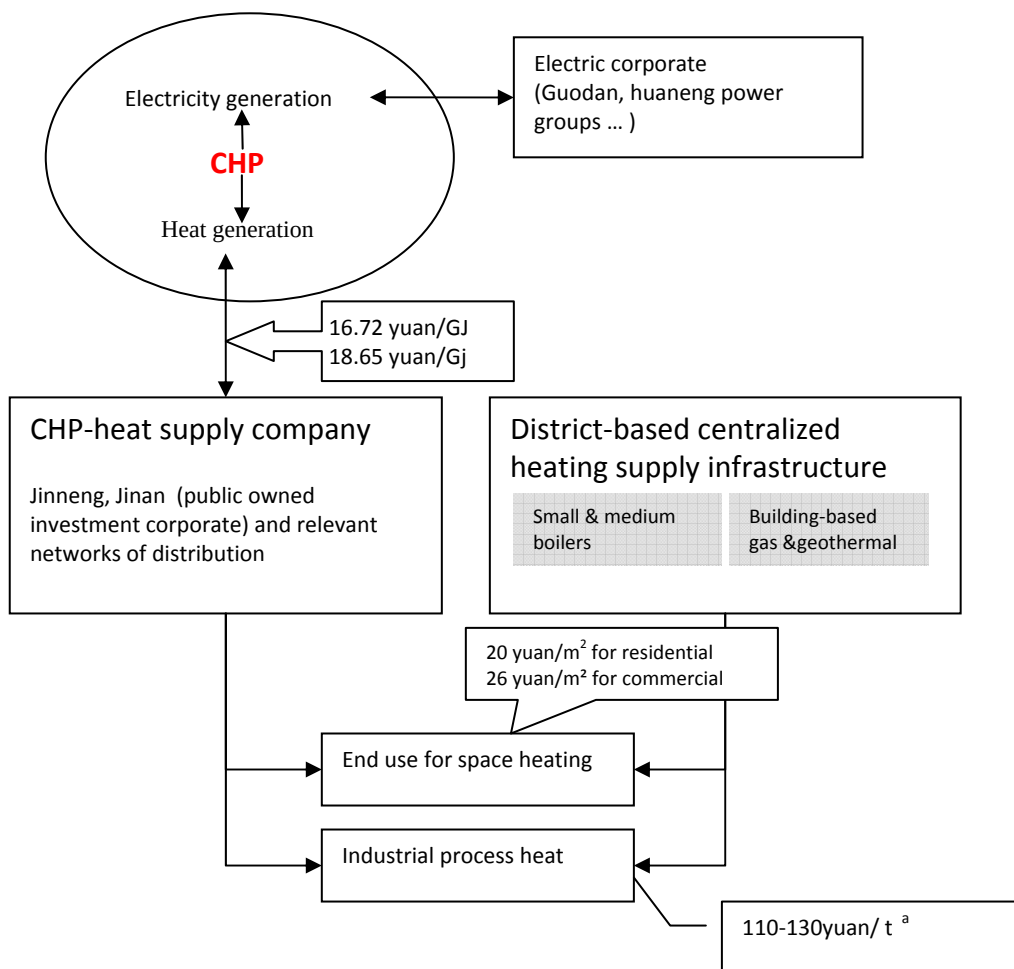
It is quite commonplace that several heat companies supply the same district since certain sections of networks are interconnected. Heat companies are comprised of three major types of operators:

⁹⁵ Strictly speaking, this distinction is less obvious energy utility like Jinneng group is also involved in the heat production since they participate in the investment of large CHP heat source installation, they are also running heating production in the CHPs.

⁹⁶ For more information on power sector reform, see the article of Xu and Chen (2006).

1. operator of thermal power network (CHP supplier)
2. District boiler stations
 - a. heat company owned by the local bureau of housing administration
 - b. heat company owned by property developer
 - c. heat company run by a non-energy corporate

In previous section we have already explained that the district boilers (network operators) are both heat producer and suppliers with the heat generation centre and network infrastructure being their main capital assets. Conversely, CHP supply companies are only in charge of the thermal part in CHP plants and the subsequent delivery to public and private users, electricity generation and distribution is CHP run by electric company under sectoral regulations.



a: the price is dependent upon the pressure and temperature of steam required by the industry

Figure 6-2. Organisational structure schema of heat supply in Tianjin

6.3.4 Urban development and energy supply

We have insisted in the introductory section that current choice of urban infrastructure will have important impact and constraints on the urban development in terms of access to fundamental services including transportation, energy, and dwelling environment but also consequences on cost incurred to the society such as pollution and GHG emission impact. Energy supply system such as district heating infrastructure and buildings energy efficiency will determine during several decades the overall energy performance of the whole district, in particular in the fast-growing cities. This is why the public authority should establish a workable mechanism that allow energy supplier and housing developer to collaborate seamlessly regarding the content of both buildings and energy consumption and supply intensities by removing the non co-operative market barriers. Understand the institutional structure and dynamics of functioning of property market and energy infrastructure development become thus increasingly important and inevitable.

6.3.5 Upfront heating design process and drawback

The decision on energy infrastructure is generally made in the Urban Energy Development Plan which specifies the time schedule and geographical distribution of installation of new energy supply infrastructure or renovation of existing energy production and distribution networks. If we look at the example of district heating, the urban heating plan is included in the GUP as an important constituent all the northern city. The local government will convene the qualified professionals (in general the municipal engineering design institute in collaboration with other qualified research institutes) to draft the district heating perspective based on the city's social-economic development aims specified by the GUP. By consulting the land use plan in the GUP, the consigned heating infrastructure designers will then estimate the evolution of heat load and their spatial distribution as to determine the plan which specifies the timeline of required new installation, renovation and decommissioning existing supply capacities. The key indicator in future heating demand in the new buildings is the heat load which in turn is closely dependent on energy performance of buildings. In general the chosen value for underlying planning object includes both building end user-side final consumption and energy loss in the energy distribution network. This is true both in the case of electricity and district heating planning.

Currently, a general heat load allocation rule is applied to a large planned area of residential buildings; it means that the urban heating planner will allocate a fix value, e.g. 40 W/m² for the whole residential building area in a city-level heating plan. Therefore, all the residential areas in the GUP are treated systematically with the same criterion. However, this uniform value may disguise largely the actual difference or variance in terms of energy demand among the different types of buildings that will be built eventually, this non differentiation policy may result in capacity oversizing in infrastructure installation and entail serious economic impact such that the installed capacity may be left at idle during excessively long period.

This practice may also discourage the innovation or improvement of energy performance of building since the developer has virtually no any influence on the upfront energy supply capacity allocated by the city heating development plan. Therefore for a typical large-scale residential area where many house are constructed, the general energy demand indicator can be expressed by the formula as follow

$$EI_R = f (H, t, m, h, p, EE, d, F, \epsilon)$$

Where

EI_R	the general energy performance indicator of the whole residential area
H	household and resident
T	building type
M	materials used
H	buildings height
PF	plot ratio
D	construction density
EE	energy efficiency of buildings and final appliances
F	fuel consumed (energy mix in the area, for example if renewable is used)
E	non observable factors

This simplified function reveals that the energy performance is dependent on several variables which can only be specified in the Regulatory Detailed Planning (RDP) in a large residential area. Nevertheless, most of heating indicator is already allocated before the RDP is established, the current institutional organisation excludes the possibility for energy supplier and housing developer to redevelop an energy(district heating) scheme in accordance with residential area design and planning. In other words, after acquiring the land, what the property developer can do is to either apply for district heating network (CHP or boiler stations) if it is available or apply for the permit of coal-fired boiler or alternative energy system (geothermal for most cases) installation, in this case, the decision of approval or not will depend on the result of an environment assessment , carried out by local environment agency.

6.3.6 Development perspective of small CHP under current institutional framework of urban planning

In 2007, the central government issued a directive on shutting down small capacity thermal power plant during the 11th five-year plan (NDRC 2007), the small-sized CHP is also subject to be closed regardless of higher thermal efficiency than the traditional condensing power plant. We can see from the city's heating planning that only large CHP is considered to be installed over the next 15 years, since large CHP has much higher efficiency during winter time, and they perform better even during the normal period, (heat load is much lower in summer than in winter), therefore the large-capacity of extraction-condensing units are favoured in both city and BNA district heating planning. CCGT and district –based medium coal or alternative energy fuelled

cogeneration have not been considered in the planning due to the fact that natural gas is still too expensive in Tianjin.

The policy of deploying the household based gas boiler instead of developing centralized CHP or trigeneration system may be misleading in fuel switch, the individual gas boiler are less efficient than centralized CHP system and raises the concerns about local environment deterioration by the fact the concentration level of NO_x risks escalating with the multiplication of installation of individual gas boiler in flat buildings. It is understandable that municipality has favoured the clean coal use policy instead of fuel switch given the obscure perspective of gas supply availability⁹⁷.

Nevertheless, the priority of developing large CHP projects to improve the energy efficiency and lower the environmental hazards raises another problem to economist because it is general more expensive and takes more time to construct than smaller one. And the load factor during the first stages of a CHP's operation is likely to be significantly lower than the full capacity. Moreover, the cost associated to the development of relevant distribution infrastructure (heat networks, substations, pumping centre etc) is also considerable. According to Xiao (2008, personal interview), the networks developed for a 300MW CHP usually use only its 40% capacity for several years because of insufficient heat demand. In the sense, the investment of public financial resources (the heat company who is in charge of network development is State-owned corporate) seems to be difficultly justified.

6.3.7 Property management company (PMC)

After the completion of construction, a professional company is contracted with the property developer to run the property management service as to ensure the normal functioning of a building. Its main task is to manage security, public spaces, elevator, cleaning, green space, O&M of electricity, water, heat supply appliances etc. The PMC is remunerated by monthly property charge based on floor area of residents.

It is quite common that the PMC collects the payment for utility companies (water, electricity, gas and heat). More and more heat supply companies charge the DH services based on metered consumption to the PMC (a heat metre installed at the entry of residential area to measure the total consumption in this sector) whereas the PMC charges in turn the consumers based on floor-space tariff since the individual metre only installed in a small part of existing buildings. These two charges are not necessarily identical. Conflict may happen if the payment that a PMC collects from the end-user is significantly lower than what heat supply company charges based on metered consumption. For instance, commodity house vacancy is a quite common phenomenon in urban area, the PMC can only charge the consumer living physically in the buildings not the house owner who leaves their premise unoccupied. Although the PMC can cut off the indoor heating valves if available, the

⁹⁷ Tianjin has been systematically "loser" in gas supply priority with Beijing for political reason. Large quantity of gas due to be supplied to Tianjin was finally re channelled to Tianjin during the rude winter in 2006. It should be pointed out that Beijing municipality imposes all the district boiler stations to retrofit their boiler to switch to gas in order to improve the city's air quality. From energy use perspective, this has a significant impact on the gas supply to Tianjin.

houses are still being supplied more or less by the “free heat” coming from the neighbours. Hence the calculation based on floor area does not equal to the billed consumption by the heat company.

6.4 District pricing and reform perspective

6.4.1 Household expenditure on heat

Heat pricing and billing reform needs evaluating the impact on household with care. Previous experiences of DH in the Eastern Europe in the 1980s and 1990s were rarely the result of smooth implementation of carefully planned and sequenced interventions. Results were achieved based on trial and error rather than on comprehensive strategies aiming to reform the (district) heating sector. Many heat companies experienced great financial difficulty due to massive disconnection of heat clients (residential, commercial and industrial users). As indicated in Meyer and Kalkum (2008), statistical information on the consumption of centralized heat and, more importantly, on the consumers themselves is not officially available, since heating due to its welfare nature has until now not been included as one of the expenditure categories covered by the regular statistical surveys in China (Meyer and Kalkum, 2008).

The cost of heat and price of heat need to be addressed very carefully when proceeding to heat reform. Heat tariffs for non-residential customers are typically slightly higher than residential tariffs. According to the survey of the World Bank project, heat prices for residential consumers have been kept stable for many years in many municipalities (e.g., since 1995 in Changchun). Heat tariffs for non-residential customers are typically slightly higher than residential tariffs. In Tianjin, cost coverage of heat company is around 80% on average from 2002 to 2003. The majority of heat companies in the Northern cities has not been able to cover operating costs with tariff revenues during the past three to five years and relies instead on government subsidies. For independent cost coverage companies, DH also needs great efforts to improve debt collections. Annual average heating bills of Chinese households connected to DH range from 700 yuan (87 US\$) in the warmer southern part of the heating zone to 1400 yuan (175 US\$) in the colder cities of northeast China. The World Bank/GEF project conducted DH consumption survey in several cities in northern China, three of them—Changchun, Harbin and Taiyuan—work units are still contributing about one-third of the payments for heating. Subsidies to poor households contribute 6 to 7 per cent in Harbin and Changchun. On average, heating bills would constitute about 4 and 24 per cent of the incomes of high and low income households, respectively, but the *de facto* burden—that is, of the self-paid heating bill—is significantly smaller. Work units in most cities still paid a large share of the bill, Tianjin being the exception. In Tianjin, the transfer of heat bill payment to the individual households occurred several years ago (see Box 6.2.), and they pay almost the entire heat bill themselves (Meyer and Kalkum, 2008, p.7). Employees in public sector receive higher wages in form of compensation; and those poor households receiving payments under the Minimum Living Standard (MLS) program are (partially) exempted from payments for heating. The yearly official heating season in Tianjin covers the period from Nov 15 to March 15, extended to the end of March if

necessary. In chapter 4, we simulated the different scenarios of heat load and energy demand for heating in buildings constructed adopting the different level of envelope thermal performance.

6.4.2 Theory of energy pricing

The district heating market is indeed a public monopoly since there is no competition at all between the heat utilities. Paradoxically, this is not a monopoly price since heat has been considered as welfare (socially public) good, the notion of marginal pricing is virtually ignored in this area. Heat price in this case does not say much about the real cost of heat companies, these firms are assuming the social responsibility of the government. Heat price paid by the end users does not reflect the equilibrium of supply and demand hence the allocation of resource is not efficient, here efficiency refers to avoiding allocation distortions caused by setting price equal to marginal cost. In other words, under current circumstances, central heating supply companies cannot differentiate the customers by pricing the services differently, differentiating the increment by pricing is an efficient means whenever the price elasticity of demand differs and price exceeds the marginal cost in monopoly utility goods. Heat companies fail to elaborate the sophisticated price menu to differentiate the customer by segmentation method. Economic theory tells that heterogeneity among customers assures that different increments have different price elasticity (Winston, 1993).

In the case of district heating, efficient price should be in theory set by the Ramsey Pricing theorem, whereby the regulated monopolist tries to maximize consumer surplus whilst at the same time ensuring that its costs are adequately covered. This is achieved by setting the price such that the mark-up over marginal cost is inversely proportional to the price elasticity of demand for that good. In the absence of perfect competition, a public monopoly should set the level of physical sales in such a way that the price at which each of its products is equal to the marginal cost of production at that level of sales. The pricing should reflect the constraints of financial equilibrium of the enterprise. DH heating service in Tianjin can be seen as an Oligopoly situation whose price is strictly regulated by the local authority. It has been argued that the often distorted domestic prices in developing countries are inadequate for assessing the relative benefits of alternative projects and propose to use world market prices for this purpose instead (Little and Mirrless, 1969 ; Sakellariou, 1980). This results in actual energy subsidy to households and profit loss even deficit of national heat Supply Company. A particular point should also be pointed out is that non-payment of heating charge is quite common under certain circumstances and the households will not be cut off necessarily from both technical⁹⁸ and social point of views.

⁹⁸ Many existing premises are supplied by the serial mono-pipe system which doesn't allow cutting off heat supply of a particular household in a building if no additional retrofit takes place. This is illustrated in heating distribution diagram in Appendix.

6.4.3 DH investment and practiced approach of heat pricing

Expansion of heating infrastructure is routinely financed in majority by connection fees imposed on real estate developers and, thus, ultimately by final consumers who buy the properties. The property developer should pay unexceptionally a universal municipal district heating connection fee (*Ru Wang Fei*) fixed at 92 RMB per metre square of heated space regardless of housing construction type or efficiency performance. Another fixed network load increase charge (*tie fei*) is also payable to developer in certain circumstances. We see immediately that whatsoever building the developer constructs, always the same charge is applicable and no incentive is given to improve the building efficiency in this case.

The local authority specifies in the municipal heating regulation imposes a binding commitment to connecting to local CHP network if this is available in the area where the program is taking, option for coal fired boiler stations is excluded in this case, whereas the developer can choose to install clean energy for heating such as geothermal or gas boiler stations. Nevertheless, a gas boiler station is often the last resort because of the high fuel cost. In most of case, the heat price is a fixed charge based on the living area of households, in this case, property management company might face a dilemma regardless of pricing option selected, for two reasons if the company bill the customers based on the traditional fixed charge proportionately to household floor space, the charge might not cover the financial cost of the company if the company bill the customers based on two-part tariff, since the gas is much more expensive than coal, the per *kWh* rate is proportionately higher, the customers might refuse to pay the bill this implies that whatever pricing method is chosen, the company doesn't have any incentive to install a gas fired boiler stations to supply heat.

According to government guideline on district heating supply regulation (State Council, 1986; MOC, 1992), heat price consists of cost, tax and profit of heat supply company. The cost is divided into fix cost (O&M, salary, materials and overheads) and variable cost (fuel, water, electricity). Regarding the pricing decision making for DH service, the municipal bureau of heating is a sectoral administrative authority which is in charge of heat price regulation and heating policy elaboration and implementation. It should be pointed out that heat price should be approved by the municipal bureau of price after audit process. The price is determined on the basis of total cost calculation of heat company. Currently, two system of heating service pricing are both practiced in the city of Tianjin, namely floor space based pricing (fixed charge) and metered pricing (two-part pricing).

1st. Traditional single-tariff method: heating bill is proportional to occupied floor space in linear manner, currently, heat sales price to residential end-users is fixed at 20 Yuan/ m²/year and 26 Yuan/m²/year in commercial buildings (hotel, public institutions, schools, commercial centres, etc). This pricing method is still dominating in most buildings and customers pay their heating bill based on the living area; and

2nd . Two-part heat tariff : in this case heat price consists of a fixed charge per square metre per annum (10 Yuan) plus a charge (0.009 yuan/kWh) for the actual energy consumed by the customers. It complements the traditional fixed charge in some newly constructed residential buildings where individual heat metres are installed and consumption-based billing is available.

The two-part tariff is only applicable to residential buildings in which the individual metres have been fitted, billing and pricing heat on the basis of real consumption is the major policy regarding the heating market reform in the northern cities in China. Nevertheless, from economic efficiency perspective, the current pricing structure still lacks to some extent the economic rationale because of its extreme simplicity and absence of discriminatory pricing structure. The tariff neglects actually the difference of price elasticity and of the utility of heating among the customers. No price discrimination has been implemented like in the electric sector. Heat price is calculated such that heat companies recover their operating cost & charge and a fixed profit rate as a percentage of revenue of the heat selling. In comparison, we see that the public utility in the developed countries have devised very elaborate non linear tariffs in energy services pricing. For example, French electricity producer and distributor EDF (public monopoly) proposes different pricing menus in the tariff bleu (blue tariff) scheme⁹⁹ to the residential and commercial customers. Household can choose the best suitable pricing menu accordingly instead of paying the same tariff regardless of how much and when the energy is consumed. In fact, the more sophisticated pricing measure is being practiced in electricity consumption, end users have choice between the liner tariff and day –night tariff.

6.4.4 Heat reform agenda

Tianjin initiated DH pricing and billing reform in 1998 based on the central government's agenda on heat commodification in urban DH service. The reform involves deployment of consumer-controlled heating systems within all newly constructed buildings and billing and pricing of heat on the basis of actual consumption instead of occupied floor space in the conventional way.

Meyer and Kalkum (2008) give a comprehensive description of the political and economic context and policy agenda of heat reform in China. In 2003, the eight involved central government ministries and commissions jointly issued "Guidelines for Pilot Projects of Urban Heating Reform", with the Ministry of Construction (MOC) designated as the working secretariat, officially launching the reform. Following two years of piloting efforts and experimentation in pilot cities in the 16 northern provinces and autonomous regions, the eight ministries issued "Instructions to Further Push Forward Urban Heat Reform" with State Council's approval. In June of 2006, MOC established a new Heat Reform Promotion Office, and this was followed with instructions at the National Heat Reform Working Conference in August 2006 for localities to set up specific offices to lead implementation of municipal heat reform efforts, beginning with the development of specific action plans. Heat reform in general and the need to achieve significant energy savings in the heating and building sector has

⁹⁹ The *tariff bleu* offers the pricing scheme to customers who power load is up to 36 KVA, this tariff consists of three different options which applies basic tariff, empty hours, critical times tariff respectively (Wilson, 1993, pp 30-31)

also been emphasized in China's "11th Five-Year Plan". Progress has been made during the last few years, especially on the heat *commodification* agenda, with pilot efforts proceeding in various northern cities. Tianjin became the first large city to adopt reforms to fully shift responsibility for paying heat bills to consumers, including the compensation of civil servants. A number of medium-sized cities have also implemented this reform, and plans are in fairly advanced stages in most cities. In most cities, poor households receiving social welfare payments (*di bao*) under the existing social assistance system based on the Minimum Living Standard (MLS) Scheme are (partially) exempted from heat bill payments or have them partially covered from special government funds. New MOC guidelines calling for deployment of consumer-controlled heating systems within all newly constructed buildings are becoming more routinely observed. A wider variety of experiments in heat-metreing technologies have been undertaken.

Box 6-2. Chinese Heating Reform

After the small-scale piloting of various components of heat reform in the 1990s, eight ministries and committees jointly issued guidelines for heat reform¹⁵ in July 2003 to scale up reform by requiring each of the 16 provinces in the heating zone to assign pilot cities and to report on progress in implementing pilot heat reform programs in those cities. These guidelines were followed up—with State Council approval—in December 2005 with "Instructions to Further Push Forward Urban Heat Reform." The goals of the heat reform program outlined in the heat reform guidelines are to commodify heating by addressing key sector issues:

- i. Shifting the responsibility for payment of heat bills from employers to consumers and transforming the non transparent subsidy into a transparent one, including improving the system of targeted subsidies for poor consumers;
 - ii. Introducing heat metreing and billing based on consumption, promoting consumer control of heating and building energy efficiency, including far stricter enforcement of the Government's building energy efficiency standards for all new residential buildings;
 - iii. Developing safe, clean and demand responsive heat supply systems;
 - iv. Reforming heat pricing; and
 - v. Accelerating reform of heating enterprises, consolidating many small enterprises in cities, introducing competition, and fostering and standardizing the heat market.¹⁶
- The first issue has attracted most attention so far, and several provinces and many cities (such as Tianjin, Hebei, Shanxi, Jilin, Inner Mongolia, Sinkiang, Qiqihar, Daqing, Mudanjiang, Liaoyuan and 10 districts of Beijing) have issued regulations requiring government work units to transform in-kind benefits into explicit cash payments.

The December 2005 follow-on circular of the eight ministries ("Instructions to Further Push Forward Urban Heat Reform," No. 220) underscores the need for progress in heat reform and, in particular, sets a two-year deadline for the completion of the transfer of heat bill payments from work units to consumers. In June 2006, MOC set up the Heat Reform Promotion Office (HRPO) to actively promote urban heat reform with a focus on transfer from invisible subsidies to visible subsidies and implementing heat metreing. This was followed with instructions at the National Heat Reform Working Conference in August 2006 for localities to set up specific offices to lead implementation of municipal heat reform efforts, beginning with the development of specific action plans.

The second priority issue is heat pricing, triggered in particular by the coal price increases during the past three years. The MOC collaborated with the ADB and the World Bank/ESMAP on the development of a new methodology for heat pricing. The pilot city approach was used here as well, culminating in the application of the methodology in several pilot areas and the drafting of implementation documents (heat pricing management method) as the basis for applying heat tariff reform principles more broadly. The heat pricing management method was issued jointly by the National Development and Reform Commission (NDRC) and MOC in June 2007 and will become effective starting October 2007. Another result of the heat pricing work was a joint regulation (No. 2200) by the NDRC and MOC in October 2005 to allow the partial automatic adjustment of heat prices in case of coal prices changes of at least 10 per cent in more than a year. Accordingly, heat prices in many cities increased just before the beginning of the 2005/06 heating season.

Excerpted from Meyer and Kalkum(2008), p.11 section “2003 Government Heat Reform Guidelines and Follow-up”.

6.5 Institutions in the property and energy efficiency

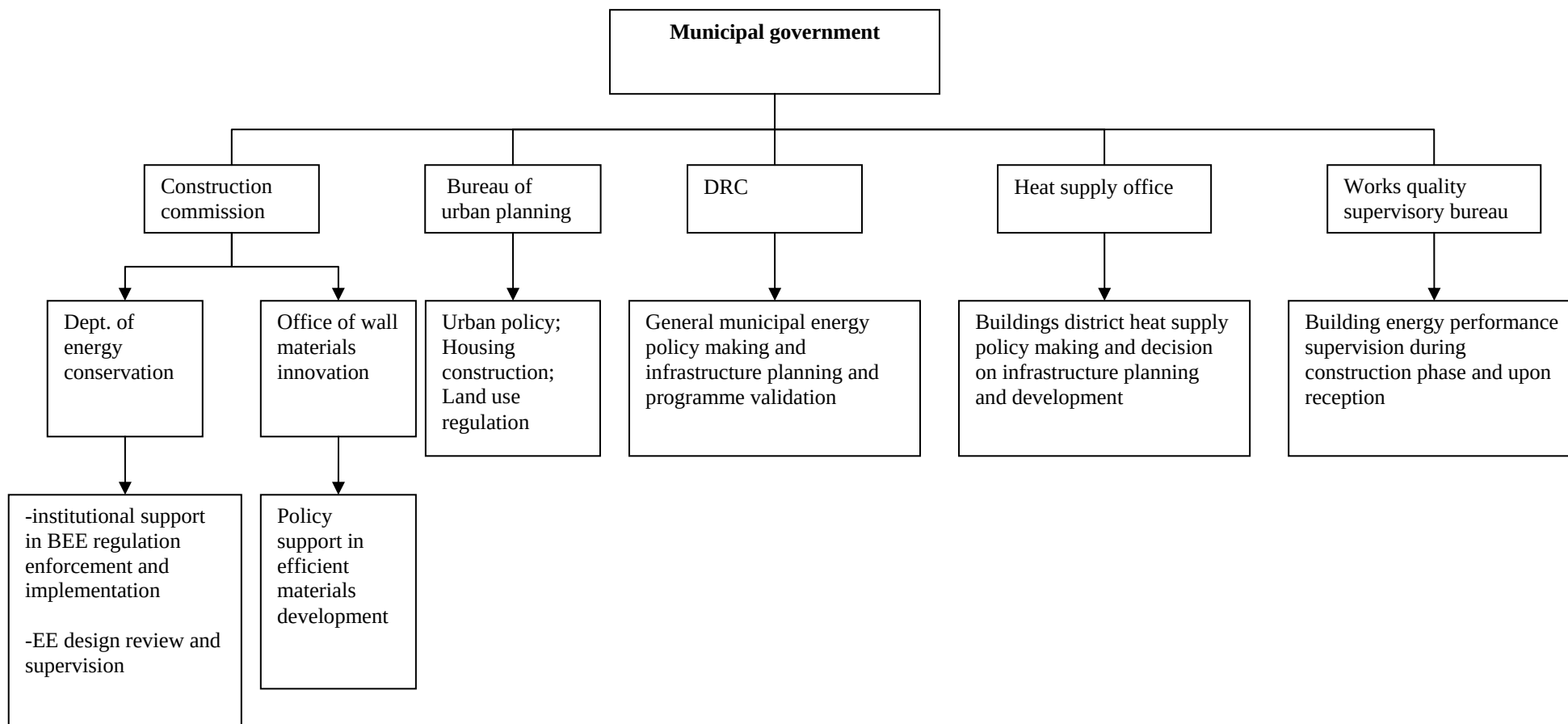
6.5.1 The main actors involved in building energy efficiency policy

The common practice in the property development program involves several private actor and public institutions.

1. developer (client) ; contractor (design and planning institutes, construction company)
2. bureau of urban planning
3. municipal Commission of construction
4. municipal /district real estate and land administration
5. municipal economic development committee
6. municipal DRC
7. municipal heat supply office
8. bureau of fiscal policy and municipal finance
9. bureau of taxation
10. bureau of price
11. Electric power company (subsidiaries of State Grid or China Southern Power Grid)
12. heat supply company (CHP, district boilers , geothermal etc)
13. Development and Reform Commission
14. Department of Energy conservation of municipal construction commission
15. Department of wall materials innovation of municipal construction commission
16. Department of energy efficiency of municipal economic committee
17. Public works quality supervision commission
18. association of buildings materials manufacturer

6.5.2 Actors and regulatory bodies in charge of building energy efficiency

Several institutions are involved in the building energy efficiency improvement regarding policy making and implementation. The main regulatory structure and respective functions of responsible institutions are illustrated as follows. We see promptly that this regulatory framework is based essential on the command and control philosophy since there are virtually no economic or fiscal instruments to supplement the implementation of EE policy. Developed policy implications and potential instruments will appear in the next chapter dealing with policy measures.



DRC is the energy policy maker in terms of energy infrastructure installation program approval and energy conservation aims with the national plan's period. So for example all the new generation of heat generation plant should be endorsed by DRC before coming into force and financed by the committee of economic development.

6.5.3 Third-part organisation :role of building materials association

Besides all the public institutions illustrated in the above schema, a non-government institution is also playing an active role in improving energy affiance in buildings constructed in the city. The building materials manufacturing association (BMMA) is a not-for-profit professional organisation . Its main rule is to promote efficient and innovative buildings materials in the local construction. Although this is not an official administrative institution, it plays a key role regarding building efficiency policy implementation. One of the main tasks of BMMA is to supervise the quality of building materials and ensure that their performances are in compliance with relevant local buildings regulatory documents. In fact, according to the municipal regulation.

Any building materials manufacturers who want to enter Tianjin's construction market will need preamble registration at the BMMA and his product can not be commercialized in the market without the certificate issued by the BMMA . Say a manufacturer of EPS insulating plate hopes to sell his products to a building contractor in a property development program, the first thing he should be is to submit the application for product certificate to the BMMA who will in turn convene the professional and expert group to evaluate the performance of the underlying products.

Secondly , it is obligatory for the manufacture to archive their sales in the local construction market , both at the BMMA and municipal real estate transaction centre. In other words, we can theoretical derive the actual utilisation of different building material from the archive data. A comprehensive list sale quantity and turnover of insulating materials of all companies registered at the BMA in 207 is reported in the Appendix. Currently , most of suppliers of insulating materials are Tianjin-based firms, followed by companies based in Beijing and other cities from the North. No market entry barriers of efficient buildings from other cities or regions can be instituted by the local authority. The current production capacity suffices to supply efficient products to local construction market.

Tightening the building efficiency design codes need a collaborative support of the BMA since it is the effective watch-dog of the quality of building materials and can make a arbitrage on the application of performing and efficient products, supposed the BMA can impose the product quality regulations to all existing suppliers as well as new entrants to the efficient product market.

However, using the numerical in the table should be prudent, since all of the effective utilized materials are provided by the suppliers to the BMA of Tianjin for various reasons, such as purpose of tax avoidance from local taxation administration. Around data indicated in the table may account for 70% of effective quantity of insulating material consumed in Tianjin (Yang, B., 2008 personal interview ¹⁰⁰). As discussed above, most of the residential buildings are of concrete-framed or concrete-frame-sheer wall structure, it

¹⁰⁰ Who is the secretary-general at the BMA of Tianjin.

is imperative to install insulating materials to meet the efficiency requirement settled by the local construction authority. One of alternative is to use the material other than concrete such as shale brick whose thermal performance complies with the building design code without additional insulation due to its physical features. Tianjin Guohuan is the biggest shale products manufacturer in Tianjin.

6.6 Institutional barriers to full implementation of BEE standards

The mandatory BEE design is implemented only very recently in the Chinese cities. The first BEE design was introduced in 1995 in China but few of new construction complied with the technical requirement in this building code. According to the Chinese Ministry of Construction's statistics, only 2.1% of the total existing buildings in China comply with relevant BEE standards. Of all new buildings completed that year, only 6% could be considered as energy efficient buildings (Tu and Wang, 2004). Although the BEE enforcement situation improved significantly since 2005 when BEE became mandatory in new construction, enforcement and implementation is still problematic in many cases. Another survey carried out in 2004 by MOC shows that at least 70 per cent of the construction does not comply with the standards that were designed to save 50 per cent of the energy required for heating (Meyer and Kalkum, 2008).

The unbalanced situation is observed across the country. First, the northern cities first began efficiency implementation and moved in advance compared with other parts of China. The southern provinces lag considerably in terms of capacity building and technical improvement. More specifically, enforcement and implementation in developed province is more effective than in poorer provinces and regions. And BEE is largely overlooked in rural areas where no technical and institutional capacities have been developed, and BEE standard and building codes are virtually unavailable.

6.6.1 Energy efficiency gap

Inflexible energy efficiency gap in buildings has undermined the energy conservation and GHG emissions reduction implementation. Substantial market barriers persist and need to be overcome through appropriate policies and programmes. These barriers include the high costs of gathering reliable information on energy efficiency measures, prevalence of common practice and techniques known by builders, lack of proper incentives between landlords who would pay for efficiency and tenants who would realize the benefits (principal-agent problem), limitations in access to financing, subsidies on energy prices, as well as the fragmentation of the building industry and the design process into many professions, trades, work stages and industries (Levine *et al.*, 2007, p. 390). These barriers are especially strong and diverse in the residential and commercial sectors; therefore, the obstacles can only be overcome through a diverse portfolio of policy instruments.

The increased construction costs associated with energy-efficient measures, combined with a dearth of available advanced technologies, give developers little incentive to comply with building codes. Moreover, the current energy billing and pricing system is not consistent with the rules of market economy. Urban space heating has always been considered a publicly delivered welfare in the Northern provinces for decades. Heating consumption is billed on the basis of floor space area instead of actual consumption. Consumers are not given any price signal to conserve energy; and no economic incentive is available for housing developers to build more energy-efficient houses. Although the central government issued a guideline in 2003 urging local governments nationwide to implement heating reform as soon as possible, the old billing and pricing system remains almost intact. The pricing reform lags behind the government's reform schedule. More specifically, a number of energy suppliers and building constructors remain reluctant to establish individual billing by installing heat metres and thermostatic valves; hence end-users are unable to regulate interior temperature accordingly. Many municipality-owned district heating companies have been in financial difficulties since the price paid by consumers is significantly lower than the real cost. Huge energy losses are caused by a series of maintenance and management deficiencies stemming from the current heat billing system. Moreover, the development of distributed energy systems such as small and medium-sized high- efficiency combined heat and power (CHP) faces tremendous difficulties in selling electricity generated to the grid. They are in keen competition with suppliers of low-cost coal-fired small boilers in absence of policy support.

6.6.2 Low uptake of BEE techniques and new materials

Chinese buildings science researchers launched various researches in new efficiency building materials and components since 1980s, many achievements have been made in innovative technologies in ventilation, solar shading, passive solar heating and cooling, waste water recycling, ground-resource heat pump, innovative envelope materials, performing doors and glazing and energy saving heat and cooling appliances . however, this high-tech efficiency innovations have hardly been commercialised and industrialised , the bridge between scientific research and product industrialisation is often missing. This results in the fact that most efficient products and technologies can only remain small-scale piloting programme and does not make significant contribution to energy efficiency improvement at scale. Moreover, many efficiency-related products have unstable technical performance or are inconsistent with other technical specification of buildings such as safety and fire prevention requirement. A comprehensive technical intervention is necessary instead of focusing on sporadic technological innovations in some products and component of buildings.

6.6.3 Efficiency gap of regulatory control

In effect, there exists a mechanism which regulates the building efficiency design and implementation during the construction stage. One of the preconditions of obtaining construction permit is that submitted architecture design should comply with the minimum efficiency requirements. Another supervisory institution is the construction supervision bureau that is in charge of supervising the construction and verifying that the materials used and practice are in compliance with relevant regulations, certainly the BEE is included in the terms of reference. During the construction time, the developer and constructors are also subject to random check by the department of quality supervision. A final examination of buildings quality is usually undertaken upon the reception when the construction is finished by sampling. This regulatory framework seems to be perfect since the buildings are under quality control in every stage of construction of the housing development program. However, the lack of qualified personnel and systematic difference between design plan and actual execution on site render the real situation of BEE enforcement and implementation less optimist.

6.6.4 Information asymmetry

House buyers are generally poorly informed about the energy performance or have little knowledge about the energy efficiency. Even when they know, the transaction costs are still high, it can be time-consuming for someone to identify the best energy saving equipment. Despite price rise in recent years, energy bill still accounts for a small share of household spending. More specifically, households are generally intended to put more emphasis on increasing revenues rather than cutting consumption costs(The Economist, 2008).From policymaker's viewpoint, it is politically easier to propose economic policies aiming at raising household income than persuading people to be scant on energy consumption. And many house owners tend to demand exorbitant rates of return on investments in energy efficiency as much as 30%. They want new efficient boilers or extra-efficient insulation to pay back the initially extra cost within two or three years.

6.6.5 Financial and behavioural barriers

One of key elements in turning the current and the new building stock onto a sustainable consumption trajectory is about financing. Energy efficiency measures need upfront financing. Unlike many other measures this financing will create many new jobs since building a house will relate several sectors, and also will reduce CO2 emissions which aggravate climate change and over a short period more than pay back the initial investment. However, without the initial investment none of this can happen. The problem is then how to finance the EE project and who will finance it. Usually, access to funding to overcome the initial investment costs associated with energy-efficiency measures is a major barrier in many countries.

6.6.6 Financing

Financing constitutes one of the major challenges to the deployment of low-carbon technologies in the building sector in China like in many other countries, which results in reduced efficiency market as consequence of persistent barrier to capital formation. Technology risk, inflexible energy pricing structures, regulatory uncertainty and other obstacles keep borrowing costs for renewable energy projects relatively high (Wellington *et al.*, 2007). In addition to these higher transaction costs, most investors in China's building sector are unfamiliar with many low-carbon technologies and therefore perceive them as risky, which increases the cost of capital.

In addition, many building efficiency projects lack sustained financial resources since the major financial actors are rarely involved in investment in energy efficiency projects. Chinese financial institutions such as commercial banks typically do not have expertise in energy efficiency technologies and thus lack the ability to assess technical risks of BEE financing programme; energy efficiency investments are typically small and come with high transaction costs, and the value of energy-efficient projects is relatively poorly recognised (Cheng, 2005). Innovation and institutional capacity-building with regard to BEE financing will play a significant role in facilitating policy implementation.

Regulatory uncertainty, proof of technical feasibility and lack of a critical mass of intellectual capital and market demand for low-carbon products and services all conspire to keep investment flows to low-carbon technologies small, relative to the scale that is required. Many technologies are ready for large-scale and rapid deployment and therefore require different financing needs from different players in the market. Because different segments of the financial community can support different levels of risk, a range of custom-designed instruments will be required to finance the deployment of low-carbon technologies. This must derive from private initiatives, as public resources will prove insufficient to meet the financing requirements of low-carbon technologies in buildings. There must be cooperation between public and private financial players (wellington *et al.*, 2007). It is urgent to remove the financial barriers to the widespread diffusion of the best practiced technologies relating to the installation of high-performance or renewable energy systems such as photovoltaic (PV), geothermal, heat and cool storage in the building sector, new ideas are required and the institutional framework needs to be reshaped. Policy instruments need to be put in place to incentivise commercial banks to get involved in the business of high-efficiency construction projects or the installation of renewable and innovative energy supply systems by supplying low interest credits.

6.6.7 The rebound effect in BEE

The phenomenon of rebound or take-back effect of energy consumption in residential sector has been discussed in a large body of literature. This effect is caused by the consumer's increase in energy service

improvement. The ultimate impact is to reduce the fuel savings associated with the adopted efficiency measures to a level that below those predicted by engineering studies of the measures (Thompson, 2002). But empirical estimates of the rebound effect in the developed countries is relatively small, about 10% of engineering estimate of energy savings (Durbin *et al.*, 1984, Haas, 2000; Henly *et al.* 1988; Schwartz and Taylor, 1995).

In addition, the rebound effect or efficiency gap is a voluntary behaviour change of consumer and should not be considered as a reduction of value of energy efficiency measures (Stoft, 1995). Some economist also suggests that the rebound effect is beneficial since it is caused by the consumer's movement to higher utility indifference bundles, in effect, rebound effect should be seen as evidence of the additional unmeasured benefits associated with increased efficiency (Thompson, 2002), hence in our modelling exercise the rebound effect is considered as the rising level of demand for energy services such as space heating, cooling or electric appliance, in other words, increase in demand for energy services results mainly from the rise of households income, whereas no endogenous price elasticity is taken into account by the model. The reason is twofold. First, it is very debatable to use a constant elasticity for a long period since the modelling period covers 20-30 years, second, uncertainty about fuel price and energy services evolution should not be ignored. Therefore, endogenous price elasticity that derived from the exogenous price index will lack consistency for long-term energy demand modelling.

A brief review of literature on rebound effect on residential heating and cooling consumption in Europe and US households is provided in Appendix VII.

6.6.8 Principal-agent problem

The principal-agent problem arises when a principal compensates an agent for performing certain acts that are useful to the principal and costly to the agent, and where there are elements of the performance that are costly to observe. This is the case to some extent for all contracts that are written in a world of information asymmetry, uncertainty and risk. Here, principals do not know enough about whether (or to what extent) a contract has been satisfied. The solution to this information problem — closely related to the moral hazard problem — is to ensure the provision of appropriate incentives so agents act in the way principals wish. In terms of game theory, it involves changing the rules of the game so that the self-interested rational choices of the agent coincide with what the principal desires.

The principal agent problem in energy efficiency

The principal-agent problem is considered to be a major barrier to the diffusion of efficient technologies (Murtishaw and Sathaye, 2006; IEA, 2007). For new residential buildings in the property markets, builders are not the ones who end up paying the utility bills, so have little incentive to add to the construction costs

by incorporating energy efficiency features (design, insulation, passive heating or cooling , natural ventilation etc) and renewable energy integration (solar, geothermal). Landlord and builders have scant incentive to invest in energy efficiency on the tenants or buyers' behalf.

In efficiency terms, a market failure arises when a technology which is both cost-effective and saves energy is not implemented. Jaffe and Stavins (1994) describe the common case of the landlord-tenant problem as a principal-agent problem. "[I]f the potential adopter is not the party that pays the energy bill, then good information in the hands of the potential adopter may not be sufficient for optimal diffusion; adoption will only occur if the adopter can recover the investment from the party that enjoys the energy savings. Thus, if it is difficult for the possessor of information to convey it credibly to the party that benefits from reduced energy use, a principal/agent problem arises."

Compared to the literal notion of principal agent problem A distinction is that the in energy efficiency is that P-A does not require any information asymmetry: both the landlord and the tenant may be aware of the overall the costs and benefits of energy-efficient investments, but as long as the landlord pays for the equipment and the tenant pays the energy bills, the investment will not be made. In this case, there is also little incentive for the tenant to make a capital efficiency investment with a usual payback time of several years, and which in the end will revert to the landlord as property. Since energy consumption is determined both by technology and by behaviour, an opposite principal agent problem arises when the energy bills are paid by the landlord, leaving the tenant with no incentive to moderate his energy use. This is often the case for leased office space, for example.

The energy efficiency principal agent problem applies in many cases to rented buildings and apartments, but arises in other circumstances, most often involving relatively high up-front costs for energy-efficient technology. In response to the existence of principal agent problem, shared-savings performance-based contracts can address partly the difficulty of efficiency measures uptake, where both parties benefit from the efficiency savings.

6.6.9 Specific barriers to energy efficiency implementation in Chinese buildings sector

-unawareness of stakeholders

Nevertheless, the necessity of energy savings are not necessarily taken into account seriously or often ignored by many actors. For example, a consumer or a house buyer is generally more concerned about the design and residency neighbourhood, security, community environment and local amenities , location in terms of access to public transport (households often tradeoff the housing quality and commuting time to job). The energy use in buildings comes quite often the last thing to be considered. More specifically, consumers hardly think their personal consumption behaviours will have ultimately impact on upstream energy supply and issue like climate change. As argued in chapter 1, most Chinese

urban dwellers are pursuing upwardly new lifestyle, more and more new services will be required as their income increases as a result of economic growth, how to access to the diverse new services appears to be the priority objective in their consumption preference. Consumers are more likely to be concerned with the first cost (housing purchase) instead of considering the life cycle operation costs which include the building energy use for several decades. The reluctance of property developers and housing constructors regarding the uptake of efficiency technology in building energy use is discussed in detail in the section of Principal-agent problem in the next chapter.

From public policy makers' perspective, BEE involves continued capital and intelligent input (R&D of BEE and implementation) , many benefits associated with improved BEE can only be "visible" or "tangible" in the long term. In addition, the long-term achievements are barely consistent with political agenda. In China, the politicians or administrative government officials (local government and administration in charge of urban development and housing) have relatively short-term political mandate¹⁰¹ in a particular position and need to move ahead swiftly administration achievements to gain political capital in the way of promotion. In China, inter-provincial or trans-institutional government officials reshuffle are quite common in the current Chinese political system. This necessarily discourages the political investment in building energy efficiency whose return on investment is almost invisible during a mandate term.

- DH pricing barriers

The urban heating sector still operate on principles dating back to the 1950s, when central heating started out as a limited all-paid welfare for state employees in severe cold regions. Heating was still largely regarded as a public service supplied to urban residents as welfare, paid for by the work units(employers). Heat was not metreed and billed on basis of square metres of heated area instead of actual consumption. The consumer has no incentives to save energy since there is no any price signals regardless of quantity of heat consumed, no economic incentive is available for housing developers to build more efficient houses than building codes. Although the central government issued in 2003 a guideline which urged the local governments to launch nation-wide heating reform, the billing and pricing system remains almost intact. A handful individual billing services and consumption-based heating pricing are only practiced in the pilot projects for demonstration purpose. The pricing reform has been postponed behind the government's reform schedule. More specifically, most of energy suppliers and building constructors remain reluctant to installation of heat metres and thermostatic valves at the expense of energy loss, the consumers are not allowed to regulate freely interior temperature according to ambient environment and comfort requirement diversities.

¹⁰¹ Under the current Chinese political regime, high-level officials in local authority in general take the designated political position for one-term (5 years) in general, and interprovincial or municipal officials transfer is more and more commonplace since 1990. This is particularly to avoid formation of local political clan within the party members holding key positions of policy-making.

- lack of economic incentives

The current BEE policies in the Chinese China is mainly based on regulation approach, i.e. local government bodies in charge of commission are very keen on the effective implementation of compulsory building codes and technical specifications relating to the building energy performance enhancement. However, the accompanying policy tools such as incentives schemes allowing the builders and developers to adopt high-efficiency construction practices are almost out of consideration. Developers have usually a push-and-go passive attitude regarding the building efficiency regulations.

6.6.10 Nash equilibrium in energy efficiency and fuel switching decision

Massive fuel-switching has not been considered by the local government for cost reason, and the debate can be represented by a game matrix between end-user and Heat Company. A rational customer would always try to minimise the energy bill whilst his required heating demand for a certain level of thermal comfort can be met by the heat company. Four situations may happen in this case, the attributes in the parenthesis indicate the preference of consumer and actual production cost of heating service respectively. The four outputs are classed by order of preference with attributes representing the preference of customer and heat company respectively:

- (low bill, low cost) customer doesn't care about environment, his only concern is the energy price, heat company also tries to minimize the supply cost
- (high bill, high cost) customer cares about environment and he is willing to pay more if the company choose the solution of gas, but he heat company tends to minimize the cost
- (high bill, low cost) customer care about environment and is willing to pay a higher bill if the company switch from coal to gas, but he heating company doesn't like to risk of non payment and want to minimize its operational cost
- (low bill, high cost) customer doesn't care about environment, and the heat company is obliged to comply with environmental regulations which exempt the construction of coal-fired boiler stations

		Heat company	
		Gas	Coal
User	Gas	2	3
	Coal	4	1

Since both 3 and 4 create the conflict between the user and the heat company, while it is generally known that both the company and end user are unwilling to have additional cost to meet the given heating demand. The solution of this game is then 1 (coal, coal). This simple game illustrates from economic

perspective why the fuel switch policy is difficult to implement in the context of district heating in China. In short, among alternative resources, renewable energies have a role to play, but no alternatives can replace efficiency as the top priority. Since the DH charge that residents need to pay will be much higher than usual coal-fired boiler stations. The outcome is a Nash equilibrium since the situation of each person could be improved if the property developers opt for high-efficient buildings and shift to natural gas-fired cogeneration supply system in the longer term.

This chapter focused on the institutional respects of property and energy markets. Both market organisation and interaction between different actors are analysed. Some institutional barriers to BEE upgrade and deployment have been identified. The next chapter will design policy and economic instruments to remove these barriers.

References

- Arrow, K. (1962), "The Economic Implications of Learning by Doing", *Review of Economic Studies*, p. 155.
- Atanasiu, B. and Bertoldi, P. 2007. Residential electricity consumption in New Member States and Candidate Countries. *Energy and Buildings*, Volume 40(2):112-125.
- Basil Sharp. 2002. Institutions and Decision Making for Sustainable Development. Working Paper for the NZ government.
- Bosseboeuf, D. (Eds.) 2007. Evaluation of energy efficiency in the EU-15: indicators and measures. 2007. Ademe.
- Capoor, K., and Ambrosi, P. 2008. State and Trends of the Carbon Market 2008. World Bank. Stockholm Environment Institute (SEI). LEAP Model User's Guide.
- Chen,X., Li,J., Wang,Y.,Tan,Y.,Yan,Y.,Li,J. 2006. 我国燃煤锅炉改用木质颗粒燃料效益分析(Benefit Analysis of Coal Boilers Being Replaced by Wood-pellet Burners in China). Journal of Central China Institute of Sylviculture. 2006.
- Cheng, C. (2005). 'Electricity demand-side management for an energy efficient future in China: Technology options and policy priorities'. Ph.D. thesis dissertation. MIT.
- Colombier, M; Hourcade, J. 1989. Developpement des reseaux et modulations spatio-temporelles des tarifs: l'equité territoriale revisitée. Développement des réseaux et modulations spatio-temporelles des tarifs: l'équité territoriale. *Revue Economique*. Vol 40 (4) ; pp 649-677.
- Datang Power Group. 2005. Environmental benefits of installation of enhanced self-cleaning heat exchanger in power generation condenser. 凝汽器中加装自清洗强化换热装置的环保效益.
- Dietz, S., and Stern, N. 2008. Why Economic Analysis Supports Strong Action on Climate Change:
- Ding, C. 2007. Policy and praxis of land acquisition in China. Land use policy. Vol (24).
- Duan,Q., Wang,J., Zhuang,X. 2004. 生物质与煤共燃研究 (Research on Co-firing of Biomass and Coal) , Power system engineering. 2004(1).
- Fan, J., Wang, J., Wang,Y. 2007 (in Chinese). 300MW 抽汽-凝汽式机组采用冷电联产的热经济性分析 Analysis Of Thermal Economic Behaviour For Adopting Cool- Electricity Co- Generation To 300 Mw Extraction Condensing Unit, 热力发电 (thermal power) > 2007(3).
- Gu, J. 垃圾发热值的实用测定方法. The Method of Measure Heating Value of Garbage in Garbage Incineration 节能与环保 Energy Efficiency and Environmental protection. 2006(12).

Henly, J., Ruderman, H. and Levine, M.1988. Energy Saving Resulting from the adoption of more efficient appliances: a follow-up. *Energy Journal*, 9, pp.163-70.

<http://www.iht.com/articles/2007/10/30/business/reneff.php>

Hu, J.; Su,L.; Jin,S.; and Jiang, W. (2006) "The Rise in House Prices in China: Bubbles or Fundamentals?." *Economics Bulletin*, Vol. 3, No. 7 pp. 1–8.

INSEE. Répartition des logements selon leur catégorie et le type de logement 2000-2007. http://www.insee.fr/fr/ffc/chifcle_fiche.asp?ref_id=NATFPS05201&tab_id=69

International Energy Agency (IEA) and Agence française du développement(AFD). 2008. Promoting Energy Efficiency Investments :case studies in the residential sector. OECD/IEA, Paris.

-----2007. Climate Change 2007 Synthesis Report.

International Energy Agency (IEA). 2000. Experience Curves for Energy Technology Policy. OECD/IEA, Paris.

-----2005. Projected costs of generating electricity 2005 update.

----- 2006. World Energy Outlook. Paris.

----- 2007a.Fossil fuel-fired power generation: case studies of recently constructed coal- and gas-fired power plants.

----- 2007b. World Energy Outlook. China and India Insights. Paris.

Intergovernmental Panel on Climate Change (IPCC), *Third Assessment Report. Climate Change 1995: Impacts, Adaptations, Mitigation of Climate Change: Scientific-Technical Analyses*. Cambridge, UK: Cambridge University Press.

Jin, J. and Zou, H.2005. Fiscal decentralisation, revenue and expenditure assignments, and growth in China. *Journal of Asian Economics*.2005

Koeppel,S. andÜrge-Vorsatz, D. 2007. Assessment of policy instruments for reducing greenhouse gas emissions from buildings. UNEP SBCI Report.

Lin, George C.S. and Ho, Samuel P.S. 2005. "The state, land system, and land development processes in contemporary China." *Annals of the Association of American Geographers* 95(2): 411-436. Malden, MA: Blackwell.

MAIZIA, M., (2007) *Pompe à chaleur et habitat. Prospective des consommations d'énergie et des émissions de CO2 dans l'habitat : les gisements offerts par les pompes à chaleur* , Les cahiers du clip 18, 1-47.

Mendelsohn,R.2008. Is the *Stern Review* an Economic Analysis? *Review of Environmental Economics and Policy* Advance Access published April 23, 2008.

Messner, S. (1997). Endogenised technological learning in an energy systems model. *Journal of Evolutionary Economics*, Vol. 7, p. 291.

Miller, B. 2005. Coal Energy Systems[M]. Academic Press. 544 p.

Ma, J. (1997) China's Fiscal Reform: An Overview. *Asian Economic Journal* 11 (4) , pp.443–458.

Ma,J. 1995. Modelling central-local fiscal relations in china. *China economic review*, vol.6(1), pp. 105-136.

Ma,j., Norregaard, j. 1998. China's fiscal decentralisation. IMF paper.

MOC (1991) Regulation on urban land use categorisation and planned urban construction land (GBJ 137-90).

MOC and State Technology Supervision Bureau 1993. Code of urban Residential Areas Planning & Design (2002 update).

MOC. 1996. Energy Conservation Design Standard for new Heating Residential Building.

Murtishaw, S and Sathaye, J. 2006. Quantifying the Effect of the Principal-Agent Problem on US Residential Energy Use. LBNL Rev.

Natarajan, S. and Levermore, G. 2007. Predicting future UK housing stock and carbon emissions. *Energy Policy*. Volume 35, Issue 11, pp. 5719-5727.

- National Bureau of Statistics(NBS) . 2000. Press Communiqué of National Population Census 2000.
- NDRC& MOC 2006. Methodology and parametres in economic evaluation of construction project . 《建设项目经济评价方法与参数》. 3^e Ed.
- Nemet, G. F. (2006). "Beyond the learning curve: factors influencing cost reductions in photovoltaic." *Energy Policy* 34(17): 3218-3232.
- Nemet, G. Learning Curves for Photovoltaics. University of Wisconsin – Madison. IEA Workshop 2007.
- Nicol, F. Standards for thermal comfort. Indoor air temperature standards for the 21st century.
- Nordhaus, W. 1991. To slow or not to slow: The economics of the greenhouse effect. *Economic Journal* 101:920–37.
- PERFORMANCE ANALYSIS OF DOUBLE EXTRACTION CONDENSING STEAM TURBINE FOR 200 MW UNITS. « 200MW 机组双抽凝汽式汽轮机性能分析 ». Thermal Power Generation. 2004 ; Vol.7
- Shanghai Land Use and Property Administration. Regulations on the Assignment of Land Use Rights Shanghai Municipality (2001 update). 上海市土地使用权出让办法.
- Schwartz , P. M. , and Taylor, T.N. 1995. Cold hands, warm hearth? Climate, net takeback, and household comfort. *Energy Journal* , 16(1), pp. 41-54.
- State Council's Government official Document. "Notice and suggestions on accelerating the shut down of small-sized thermal power units". 国务院批转国家发改委、能源办关于加快关停小火电机组若干意见的通, 2007.
- Stein, Gregory M., "Acquiring Land Use Rights in Today's China: A Snapshot from on the Ground" . UCLA Pacific Basin Law Journal, Forthcoming Available at SSRN
- Tianjin Bureau of Planning. 2007. General Urban Plan of Tianjin 2005-2020.
- Tianjin Bureau of Planning. 2006. Specification Plan for Housing construction 2005-2010.
- Tianjin Development and Reform Commission , Tianjin Heating Office, North China Urban Engineering Design Institute, Tianjin Jinneng Energy Group. 2003 Tianjin City District Heating Planning.
- Toh, M. and Lin, Q. 2005. An evaluation of the 1994 tax reform in China using a general equilibrium model. *China Economic Review*. 2005 (16). pp 246-270.
- Tu, F. and Wang, Q. 2004. Building Energy Efficiency: Priority in China's Energy Policy (in Chinese). *Buildings Science and Technology*. 2004(5): 13-15.
- Ürge-Vorsatz, D.and Novikova, A. 2008. Potentials and costs of carbon dioxide mitigation in the world's buildings. *Energy Policy* (36), 642–661.
- Wang, S. 1997. China's 1994 Fiscal Reform: An Initial Assessment. *Asian Survey*, September, 1997. Yale University.
- Wang,Z. *et al.*, 王振铭等 Regulation on development of Combined Heat &Power Plant in China. 2000. Government Policy Act.
- Xu, S. and Chen, W.2006. The reform of electricity power sector in the PR of China. *Energy Policy* 34 (2006) 2455–2465.
- Xu, J, Liao, B, Shen, Q. Zhang, F. and Mei, A.2007 Urban spatial restructuring in transitional economy—Changing land use pattern in Shanghai. *Chinese Geographical Science*. Vol.17 (1) pp. 19- 27.
- Yang, J. and Li, Z. 2008. Analysis of impact of property taxation on local governemnt. 房地产税收改革对地方政府的影响效应分析 . http://www.lrn.cn/zjtg/academicPaper/200805/t20080527_235239.htm
- Zhang, H; WENG,S. and ZHOU X. 2007. Housing Price Fluctuations across China: An Equilibrium Mechanism Perspective. *Tsinghua Science and Technology*. Volume 12(3). pp302-308.
- Zhao T; Liu J and Deng X. 2004. Spatial patterns of Urban Land Expansion of Super-cities of China in 1990s. In proceedings of 2004 IEEE International Geoscience and Remote Sensing . 20-24 September, 2004, Anchorage, Alaska. USA.

- Zhou, X., and Xiao, X.. 2004. Three connections and one levelling and seven connections and one levelling (三通一平与七通一平) Shanxi Architecture. 山西建筑 Vol. 14.
- Zhu, J. 2004. From land use right to land development right : institutional change in china's urban development . Urban Studies, Vol.41(7), 1249-1267.

Chapter 7 Policy instruments design

7.1 Summary

This chapter seeks relevant policy and economic instruments to address the institutional barriers described in chapter six from both theoretical and implementation perspectives. The first section reviews theories of institutions and incentives related to energy conservation and energy efficiency in existing literature. Typical market failures like principal-agent problem, information asymmetry, and rebound effect are discussed. It is shown that these market distortions (inefficiency or welfare loss) can be corrected by relevant policy instruments (tax, subsidy, carbon financing incentives and land use policy) which aim to maximise the likelihood of adoption of efficiency measures in buildings sector by public and private actors. Energy price and vision on uncertainty (translated into discount rate) also play critical roles in individual's decision on when and to what extent one will opt for a more efficient technology in the buildings. We argue that technical and institutional obstacles to BEE need to be removed by implementing appropriate policies on both regulatory and incentives options. Section 2 discusses the theory of BEE and instruments design to improve BEE in different parts of the world and the implications for institutional innovation. Section 3 reviews different regulatory and economic-incentive policy portfolios in order to address market and or non market failures. It discusses how to remove barriers to effective implementations and widespread diffusion of efficient technology. Section 4 deals with policy and economic instruments design to bring about improved building energy efficiency in the context of organisational characteristics by taking into account the property market characteristics (e.g. land use policy) and institutional barriers to achieve the optimal pathway of BEE, three instrumentation models are proposed to policy makers. Section 5 outlines the policy assessment framework.

Recent literature has extensively investigated institutional barriers to BEE implementation in the buildings sector in the world (see for example Koeppel and Ürge-Vorsatz, 2007; IEA and AFD, 2008). Successful BEE enforcement and implementation requires a systematic approach and involves synergetic cooperative actions among different actors in the whole supply chain of buildings construction and property market, urban planner, architect, engineer, property developer, financial institutions (commercial bank is often the money supplier to the property development programme), urban administration commission of construction, office of housing and land administration bureau, land use regulator, buildings constructors, materials manufacturers, construction supervisor, property managers, end users (consumers) and so forth.

The role of policy designed to increase energy efficiency can not be overstated since the EE policies have already delivered significant benefits (IEA and AFD 2008). An ex post assessment study carried out by IEA(2007) suggested that energy consumption in IEA countries would be 56% higher than actual consumption today in absence of various EE policies that had been implemented since 1973 in the OECD

countries. It means that the energy-related CO₂ would have increased more than 50% otherwise. Based on *ex post* evaluation method, the cumulative energy savings following implementation of energy efficiency policies in all economic sectors in China during 1990-2005 is estimated at more than 800 mtce, resulting in reduction of 1800 million tons of CO₂ emissions (Xie, 2007; UN, 2008). Experiences in both developed and transition economies provide insightful policy implications. More specifically, improvement in BEE requires a comprehensive approach consisting of DSM and supply technology optimisation, but also the establishment of coherent institutional framework. Energy billing and pricing issues are indispensable to accompany successful infrastructure performance amelioration. Based on economic analysis, we recommend that the policy makers implement four key instruments to approach optimal BEE trajectory. 1). climate financing mechanism such as the *Clean Development Mechanism* (CDM); 2) taxation instrument (property, energy and carbon tax); and 3) land use policy, the flexibility of the key parameter “*plot ratio*” in property development market among others. 4) district-based efficiency procurement programme for encouraging efficient household appliances in new urban development zone.

7.2 Policy instruments for BEE

7.2.1 Rationale of BEE

As mentioned in Keohane *et al.* (1993), “Two fundamental questions arise when we attempt to design environmental policy. First, what is the level of environmental policy? Second, what policy instruments should be used to achieve the level of protection?” Chapter 4 and 5 identified the best BEE decision in a static and dynamic buildings stock in a new development zone and whole city, respectively. The question arises subsequently about how to design policy instruments including both regulatory tools and economic-incentive schemes to achieve the optimal BEE by removing the pertaining institutional and market barriers to attaining the objective. From economist’s perspective, energy efficiency is not necessarily considered a goal in itself, but rather a means to the end of overall efficient resource allocation (Jaffe and Stavins, 1994; Dennis, 2006).

Energy conservation focuses on how much energy is consumed while energy efficiency focuses on how much energy is used relative to the services demanded (Moezzi, 1998). Both economic and social benefits can be offered by EE policies, as noted by Ferran Tarradellas Espuny in the European context, “The benefits of energy efficiency are so high in terms of security of supply, in terms of reductions in carbon dioxide emissions and in terms of creating jobs and growth in the European Union that any measure that’s aimed at efficiency is good”. The relationship between energy efficiency and energy services can be illustrated by Figure 7-1. The horizontal axis represents the services demanded by the consumer, the vertical axis is the energy input needed to meet the demand for energy services. Logically, higher-level services require more energy input, as shown by the lines in the chart. The slope of lines is inversely proportional to the energy efficiency, i.e. higher energy efficiency produces smaller slope of lines. As far as space heating is concerned, improved building insulation and high efficient appliance will supply the same

energy services while using less energy compared to an inefficient house. Graphically, the service line will shift from L1 to L2.

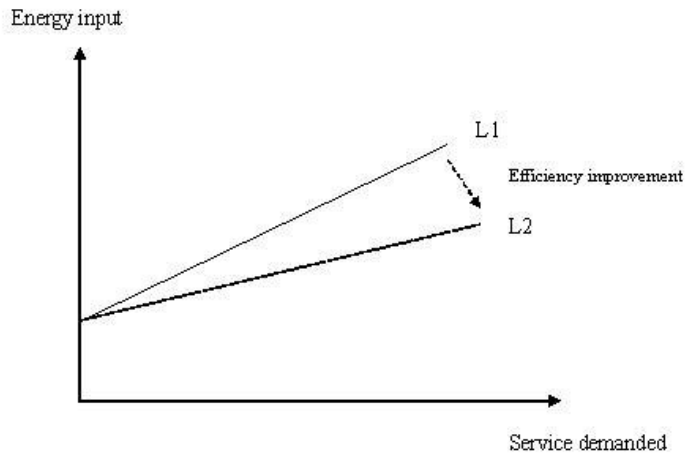


Figure 7-1 Relationship energy efficiency and energy service (Meier, 1996)

The aim of policy instruments design is thus to give incentives to stakeholders to invest in BEE technologies in order to lower the slope of the energy services lines.

Promoting building energy efficiency will allow households to enjoy more energy services with the same input compared to inefficient house; if we assume that the household has a convex preference, then the problem for the decision can be written mathematically as follows:

$$\begin{aligned} & \text{Max } U_e \\ & \text{s.t.} \\ & C_e \leq I \end{aligned}$$

Where we assume the households can only allocate a part of his revenue in purchasing the energy services at cost C_e . This means that a household (Say a rational economic agent, otherwise we don't need really to do anything more), tries always to maximize the utility (energy services U_e) subject to the budget constraints (scarcity of resources I)¹⁰², more efficient energy use (e.g. heating in a well-insulated house) can supply the same quantity of energy services (the indoor thermal comfort in case of space heating) with less energy consumption, thus more efficiently than a inefficient house. The household spent less money on space heating and spent more money in food or other goods, again, his welfare is improved and this is a Pareto efficient improvement.

¹⁰² We can of course reason from societal perspective, that is how to meet the requirement of energy services of the whole society, say a country even the world with subject to the availability of energy resources and also the constraint of climate change, this is $\text{Max } U(e)$ subject to $S(e)$ and probability of carbon dioxide concentration $CC(e) \leq 550$ ppmv in 2050 larger than 75% (IPCC, 2007) in order to mitigate climate change.

7.2.2 Institutions and information

Indeed, there is a clear preference for command and control by the public authority in dealing with the building energy efficiency issues where local authority provides a legal framework for market based instruments. But the options for using market-based instruments are limited and thwarted either by immature property market and volatile regulations to keep up with the unprecedented fast-growing urban development pattern, or due to lack of co-ordination between the different institutions. How to design institutions that provide good incentives for economic agents has become a central question of economics (Laffont, 2001).

Various technical and institutional barriers persist and reduce the possibility of implementing the most efficient design and construction in buildings. For the consumer's perspective, the end-users may not necessarily choose the best performing houses and efficient equipment since energy bill is not considered the priority to the same extent to location or orientation of house. Lack of government public policy and inherent inertia between the concerned players are the main barriers to uptake of energy performance improvement in buildings. In fact, policies to improve energy efficiency in new and existing buildings need to be designed to ensure that new structures are built to the highest standards of efficiency. Policies should foster new technologies to meet the requirements of new generations of buildings and energy-consuming appliances (IEA, 2006b).

It is important to use the public policies as a major tool to facilitate the diffusion of efficient construction technologies. Government usually plays a key role in encouraging the development of new building technologies. Since the building technology sector is highly fragmented industry, there are few private firms large enough to engage in expensive R&D (IEA, 2006b). Government policies can help improve actual energy efficiency in buildings through vigorous policies in favour of higher energy performance standards.

7.2.3 Incentives and organisational form of BEE institutions

Incentive and political institutions are two central elements in economic theory, and modern economic theorists since the time of A. Cournot began to analyse optimal decisions of rational individuals as a tool for understanding supply and demand in price theory. The objective of introducing incentives in the public policy package is to facilitate the effective implementation of BEE measures. The understanding of political and institutional organisations of the building and energy market is thus of critical importance. Mechanism design has added incentive constraints to resource constraints in the definition of the economic problem in the modern economic theory (Myerson, 2008). Thus it is necessary to emphasise the importance of the institutional aspects with respect to devising policy instruments for BEE from economic analysis perspective.

On the other hand, the fast-growing economy and the evolving regulatory system offer flexibilities for improvement in political and institutional organisation. In response to the question how organisation makes a difference to economic performance of private corporate, Maskin *et al.*(2000) show that different organisational forms gives rise to different information about managers (this notion can be interpreted as property developer with aims to maximise his profit) performance and therefore differ according to how effective incentives can be in encouraging a good performance. In recognition of influence of technology on the way a firm or economy performs, they argued that organisation form can affect the quality of incentives schemes that can be given to the managers, the organisational forms differ according to how effective incentives can be encouraging good performance of managers. More specifically, different organisational forms give rise to different information on which incentives can be based (Maskin *et al.*,2000) . The main lesson that we can draw from their study is that organisational form in the property development and energy supply infrastructure development in a Chinese city will also affect the performance of BEE implementation. In other words, appropriate institutional organisations can give rise to effective enforcement and implementation of BEE policies.

7.2.4 The need of policy and economic instruments to correct market imperfection

The fundamental theorem of microeconomic states that under the competitive equilibrium condition, every individual economic agent maximize its utility while the social welfare is maximized, thus the efficient allocation of resources can be sustained. But in the economics of climate change, the modern microeconomic analysis cannot hold since climate change is the greatest market failure eve seen in the world (Stern, 2006) and would generate invaluable environmental externalities to humanity , the hypothetical competitive equilibrium in the traditional microeconomics can no longer be held. Since the environmental externalities and other market failures need to be corrected by public policies. Aggressive government intervention is needed to address this market failure.

In the building sector, the dynamics of impact of economic instruments that encourage energy-efficient buildings can be illustrated by Figure 7-2 a). The supply curve is represented by PMC , the initial demand of buildings is represented by D_0 , and the equilibrium quantity of supply and demand is q_0 ; since we know that the social marginal cost SMC is higher than PMC since the cost of environmental impacts of energy use in buildings is not internalised in the PMC of buildings developers. The public authority can give incentive δ to builders in order to move the PMC curve upward to approach the SMC curve. Developer will reduce the supply of non-efficient buildings when he perceives the existence of subsidy δ he will have incentive to reduce the supply of non efficient buildings until reaching the new equilibrium point q^* . Note that over the course of movement from the supply curve PMC to SMC, the cost of efficient buildings promotion, i.e. the incentive δ is likely to decrease as a result of technological learning and economies of scale. When more and more efficient buildings enter into the property market, the new practices of pro-BEE will spread as a positive externality to replace gradually the traditional way of and techniques of

Figure 7-2 interaction of policy instruments and building efficiency in two markets(adapted from Zhang,2007)

goals (e.g. Greenhouse gas emission mitigation) and selecting policy instruments to achieve these goals (Stavins, 1996). Both regulatory and market-based instruments can be introduced to managing BEE and carbon emissions in the buildings sector.

7.3.1 Regulatory measures versus economic instruments for BEE

So far in most of the developed countries and developing countries, the building codes relating to energy efficiency have been adopted by government. Compliance with these regulations is obligatory, failing to comply would risk monetary penalty even juridical sue in some cases. The foremost incentive relies on the fact that the building energy efficiency design is a prerequisite to applying for the construction permit. However, the enforcement and implementation faces different kinds of resistance and the actual implementation is not always smooth. Lack of experience in EE practices and additional cost constitute the major barriers. While efficiency measures in buildings are generally simple to and experiences can be accumulated with the learning by doing process, the issue of financing is not so easy to deal with. Most housing developers assert that the houses they construct are consistent with initial thermal design and thus should be energy efficient and use less energy. However, many experiences reveal that the actual performance of the constructed buildings is systematically lower than designed one. This is in part due to the overly optimistic estimation of the EE measures taken, but also the customer's change in consumption behaviour after and before the EE measures are being implemented.

There is a wide range of economic instruments or incentives which can be used to internalize externalities of economic activities. Economic instruments have an important role to play to cope with transboundary and global environmental issues in the plea for a sustainable development path (Panayotou, 1994). Every incentive that aims to induce a change of behaviour of economic agents by internalizing environmental or depletion cost qualifies as an economic instrument. A very general classification of economic instruments is, to divide them into two groups. The first group is the so called market based instruments. This covers all instruments and incentives that work by a change of either product or factor prices, e.g. taxes or pollution charges. Such instruments generate in one or the other way income for the governments. The second group refers to the non-market based instruments, such as command-and-control activities or land reclamation bonds. A perhaps better and more accurate typology of economic instruments was proposed by Panayotou (1994). He classified economic instruments into the following seven categories:

- property rights
- market creation
- fiscal instruments
- charge systems
- financial instruments
- liability instruments

- performance bonds and deposit refund systems

Indeed, the climate change is the foremost global externality that the world has ever seen, a carbon tax is necessary to correct the market failure and inefficiency along with other command-and-control governing instruments (Stern, 2006). Thus, clear property right of carbon emissions and appropriate carbon price are needed to correct the market failure. Emissions trading and carbon tax are the two most common administrative approaches with economic incentives in carbon emissions regulation.

Numerous papers have studied Price VS quantities tools since Weitzman(1974) who derived conditions under which one or the other policy is preferred in expected efficiency terms based on the relative slopes of the curves for the marginal cost and marginal benefits of emissions control. Most of these studies agreed that price-based policies are preferred in terms of economic efficiency (Murray *et al.*,2008).

7.3.2 Common price-based economic tools for BEE

7.3.2.1 Tax

Tax is the mostly used price-based economic instrument in many countries in the environmental policy to regulate emissions. By raising the price of goods and services that have negative impact on environmental. Taxation instruments are used to encourage environmentally friendly behaviour. Corporate will have incentive to reduce pollutants emissions by increasing production efficiency. Levies put a price increase on fuels or activities that contribute to greenhouse gas emissions whilst tax rebates act as an incentive to adopt more climate friendly behaviours. Economists say that even modest reductions in the after-tax cost of capital purchases provide strong incentives for increased investment (House and Shapiro, 2006). On the other hand, the economists use choice experiment to evaluate consumers' willingness to pay for energy saving measures in the buildings (Banfi *et al.*, 2008). Their research results show that households react differently to the increase or decrease in price of premises relating to improved energy performance, and consequently the energy bill would be much lower than a non efficient one. The empirical study outcome tells us that the price or income elasticity varies between the different groups of households (classified by education, profession, income, neighbourhood, social status et cetera) for whom, to some extent, the environmental consideration may change their consumption patterns.

7.3.2.2 Fiscal instruments

Fiscal instruments such as taxes or subsidies for environmentally sound production can be used for full cost pricing of production and consumption. For example current prices of fuel do not incorporate the social costs of these products. Their effects on environment are not considered at all. Fiscal instruments therefore try to bridge the gap between the private and social cost of production and consumption. Ideally, the taxes or subsidies should be equal to the marginal environmental damage caused by a certain activity. If this is the case it would adjust the price of a good exactly by the amount of reduction in social welfare

caused by the externalities associated with such a product. Taxation of environmentally hazardous products is a rather old instrument which was already proposed by Pigou in the early twenties of this century. Environmental taxes can be imposed on the production side (e.g. taxation of raw materials) as well as on the consumption side (e.g. taxation of petrol or pesticides).

Financial instruments could give incentives to support environmentally friendly activities or projects with positive externalities, such as reforestation or advanced techniques to control soil erosion. Financial instruments such as revolving funds, green funds, subsidized interest rates or soft loans may be justified as instruments for mobilizing additional financial resources for conservation, environmental protection and sustainable development. Financial instruments might be effective under certain circumstances and conditions, but they are mostly considered to be too blunt for an efficient internalisation of social costs, since they only encourage a certain form of behaviour but do not internalize costs.

7.3.2.3 Removing subsidies

In many cases governments are effectively subsidizing environmental bads. For example, the application of a carbon tax where governments are paying subsidies for the production of electricity is likely to be relatively ineffective. Before starting to assess the use of economic instruments, it is necessary to detect such unsustainable market distortions and reduce them. Perhaps this might already be sufficient to induce environmentally friendly production and no further action might be necessary.

The above mentioned instruments might give the impression that persons or companies always need to be forced by certain rules or regulation to take care of the environment. But a more efficient and cost effective way to achieve cost internalisation is to induce self-regulation on the polluters side. In most of the cases the polluter knows best how to control their hazardous output or environmental damages.

In this chapter a brief overview was given on the different economic instruments which can be used. There are many more instruments available than outlined above. Sometimes it is not possible to fit an instrument into any of the above groups. It is clear that there is a bundle of different instruments available for the internalisation of external costs. Each one has its advantages and disadvantages and they might only be effective under certain circumstances.

7.3.3 Carbon financing

7.3.3.1 Emissions trading and carbon tax

Governments can make efficient technology (buildings and appliances) more appealing. The choice between tax and CO₂ trade permit reflects the trade-off of policy makers between cost and quantities as in most environmental regulatory instruments implementation (Weitzman, 1974). Emissions trading among industrialised and transitional countries (former Soviet bloc) was included in the Kyoto Protocol to the UN Framework Convention on Climate Change. Carbon tax is an example of environmental tax, it has been

considered in the EU prior to the Emission Trade Scheme (EU-ETS) . Carbon taxes have been introduced in Denmark, Sweden, Norway, Finland, Italy, the Netherlands, and the United Kingdom, while Germany, Austria, Belgium, and Japan have adopted broader energy taxes (Rich, 2004). Although an international emissions trading system does not necessarily preclude the use of carbon taxes (domestically or internationally), the two are commonly seen as competing policy instruments to reduce GHG (Baumert, 1998). Both taxes and tradable permits put a price on emissions, and that price is equal to all parties involved. Therefore, emission reduction targets are met at minimum cost.

7.3.4 Carbon tax

Contrarily to cap-and-trade system which aims at specific quantity objective, tax instrument leaves the quantity of emission reduction uncertain. Economic theory tells that tax is more efficient than subsidy instrument by reducing the free-rider and transaction costs in competitive market. The well-known Pigovian tax which is equal to the marginal cost of emission abatement will give industrials clear price signal to reduce their emission such that the total cost of abatement will be minimised.

Although sensibility in sectoral energy demand scenarios in China has been tested in response to the degree of global climate constraints in previous modelling (IEA, 2006; Jiang and Hu, 2006), no explicit cost of externalities, i.e. carbon is considered being imposed on buildings industrials and end-user in the policy scenario. Larson *et al.* (2003) build a MARKAL-China model of energy system representing all sectors of the economy and including both energy conversion and end-use technologies. Strikingly, they found that even when significant limitations on carbon emissions were stipulated, an advanced energy technology strategy on the basis of the author's technology-cost assumptions would not incur a higher cumulative (1995–2050) total discount cost in energy system than the business-as-usual strategy. This result has a strong energy and environmental policy implications in China. Low-carbon technologies like ultra-efficient buildings can only be commercially viable with explicit CO₂ price incentive. The lack of carbon constraint in energy demand and CO₂ emission scenario would render the implementation of cost-effective building efficiency policies more difficult and low-carbon technologies less competitive, low-carbon perspective of buildings in China will hardly be realisable in the absence of carbon price. In this respect, a State carbon tax can be levied with environmental tax and pollution charges by central and provincial governmental and redistributed to financing the investment gap in the dissemination of appropriate efficient technologies such as integrated PV, high-efficiency boilers, renewables and geothermal, district biomass-fuelled CHP etc.

7.3.5 Other instruments

7.3.5.1 Voluntary approach

Voluntary approach is one of major environmental policy instruments along with regulatory and economic instruments. And increasing number of VA has been implemented in OECD countries. They have been introduced as supplement to the existing “command-and-control” regulatory approach.

It include a variety of tools such as unilateral commitment; private agreements through direct bargain between pollutees and polluters, environmental negotiation between industry and public authority and voluntary programmes developed by public authorities to which firms are welcomed to participate (Börkey *et al.*, 1998).

In the OECD countries, various private and public voluntary initiatives have been implemented in the building sector to enhance buildings energy efficiency and encourage efficient use of energy consumption appliances. The famous examples include the US Energy Star Label, European Passivhaus and Minergie labelling, Japanese Top runner of households electric appliances etc.

7.3.5.2 Energy efficiency and carbon labelling and certification

Some developed countries have successfully introduced ultra-low and zero energy and or 'environment-friendly' labelling schemes in buildings sector, e.g. the European passive Habitat label (*Passivhaus* in Germany, *Minergie* in Switzerland and the *HQE* label in France, the British BREEM) and LEED® label in the United States. The two latter integrate energy efficiency and environmental impacts indicators into the general housing quality assessment for new housing construction projects. Moreover, the use of renewable energy is strongly encouraged in exchange of land use incentive and financial or other in-kind advantages. The French Urban Planning Act stipulates that a developer can be partly exempted from land use regulations or urban planning codes or other specified technical requirements such as plot ratios when high-efficiency buildings are constructed or large-scale renewable energy use is included in the property development project.

On the basis of experience in the US and EU countries, BEE and carbon labelling and certification can be introduced to new construction and retrofits programme in Chinese cities. Actually, the labelling approach has already been implemented in China for several years in the white goods sector (refrigerators, air-conditioners). The next step is to extend the national administrative standardisation process to the third-party assessment and building energy and carbon efficiency certificate market.

7.3.6 Energy service companies (ESCO)

The commercial ESCOs offer an alternative to bridge the technical and financial gap in the efficiency market. Three major types of ESCO contract terms can be identified: 1. shared saving; which has kept the most common ESCO contract; the service supplier shares the saved energy cost with clients; 2. guaranteed saving; which is mostly used in industry. 3. Outsourcing energy management; especially adapted to the commercial buildings but is still under development in China. There may be various areas in which ESCOs can intervene based on integrated energy management experience.

Currently, most ESCO development projects in China focus on industry and high-end commercial buildings efficiency improvement, yet the technical intervention in these projects remains limited since the major actions have been concentrated on the supply-side technical improvement such as electric machine efficiency improvement. ESCO service in China is often characterised by its short-term contracting period, less than 3 years in general instead of 8-10 years in developed countries. The ESCO market in most Chinese cities remains immature and short-sighted.¹⁰³ Longer term ESCO contract face a number of market barriers and unforeseeable risks such as client's financial accountability¹⁰⁴. Furthermore, many contractors are more concerned about investment payback rather than integrating energy performance improvement proposals. There are also institutional barriers to the ESCO development such as the leasing regime constraints which hinders the development of efficiency management project.

In addition, some ESCOs in China are becoming more or less a purely professional efficient energy product promoter instead of energy service supplier. From the client's perspective, the *hard* investment (equipment, appliances) is more tangible than the *soft* investment (idea, organisation; management). ESCO is likely to offer single solution such as installation of high performing equipment while ignoring the importance of comprehensive energy management in building.

ESCO involvement in the building sector implies huge preliminary diagnostic work on the energy performance of buildings, including their thermal quality, lighting, high-voltage alternating current (HVAC) system efficiency and electric machinery. Nevertheless, only a few energy companies are capable of supplying such a comprehensive provision in the ESCO market since it requires technical proficiency and high capacity.

The opening of the energy service market in China offers an unprecedented opportunity for the international energy utilities and their energy service provisions subsidiaries that are specialised in the building energy performance improvement. Many well-known international energy companies have stepped in China's ESCO market such as Siemens, Schneider Electronics and so forth. The technology transfer is one of the key elements of ESCO market development. Patent protection institutions should be established to protect the IPR and make the technical know-how transfer smoother. The Market regulation and legislative specification are the most urgent issues to be addressed by the government if more and more world-leading ESCOs become involved in China's market, since the stakeholders require risk aversion guarantee in energy service investment.

Discussions of energy policy in an environmentally constrained world often focus on the use of tax instruments to internalise the external effects of energy utilisation or achieve specified reductions in

¹⁰³ According to Ye Wenbiao, director of Shanghai Energy Conservation Service Centre (SHECSC), one of the earliest ESCOs. It was once a government agency in charge of energy conservation management in the municipal administration, particularly in the industry sector. In 1998, the World Bank launched a series of demonstration projects to promote ESCO services in China in collaboration with other international organisation such as UNIDO, in which the SHECSE was involved.

¹⁰⁴ This matters in particular in the industry where a number of firms went bankruptcy after signing the ESCO contract and the payment capacity of energy efficient services crumbled

energy use in the most cost-effective manner. A substantial literature suggests, however, that significant opportunities exist to reduce energy utilisation by implementing technologies that are cost-effective under prevailing economic conditions but that are not fully implemented by existing market institutions.

Stavins (1994) examines the theory of the market for energy-using equipment, showing that problems of imperfect information and transaction costs may bias rational consumers to purchase devices that use more energy than those that would be selected by a well-informed social planner guided by the criterion of economic efficiency. Consumers must base their purchase decisions on observed prices and expectations of post-purchase equipment performance. If it is difficult or costly for individuals to form accurate and precise expectations, the level of energy efficiency achieved by competitive markets will vary from the socially efficient outcome. Such 'market barriers' suggest a role for regulatory intervention to improve market performance at prevailing energy prices. Also constructor worries about the extra cost and expertise in standards compliance. Similarly, the housing purchasers often ignore the issue of energy efficiency while paying more attention on architecture design or housing location.

7.3.7 Land use regulation and building energy efficiency improvement

There are abundant researches on interaction between land use regulation and housing price in previous economic literature (Asabeare and Colwell, 1984; Rueter, 1973; Schwartz, David and Green, 1984; Rose, 1989; Pollakowski and Wachter, 1990; Quigley and Rosenthal, 2005). Measuring the effect of local land use regulation on housing prices is a formidable empirical challenge. Land use rules are intended to recognize local externalities, providing amenities that make communities more attractive and housing prices higher. Restrictive zoning and growth controls, however, also tend to slow expansion and reduce net densities of the housing stock. We would expect these supply constraints to increase home prices. Distinguishing between these various impacts is complicated in practice. Local homeowners seeking to maximize home values and minimize tax burdens typically control the politics underlying land use enactments. In addition, many localities combine restrictions on new development with a range of economic incentives meant to spur it along. Measuring the economic constraints imposed by actual regulatory behaviour and decision-making, as opposed to merely observing formal rules as adopted, is a difficult empirical problem, and comparisons across metropolitan areas are frustrated by the sheer variety of local practices.

7.3.8 Appraisal of tools

Table 7-1 summarises the main advantages and disadvantages of different policy and economic instruments.

Table 7-1 Instruments appraisal

Policy instruments	Pro	Cons
Tax	-Economically and ecologically efficient, minimise the cost of reduction of pollutants and GHG ; -taxes encourage enterprises to develop or introduce cleaner and more efficient production techniques since they will then save taxes - flexibility : this instrument will leave private enterprises the freedom to decide whether they pay taxes or invest in cleaner production technology	-Uncertainty about quantitative objective - politically there is a tendency to impose low taxes which do not cover the whole social cost - inflation may decrease the effects of a taxation of environmental damage - high administrative costs - low willingness to accept by the public as well as by the target group concerned
Subsidy	-direct incentive and easy for enterprise or industrials to perceive -clear objective and targeted object & subject	asymmetry of information , higher cost, inefficient energy savings and GHG reduction
Permit trading	Maintain of environmental objective	Uncertainty about the marginal cost
Regulatory	Low transaction cost , relevance of objectives	Ignorance of difference of capacity among various actors , inflexibility
Kyoto Flexibility mechanism	-burden sharing of environmental objective -Economically efficient by minimising the mitigation cost -encourage efficiency technology transfer -help developing countries to achieve sustainable development	-High transaction costs -ambiguity on reduction objective -give incentive to develop non-efficient and high-emissive technology in baseline case - complexity of administrative procedure
Energy efficiency certificate	- clear information can be passed on to consumer - encourage competition in efficiency buildings technology	-transaction cost is high since it involves various technical and administrative procedures such as monitoring, verification and registration
Voluntary approach	-Low transactional cost - information dissemination and awareness raising in public opinion	-free-riding -regulatory capture -lack of environmental effectiveness - lack of credibility to give incentive to innovation
Public procurement	- Encourage private sector to uptake efficiency technology	

Source: adapted from Panayotou (1994) , IEA(1997), OECD(2003), Koepfel and Ürge-Vorsatz(2007)

7.4 Proposition of instruments

This section discusses different policy instruments design and implementation propositions. The relevance of economic and policy instruments in promoting buildings energy efficiency is justified by both quantitative and qualitative analyses. We assess the relevance and effectiveness of different propositions of policy and economic instruments in the property market in order to achieve the optimal BEE standards and encourage the state-of-the-art construction techniques and practices.

7.4.1 The role of public policy to enhance building energy efficiency

A key question implied in this thesis is how to use public policy to address barriers to energy efficiency uptake and move the market towards the right direction. Sound policy framework is the linchpin upon which the success or failure of BEE implementation will depend. In the area of buildings energy efficiency improvements, the chart below illustrates the role of public policy in efficiency market transformation.

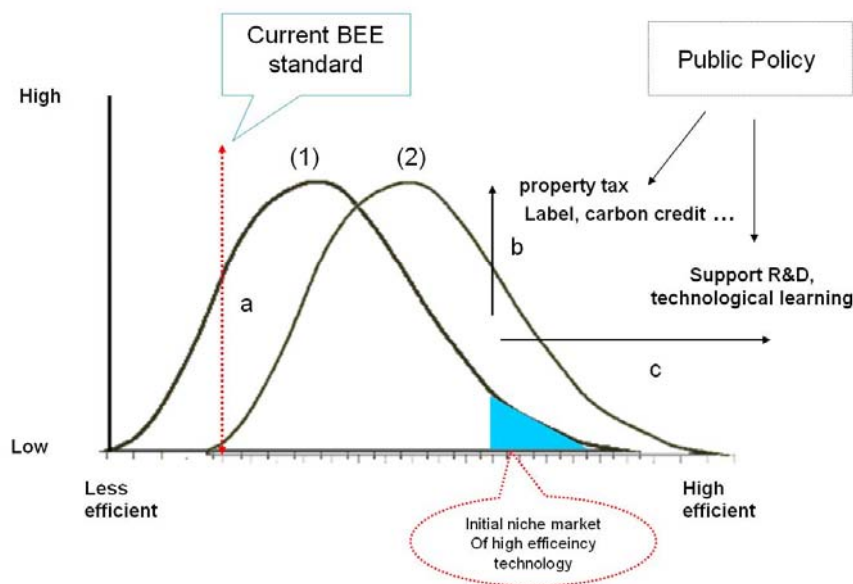


Figure 7-3. Role of public policy in fostering BEE market transformation

Source: Laponche *et al.* (1997), p.199

Figure 7-3 illustrates how public policy can intervene to push the market towards the high efficient direction.

curve (1) represents the initial distribution of a given level of energy efficiency buildings in the construction market.

curve (2) shows the distribution of market penetration of buildings complying with different levels of energy efficiency in response to a variety of policy instruments

- a) is a minimum standard to eliminate the inefficient buildings from the market
- b) efficient buildings label (green buildings, low carbon or sustainable buildings...) to keep the share of more efficient buildings rising
- c) supportive public policy (tax, land use regulation, economies of scale...) to encourage the R&D and technological learning to new techniques of construction (adopting high-level efficiency standards for example, upgrading current national building code to the Swedish equivalent standard , fuel switching from coal to NGCC, CCS power plants for example)

7.4.2 Tightening buildings energy efficiency regulations

The modelling results in chapter 4 and 5 show unambiguously that the efficiency requirement in the current buildings codes enforced in the Chinese cities is at suboptimal level and should be improved significantly to achieve a better economic performance in terms of total costs for the society. The priority for the buildings efficiency agenda is to upgrade the minimum standard of quality in terms of energy efficiency in the buildings codes and enforce new regulations through supportive policies. It is true that the regulatory instruments such as mandatory requirement of BEE can be the cost-least measure due to low transaction costs. However, regulations become ineffective if they are not enforced and implemented. The imminent issue for the local authority is to put in place efficient institutions and policies to enable effective enforcement and implementation of high-efficient standards. The instruments proposed hereafter aim at complementing the inadequate aspect of regulatory approach.

7.4.3 Proposal 1 –BEE procurement : property tax to building energy efficiency

7.4.3.1 Public procurement and property tax

An efficiency procurement scheme can be defined to encourage high –efficiency buildings construction and performing energy using appliances, public authorities can use the procurement instrument. For example, government can negotiate with private actor (e.g. property developer) to define the buildings efficiency standards (higher than the requirement of current building code) based on a voluntary principle and commits to

- granting a lower LUR price (in form of property tax in project design stage) or
- issuing a high-efficiency or low-carbon buildings label or
- purchasing the carbon emissions savings credits (compared to baseline case)

for a certain period. This procurement arrangement will give incentives for property developers to invest in new techniques and practices learning of efficiency constructions. Given the incentives scheme, more

and more private developers will participate in this negotiated process. This will give a “push” force to move the market forwards, and the efficiency quality distribution curve will shift towards right hand side, as shown in Fig 7-3. Eventually the general practices will converge in the construction market, and the initially subsidised high-efficiency practice will be generalised eventually in the market, the provisions specified initially based on voluntary instruments will become finally mandatory standards following the market transformation. Incentives given to developers will play a facilitator or stimulus role to accompany the market and institutional transformation. Property tax incentives can be used to play this role for instance, box 7-1 describes major characteristics of this tax.

Box 7-1. Characteristics of property tax

Property tax is an *ad valorem* tax that an owner pays on the value of the property being taxed. There are three species or types of property: Land, Improvements to Land (immovable manmade objects; i.e., buildings), and Personality (movable manmade objects) (Wikipedia website).

Real estate or property are all terms for the combination of land and improvements. The taxing authority requires and/or performs an appraisal of the monetary value of the property, and tax is assessed in proportion to that value. Forms of property tax used vary between countries and jurisdictions.

The property tax rate is often given as a percentage. It may also be expressed as a permille (amount of tax per thousand currency units of property value), which is also known as a millage rate or mill levy. (A mill is also one-thousandth of a dollar.) To calculate the property tax, the authority will multiply the assessed value of the property by the mill rate and then divide by 1,000. For example, a property with an assessed value of US\$ 500,000 located in a municipality with a mill rate of 20 mills would have a property tax bill of US\$ 10,000.00 per year.

Taxation on property can be classified in three categories depending on choice of tax base (McCluskey and Franzsen, 2005)

- Tax based on income derived from property
- Tax bases on area (i.e. Property size), and
- Tax based on rental or capital (i.e. *ad valorem*)

Therefore there are tax specifically related to land, Land value taxation (LVT) (or site value taxation) is a tax that charges landholders a portion of the unimproved value of a site or parcel of land. Uses tax incentives to influence households' decision on purchasing energy-saving appliance and uptake of efficiency measures building efficiency. Under the current Chinese taxation regime, tax base is made up of central and local taxes practices and experience in foreign countries and regions regarding property tax can help to devise an implementable framework to guide the property taxation employment in urban land and housing market in China in the future. An article published in Wikipedia gives a comprehensive overview and comparative analysis of practices of taxation on property in the world (Smith, K. 1998 and http://en.wikipedia.org/wiki/Land_tax).

7.4.3.2 Integrating property tax into BEE policy portfolio

A possible policy instrument is to relate the property tax rate to the energy performance of buildings constructed in the terms of land use right transaction contract. Land supplier (local government) and land use right purchaser (developer) will have incentives to impose building energy performance in the property development programme if energy performance-related property tax can be instituted.

Likewise, similar tax can be also applicable to housing and other property purchaser or owner to encourage them to opt for more efficient constructions. Consequently, property tax will push and pull the property market towards higher efficiency supply and create the demand for efficient buildings. This can help create a virtuous cycle in the whole property development market in the Chinese cities.

On the other hand, Vickrey (1999) pointed out that “the property tax is, economically speaking, a combination of one of the worst taxes—the part that is assessed on real estate improvements and one of the best taxes—the tax on land or site value.” It is thus important to devise an appropriate taxation framework in current Chinese property market such that tax on building (improvements on land) can be levied such that significant side effect can be avoided (to minimise economic distortions of taxation).

There have been many hot debates in China as to whether the property tax should be levied to curb the current speculation activities in urban property development market. Tax on immovable and land value tax are extensively used in US, France, UK and other developed countries, to discourage speculation on values of improved land (i.e. buildings) or unimproved parcel or plots of land. At present in China, there exists no specific statute empowering local authorities to tax the land developer¹⁰⁵ (who acquires the land in the LUR transfer market) or property owner (who purchases the house) based on the property tax model. An institutional reform is required to legitimise relevant authorities to differentiate tax rate of constructed buildings on the basis of energy efficiency level.

According to the Chinese Real Estate Ordinance, certificate of property (buildings) means holding only the property of building but not the LUR. In fact, in the commodity housing market, the full house property ownership is only acknowledged by relevant administration if and only if the owner holds two official documents: 1) house property and 2) land lease certificate which entitles the lease holders the right of land use. Acquisition of both two certificates are required when application is submitted to local governments and are prerequisite in case of house transaction. In other words, a house owner can not sell his property freely through the secondary market without holding simultaneously both of them.

Lin *et al.*(2005) analyze the characteristics of tax relative to real estate in China and conclude. First, tax on property in China does not exist *per se* as a single tax, but rather a combination of different tax species such as transfer tax, income tax, property tax, resource tax and behaviour tax etc. Second, real estate tax has strong adjustment effect since it can be applied in every single stage along the property development process (land improvements, distribution and transaction, buildings operating period, revenue redistribution etc). Third, most of taxes on real estate are levied by local government and thus constitute the major tax income of local-level authority. Fourth, real estate taxes are diffuse and fragmented in terms of tax base. Most of tax rates related to real estate are relatively miniscule and the taxable person is fairly diffuse, which render the taxation more difficult compared to the VAT or corporate business tax.

¹⁰⁵ The word *Landlord* is widely used in western countries, but private ownership of land is prohibited by the Chinese constitution.

In most developed countries, fiscal policy is extensively being used as a tool to support government’s goal in improving building energy efficiency in many developed countries, tax incentives such as tax deduction , tax credits are devised to encourage residents to undertake building efficiency improvement measures such as shell insulation, use of high-efficient electric appliances and more renewables for space heating and other utilisation. Nevertheless, to use land tax as a tool to relate land improvements efficiency to value property is still very rare. Property developer has no strong incentives to enhance the buildings efficiency provided that the land tax .

The reflection on tax-based instruments to regulate the property’s behaviour regarding the uptake of energy efficiency measures requires an insight of cost analysis. Below are some examples related to breakdown of house sales price. The example of Tianjin is taken from the HXJD project mentioned in Chapter 4, the average house sale price is 7000 Yuan per square metre of floor space.

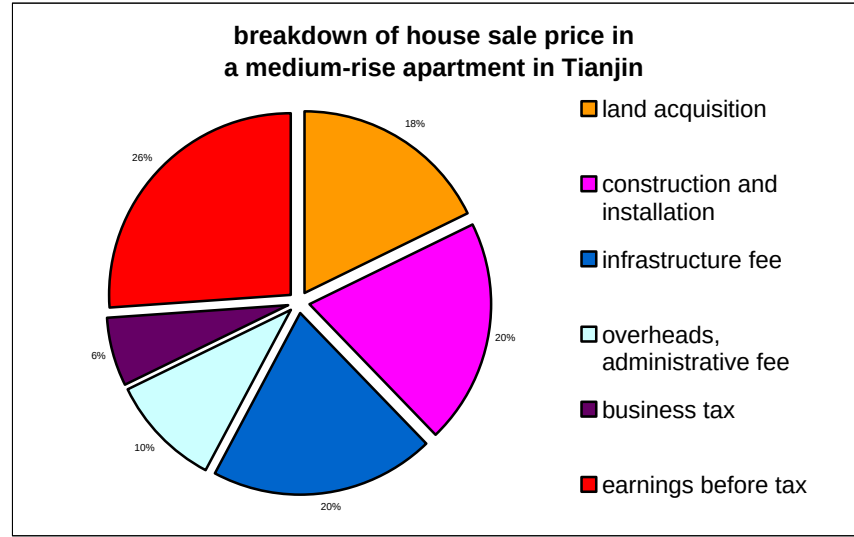


Figure 7-4: house price breakdown in Tianjin’s new medium-rise residential buildings (estimated by author)

Developer’s earnings in property market vary significantly from each other mainly because of land differential rent in urban development area. Values in the above graphic are solely indicative and should be interpreted as a representative case in the city of Tianjin .

In fact, number of administrative fees and charges are accounted for in the category of infrastructure since they are charged by utility companies and authorities in charge of urban infrastructure development. These fees are generally associated with the development procedure advancement along with property development program. This means that current taxation on property market is still immature since many fees are levied without regulatory framework or institutional justification. There are hence the DWL from the society as a whole since the fees imposed on developer will eventually be shouldered by the house

purchasers, and the local taxation administration have many difficulties to collect the fees since they are levied by various municipal services and utility companies.

7.4.4 Proposal 2—Programmatic CDM in BEE financing

7.4.4.1 How to make it happen ?

The Clean Development Mechanism (CDM) was established by Article 12 of the Kyoto Protocol and refers to climate change mitigation projects undertaken between Annex 1 countries and non-Annex 1 countries . It has paved the way to alternative financing portfolio regarding energy efficiency improvement projects in this sector, in collaboration with the international financial actors.

European and Japanese actors have been especially active in the global carbon markets over the past years, and European buyers totally dominated the CDM market in 2006 with 86% of volumes transacted , as can be seen from Fig.7-5, China is dominating the CDM market accounting for more than 70% of global CDM transaction volumes (Capoor and Ambrosi,2008).

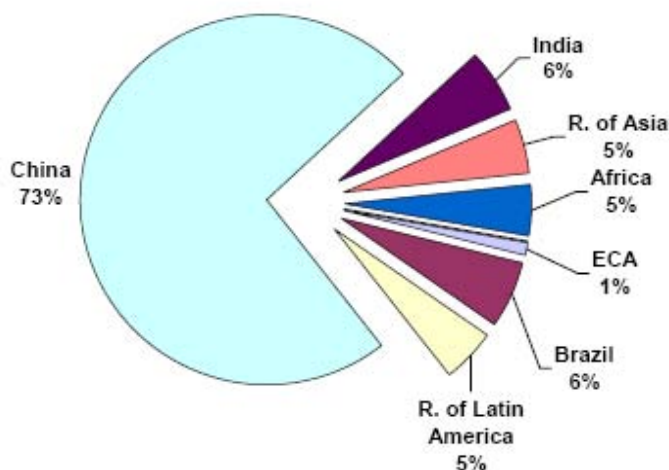


Figure 7-5 Global CDM market (Capoor and Ambrosi, 2008)

The inclusion of building energy efficiency in the CDM markets can be of interests if a large part of new buildings programmes is included in the scheme otherwise the transaction costs would be too high to be implementable for industrials and private entrepreneurs. Suppose that a Chinese housing developer in Tianjin decides to develop a large residential buildings programme in a new development zone of the city, say 10000 multi-family apartment houses. It is assumed that no price escalation will be envisaged in house selling. He may face two choices : 1) a business as usual case, i.e. complying with the current building energy efficiency code (TJ-2004) whereby no extra cost will be generated since the underlying BEE standard is mandatory for every new construction in the city; 2) adopting a more efficient building design and construction practice (equivalent to the Swedish building code requirement) if the extra cost can be

covered by a third party, say the CDM carbon credit buyer. The developer will be interested in CDM if the adoption of non mandatory higher BEE can yield sufficient carbon emission credits tradable with competitive price. A simplified calculation can be illustrative on this financing mechanism. Assuming that a house builder in the city of Tianjin would be ready to adopt the best available techniques (BAT) of building energy efficiency (equivalent to the Swedish building code) coupled with the natural gas combined cycle (NGCC) energy supply (baseline is coal-fired district boiler) if he perceives the CDM financing profitable for him, in other words, the discounted overall Certified Emissions Reductions (CER) credits of CDM will allow him to pay off the initial extra cost. Putting it formally,

A builder adopts higher efficiency practice package (compliance with Swedish standard equivalent requirement + 24 MW NGCC)

if and only if

$$P_{CER} \geq EAC$$

and

$$EAC = \frac{IC}{\int_0^T (E_{tjt} - E_{swt}) \cdot e^{-rt} dt} \quad (1)$$

where

P_{CER} is the CER price of net CO_2 removal in CDM project($US\$/tCO_2$)

EAC is the discounted emission abatement cost:($US\$/tCO_2$)

IC is the incremental cost of building efficiency update: $US\%$

E_{tjt} is the per floor space emission in baseline building($tCO_2/\text{year}/m^2$)

E_{swt} is the per floor space emission in buildings complying with BEE equivalent of Swedish building code($tCO_2/\text{year}/m^2$)

r is discount rate: 6% which is equal to the long-term mortgage interest rate in China

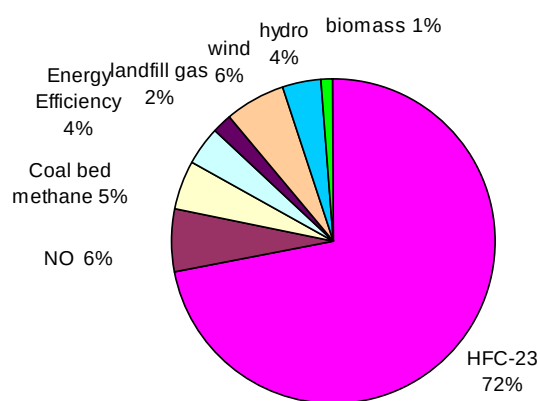
The data from Liu (2006) is used here to estimate the cost of BAT practices and to calculate the emission reduction potential and relevant costs. The overall envelope (wall, window, roof) cost of a typical multi-storey apartment under the baseline scenario (built in compliance with the current building code in Tianjin) is around 280 Yuan per square metre of floor space in 2005 prices (36 US\$ per m^2). Updating the equivalent Swedish efficiency performance¹⁰⁶ in the same building entails an incremental cost of 61 Yuan/ m^2 (7.9 US\$/ m^2 in 2005 prices), including the optimised building design, and the cost of an improved ventilation and heat recovery system. Final heating consumption of a house complying with the two BEE standards are 49 kWh and 18 kWh per square metre, respectively. It is assumed that the upstream heat

¹⁰⁶ It must be mentioned that the Swedish reference mentioned here refers to the equivalent performance in terms of U -value, rather than the actual construction techniques practiced in Sweden due to difference of building materials and local characteristics, also the labour training and know-how.

supply system will switch from coal-fired district boilers with 65% efficiency to gas-fired CHP with 80% heat efficiency under CDM package. The corresponding emission factor is 49.8 kg CO₂/ m²a and 10 kg CO₂/ m²a in the base year, and 59 kg CO₂/ m²a and 11.5 kg CO₂/ m²a in 20 years (the increase in demand for heating service is taken into account to mirror the rise in living standard; full data for the calculations is available upon request). Thus the total estimated emissions reduction over the 20 years of CDM crediting period (shorter than the actual building lifetime) is 873.4 kg CO₂/ m². With equation 1, it can be easily calculated that the EAC is 16 US\$/tCO₂ (at 2005 prices), which is slightly higher than average CERs price of China's CDM projects, but still significantly lower than the EU-ETS Allowance (EUA) price that is close to 30 US\$/t CO₂ (Point Carbon, 2008). The EUA price reached €30 per tonne in April 2006. In addition, the carbon price in the European market should continue to rise over the next decades as the European Union is expected to tighten the emission reductions objective for the post-Kyoto regime. Recent literatures on the economics of climate change and energy modelling all suggest that the benchmark CO₂ price such as the EUA price and the marginal abatement cost (MAC) of CO₂ in the European countries and other parts of the world are likely to range between 30 to 40 US\$/t CO₂ in the 2020-2030 timeframe (Anderson, 2006; IPCC, 2007; Stern, 2007; PowerPoint, 2007; Blanco and Rodrigues, 2008; Colombier et al., 2008). Thus, the CDM CER price of residential BEE upgrading in Chinese northern cities is very competitive for carbon financiers and investors. Moreover, the transaction costs of CDM are expected to decrease further with the city-level and sector-based programmatic CDM models. The potential demand for ERs in EU countries could increase to 300 Mt CO₂e per year to attain the European target of reducing GHG emissions further to a 30% below 1990 levels by 2020 (Capoor and Ambrosi, 2008).

7.4.4.2 Toward a Programmatic CDM model in Chinese buildings market

Some flaws are pertaining under current CDM operation framework. As pointed out in Zhuang (2006), most of CDM projects in China are focused on Non CO₂ GHG reductions, with detriment to energy efficiency projects in particular (see Fig.4). This is mainly due to the high imbalance between different GHG in terms of GWP (global warming potentials). Although the Chinese government has issued taxation instruments to de-incentivise the HFC mitigation project. The central government imposes differentiate tax rate according to project nature and sort of GHG mitigated. Institutional reforms are necessary to bring CDM projects onto the sustainable infrastructure development such as building sector in Chinese cities in the next steps.



70Mt CERs in 2007

Figure 7-6 Breakdown of CERs of CDM projects in China total (source: IEA, 2007; UNEP CD4CDM database)

One of the key points in CDM is the additionality in the project assessment and approval process. The example illustrated before shows that although the carbon credit generated by improving building energy efficiency standards could allow property developer to finance the upfront extra costs of construction, however, the implicit rate of return on investment (6%) seems to be too low to incentivise them incorporate CDM in construction. Moreover, the high transaction cost may be incurred for the project-based building energy efficiency amelioration.

7.4.4.3 Proposed new model of functioning

On the contrary, suppose now that a local authority plays an intermediate role as carbon credits trader on behalf of distributed individual house builders and property developers in negotiating with international CDM financial institutions and private actors. Schematic representation of programmatic CDM operation is illustrated in Fig. 7-7.

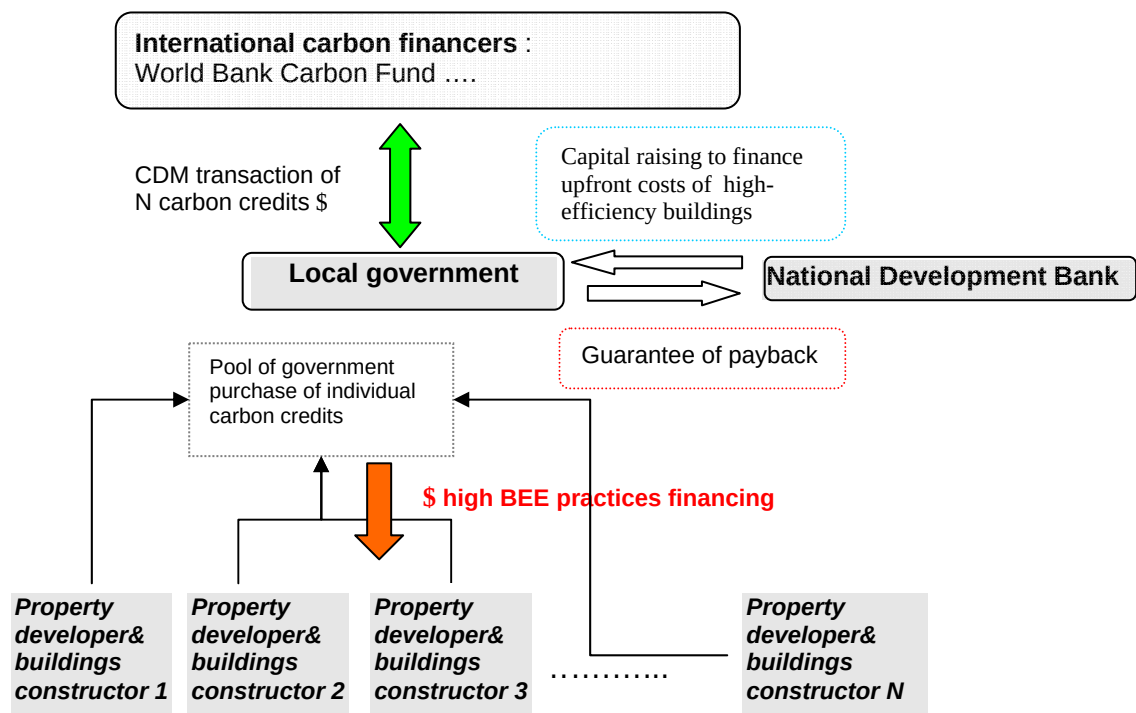


Figure 7-7 A schematic representation of programmatic CDM for BEE in the Chinese municipality-level (compiled by author)

Under this model, all carbon credits in this case will be centralised to local government (a carbon pool could be step up as indicated in the diagram). Under this scheme, local government commits it self to financing (by means of public bank or social development funds) the extra cost of adoption of the BAT to improve buildings energy efficiency to the public. The carbon savings from improvements to buildings will be sold to the international CDM financiers (e.g. World Bank Carbon Fund or other carbon trust etc) by the local government. In other words, the actors of CDM are concentrated in the upstream stakeholders (local government, financiers, bankers and other consulting companies). The same model can be used to assess the price of carbon credits, except that the discount rate used here is interpreted as in the social development plan. It is plausible that the public bank (National Development Bank among others) which supplies the loan the local government to finance the public procurement of buildings carbon savings is ready to expect a 6%-rate of return on investment as financing a public-utility improvements project.

Indeed this initiative should be undertaken with a greater extent of participation of property development programmes to create economies of scale and drive down eventually the extra cost of BAT of high-efficiency buildings construction relative to the prevalence of techniques practiced today. Actually, this is related to public policy making and urban development strategy. Since the local government will commit itself to financing the extra cost of programmed housing construction during a transition period (next 10 years) before instituting higher level of mandatory BEE standards (more performing than the current Swedish code requirement). The CDM is finally served as a financial tool to accompany the Chinese building

industry to transform the sector into a high-efficiency and low-carbon infrastructure by anticipating the BAT construction techniques, instead of a purely project-based financial tool by generating additional carbon credit in the narrow sense. The current CDM has already flaws in the sense that it may give incentive to Non-Annex I countries to use inefficient or higher carbon-intensive technology in the baseline scenario to generate more carbon credits.

Therefore, the most distinguished point in this scheme is that the CDM carbon credits will not confined to finance an individual ultra-efficient housing development project, it is almost certain that the high-end buildings constructor is unlikely to be interested in accepting a rate of return of 6% by taking a long-term investment risk of 20 years. However, this investment in improvements in BEE entails very low-risk for a public-owned commercial bank with the engagement of local government and international financial institutions. It should be pointed out that all CDM projects in China need to be endorsed by the National Development and Reform Commission before implementation. In other words, a signed BEE-CDM contract is nearly risk-zero in terms of financial return for public investment.

It is therefore necessary to achieve a city-level or sectoral agreement between different stakeholders including local government, local subsidiary of the National Development Bank or other public funds and financial institutions (The proactive investment of French Caisse des Dépôts et Consignations in social housing and carbon fund is a good example of involvement of public financial institutions in large programme of social and urban development).

China's building sector offers tremendous potential for mitigating CO₂ emissions through the implementation of clean technologies under a properly designed programmatic CDM framework, and Chinese policy-makers should move more quickly to take advantage of this win-win finance mechanism. Institutional change is needed to enlarge the scope of CER-EUA interchange on the global carbon market and facilitate the programmed CDM based on a whole jurisdiction of local authorities.

7.4.5 Proposal 3 –Creating interactive dynamic link between land use regulation and buildings efficiency

7.4.5.1 Determining the range of flexibility

As described in Chapter 5, the land and property development in the Chinese cities is highly regulated by the local authorities. The plot ratio regulation is one of the key parameters in the evaluation of urban planning and site development project submission. In generally, prescriptive minimum and ceiling value are defined a priori by the local authority in charge of urban planning for each specific category of land depending on land use nature, property types and site location. For example, in the "Tianjin Municipal Regulation on Buildings volume& height and plot ratio 2007", different threshold values of plot ratio have been specified or updated with regard to urban land and property developed. More specifically, the plot ratio should be indicated explicitly when the land is passed on to the land use transaction market. In fact,

the land use regulation flexibility is an indirect economic tool albeit no cash inflow is perceived by developers nor does he receive explicit tax rebate or reduction. Instead, the increased plot ratio allocated to the property developer who adopts high-efficiency BEE will allow him to sell more floor spaces to compensate the incremental cost in initial construction stage compared to the business-as-usual case.

Relating the question of building energy efficiency to land policy can be justified by the fact that similar initiative of integrating buildings energy performance into urban land development is already implemented in some EU countries. For example , French building energy regulation 2005 specifies that the land use restriction imposed by local council can be adjusted depending on what kind of energy infrastructure will be developed such as energy supplied for space heating and what level of efficiency the projected building can reach (RT 2005) . For a housing development program in which large deployment of cogeneration and renewables energy use or buildings certified as HPE (*Haute Performance Energétique*) are constructed can be allocated more flexibility with regard to plot ratio or COS (plot ratio) by land use regulations.

A case study is undertaken here to discuss the extent to which the flexibility of land use regulations can give developer incentives to improve the BEE aggressively. A parcel of land in the south-eastern Tianjin (Meijiang area) is selected as study object. This land is located in the inner side of outskirt and is adjacent to the area where the World Bank/GEF Tianjin Piloting project has been implemented. The main advantage is that this zone is dedicated to residential buildings development. Total usable land area is 7.42 hectares and plot ratio is 1.63 (information in Chinese about the terms of transaction of the land is available at <http://tj.focus.cn/ztdir/tjtd/index.php>) according to the municipal urban planning regulation. Assuming that 30% built floor area in the underlying land is public and commercial buildings and 70% is for residential buildings¹⁰⁷. Therefore, the total housing floor space is roughly 85000 m². Assuming also all houses consist of two types of multi-family apartments: high-rise and low-rise buildings, accounting for 60% and 40% of total floor area, respectively.

Land acquisition cost in this zone is expected as 18 M RMB/hc, it is assumed that all property development related tax rates remain identical before and after the introduction of plot ratio adjustment policy, developer is not allowed to pass on the incremental cost to the final consumer (house buyers),i.e. The housing sale price P remain unchanged regardless of whether the PR adjustment policy is implemented or not. Thus the net welfare of consumer will be improved ultimately, and housing developer is indifferent if the net income is not affected by adopting new building techniques. Putting it formally , developer has incentives to adopt SWE-equivalent practice if and only if

$$\Pi' \geq \Pi_b$$

¹⁰⁷ This assumption is somewhat discretionary or arbitrary, yet it is consistent with most land development projects in similar situation.

and

$$\Pi_b = (P \cdot A - (C_{eng} + C_{env} + C_{OH} + C_l) \cdot A - P \cdot A \cdot t_b)(1 - t_r) \quad (7.2)$$

$$\Pi' = (P \cdot A' - (C_{eng} + C_{env'} + C_{OH} + C_l) \cdot A' - P \cdot A' \cdot t_b)(1 - t_r) \quad (7.3)$$

$$A = S_l \cdot PR; \quad A' = S_l \cdot PR' \quad (7.4)$$

where

- P_b is the net profit of developer in baseline case
- P' is the net profit of developer after implementing PR adjustment policy
- C_{eng} is cost of buildings shell and engineering works
- C_{env} is the cost of building envelope and ventilation system in baseline case
- C'_{env} is the cost of building envelope and ventilation system in enhanced buildings
- C_{OH} is overhead of buildings construction and sale
- C_l is cost of land development including cost of acquisition and development
- t_b is the aggregate business tax rate
- t_i is the rate of tax on profit-after-tax
- P is housing sale price per square metre
- S_l is land area
- A is floor area of built house in baseline case
- A' is floor area of built house after PR adjustment
- PR_b is baseline plot ratio
- PR' is the adjusted plot ratio

To keep the presentation as simple as possible, all taxes and charges on revenue before tax are aggregated into a universal tax rate t_b which consists of business tax, obligatory contribution to education fund and urban development charge, tax on incremental value of land development is ignored in the computation since the adjustment on plot ratio has no impact on land value.

CL is comprised of cost of land acquisition and infrastructure development costs such as road, electricity, heat, water, gas, telecom, sewage etc (*qitong yiping*).

Tax rates

Business tax and supplementary charges: 5.5%

Tax on revenue :33%

Urban development tax:7%

Education contribution charge: 3%

Results

The average housing sale price is 7000 RMB per square metre in this zone, land cost is around , the composition of housing sale price has been illustrated in Fig.7-4. By Using the equations above, it can be

easily calculated that the minimum PR' should be no less than 1.7, or 5% increase compared with baseline case.

Policy recommendation

If the municipality intend to use land use regulation to encourage the housing developers to build higher efficient buildings, plot ratio can play a policy lever. In fact, the local government can use regulatory measurement indicator "plot ratio" as an incentive to adjust the builder's decision on BEE. PR is perceived as an effective non-monetary or in-kind subsidy since higher PR means increased floor area of sale and consequently increased profit. This is a non-lose strategy as government, builders, consumers are all better-off as a result of increased BEE in newly built houses. However, in either case of implementing programmatic CDM or land use regulation adjustment policies, the energy supplier, the heat company seems to be worse-off without any price revision since the quantity of heat supply will decrease as a result of an improved BEE and other DSM techniques. Therefore, a comprehensive heat reform scheme needs to be implemented to make the heat company better-off as well. The extent to which increase in heat price should be allowed depends upon how public authorities decide to let the stakeholders to share the gain. The next section discusses the DH reform perspective.

7.4.6 Proposal 4— DH pricing reform

Improvement in BEE requires a comprehensive approach consisting of DSM and supply technology optimisation, but also the establishment of coherent institutional framework. Energy billing and pricing issues are indispensable to accompany successful infrastructure performance amelioration. As noted in Laponche *et al.*(1997), "to encourage the efficient operation of energy companies and to improve their performance, to reduce government expenditure and to assist the economy to operate efficiently, it is essential that energy prices reflect energy costs(p.63)". In short, energy price should be cost-reflective and take into account costs of externalities such as CO₂ emissions.

DH techniques and management model in the northern cities in China is quite similar to the situation in the eastern Europe in before the introduction of DH reform in 1980s and 1990s. The Chinese decision makers can draw useful lessons from the DH reform experiences in the Eastern Europe. However, as indicated in Meyer and Kalkum (2008), "*Heat reform in Eastern Europe was rarely the result of smooth implementation of carefully planned and sequenced interventions. Results were achieved based on trial and error rather than on comprehensive strategies aiming to reform the (district) heating sector. The analysis of the Eastern European experience and knowledge of the pros and cons of approaches and their practical implementation was an advantage to Chinese decision makers in devising a reform process that could avoid much trial and error and lead to a smoother implementation with quicker results*". The cost reflective method should be promoted to supplement the technical intervention in building energy

efficiency improvement; consumers must be given appropriate price signal to save energy without compromise of thermal comfort, otherwise the saving resulting from efficiency improvement would be offset by the significant energy consumption rebound without consideration of cost.

7.4.6.1 Putting heat tariff increase within the framework of this public/private partnership

To determine the extent to which the heat price should be increase in order to make all stakeholders better-off, we take again the example of land plot where the plot ratio adjustment degree has been determined in proposal 3. Baseline heat supply is district coal-fired boiler, alternative energy supply options will be the municipal CHP or district-based NGCC . as discussed above, builders will adopt the SWE equivalent building performance standard if

Either a third party is committed to covering the total extra cost of adopting SWE by means of subsidy (finance may comes from the National Development Bank in Tianjin with the purchase guarantee of international carbon financiers by the local government) or is covered by the heat company,

alternatively,

Local urban planning authority is committed to granting a land use flexible adjustment, e.g. a minimum 5 per cent of increase in plot ratio as a form of compensation to adoption of SWE instead of implementing TJ2004 performance standard as usual.

In both cases, the final energy demand will be reduced by 40% and 58% under 18 degree Celsius baseline for low-rise and high-rise buildings, respectively, by engineering estimation. However, it is plausible that the consumer's demand for thermal comfort will increase continuously over the next two decades. As mentioned in the CDM financing case, two factors will influence the choice of final demand for heat: namely price effect and income effect respectively, hereafter we simulate 2 different cases. We consider a programme of 20 years of services, roughly equivalent to the lifetime of medium-sized boiler and efficiency materials of buildings components. The existing model of two-part heat tariff in China is assumed to be implemented in this zone, and the heat wholesale price will increase 1% (the fix –part of tariff remain unchanged) per year over the study period in each of the cases discussed below (with or without upgrading to SWE).

7.4.6.2 Property developer /energy suppliers co-operation package

Assuming there were a residential area in Tianjin with identical characteristics as in Proposal 3, except that only residential buildings will be constructed (public buildings are excluded for simplifying analysis). Total floor area of houses is then 120000 m² in this area. Assuming also that a heat supply company is committed to financing the upfront extra cost of BEE upgrading when he perceives the discounted costs

reduced or profit increased. The profit associated with efficiency improvement is accrued to the company if the energy price will be raised enough high. Without losing generality, the costs of heat supply include construction cost (heat source and distribution infrastructure installation); capital depreciation costs; maintenance costs; overhead cost, fuel cost, water cost and power consumption cost and tax (sales tax plus urban construction and education taxes)¹⁰⁸. The fuel price increase (NG and Coal) is assumed to follow up the same hypothesis in Chapter 5. Only metered heat tariff (two-part price) will be tested in the following analysis, because non-metered heat price (fixed charge per square metre heated floor space) can not reflect the income variation before and after adoption of a new BEE standards by the developer. The baseline two-tariff is based on the data from the World Bank Tianjin project experts report (World Bank, 2003) and author's interviews with Tianjin local experts in 2007 and 2008.

- Income effect

In this case, we assume that the inhabitant in Tianjin would catch-up with the current European thermal comfort level by 2020, the rhythm of catch-up is identical with the assumption in the modelling framework in Chapter 5. It is assumed that no price effect will have significant impact on consumer's decision on the demand for thermal comfort.

- Price effect

Or take-back or rebound effect, as discussed in detail in Appendix VII, this effect comes from the fact that improved energy efficiency in buildings give incentives for the consumers to use more energy since the price of energy service falls when efficiency improves in built houses. No empirical study on the Chinese consumer's behaviour in district heating with respect to the district heating price although Tianjin began implemented the heat price reform several years ago. The piloting project of the World Bank/GEF does not tell much about the consumers' behaviour since no systematic survey has been undertaken. The empirical data from literatures are used to estimate the price elasticity of Chinese residential consumer. However, this number should be used with carefulness since most empirical studies concerned the European and American households. No empirical study has been undertaken to investigate the price elasticity of demand for space heating in the Chinese buildings sector. However some studies have been conducted regarding price elasticity of residential electricity demand; most results showed that households are relatively inelastic with the electricity price (Lou and Shou, 2000).

We assume that Tianjin households' demand for heat is relatively elastic with respect to the real comfort price if the cost-reflective heat tariff is implemented— between -0.4 and -0.6 (these figures refers to previous studies in European and US cities), implying that a 10% fall in energy heating comfort price in terms of energy efficiency improvement would result in 5%-6% rebound in consumption. A simplistic way

¹⁰⁸ Recall that this tax is also applicable to the property developer and all categories of urban infrastructure development.

is to say that the engineering efficiency achieved by adopting SWE will be offset by 15%-25% due to rebound effect of consumer. Thus, the actual final demand were to decrease by 30-32% and 43%-47% in low-rise and high-rise buildings, respectively. In order to quantify the orders of magnitude, we exclude the convergence of thermal comfort. However, the increase of heat price will have negative impact on the demand for thermal comfort in this case. The ultimate final demand is dependent upon the extent to which the heat regulator will raise the heat price. Therefore, consumer's behaviour in this case is influenced by both income and price effect, the combination of the two effects implies that the thermal comfort will reach 22°C by 2025 in all households with the same price elasticity of demand for heating comfort. Detail of energy consumption is not presented here, the same technical model for heating consumption estimation as in chapters and is used.

Note that upgrading BEE to SWE will reduce both capital investment and operation costs in heating service distribution for the heat company. Our primary objective is to devise a pricing reform scheme such that the heat suppliers and households will both be better-off with the improvement in BEE. Strictly speaking, the consumer is still better-off even if the heat bill remain identical after and before upgrading the BEE standards, since the absolute thermal comfort is definitely improved and this is not capitalised in the benefit of consumer. Hot water consumption in residential buildings is excluded in the calculation since the BEE upgrading does not have direct impact on individual consumption on water heating, furthermore, centralised hot water distribution system is still very rare in the context of urban China. The programme for heat supplier is to keep its profits not less than the case where it does not invest in BEE in property development. Putting it formally,

Heat supplier is better-off (It invests) if and only if

$$\Pi'_c \geq \Pi_{C0} \quad (7.5)$$

s.t

$$B'_u \leq B_{U0} \quad (7.6)$$

Π_{C0} is the heat company's profit in baseline (Implementation of TJ-2004) and Π'_c is the heat company's profit after financing developer's extra cost of upgrading to SWE equivalent. And B'_u is the heat supply bill paid by the end users when SWE is implemented, B_{U0} is the energy bill paid by end users in baseline case. Heat company's profit Π_c is estimated by following equation

$$\Pi_C = \sum_{i=1}^{20} (P_{fi}A + P_{vi}E_{hi})(1 - T_b) - (C_{inf} + CBEE_i + \sum_{i=1}^{20} \frac{C_{mi} + C_{fi} + C_{ai}}{(1 + d)^i}) \quad (7.7)$$

where

- Π_C is the net profit of heat company
 P_{fi} is the fix part of heat price in year i
 P_{vi} is variable part of heat price in year i
 A is the total floor area of the residential zone
 E_{hi} is billed energy consumption in year i
 T_b is the aggregate tax rate of business of heat supply
 C_{inf} is the overnight cost of energy supply infrastructure(heat source+networks)
 $CBEE_i$ is the investment cost in BEE which is a dummy variable
 "0" is $TJ - 2004$; "1" is SWE
 C_{mi} is the maintenance costs(electricity, workforce,water) in year i
 C_{fi} is fuel cost in year i
 C_{ai} is capital depreciation cost in year i
 d is discount rate , 8%

Variation of total costs of heat supplier is driven by three factors, first, the improved BEE will allow him to reduce upfront investment in heat capacity and network infrastructure installation as well as subsequent maintenance costs. Second, he will see his revenue of heat sale decrease because the final consumers will consume less heat than before as a result of updated BEE even with assumption of rebound effect. This implies that the heat price must be reviewed by the regulatory authority and raised enough to make energy company better-off whilst the energy bill for final consumer is not greater than baseline case.

7.4.6.3 Without fuel- switching policy (coal-fired boilers)

In this case, heat supply company is assumed to use the same technology of supply regardless of whether it will finance the extra cost of BEE upgrading for the housing developer. With equation 7.7, we can easily find out that the total discounted profit for the heat company in baseline case is 4.77 million RMB, implying that proposed two-part tariff heat price can allow the heat company to equilibrate its budget by selling heat as a commodity. And if the heat company finances the BEE upgrading works, as expected the total discounted profit becomes much lower: 2.34 million RMB , nearly cut by 50% as a result of reduced heat being purchased by final consumers in this area.

In order to satisfy the equation 7.5 and 7.6 , and assuming the final consumers had a price elasticity of -0.4 (this is chosen arbitrarily) with respect of heat price, if can be estimated that if the regulatory authority (Tianjin District Heating Office and Tianjin Price Administration) is concerned with the fact that financial situation of heat company needs to be improved, the heat price must be raised up to between 16% and

21%, beyond which the final consumers will be worse-off. Clearly, there is a tradeoff of increase rate between the benefits of heat supplier and final consumers. If the price is allowed to increase 20%, the profit of heat company will reach 5.6 million RMB, whereas the consumers will be indifferent since they pay the same energy bill as before, however their comfort level is improved significantly.

This result has extremely important policy implications for the climate policy. Since the price increase will enable the heat company to create benefits without any loss of welfare of end-users who will always pay the same energy bill and with improved thermal comfort condition. The benefits could be served to finance the retrofitting of inefficient district boilers and adoption of new environmentally friendly supply technology such as NGCC or CCS etc. Most important point is that this is a Pareto efficient strategy.

7.4.7 Proposal 5— Public procurement, renewable obligation and green job creation

Besides the aforementioned economic and policy instruments, many other good practices can also be introduced in Chinese building sector such as public efficiency procurement and renewable obligation. Although residential and commercial buildings represent the largest energy savings potentials, energy consumption can be further reduced considerably by promoting efficient energy use in public sector. Many public buildings use low-cost inefficient appliances and equipment due to historical purchasing policies. Promoting energy efficient products in public sector can contribute to reduce wasted energy and saving money, as well as encouraging efficiency product market and creating green jobs. The model of Agreement on Government Procurement of the WTO can be used as reference model of efficient appliance purchasing in public and government buildings. European countries have valuable experiences with regard to public procurement for energy efficiency, for example, the Dutch government stipulated that by 2010, 100% of national public procurement will include sustainable procurement criteria and 50% for local and regional government (EC, 2008).

Likewise, the policies of thermal solar energy obligation in new residential buildings and the share of solar heating in the total building stock have been implemented in the building codes of Spain and Portugal since 2007. China could also introduce such regulation stipulating that all new residential and commercial buildings have obligation of installing solar thermal system provided that there is favourable climate conditions with available technologies.

The policies that encourage energy efficient, sustainable and low-carbon buildings will be decidedly powerful driver of BEE market and subsequently create green employment in the whole supply chain and industry of energy efficiency and renewable products. The total market potential for BEE is expected at 2000 billion Yuan (263 billion US\$ in 2005 price) in 2020 in the scenario of proactive implementation of BEE policy (CCN, 2008). With a total turnover is projected to reach 100 billion Yuan (13 billion US\$ in 2005 price) by 2020, more than two million jobs would be created in the renewable sector by 2020 if the objective of

the national renewable energy plan can be achieved (NDRC, 2007). BEE-related industries would be the backbone of environmentally friendly economic development in China.

7.4.8 Proposal 6 –“Obligation of energy savings of energy suppliers”

The previous proposals are focused on different instruments that give incentives to property developer and housing constructor to adopt higher efficiency standards and change the prevalence of techniques and practices in the market. This proposal integrates energy distributors and suppliers into the BEE scheme. As demonstrated in chapters 4 and 5, both supply-side technology options and buildings energy performance have significant impact on economics and environment. Yet energy companies have not been actively involved in BEE investment to share subsequent benefits. Based on European model, an obligatory energy efficiency scheme can be devised. It will consist of concrete energy efficiency objectives for energy suppliers with relevant “bonus-malus” mechanism. One of key component is to establish the “BEE white certificate”.

“White certificates of BEE”

A white certificate, also referred to as an *Energy Savings Certificate (ESC)*, *Energy Efficiency Credit (EEC)*, or *white tag*, is an instrument issued by an authorized body guaranteeing that a specified amount of energy savings has been achieved. Each certificate is a unique and traceable commodity carrying a property right over a certain amount of additional energy savings and guaranteeing that the benefit of these savings has not been accounted for elsewhere.

White certificates are documents certifying that a certain reduction of energy consumption has been attained. The certificates scheme can be devised under which emission permits will be allocated to utility companies (e.g. utilities). In most applications, the white certificates are tradable and combined with an obligation to achieve a certain target of energy savings for retail energy supplier or distributors. Under such a scheme, producers, suppliers or distributors of electricity, gas and oil are required to undertake energy efficiency measures for the final user that are consistent with a pre-defined percentage of their annual energy deliverance. If energy producers do not meet the mandated target for energy consumption they are required to pay a penalty. The white certificates are given to the producers whenever an amount of energy is saved whereupon the producer can use the certificate for their own target compliance or can be sold to (other) parties who cannot meet their targets. The tradability aspect enables to meet the objectives in a cost-effective way(EU WhiteCert: <http://www.euwhitcert.org>).

Some American States implemented further to decouple the profits from sales. Regulators forecast demand and allow utilities to charge a price that would recoup their costs and earn a fix return on the basis of the forecast. If demand turns out to be lower than expected, the regulators let the prices rise so that the

utility can make mandated profit. if it is higher, the regulators cuts prices to return the excess to consumers. Beside electricity and gas, California adopted a scheme called “decoupling plus” , which aims to make investments in energy efficiency more profitable for utilities than new power stations would be. Fees to finance the energy-saving measures are added to each bill, and utilities spend the money in pursuit of targets set by the regulator, the California Public Utility Commission(CPUC). The commission then calculates the savings from the investments, compared with the cost of new power plants. If a utility achieves between 85% and 100% of the target, it is allowed to keep 9% of these savings . If it exceeds the regulator’s target, it gets 12%, more than it would earn from building new infrastructure. Between 65% and 85%, it does not earn any return at all, and below 65%, it pays a fine for every kilowatt-hour by which it has fallen short. (The Economists, issue 8579).

7.4.9 Innovative Economic& institutional instruments

7.4.9.1 Energy pricing and BEE

Previous chapters demonstrated how building more efficient homes and offices in Chinese cities will be profitable for the whole society, either from environmental or economic point of view, since the discounted total cost of implementing more stringent building efficiency standards is lower than in the case of business as usual would even without consideration of carbon emission constraints.

Both economics theory and practical observations tell that higher energy prices will result in energy savings by more efficient energy consumption. To take an example, in the US, for every cent per kilowatt-hour by which prices exceed the national average, energy consumption drops by about 7% of the average. Conversely, consumers in Russia and Saudi Arabia will care much less in the fuel consumption since the gas and oil prices are heavily subsidised. Gas in Russia for domestic consumers is priced at only a quarter of international price. Drivers in Saudi Arabia have little incentive to scrimp on fuel when they pay barely a dollar a gasoline for it (The Economist Vol.387(8579), 2008). However, the problem of energy efficiency gap is related to a series of distortions and market failures that discourage investment in building energy efficiency.

7.4.9.2 Emission trading

A national CO₂ emission allowance scheme based on the cap-and-trade (CAT) principal may be devised in China. Under the framework of the scheme, the major energy-intensive industries, of which a large number are involved in building materials and appliances manufacturing (cement, steel, glass, concrete bloc, insulation materials, white appliances), as well as property developers and builders will be subject of quantitative CO₂ emissions caps, determined beforehand in the national allocation plan on the basis of *grandfathering*. Emissions permits can be traded openly at the national carbon exchange centre, and the

price of carbon would be dependent on both supply and demand dynamics. Thus industries will be obliged to move more quickly to improve production efficiency and curb the GHG emissions given a clear price signal about the environmental externalities associated with production process. Design of such a national carbon trading plan must involve comprehensive consultation with international experts across different areas (engineering, economics, finances, policy etc), taking into account the industrial development context. The targets of the carbon emission caps imposed on the industrials should be consistent with the development perspective of the building sector. The carbon trading market will be regulated by a special scrutinizing commission under the leadership of the National Development and Reform Commission (NDRC). Proposals for the allocation plan should be reviewed thoroughly with extensive diagnostic evaluation of sectoral and industry performance. A national carbon emissions trading market should be established to allow industries to buy or sell emission rights.

7.4.10 Implications of institutional innovation

Experiences in the OECD countries show that energy efficiency improvements since 1973 mainly resulted from ongoing technological progress and also response to rising energy prices (Geller *et al.*, 2006). However, energy prices for end users in China are often biased and subsidised by the government. Transparent and effective energy pricing mechanism must be set up to reflect the actual economic cost and internalise environmental externalities. Apart from government intervention and industry mobilisation in energy efficiency programmes in the building sector, private consumer-side initiatives should also be encouraged through energy pricing mechanism combined with fiscal incentives. Consumers will not be interested in energy efficiency programmes without a clear price signal or other market incentive. In China, both central and local government revenues still rely heavily on the tax base from public and private corporations, whereas individual income tax represents only a very small part of government revenue under the current fiscal regime. Tax instruments should be integrated into building efficiency policies to encourage urban households to choose high-efficiency building materials and appliances in residential buildings.

Similarly, land use and fiscal incentives could also be introduced into the property market to induce developers and/or constructors to build more efficient houses and adopt low-carbon technology; property developers should benefit from tax reductions or increased plot ratio in property development project provided that more efficient buildings and low-carbon or carbon-free energy supply is considered. The fiscal advantages of fixed capital investment, applicable in the 1990s could be duplicated into BEE programmes. In addition, property tax could be instituted according to clearly-defined energy efficiency criteria.

Box 7-2 Heat reform in Tianjin

Tianjin has the highest per-capita income among large cities in northern China after Beijing and Dalian, while unemployment and poverty rates are among the lowest in northern China (for example, in 2003 only 3.7 percent of Tianjin's population participated in the MLS program, compared to 11.1 percent in Changchun, 9.4 percent in Harbin and 4.9 percent in Taiyuan; (Zhang/Xu 2005). As of 2005, Tianjin was the most advanced large city in China in the development of heat reform. Over a period of three years, starting in 2000, responsibility for heat bill payment was shifted completely from work units to households. Employers in the public sector are required to provide heating fee compensation as a non wage benefit. Heat metreing with different technologies has been applied in demonstration projects since 1997 . The strengthened enforcement of energy efficiency standards for new residential buildings has led to the best compliance record among northern Chinese cities in the country. In addition, Tianjin tightened the energy efficiency requirements for new residential buildings in a new standard in 2005. s part of the ESMAP project "Heat Pricing and Billing Reform in China," Tianjin was chosen as the first case study for the development of a new tariff system. Local and national expert groups cooperated to design a practical tariff system based on the review of the operations of representative heating companies . The resulting two-part tariff covers, on average, the reasonable costs of heat supply in Tianjin, and includes taxes and a small profit margin. Heat tariffs continue to be uniform. Compared to the existing tariffs, the new tariffs are slightly higher due to increases in costs reflected in the tariffs. Variable and fixed part component have equal weight in the tariff, deviating slightly from the actual cost structure where variable costs have a 55 percent share. The Municipal Pricing Bureau has approved the methodology and the individual tariff components.

For the 2004 to 2005 heating season, after going through a formal tariff approval process, the Tianjin government raised the heat price for residential customers from 15.4 yuan/m² to 20 yuan/m². The tariff for non-residential consumers was increased to a unified level of 26 yuan/m², from previously 18.5 yuan/m² for public, 21 yuan/m² for enterprises and 24 yuan/m² for hotels. All approved tariff increases are below the levels calculated according to the new heat-price methodology. At the same time, government employees received additional compensation for the heat price increases. *Di bao* continue to receive a 50 percent discount, while the local government will pay the remainder. Starting in the 2005 to 2006 heating season, the two-part tariff was applied on an experimental basis for an area of two million m² in 12 residential communities. Residents were informed about this change by mail and published advertisements. All participating buildings comply with the 1995 buildings energy efficiency standard. The apartments are equipped with radiator valves and have either individual heat metres or heat cost allocators. Even though differences in heat consumption in the apartments of these new, well-insulated buildings should be fairly minimal (except for those triggered by the behaviour of residents), simple compensating factors are used for calculating the heating bill. Heat tariff and billing reform in Tianjin is part of the citywide heat reform plan to which Tianjin has committed as participant in the World Bank / GEF "Heat Reform and Building Energy Efficiency" project, which is currently under implementation. The project is also supporting several new housing projects in the application of both improved building energy efficiency standards and improved heat supply technologies.

Source: excerpted from (World Bank, 2008)

7.4.11 Proposal 7— public policy for BEE R&D and innovation and public-private partnership in buildings development promotion

R&D and Innovation play crucial rule in bringing in new BEE technologies and helping transformer buildings in China into high-efficient and low-carbon sector for longer term. Also, innovation in BEE technologies can contribute to sustainable economic growth, namely green GDP growth, since the R&D and development and deployment will necessarily create more job opportunities in the whole supply chain of buildings.

Although the outcomes of the modelling exercise in Chapter 4 and 5 show that the current building energy performance standards is below the optimal frontier and should be strengthened further by 20-50% depending on specific assumptions and policy targets, it is by no means that transformation may happen fortnightly without appropriate policies. Implementing new standards and technical codes with equivalent performance of the Best Available Practices (Swedish building code among others) or even the high-performing house such as German Passivhaus requires a fundamental transformation of the whole supply chain of buildings sector, from efficient materials and appliance manufacturing to the workforce training of new techniques of construction. The Swedish building standards cannot be simply be replicated and applied to the Chinese cities without any knowledge of specific context and buildings characteristics. An adoptive and adaptive procedure is certainly of necessity. Moreover, the builders and constructors will also have to learn how to adopt the updated standards in the construction. Furthermore, performing materials and appliances complying with the new efficiency standards should be able to be produced by the Chinese manufacturers, it does not make any sense to import all the state-of-the-art buildings components from abroad and simply assemble them in the Chinese cities although some technologies need to be imported from foreign countries in initial stage. Thus, the implementation of higher efficiency involves necessarily a progressive learning process. As economic theory suggests, the information diffusion among the different parties in economic activities will finally help all economic agents to adopt the new technology. however, no magical stick is available to make it happen spontaneously without any enabling environment and appropriate policies. And more importantly, the business model of buildings market and products supply need also fundamental change. Construction of high-efficiency buildings requires interactive and cooperative synergy between property developer, architect , engineer and builder otherwise the energy-performance target would not be achieved or with much high costs. Economic theory and empirical studies show that both adoption and adaptation of new technologies play substantial role in domestic innovation capacity buildings in order for developing countries to catch up with advanced countries in terms of economic growth and S1&T development. There are both constraints and opportunities for the Chinese buildings sector in the way towards high-efficiency and low-carbon transformation. Implementing higher efficiency buildings standards with international benchmark, China has actually already engaged to become leading players in many areas of such as aerospace, genetic science , biotechnology and new energy etc.

Currently, many private enterprises are unlikely to take the risk associated with longer time energy efficiency program R&D and only develop projects that are close to full commercialisation. Public-private partnerships can in this situation become a powerful tool to involve both government intervention in new technology RD&D, in particular related to the components of the building envelope and in heating system.

In addition to technical aspects, the innovation and technological knowledge also involves the capacity to learn from others and innovate. BEE policy is not simply dealing with learning of new technologies but also to form capacity of institutional innovation including regulatory instruments and market-based approaches. China has a relatively good policy framework for innovation in science and technology. the ratio of R&D investment to GDP in China grew from 0.6% in 1996 to 1.42% in 2004 as a result of proactive national strategy.

7.4.12 Proposal 8 –foster collaboration between property developer and energy supplier

Of all previous proposals of policy instruments aiming to give incentives to property developer and buildings constructor to improve aggressively building energy efficiency, it can be clearly found that the heat company can be both winner and loser. Winner, because the improved efficiency of buildings reduce the capacity addition cost which is heavily capital intensive investment. The improved BEE also reduce the operation costs and investment in infrastructure(reduced distribution network dimension). Loser, because the BEE programme means ex post reduced final demand for heat as a result of efficiency performance improvement. Thus, if the heat price remains unchanged regardless of the buildings efficiency and energy supply options, the heat company's financial situation may deteriorate compared with the business as usual scenario, while the final consumer is better-off Furthermore, the assumption of substituting NGCC to the baseline coal-fired boilers will increase the operation costs since gas price is much higher than coal. The financial profit generated by BEE improvement is not evenly redistributed since heat company is worse-off, implying that this is not Pareto improvements.

A fairer way to rebalance the interests of all the stakeholders is to raise the heat price in cost-reflective way. Therefore, the possible bilateral or multi-lateral arrangements can be reached between different stakeholders. The scheme can be designed as follows: The government or heat companies finance the upfront extra costs of BEE upgrading (including energy supply system, e.g. adopt NGCC or clean-coal technology). Then the DH regulator raises the final-consumption price to compensate the loss of quantity of heat distributed compared to BAU case while the energy bill for end users who consume DH service should not exceed what they pay before the introduction of the new scheme. Consequently all actors in this case are better-off compared to business-as-usual scenario. The main idea of this public/private partnership is that commercial bank or energy supplier (Heat Company) will finance the extra upfront costs of higher efficient houses, reducing the investment costs in generating capacity addition. Higher efficient buildings means reduced heat load and downsizing infrastructure (substation, distribution network etc) as well as reduced fuel consumption. Improved efficiency results in reduced energy consumption and better

thermal comfort for end-user. Heat supply company would see their revenue decreased accordingly if no energy pricing reform (higher energy price, rebound effect is excluded from consideration since empirical studies show that the price elasticity is quite low for district heating service, implying that basic thermal comfort should be maintained regardless of price) will be undertaken. Consequently, energy company equilibrates the financial balance by raising the price of heating services (selling fewer products at higher price). Both energy company and end-users will be better-off in this case. Apparently, house builders or property developer's interests remain intact or unchanged from cost perspective, but they are actually better-off in terms of long term competitiveness and innovation capacity. In other words, builders are financed by third-party to learn to adopt and adapt the new construction techniques and comprehensive buildings efficiency package design at no cost or even negative cost (since the extra cost is covered by third-party), thus the builders participating in these programmes are implementing a strategy in investment in human capital in terms of personnel capacity building and workforce training, but also anticipation of sectoral transformation in the long run. The technological innovation and adoption of new practices will make these pioneers firms more competitive in terms of capacity of adaptation and innovation. Moreover, the entry of numerous new enterprises into the efficiency buildings market will help drive down the costs of high and ultra-efficiency technologies due to economies of scale. In short, implementation of the combinatory policy instruments is Pareto improvement and economically efficient, thus should be adopted as the long term citywide urban development strategy. Because sooner or later, the BAT or low-carbon buildings technology will be generated and enforced as normal regulatory standards. Many buildings engineers have foreseen that zero consumption or even energy-producing buildings would be prevalent in the next decades. One who can anticipate this future trend of sectoral development and public policy will have prevalence of advanced technologies and become the market dominant or leader in a highly competitive built environment.

Addition, there is a potential gain for corporate reputation (immaterial assets) since higher-efficient and green buildings will add to developer's reputation, in the long-run builders are also better-off as the buildings values could be appreciated potentially.

7.5 Policy assessment

Systematic ex post evaluation of energy efficiency policies can reveal factors that explain success and failure related to policy design as well as the implementation (Hamerlink *et al.*, 2008). A comprehensive policy appraisal tool should allow for quantifying retrospective energy savings and market effect of advanced technology deployment.

One of difficulties in energy efficiency policy instruments design is related to the lack of sufficiently large number of systematic evaluation of implemented policies in various countries, whilst effective policy instruments evaluation is a key factor to enable the success of implementation. The *ex post* assessment approach is so far the mostly used method. However, this approach is likely to focus on "final effects" of

policy implemented according to past experiences in European countries, i.e. energy savings resulting from energy efficiency measures taken and cost-effectiveness (Harmelink et al., 2008). Interestingly, in the critique study of ex post assessment approach of policy instruments for EE, Harmelink et al. (2008) proposed an integrated assessment framework consisting of programming various steps of logic of intervention to achieve energy efficiency targets, based on the theory-based approach described in Blumstein et al. (2000). They argue that the defining factors in the process of design and implementation of policy instruments should include: 1) clear goal and a mandate for the implementing organisation; 2) the ability to balance and combine flexibility and continuity and 3) the involvement of stakeholders and 4) the capacity of adapt and integrate adjacent policies or develop consistent policy package. This approach is distinguished from conventional ex post method by two remarkable points; 1) it evaluates the whole policy implementation process instead of focusing on one specific final impact; 2) it develops indicators for each step in the implementation process to facilitate auto-correction in case of failure or deviation from designed objective; 3) it gives rise to insightful explanation about causality of success or failure of the underlying policy in lieu of simply demonstrating the effect. Similarly to diverse energy demand projection modelling approach, three families of ex post policy evaluation can be identified, characterised each by the method to proceed in Harmelink et al. (2008).

d) “Top-down” approach

this refers to assessment of aggregate indicators on energy consumption per sector and by use, the energy savings is obtained by subtracting the actual energy demand from hypothetical consumption which in turn, is derived by assuming that no explicit efficiency policy will be implemented throughout the period. However, this approach doesn't give enough insight in the impact of individual policies due to aggregated level in analysis

e) “econometric approach

This approach assesses the policy instruments by drawing up a list of factors that have potential impact on energy use in a sector and quantifying their impact through statistical method. This approach is quite relevant for evaluating general policy such as taxation policy, nevertheless, it does not provide explanation about why instruments performs as expected or poorly.

f) “bottom-up” approach

the bottom-up approach calculates the energy savings through the implementation of a specific type of energy efficiency improvement (e.g. insulation, lighting appliance...) determined in kWh term. However, it is often difficult to determine the effect of single-policy instruments due to the fact that energy efficiency improvement comes in general from policy package, the autonomous efficiency improvement cannot be clearly separated from policy-induced savings, and the impact of rebound effect, free riders cannot be identified in efficient way. Thus, a hybrid method combining the two approaches is more likely to address the shortcomings abovementioned.

g) Theory approach

This approach complements to all three evaluation method. it applies when a likely theory is drawn up on how the policy instrument should achieve its target impact in terms of energy efficiency. Logic model analysis, realistic evaluation theory, programme theory , theory-based approach and intervention theory are included in this approach.

7.6 Conclusion of the chapter

In this chapter, we discussed the major policy and economic instruments and policy portfolios to address the institutional barriers described in chapter six from both theoretical and implementation perspectives. It is shown that both market and non market barriers (inefficiency or welfare loss) can be corrected by relevant policy instruments (tax, subsidy, carbon financing incentives and land use policy) which aim to maximise the likelihood of adoption of efficiency measures in buildings sector by private actors.

We proposed four major policy and economic instruments in property market to accompany the implementation of higher building energy performance standards and new energy supply technologies. The first instrument is to establish link between property tax (LU transfer fee) and level of building performance adopted by property developers. The second instrument is related to introduction of carbon financing in form of programmatic CDM in buildings. it was agued that cost of financing would be around 15-16 US\$/t CO₂ avoided compared to baseline scenario (implement the current building code with conventional coal-fired district boilers). The third proposition concerns the flexible mechanism of urban land use regulation through adjustable plot ratio indicator. It was shown that if a property developer is committed to adopting SWE equivalent standard, PR adjustment needed is around 5% compared to the most common regulatory values. The last instrument propose creating third-person financing in BEE upgrading, a model of heat supply company financing was investigated. The heat price rise is necessary condition for the commitment of heat supply company. We found that end user's payoff will remain indifferent until the heat price rise exceeds 20% of current price level. Importantly, if the price is allowed to raise 20%, a considerable benefit will be generated for heat suppliers. This will allow the energy company to modernise their supply technology and prepare for fuel-switching actions in next step.

Nevertheless, success of implementation of these instruments requires necessarily coherent policy framework, institutional innovation will also be required in many cases. For example, it was argued that implementing programmatic CDM in buildings must incorporate local authority and public financial institutions otherwise the barriers of high transaction costs and uncertainty could not be overcome.

Finally, our analysis gives meaningful policy implications in the area of international climate negotiation. The Chinese policymakers could use international carbon financing tool as a means to promote energy supply decarbonisation and sectoral transformation in buildings, for example, through fuel-switching policy.

A key criterion of financing BEE in China by CDM is that the government should update higher-efficiency BEE standards and commits to generalising stricter standards in the next step. By using the economic analysis result in chapter 4 and 5, we found that the carbon price of the integrated strategy (Buildings switch) is four times lower than supply-only strategy (keep current building efficiency regulations and implement fuel-switching policy). Therefore, carbon financing is more likely to intervene in the former strategy to accompany energy supply decarbonisation eventually in cost-effective way compared with the pure-switching option.

References

- Adams, Gerard F., et al. 1968. "Undeveloped Land Prices During Urbanisation: A Micro-Empirical Study Over Time," *Review of Economics and Statistics* 50 (2): 248–258.
- Alchian, Armen A., and Demsetz, Harold (1972), "Production, Information Costs, and Economic Organisation", *American Economic Review* 62 (5), p777-795
- Asabeare, Paul K., and Peter F. Colwell. 1984. "Zoning and the Value of Urban Land," *Real Estate Issues* 8 (1): 22–27.
- Bailey, Martin J., Richard Muth, and Hugh O. Nourse. 1963. "A Regression Model for Real Estate Price Index Construction," *Journal of the American Statistical Association* 58 (304): 933–942.
- Blumstein, C., Goldstones, S., Lutzenhiser, L.(2000). A theory-based approach to market transformation. *Energy Policy*, Vol.28, 137-144.
- Clas-Otto Wene Experience and Learning Curves: Improving the understanding of Technology Diffusion. IPTS-Workshop "Clean Technologies diffusion modelling" Sevilla, 14 November 2003.
- Corporate Income Tax Law of the People's Republic of China. 2008. 中华人民共和国企业所得税法. Beijing.
- Dennis, K. 2006. The Compatibility of Economic Theory and Proactive Energy Efficiency Policy. *The Electricity Journal* Volume 19(7), Pages 58-73.
- Edited by William J. McCluskey. 2005. University of Ulster, Northern Ireland and Riël C.D. Franzsen, University of South Africa, South Africa Land Value Taxation.
- EU Directorate-General for Energy and Transport (2002).
http://ec.europa.eu/energy/demand/legislation/buildings_en.htm
- Flyvbjerg, Bent and Cowi, 2004, Procedures for Dealing with Optimism Bias in Transport Planning: Guidance Document (London: UK Department for Transport, June 2004).
- Fukuyama, Francis, Trust: The Social Virtues and the Creation of Prosperity, Hamish Hamilton: London, 1995
- Glaeser, E., J. Schultz and B. Ward. 2006. Regulation and the Rise of Housing Prices in Greater Boston.
- Granovetter, Mark, 1985, "Economic Action and Social Structure: The Problem of Embeddedness", *American Journal of Sociology* 91:3, p481-510
- Green, J. R. and N. L. Stokey. 1983. "A Comparison of Tournaments and Contracts", *Journal of Political Economy*, 91, 349-364.
- Gurria, A. Tackling Climate Change. *OECD Observer*. No.266, March 2008.
- Hawkins, J., David Blaine, Daniel Nielson, and Tommy Tiernan, 2006. Delegation and Agency in International Organisations. Cambridge University Press.
- Howarth, R. and Andersson, B. 1993. Market barriers to energy efficiency. *Energy Economics* Volume 15, Issue 4, Pages 262-272
- Howarth, R. 1997. Energy efficiency and economic growth, *Contemporary Economic Policy* 15(4) , pp. 1–9.

- Howarth, R., B.M. Haddad and B. Paton.2000. The economics of energy efficiency: insights from voluntary participation programs, *Energy Policy* 28 (6-7), pp. 477–486.
- IEA (2000), *Experience Curves for Energy Technology Policy*, International Energy Agency, OECD/IEA, Paris.
- IEA (2003), *Creating Markets for Energy Technologies*, International Energy Agency, OECD/IEA, Paris.
- IEA (2007a) Mind the Gap- Quantifying Principal-Agent Problems in Energy Efficiency.
- IEA(2007b). Energy Use in the New Millennium—Trends in IEA Countries. OECD/IEA, Paris.
- Jaffe, A. and Stavins, R. 1994. The energy-efficiency gap - What does it mean?, in *Energy Policy*, Vol. 22 (10) 804-810.
- Keohane, N. Revesz, R., Stavins, R.1993. The choice of regulatory instruments in environmental policy. Harvard Environmental Law Review, volume 22, issue 2, pages 313-367
- Khazzoom, 1987 D.J. Khazzoom, Energy saving resulting from the adoption of more efficient appliances, *Energy Journal* 8 (1987), pp. 85–89.
- Kiewiet, D. Roderick and Matthew D. McCubbins, 1991. The Logic of Delegation: Congressional Parties and the Appropriations Process, University of Chicago Press.
- Laffont, J and Martimort, D. 2001. The Theory of Incentives: The Principal-Agent Model. Princeton University Press.
- Laffont, J. and Tirole, J. 1993. A theory of Incentives in Procurement and Regulation . MIT Press.
- Laponche, B., Jamet, B., Colombier, M., Attali, S. 1997. Energy Efficiency for a Sustainable World. ICE Paris.
- Lin, G.2006. Research On Current Real Estate Taxation System and Management 当前我国房地产税收制度与税收管理问题研究. Ms Thesis. Xiamen University.
- Lorna A. Greening, David L. Greene and Carmen Difiglio. Energy efficiency and consumption — the rebound effect — a survey.
- Lou, Q. and Shou, J. 2001. Analysis of household electricity demand and price elasticity.(居民用电需求及其价格弹性分析). Electricity Consumption, Vol(11).
- McCluskey , W. and Franzsen, R.2005. Land Value Taxation: An Applied Analysis. 263 p
- Meier, A. 1996. Toward More Efficient Energy Use Through Demand-Side Management. Berkeley, University Of California.
- Milgrom, Paul, and Roberts, John, Economics, Organisation and Management 1992, London: Prentice-Hall
- Mirjam Harmelink , Lars Nilsson and Robert Harmsen 2008. Theory-based policy evaluation of 20 energy efficiency instruments. *Energy Efficiency*. Volume 1, Number 2 / May, 2008 ; Pages131-148
- Murray, B., Newll, R., Pizer, W. 2008. Balancing Cost and Emissions Certainty : an allowance reserve for cap-and-trade. NBER Working Paper.
- Murtishaw, S. and Sathaye, J. 2006. Quantifying the Effect of the Principal-Agent Problem on US Residential Energy Use. Lawrence Berkeley National Laboratory, Berkeley, California.
- Myerson, R. 2008. Perspective on Mechanism Design in Economy Theory. *American Economic Review* 98:3, 586-603. Nobel Prize Lecture 2007.
- Newell, R., Jaffe,A., Stavins, R. The Induced Innovation Hypothesis and Energy-saving technological change. *The Quarterly Journal of Economics*, 114:3 (August 1999), pp. 941–975.
- Nikkinen, Jussi and Sahlström, Petri (2004): Does agency theory provide a general framework for audit pricing? *International Journal of Auditing*, 8: November, 253-262.
- Pollakowski, Henry O., and Susan M. Wachter. 1990. "The Effects of Land-Use Constraints on Housing Prices," *Land Economics* 66 (3): 315–324.
- Prendergast, Canice, "The Provision of Incentives in Firms", *Journal of Economic Literature* 37 (March 1999), 7-63.
- Production, Information Costs, and Economic Organisation", *American Economic Review* 62 (5), p777-795

- Provisional regulation on urban real estate taxation. 中华人民共和国城市房地产税暂行条例. 1951.
- Quigley, J. Transactions Costs and Housing Markets. *Housing Economics and Public Policy*, edited by A. O'Sullivan and K. Gibb. Blackwell Publishing, 2002: 56-64.
- Quigley, John M. and Steven Raphael (2004). "Regulation and the High Cost of Housing in California." *Berkeley Program on Housing and Urban Policy Working Paper W04-008*.
- Robert L. Sexton; Philip E. Graves; Dwight R. Lee. The Short- and Long-Run Marginal Cost Curve: A Pedagogical Note *The Journal of Economic Education*, Vol. 24, No. 1. (Winter, 1993), pp. 34-37.
- Rosen, S. 1986. "Prizes and Incentives in Elimination Tournaments", *American Economic Review*, 76, 4, 701-715.
- Rose, Louis A. 1989. "Urban Land Supply: Natural and Contrived Restrictions," *Journal of Urban Economics* 25 (3): 325-345.
- Rueter, Frederick J. 1973. "Externalities in Urban Property Markets: An Empirical Test of the Zoning Ordinance of Pittsburgh," *Journal of Law and Economics* 16 (2): 313-350.
- Sappington, David E.M., "Incentives in Principal-Agent Relationships", *Journal of Economic Perspectives* 5:2 (Spring 1991), 45-66
- Schwartz, Seymour I., David E. Hansen, and Richard Green. 1984. "The Effect of Growth Management on the Production of Moderate Priced Housing," *Land Economics* 60 (1): 110-114.
- Smith, K. 1997. Real estate taxes in USA, France, and Japan. IRED. <http://www.ired.com/news/tax/>
- Stiglitz, Joseph E. (1987). "principal and agent, The New Palgrave: A Dictionary of Economics, v. 3, pp. 966-71. The Economist Vol.387(8579), 2008.
- United Nations. 2009. China's Progress Towards the Millennium Development Goals (中国实施千年发展目标进展情况报告).
- Van Hook, E. 1993. Conservation Through Cooperation: The Collaborative Planning Process for Utility Conservation and Load Management. *The Yale Law Journal*, Vol. 102(5): 1235-1263.
- Wang, X.. Property tax only scratches the surface vis à vis the housing price hikes. 开征物业税治标不治本. China Economic Times. 2004.
- Weitzman, M. 1974. Prices vs Quantities, *Rev.Econom.Stud.* 41, 477-491 (1974).
- Wigley, T.R., Richels, R., Edmonds, J., 1996. Economic and environmental choices in the stabilisation of atmospheric CO2 concentrations. *Nature* 359, 240.
- Williamson, Oliver E., *Markets and Hierarchies: Analysis and Antitrust Implications*, NY: The Free Press, 1975.
- Xie, Z. 2007. Speech of Xie Zhenhua on the Bali Conference of Parties (COP 14), Bali, Indonesia; 12-December 2007.
- Youngman, J. and Malme, H. *An International Survey of Taxes on Land and Buildings*. 1994.
- Zhang, L. 2007. Analysis Report on Building Energy Efficiency in China. China Buildings Industry Press.

Chapter 8 Conclusion

This research investigated the role of the quality of large-scale infrastructure in China in energy supply security, climate change mitigation and sustainable socioeconomic development in China over the next decades. Buildings have been selected as one of the most illustrative example of long lifetime infrastructure. First, most more than 20 billion m² of buildings are expected to be constructed in China's urban area by 2020 driven by fast-growing urbanisation. Second, improved living standard in China may drive up the household's demand for various energy services, thus huge potential for increase in energy consumption in buildings sector needs to be addressed effectively and smartly. Third, many buildings in the north of China are still being built in inefficient way, although energy efficiency can be improved significantly without necessarily much higher first investment using the techniques of construction available. The failure in BEE is related more to the institutions than to the lack of technology. Incoherent policy framework, weakness and or lack of capacity, information dissymmetry, prevalence of principal-agent problem, and inconsistent energy pricing and regulations are all intertwined to undermine the penetration of BEE in the market.

Failing in addressing BEE fast and effectively in China will result in disastrous carbon lock-in for several decades. Based on a bottom-up modelling exercise, we discussed different scenarios of adoption of different levels of BEE standards and energy supply system prospects. The associated energy, environment and economic implications are then discussed based on the outcome. An institutional analysis is then undertaken to investigate the major barriers to fast deployment of efficiency technologies in the Chinese building sector, some specific policy and economic instruments were then proposed to address these market and non market failures in order to attain the optimal objectives defined in chapter 4 and 5. However, it is argued that implementing these policies requires a coherent institutional framework otherwise effectiveness and relevance of policies may be limited.

Chapter 1 reviewed the existing literature on scenario analyses of energy demand and CO₂ emission in China. It also discussed different energy modelling methodologies in these studies. The fundamental question arises about what optimal decision on BEE and what are the policy implications in terms of instruments design and institutional reform and transformation in order to accompany the China's buildings sector towards a sustainable development model.

Chapter 2 explained the origin of the fundamental questions of the research on the basis of comprehensive analysis of the existing literature on long-term energy demand in China's building sector. It demonstrated the limitation in previous energy economic analysis because the optimal energy efficiency technology choices in buildings and the relevant energy supply system development options have not been not specified.

Chapter 3 explained the principal methodology employed in this thesis and the modelling framework. It presented the logic and variables introduced in the LEAP model.

Chapter 4 analysed the optimal choice of building energy efficiency (BEE) standard and appropriate energy supply system in the context of district heating services in a virtually new development zone in Chinese city. The analyses strongly indicate that the current BEE standard implemented in the Chinese cities is not an optimal choice and should be tightened immediately in order to approach the optimal frontier and achieve a better energy and environmental performance while reducing the associated social costs. Some important remarks can be drawn based on the modelling results of building efficiency strategy in new construction.

- The current Chinese building energy efficiency standard (TJ-97 is a local equivalent to the national 95 building code that aims at 50% of heating energy consumption reduction) is the most costly scenario and must be updated in all northern zones
- The improvement in BEE standards (represented by TJ-2004) is not sufficient
- Without consideration of carbon price for CO₂ emissions , the optimal level of building energy efficiency would be RT 2005, in other words, the current building code could be improved by 30% with enhanced insulation and ventilation system.
- Strikingly, the global costs will be lower if China adopts the most stringent BEE standards (Swedish code equivalent) in buildings even without any consideration of carbon price, implying that CO₂ emissions mitigation is negative if the current national buildings codes is updated to the reference level of the world's best practiced techniques (SWE equivalent standards)
- Energy supply decarbonisation strategy should integrate buildings energy performance improvement scheme, the cost of CO₂ mitigation may be three times costlier than otherwise.

The modelling results suggest that the French code *RT-2005* (30% improvement in terms of building envelope performance and overall efficiency compared to the current building code) allows for the lowest net present value of overall life cycle costs thus should be adopted by BEE policy maker in China. By contrast, energy performance equivalent to the Swedish code (Best Available Technology) is preferred in the case of explicit carbon emission restriction if and only if the marginal cost of carbon emission (carbon tax price) is sufficiently high (25-35 US\$/t CO₂ by 2020). The shadow price which could potentially enable the Chinese constructors to adopt much more energy-efficient building standards is of the same orders of the current CO₂ emission allowance price in the EU-ETS 2008-2012 CO₂ price¹⁰⁹ that averages about 30 US\$/tCO₂. importantly, the financial gain generated from building energy performance will allow the Chinese energy sector to increase their financial capacity in investing low-carbon energy supply technologies such as NGCC and CCS. A policy portfolio combining property taxation, land use flexibility and

¹⁰⁹ The dramatic drop in allowance price in May 2007 is mainly due to over-estimation of emission level in the National Allocation Plan (NAP) in the first period of EU-ETS. This technical *incident* is unlikely to happen again in the future.

Kyoto CDM financing mechanism can contribute to removing the market barriers to BEE and dealing with climate change in cost-effective way. More importantly, we show that appropriate institutional framework combining regulatory measures and economic incentives is the linchpin upon which the BEE measures uptake probability will depend in buildings in China for the coming decades.

Without integrating buildings energy efficiency into a comprehensive energy policy package, the fuel-switching policy (from coal to natural gas) in the urban district heating system can hardly be justified for this policy implies significant increase in social costs, the present value of overall cost of natural gas-fired district heating system is 30-35% higher than the coal-fired CHP with desulphurisation process, depending on building efficiency options. The French *RT2005* equivalent building energy performance combined with a properly designed district small coal CHP (20 t/h +2MWe) can be viewed as the best choice of BEE standard and heat supply infrastructure given the underlying assumptions in the model.

Chapter 5 employs a bottom-up approach to modelling the scenarios of different BEE standards adoption in the city of Tianjin and investigating both environmental and economic implications over the period 2005-2030. Contrarily to chapter 4 which assesses the decision strategy of one-time investment on BEE and supply technology today, a dynamic housing stock was investigated in this chapter. The economic implications of both retrofitting in existing houses and adoption of different BEE standards in new construction have been quantified. Similar to the outcome in chapter 4, the modelling results show that the current BEE regulation is not the optimal choice from social costs viewpoint. The LC(high energy performance scenario) is preferable for the decision makers in the future since it will allow for the least-cost operation. However, if a policy maker need to make a decision today, the total discount rate will play a critical role in outcome preference ordering. Based on the principle of minimised discounted cumulative cost, the SWE (equivalent to Swedish performance) and RT-2005 (equivalent to French efficiency) are the optimal choices in most scenarios depending upon the discount rate and the assumption on carbon price imposed on energy use-related emissions. The current national standard is a suboptimal choice in most cases and needs to be upgraded as soon as possible. The improvement in efficiency requirements specified in the TJ-2004 standard is still insufficient to allow attaining the optimal objective. Scenarios of failure or partial implementation of BEE performance standards were also investigated.

In addition, we also investigated alternative energy supply options such as CCS and fuel switching policies from decarbonising energy supply perspective. Introduction and deployment of these technologies will necessitate considerable financial resources since they will still remain fairly costly to implement. Strikingly, the sequential annual cost analysis shows that if the local authority decides to upgrade the current TJ2004 to RT2005 or SWE equivalent level, finance appears not to be a fundamental barrier to implement the higher efficiency standard since considerable revenue can be created, the reduced costs will largely compensate the upfront extra costs associated with performing buildings construction. Nonetheless, an efficient and effective institutional organisation is the precondition of realising the benefits. It must be

pointed out that efficient buildings scenarios have more flexibility in facilitating the technological transition in energy supply, contrarily to the sharp increase in costs in the starting year of new technology penetration in the less efficient scenarios. In the long run, efficient buildings can help achieve the investment strategy which allows smooth sectoral transformation toward gradual decarbonisation of the city's coal-fired supply system without significant impact on financial resources allocation. The implicit carbon price that will give incentives for the local authority to opt for new supply technology is significantly lower if the buildings energy performance is higher otherwise the cost of abatement would be prohibitive. Our calculation reveals that the cost of carbon emission abatement of CCS options is around 20 and 50 US \$/tCO_{2-eq} reduced in 2030 if the SWE and RT05 BEE standards are implemented in current buildings stock; whereas the cost would reach nearly 130 US\$/tCO_{2-eq} if the city fails to implement current BEE regulations in part of new construction. Moreover, the fuel-switching policy is likely to result in high carbon emissions abatement cost despite the fact that it is technically easier than CCS. In other words, the investment in CCS is more cost-effective in terms of carbon reduction than fuel-switching policy. Furthermore, we compared the current Municipal heating plan and appropriately designed energy supply capacity addition; it is found that the "plan follow-up" scenario is more costly than optimised energy supply capacity.

The quantitative examinations of modelling confirm that it is judicious to update the current BEE mandatory requirements to minimise the latent demand rise and relevant social costs in the future. The option value of wait to see strategy to deal with the uncertainty is particularly risky in the sense that the whole infrastructure could be trapped in irreversible process of lock-in dilemma and would entail enormous difficulty in retrofitting the historical energy-greedy urban heritage under a cost and institutional constraints even tougher than today. The city would find itself in extreme difficult situation about the capacity in financing by new and low-carbon supply technologies (CCS, fuel switching or renewable heating) with a large quantity of historical low efficient buildings stock in the future. More specifically, retrofitting inefficient houses constructed historically will be very costly and contribute to marginal reduction in energy demand and carbon emissions reduction due to high inertia characteristics of buildings. In contrast, it will be much easier for local authority to find financial resources by allocating the "benefits" offered by cumulative reduction in operation costs with a high efficient building stock.

Chapter 6 and 7 analysed different institutional structure in the property and energy market. The procedure or property development and how to intervene on the issues of BEE was described. Some inconsistency has been identified as the property market is extremely fragmented. Also the self interest maximisation between central and local government in the fiscal policies also undermines to some extent the uptake of faster and effective implementation of BEE. We also discussed how to use policy instruments to address these barriers in theory and in practice.

Based on the institutional analysis, we proposed some economic and policy instruments as supplements to the traditional regulatory instruments:

carbon credits financing , we proposed to introduce the Kyoto CDM financing into the Chinese BEE market, it is shown that a carbon price of around US\$ 16 per tons of CO₂ avoided could give the Chinese local government (Here example is applicable to Tianjin) by updating the current BEE standards to the equivalent Swedish performance requirement. However, a programmatic CDM should be organised to lower the transaction cost and simplify the implementation procedure. The Chinese local authority could use the CDM as a springboard to anticipate generalisation of higher efficiency in all new buildings in the future. During the transition period, builders willing to adopt the SWE could be financed by the government specific funds and sell the carbon credits in turn. This would speed up the new techniques learning and shift market to low-carbon buildings driven by economies of scale.

Local government could use the land use regulation as a non monetary incentive to property developer to build much higher efficiency house. Our analysis suggests that a rational builder will have incentives to update to SWE standard if 5% or more increase in plot ratio could be granted by the urban planning authority, the house selling price remain intact will be imposed as a prerequisite . This is also a win-win policy in the sense that the government doesn't need to subsidy the efficiency programme, property developer will not pass on the extra cost to the final consumer since the costs can be sufficiently covered by the increased floor area to be commercialised in the property market.

Pricing reform is prerequisite to implement other any policy and economic instruments. A priori, heat company would be worse-off if the non metred heat tariff is still practiced regardless of the actual efficiency performance of buildings. The calculation results shows that upgrading the current BEE to the state-of-the-art performance requirements of buildings (Swedish standard) would make the heat supply company worse-off if no pricing reform will be undertaken. To give heat company incentives to take part in the BEE financing programme, heat price should be raised at least 16% compared to the current two-part tariff. However, a pricing increase ceiling should also be defined in order to protect the end users' interests. Our analysis shows that if increase in the heat price is lower than 21%, then the end users will remain indifferent since he (she) does not pay more for energy bill while the indoor thermal condition is significantly improved.

Lastly, successful implementation of BEE needs a comprehensive approach that integrated all the actors in the whole supply chain of buildings. The Chinese government should formulate appropriate policy to encourage the R&D of innovation in BEE-related products and techniques, as well as the capacity building in the knowledge of BEE and energy management in urban infrastructure. In the long run, this will enhance the competitiveness of Chinese firms in the area of construction and energy in a globalised world.

Future research on the optimisation of heat supply system and BEE standard is expected to be encouraged further regarding the R&D of renewable energy and urban household wastes in district heating supply. They could be used to substitute partly the fuel combustion in the district coal-fired CHPs to address the double challenge of energy supply security and carbon emission mitigation. Biomass co-firing and refuse incineration for heat and power generation have been recognised as promising technologies to CO₂ emission mitigation in power sector. However, as our analysis shows, further improvement of BEE standard in residential buildings is the most cost-effective option and should be regarded as the primary priority since it allows for more efficient energy use with negative costs.

The modelling results per se convey meaningful policy implications in terms of timing and costs of actions on buildings energy efficiency and energy supply options. Based on a concrete example of the city of Tianjin, we showed that the future costs of slow adoption of BEE measures or inaction would be far costlier than immediate adoption of high efficiency standards and performance requirement. However, the market can hardly transform itself to the ideal development path without appropriate policy and institutional framework since fall short of sound policies will result in inefficient resources allocations. Both the modelling outcome and market analysis imply that considerable investment is necessary in the Chinese buildings sector for the coming decades, in terms of social capital investment. This necessitates long-term strategy of energy efficiency and climate change adaptation, innovation and R&D for the Chinese government and construction business. The central question then arises about how can we achieve the investment to the expected extent?

The institutional and policy analyses in chapter 6 and 7 show that various economic tools and policy instruments or policy mix are expected to be implemented in the buildings market to facilitate the technological transformation including R&D and adoption of innovative practices and techniques. Although many high efficiency and ultra-performing buildings technologies exist already, the large-scale deployment requires strong public policy and enabling environment.

No silver bullet climate policies can address the technical and institutional barriers to BEE implementation and upgrading. We proposed different economic and policy instruments in property market development aiming at addressing these barriers. It was shown that regulatory instruments such as land use can be complemented by economic instruments such as property tax and carbon financing tools in order to achieve the optimal level of BEE effectively and efficiently. More importantly, we investigated the extent to which the DH pricing reform should be undertaken to give heat suppliers incentives to participate proactively in improving energy efficiency in buildings and also allow them to invest in high-efficiency supply technology including the low-carbon or carbon free generation technologies such as NGCC, biomass co-firing and CCS and so forth.

From the long-term economic development and welfare improvement perspectives, the incentives given to the property developers and energy supply companies should be conceived as a means for the public authorities, the local governments among others, to define the long-term energy policy and urban development planning. The programmatic CDM and efficiency housing procurement programme proposals in chapter 7 are based on the argument that all economic incentives should be coupled with dynamics of continuous development of energy efficiency and governance amelioration in the property and energy markets.

Furthermore, we also argued that the BEE policy should be integrated into a comprehensive policy framework of urban development in China to facilitate both technological and institutional transformation of buildings sector in China. The whole supply chain of buildings needs fundamental revolution. Coherent public policies regarding the R&D and innovation and sectoral capacity building in terms of personnel training in high efficiency infrastructure. Apart from hard investment (materials, techniques, appliances & equipment etc), the soft capacity (education and training of qualified engineers , architect, urban planner and construction workforce) of EE management should receive neck –and-neck attention in terms of human capital investment.

From socioeconomic development and competitiveness enhancement of the Chinese economy, government policies should be designed to allow accelerating institutional transformation in energy efficiency financing and investment.

The BEE policy should not refrain itself from interacting with other policy levers addressing different economic sectors in the city, for example the dynamics between residential and transport sectors. Comprehensive approach to tackling issues on urban energy and climate change must be adopted in the process of policy-making. Relevant development of economy-wide or sectoral decarbonisation experimentation programme such as citywide or regional low-carbon zones (LCZs) can be established , based on the model of the Special Economic Zones (SEZs) --geographical regions with more liberal economic laws than the rest of the country played a vital role in the 1980.

LCZs would aim to stimulate transformational regional political leadership, endorsed at the national level, to create an enabling environment for large-scale innovative low carbon private and public investment. China with a laboratory to shape its participation in the global market economy, so LCZs would pioneer approaches to decarbonisation compatible with Chinese institutions and development approaches (Chatham House and E3G, 2008). LCZs could commit to accelerated targets for upgrading buildings efficiency and promoting renewable energies. LCZs could also become the location for the Carbon Capture and Storage demonstration plant supplying electricity and heat. Eco-design or low-carbon buildings Directives could also be implemented by setting high-standard of efficiency and low carbon footprint. It could also offer technical assistance in developing carbon labelling schemes for buildings materials manufacturing and supply .

To conclude , policies aiming at encouraging enhanced buildings energy efficiency could be integrated into a global energy-climate policy packet by the Chinese policymakers at different political levels. The economic and policy instruments introduced in property and energy sectors to improve BEE performance should not be designed as an incentive for the local government to hold back new standards and continuous building energy performance improvement. It was argued that improving BEE aggressively in the buildings sector is by no means easy and costless, economic efficiency judgement is somewhat subjective and there is no unique assessment criterion. More importantly, BEE implementation also requires active co-operation between the government, developers and other stakeholders in the form of public-private or private-private partnership to achieve a global target. As such, the subsidy attributed to high-efficiency buildings developers can be used as a provisional incentive and transitional tool that allow the developers to accelerate their learning and innovation capacity of efficiency techniques, subsidy is granted during the preparatory process before the introduction of the next generation new building efficiency standards. In other words, builders are eligible for the subsidy for a certain period by adopting higher efficiency standards until the latter become mandatory for all new construction eventually. The subsidy is thus conceived as a component of facilitator of the public policy for improvement in efficiency standards, otherwise the construction market will not move towards high efficiency and low-carbon .

In summary, a holistic approach should be adopted by integrating the quality of energy infrastructure, building design and efficiency optimisation and public policies to remove the barriers to implementation of energy efficiency in buildings. Establishing long-term BEE objective with appropriate economic and institutional scheme is of critical importance in the policy making. A dynamic link needs to be created to incentivise both upstream and downstream actors within the whole building supply chain to move towards low-carbon buildings technologies. Capital flow needs to be channelled into LC buildings financing through policy induction.

Limitations and perspective of research

This research is mainly focused on the residential buildings heating consumption performance in the northern part of China. The cooling issue in the transition climate zone(such as Shanghai) has only been analysed qualitatively and no modelling exercise has been employed to investigate what will be the best path to BEE development in this region as we have done for the city of Tianjin . Huge potentials for energy efficiency improvement remain untapped in China's transition zone and southern provinces where electricity-based space cooling becomes an extremely issue. Air condition accounts for nearly 40% of peak load in many southern provinces during summer. More research will be concentrated on these problematic in the next step of works.

From methodological point of view, for the research agenda ahead, one of the main aspects to be addressed is about equilibrium modelling approach which can be used to quantify the climate consequences of different energy demand scenarios in buildings in China from economist's perspective.

Policies regarding the building energy efficiency will focus on creation of specific financing mechanisms in favour of extensive partnership between public institutions and private actors (industry, consumers) to foster the large-scale diffusion and deployment of energy-efficient, low-carbon technologies in the building sector in China. An innovative institutional framework is required to scale up BEE deployment across the nation, a national BEE market should be established by linking low-carbon or zero-carbon buildings programme with international carbon market to diversify the investment portfolios with regard to BEE financing. Lastly, wide collaboration and consensus on BEE between different actors in both public and private sectors are critically need to ensure viability, availability and performance of the long-term BEE and GHG mitigation in China. In this regard, more attention must be paid to theory of organisation and incentives.

Appendix

Appendix I. Appliance consumption analysis methodology in LEAP Model

For a given technology branch, say the household appliance energy consumption estimation, the stock analysis is conducted in LEAP. The model incorporates selected technologies and related data including stock, energy intensity and saturation levels, to reach the energy consumption levels envisioned. The end uses were further broken out by technologies; TV, Refrigerator, Air conditioning, PC, DVD, Washing machine are broken out into two efficiency levels namely conventional and performing technology based on their relevant energy efficiency, for example, room air-conditioner (RAC) is classified into two efficiency technology by their seasonal energy efficiency ratio (EER)¹¹⁰. Higher is value, more efficient is the appliance. In this method, energy consumption is estimated based on analyzing the current and projected future stocks of energy-using devices, and the annual energy intensity of each device. LEAP then calculates the stock average energy intensity and across all vintages and hence, ultimately, the overall level of energy consumption. The stock analysis uses the following equations in the stock analysis

$$Stock_{t,y,v} = Sales_{t,y} * Survival_{t,y-v}$$

$$Stock_{t,y} = \sum_{v=0..Y} Stock_{y,v,t}$$

where

t is the type of technology (i.e. the technology branch)

v is the vintage (i.e. the year when the technology was added)

y is the calendar year

$Sales$ is the number of appliances added in a particular year

$Stock$ is the number of devices existing in a particular year

$Survival$ is the fraction of devices surviving after a number of years which reflects the appliance's lifecycle profile

V is the number of vintage years

The energy intensity of the whole appliance stock is then estimated using following methodology :

$Degradation$ is a factor representing the change in energy intensity as a technology ages. It equals 1 when $y=v$.

Energy consumption of the total stock in year y can be easily estimated by using the following equation

$$EnergyConsumption_{t,y,v} = Stock_{t,y} * EnergyIntensity_{t,y-v}$$

and the subsequent energy-related CO₂ emission is then estimated by multiplying the energy consumption by the emission factor of fuel consumed.

It is assumed that two types of technologies will coexist on appliance market during the modelling period. Namely conventional and efficient technology. The penetration rate of the latter is assumed to be much higher in alternative scenario than in the baseline.

¹¹⁰ EER of most of RAC on retail market is in the range 2.3 to 2.6.

Air condition consumption

Final energy intensity of RAC is determined by consumption hours and the average EER. The table below compares the impact of two types of technology.

Variable: Air condition: Activity Level (KW/KW)

Scenario: Baseline scenario TJ2004

Branch: Key\Air condition\EER

Region: Tianjin

	2005	2010	2015	2020	2025
conventional	2.3	2.4	2.6	2.7	3
EE	2.6	3	3.4	3.8	4

Variable: Electricity: Marginal Final
Energy Intensity (Kilowatt-Hour per
Device)

Scenario: Baseline scenario TJ2004

Branch: Demand\Cooling\RAC

Region: Tianjin

	2005	2010	2015	2020	2025	2030
conventional	365.2	382.1	382.3	396.7	383	408.3
EE	323.1	305.7	292.4	281.8	287	306.3

Appendix II. Complete modelling results of city modelling

I. SYS2 Supply options

Emission scenarios

Table A- 1 yearly Emission Scenarios comparison

Year-by-year emission In million metric tonne CO₂.eq

emission in Mt	2005	2010	2020	2030
<i>TJ-2004</i>	18.36	21.32	33.39	35.19
<i>RT2005</i>	18.36	20.38	30.50	31.71
<i>SWE</i>	18.36	20.13	26.82	26.98
<i>A1</i>	18.36	21.39	31.72	31.79
<i>A2</i>	18.36	21.32	30.57	30.19
<i>A2+CCS</i>	18.36	21.30	11.10	9.94
<i>A2+Gas Switching</i>	18.36	20.83	25.00	25.52
<i>A3</i>	18.36	18.05	18.90	18.12
<i>PartCom with Re</i>	18.36	23.69	37.88	38.88
<i>PartCom without Re</i>	18.36	24.02	40.05	40.87
<i>Applmp</i>	18.36	21.39	33.66	35.63
<i>LC-R1</i>	18.36	18.05	18.62	17.53
<i>LC-R2004</i>	18.36	18.15	18.49	17.49
<i>Ref No retrofit</i>	18.36	21.63	33.93	36.84
<i>SWE-No retrofit</i>	18.36	20.15	27.97	28.64
<i>RT2005 No retrofit</i>	18.36	20.67	31.46	33.06
<i>Ref CCS</i>	18.36	21.55	11.90	11.19
<i>Ref GS</i>	18.36	20.83	27.26	29.89
<i>A1 No Retrofit</i>	18.36	21.68	32.69	33.15
<i>A2 No Retrofit</i>	18.36	21.68	31.78	31.91
<i>LC-R1 CCS</i>	18.36	18.09	8.04	7.29
<i>LC-R1 GS</i>	18.36	18.24	15.36	15.25
<i>CAN</i>	18.36	20.65	30.73	33.36
<i>CAN No retrofit</i>	18.36	21.21	33.13	35.11
<i>SWE CCS</i>	18.36	19.94	10.11	8.78
<i>SWE GS</i>	18.36	19.95	22.33	22.72
<i>SWE REN</i>	18.36	18.96	18.60	17.37
<i>A2 REN</i>	18.36	19.37	20.78	17.07
<i>LC REN</i>	18.36	17.75	15.55	14.08
<i>A2+GS+CCS</i>				
<i>ParCom No retro +CCS</i>	18.36	23.83	10.03	8.58
<i>ParCom No retro +GS</i>	18.36	23.35	36.57	37.36
<i>temperature</i>	18.36	21.64	31.27	31.27
<i>RT2005+GS</i>	18.36	20.27	23.58	24.91
<i>RT 2005 + CCS</i>	18.36	20.54	10.27	8.98

Table A- 2 . Cumulative emission up to a specific year

In million metric tonnes CO₂eq

	2010	2015	2020	2025	2030
<i>TJ-2004</i>	118.79	244.16	399.46	571.20	747.07
<i>RT2005</i>	117.05	234.42	376.86	532.75	691.45
<i>SWE</i>	116.08	226.27	352.83	488.30	624.06
<i>A1</i>	118.71	241.51	389.92	549.98	710.07
<i>A2</i>	118.79	241.02	385.71	539.14	691.51
<i>A2+CCS</i>	118.70	225.14	282.34	337.35	388.93
<i>A2+Gas Switching</i>	118.38	233.46	352.03	478.41	605.95
<i>A3</i>	110.37	202.20	294.91	388.76	480.69
<i>PartCom with Re</i>	122.82	266.49	445.54	636.20	828.43
<i>PartCom without Re</i>	123.36	270.38	456.73	659.82	864.89
<i>Applmp</i>	118.54	244.51	400.91	574.28	752.19
<i>LC-R1</i>	110.37	201.89	293.97	385.88	475.12
<i>LC-R2004</i>	110.59	203.12	296.52	388.26	477.30
<i>Ref No retrofit</i>	119.41	247.54	406.93	581.48	761.92
<i>SWE-No retrofit</i>	116.17	227.54	359.02	501.13	644.75
<i>RT2005 No retrofit</i>	117.56	237.39	383.98	545.37	710.51
<i>Ref CCS</i>	118.97	229.29	290.08	350.03	407.50
<i>Ref GS</i>	118.38	236.22	363.22	504.72	652.48
<i>A1 No Retrofit</i>	119.21	244.50	397.08	562.65	729.20
<i>A2 No Retrofit</i>	119.21	244.50	394.37	554.73	715.30
<i>LC-R1 CCS</i>	110.49	192.68	234.40	273.96	311.36
<i>LC-R1 GS</i>	110.94	200.70	277.28	353.96	430.51
<i>CAN</i>	117.64	237.10	382.17	539.79	702.89
<i>CAN No retrofit</i>	118.42	242.86	396.88	567.49	742.74
<i>SWE CCS</i>	115.98	211.89	264.71	314.43	360.24
<i>SWE GS</i>	115.96	221.28	327.39	440.35	554.11
<i>SWE REN</i>	113.79	212.54	310.97	403.07	490.23
<i>A2 REN</i>	115.56	218.37	324.71	423.76	512.59
<i>LC REN</i>	110.12	199.08	283.06	361.25	433.85
<i>A2+GS+CCS</i>	0.00	0.00	0.00	0.00	0.00
<i>ParCom No retro +CCS</i>	123.47	246.46	301.14	350.30	395.02
<i>ParCom No retro +GS</i>	122.65	263.12	436.40	620.25	805.01
<i>temperature</i>	119.42	244.37	392.34	549.98	707.46
<i>RT2005+GS</i>	117.17	227.27	337.65	458.46	582.39
<i>RT 2005 + CCS</i>	117.46	219.81	273.87	324.69	371.53

Table A- 3 Variation of year-on-year emission

	2010	2015	2020	2025	2030
<i>TJ-2004</i>					
<i>RT2005</i>	-4.4%	-7.3%	-8.7%	-9.4%	-9.9%
<i>SWE</i>	-5.6%	-16.0%	-19.7%	-21.8%	-23.3%
<i>A1</i>	0.3%	-3.2%	-5.0%	-7.8%	-9.7%
<i>A2</i>	0.0%	-3.8%	-8.4%	-11.9%	-14.2%
<i>A2+CCS</i>	-0.1%	-59.6%	-66.8%	-70.0%	-71.8%
<i>A2+Gas Switching</i>	-2.3%	-21.5%	-25.1%	-27.2%	-27.5%
<i>A3</i>	-15.3%	-36.1%	-43.4%	-46.1%	-48.5%

<i>PartCom with Re</i>	11.1%	15.9%	13.5%	10.5%	10.5%
<i>PartCom without Re</i>	12.7%	19.2%	20.0%	17.4%	16.1%
<i>Applmp</i>	0.3%	0.6%	0.8%	1.0%	1.2%
<i>LC-R1</i>	-15.3%	-36.4%	-44.2%	-47.5%	-50.2%
<i>LC-R2004</i>	-14.9%	-35.4%	-44.6%	-47.7%	-50.3%
<i>Ref No retrofit</i>	1.5%	2.6%	1.6%	2.4%	4.7%
<i>SWE-No retrofit</i>	-5.5%	-13.4%	-16.2%	-17.7%	-18.6%
<i>RT2005 No retrofit</i>	-3.1%	-5.0%	-5.8%	-6.0%	-6.1%
<i>Ref CCS</i>	1.1%	-58.6%	-64.4%	-67.1%	-68.2%
<i>Ref GS</i>	-2.3%	-18.6%	-18.4%	-17.3%	-15.1%
<i>A1 No Retrofit</i>	1.7%	-0.9%	-2.1%	-4.4%	-5.8%
<i>A2 No Retrofit</i>	1.7%	-0.9%	-4.8%	-7.6%	-9.3%
<i>LC-R1 CCS</i>	-15.1%	-70.3%	-75.9%	-78.3%	-79.3%
<i>LC-R1 GS</i>	-14.5%	-47.5%	-54.0%	-55.7%	-56.7%
<i>CAN</i>	-3.2%	-5.5%	-8.0%	-7.5%	-5.2%
<i>CAN No retrofit</i>	-0.5%	-0.8%	-0.8%	-0.5%	-0.2%
<i>SWE CCS</i>	-6.5%	-63.0%	-69.7%	-73.2%	-75.0%
<i>SWE GS</i>	-6.4%	-29.5%	-33.1%	-35.0%	-35.4%
<i>SWE REN</i>	-11.1%	-30.8%	-44.3%	-50.8%	-50.6%
<i>A2 REN</i>	-9.2%	-24.0%	-37.8%	-46.7%	-51.5%
<i>LC REN</i>	-16.8%	-39.9%	-53.4%	-58.3%	-60.0%
<i>A2+GS+CCS</i>					
<i>ParCom No retro +CCS</i>	11.8%	-61.2%	-70.0%	-74.1%	-75.6%
<i>ParCom No retro +GS</i>	9.5%	12.6%	9.5%	6.2%	6.2%
<i>temperature</i>	1.5%	-1.9%	-6.4%	-9.3%	-11.1%
<i>RT2005+GS</i>	-4.9%	-28.2%	-29.4%	-29.8%	-29.2%
<i>RT 2005 + CCS</i>	-3.7%	-62.4%	-69.2%	-72.8%	-74.5%

Variation of cumulative emissions

	2010	2015	2020	2025	2030
<i>TJ-2004</i>					
<i>RT2005</i>	-1.5%	-4.0%	-5.7%	-6.7%	-7.4%
<i>SWE</i>	-2.3%	-7.3%	-11.7%	-14.5%	-16.5%
<i>A1</i>	-0.1%	-1.1%	-2.4%	-3.7%	-5.0%
<i>A2</i>	0.0%	-1.3%	-3.4%	-5.6%	-7.4%
<i>A2+CCS</i>	-0.1%	-7.8%	-29.3%	-40.9%	-47.9%
<i>A2+Gas Switching</i>	-0.3%	-4.4%	-11.9%	-16.2%	-18.9%
<i>A3</i>	-7.1%	-17.2%	-26.2%	-31.9%	-35.7%
<i>PartCom with Re</i>	3.4%	9.1%	11.5%	11.4%	10.9%
<i>PartCom without Re</i>	3.8%	10.7%	14.3%	15.5%	15.8%
<i>Applmp</i>	-0.2%	0.1%	0.4%	0.5%	0.7%
<i>LC-R1</i>	-7.1%	-17.3%	-26.4%	-32.4%	-36.4%
<i>LC-R2004</i>	-6.9%	-16.8%	-25.8%	-32.0%	-36.1%
<i>Ref No retrofit</i>	0.5%	1.4%	1.9%	1.8%	2.0%
<i>SWE-No retrofit</i>	-2.2%	-6.8%	-10.1%	-12.3%	-13.7%
<i>RT2005 No retrofit</i>	-1.0%	-2.8%	-3.9%	-4.5%	-4.9%
<i>Ref CCS</i>	0.2%	-6.1%	-27.4%	-38.7%	-45.5%
<i>Ref GS</i>	-0.3%	-3.3%	-9.1%	-11.6%	-12.7%
<i>A1 No Retrofit</i>	0.4%	0.1%	-0.6%	-1.5%	-2.4%
<i>A2 No Retrofit</i>	0.4%	0.1%	-1.3%	-2.9%	-4.3%
<i>LC-R1 CCS</i>	-7.0%	-21.1%	-41.3%	-52.0%	-58.3%
<i>LC-R1 GS</i>	-6.6%	-17.8%	-30.6%	-38.0%	-42.4%
<i>CAN</i>	-1.0%	-2.9%	-4.3%	-5.5%	-5.9%

<i>CAN No retrofit</i>	-0.3%	-0.5%	-0.6%	-0.6%	-0.6%
<i>SWE CCS</i>	-2.4%	-13.2%	-33.7%	-45.0%	-51.8%
<i>SWE GS</i>	-2.4%	-9.4%	-18.0%	-22.9%	-25.8%
<i>SWE REN</i>	-4.2%	-13.0%	-22.2%	-29.4%	-34.4%
<i>A2 REN</i>	-2.7%	-10.6%	-18.7%	-25.8%	-31.4%
<i>LC REN</i>	-7.3%	-18.5%	-29.1%	-36.8%	-41.9%
<i>A2+GS+CCS</i>					
<i>ParCom No retro +CCS</i>	3.9%	0.9%	-24.6%	-38.7%	-47.1%
<i>ParCom No retro +GS</i>	3.3%	7.8%	9.2%	8.6%	7.8%
<i>temperature</i>	0.5%	0.1%	-1.8%	-3.7%	-5.3%
<i>RT2005+GS</i>	-1.4%	-6.9%	-15.5%	-19.7%	-22.0%
<i>RT 2005 + CCS</i>	-1.1%	-10.0%	-31.4%	-43.2%	-50.3%

Table A- 4 annual cost scenarios

	million RMB					
<i>DR=0%</i>	2005	2010	2015	2020	2025	2030
<i>TJ-2004</i>	8941	13595	19862	24232	27007	28938
<i>RT2005</i>	8941	13535	19051	22686	24870	26387
<i>SWE</i>	8941	13777	18479	21387	22981	24110
<i>A1</i>	8941	13595	19634	23336	25496	26700
<i>A2</i>	8941	13595	19634	23299	25284	26244
<i>A2 CCS</i>	8941	13791	26935	32003	34193	34806
<i>A2 GS 70%</i>	8941	13616	24817	31355	34762	36244
<i>A3</i>	8941	15355	20292	21811	22632	22698
<i>ParCom with Re</i>	8941	14370	21828	26345	29521	32763
<i>ParCom without Re</i>	8941	14968	22611	27813	30205	32080
<i>Applmp</i>	8941	13595	19862	24232	27007	28938
<i>LC-R1</i>	8941	15355	20226	21692	22425	22492
<i>LC-R2004</i>	8941	15370	20237	21785	22539	22653
<i>Ref No retrofit</i>	8941	13676	20237	24878	27789	29770
<i>SWE-No retrofit</i>	8941	13765	18661	21745	23507	24775
<i>RT2005 No retrofit</i>	8941	13529	19235	23047	25400	27074
<i>Ref CCS</i>	8941	13579	27077	33443	36832	38550
<i>Ref GS</i>	8941	13651	25416	33566	38601	41753
<i>A1 No Retrofit</i>	8941	13618	19820	23699	26027	27357
<i>A2 No Retrofit</i>	8941	13618	19820	23661	25795	26881
<i>LC-R1 CCS</i>	8941	15358	24726	26598	27284	26893
<i>LC-R1 GS</i>	8941	15235	24001	27025	28483	28516
<i>CAN</i>	8941	13562	19505	23550	26061	27811
<i>CAN No retrofit</i>	8941	13585	19691	23913	26594	28500
<i>SWE CCS</i>	8941	13944	24647	28984	31013	31994
<i>SWE GS</i>	8941	13788	22740	28245	31157	32744
<i>SWE REN</i>	8941	14070	18854	21642	23682	26505
<i>A2 REN</i>	8941	13812	19880	23531	25661	26995
<i>LC REN</i>	8941	14895	19509	21644	23226	23986
<i>A2+GS+CCS</i>						
<i>ParCom No retro +CCS</i>	8941	15225	32728	40628	43480	44946
<i>ParCom No retro +GS</i>	8941	14592	22472	27194	30474	33744
<i>temperature</i>	8941	13648	19731	23643	25984	27603
<i>RT2005+GS</i>	8941	13541	25871	32749	36638	38873
<i>RT 2005 + CCS</i>	8941	13535	25117	30062	32511	33726

DR=4%	2005	2010	2015	2020	2025	2030
<i>TJ-2004</i>	8941	11174	13418	13455	12326	10855
<i>RT2005</i>	8941	11124	12870	12597	11350	9898
<i>SWE</i>	8941	11323	12484	11876	10488	9044
<i>A1</i>	8941	11174	13264	12958	11636	10016
<i>A2</i>	8941	11174	13264	12937	11540	9845
<i>A2 CCS</i>	8941	11335	18196	17770	15605	13056
<i>A2 GS 70%</i>	8941	11191	16766	17410	15865	13596
<i>A3</i>	8941	12620	13709	12111	10329	8514
<i>ParCom with Re</i>	8941	11811	14746	14629	13473	12290
<i>ParCom without Re</i>	8941	12303	15275	15444	13785	12034
<i>Applmp</i>	8941	11174	13418	13455	12326	10855
<i>LC-R1</i>	8941	12620	13664	12045	10235	8437
<i>LC-R2004</i>	8941	12633	13671	12097	10286	8497
<i>Ref No retrofit</i>	8941	11240	13671	13814	12682	11167
<i>SWE-No retrofit</i>	8941	11314	12607	12074	10728	9293
<i>RT2005 No retrofit</i>	8941	11120	12995	12797	11592	10156
<i>Ref CCS</i>	8941	11161	21868	22018	19616	16554
<i>Ref GS</i>	8941	11220	17170	18638	17617	15662
<i>A1 No Retrofit</i>	8941	11193	13390	13159	11879	10262
<i>A2 No Retrofit</i>	8941	11193	13390	13138	11773	10083
<i>LC-R1 CCS</i>	8941	12623	16704	14769	12452	10088
<i>LC-R1 GS</i>	8941	12522	16214	15006	12999	10697
<i>CAN</i>	8941	11147	13177	13076	11894	10432
<i>CAN No retrofit</i>	8941	11166	13303	13278	12137	10691
<i>SWE CCS</i>	8941	11461	16650	16094	14154	12002
<i>SWE GS</i>	8941	11333	15362	15684	14220	12283
<i>SWE REN</i>	8941	11564	12737	12017	10808	9942
<i>A2 REN</i>	8941	11352	13430	13066	11711	10126
<i>LC REN</i>	8941	12243	13180	12018	10600	8998
<i>A2+GS+CCS</i>						
<i>ParCom No retro +CCS</i>	8941	12514	22110	22559	19844	16860
<i>ParCom No retro +GS</i>	8941	11993	15181	15100	13908	12658
<i>temperature</i>	8941	11218	13330	13128	11859	10354
<i>RT2005+GS</i>	8941	11130	17478	18184	16721	14582
<i>RT 2005 + CCS</i>	8941	11125	16968	16692	14838	12651

DR=8%	2005	2010	2015	2020	2025	2030
<i>TJ-2004</i>	8941	9252	9200	7639	5794	4225
<i>RT2005</i>	8941	9211	8824	7152	5336	3853
<i>SWE</i>	8941	9376	8559	6742	4931	3520
<i>A1</i>	8941	9252	9094	7357	5470	3899
<i>A2</i>	8941	9252	9094	7345	5425	3832
<i>A2 CCS</i>	8941	9386	12476	10089	7336	5082
<i>A2 GS 70%</i>	8941	9267	11495	9884	7458	5292
<i>A3</i>	8941	10450	9399	6876	4856	3314
<i>ParCom with Re</i>	8941	9780	10110	8305	6334	4784
<i>ParCom without Re</i>	8941	10187	10473	8768	6480	4684
<i>Applmp</i>	8941	9252	9200	7639	5794	4225
<i>LC-R1</i>	8941	10450	9369	6838	4811	3284
<i>LC-R2004</i>	8941	10461	9374	6868	4836	3308

<i>Ref No retrofit</i>	8941	9307	9374	7842	5962	4347
<i>SWE-No retrofit</i>	8941	9368	8644	6855	5043	3618
<i>RT2005 No retrofit</i>	8941	9207	8910	7266	5450	3953
<i>Ref CCS</i>	8941	9241	14993	12500	9221	6444
<i>Ref GS</i>	8941	9291	11772	10581	8282	6097
<i>A1 No Retrofit</i>	8941	9268	9181	7471	5584	3995
<i>A2 No Retrofit</i>	8941	9268	9181	7459	5534	3925
<i>LC-R1 CCS</i>	8941	10452	11453	8385	5854	3927
<i>LC-R1 GS</i>	8941	10369	11117	8519	6111	4164
<i>CAN</i>	8941	9230	9035	7424	5591	4061
<i>CAN No retrofit</i>	8941	9246	9121	7538	5706	4161
<i>SWE CCS</i>	8941	9490	11416	9137	6654	4672
<i>SWE GS</i>	8941	9384	10533	8904	6685	4781
<i>SWE REN</i>	8941	9576	8733	6823	5081	3870
<i>A2 REN</i>	8941	9400	9208	7418	5506	3942
<i>LC REN</i>	8941	10137	9036	6823	4983	3502
<i>A2+GS+CCS</i>						
<i>ParCom No retro +CCS</i>	8941	10362	15159	12808	9329	6563
<i>ParCom No retro +GS</i>	8941	9931	10409	8573	6538	4927
<i>temperature</i>	8941	9289	9139	7453	5575	4030
<i>RT2005+GS</i>	8941	9216	11983	10324	7861	5676
<i>RT 2005 + CCS</i>	8941	9212	11634	9477	6975	4925

DR=10%	2005	2010	2015	2020	2025	2030
<i>TJ-2004</i>	8941	8441	7658	5801	4014	2671
<i>RT2005</i>	8941	8404	7345	5431	3697	2435
<i>SWE</i>	8941	8554	7125	5120	3416	2225
<i>A1</i>	8941	8441	7570	5587	3790	2464
<i>A2</i>	8941	8441	7570	5578	3758	2422
<i>A2 CCS</i>	8941	8563	10385	7661	5083	3212
<i>A2 GS 70%</i>	8941	8454	9568	7506	5167	3345
<i>A3</i>	8941	9534	7823	5221	3364	2095
<i>ParCom with Re</i>	8941	8923	8415	6307	4388	3024
<i>ParCom without Re</i>	8941	9294	8718	6658	4490	2961
<i>Applmp</i>	8941	8441	7658	5801	4014	2671
<i>LC-R1</i>	8941	9534	7798	5193	3333	2076
<i>LC-R2004</i>	8941	9544	7802	5215	3350	2091
<i>Ref No retrofit</i>	8941	8492	7802	5956	4131	2748
<i>SWE-No retrofit</i>	8941	8547	7195	5205	3494	2287
<i>RT2005 No retrofit</i>	8941	8400	7416	5517	3776	2499
<i>Ref CCS</i>	8941	8431	10439	8006	5475	3558
<i>Ref GS</i>	8941	8476	9799	8035	5738	3854
<i>A1 No Retrofit</i>	8941	8456	7641	5673	3869	2525
<i>A2 No Retrofit</i>	8941	8456	7641	5664	3834	2481
<i>LC-R1 CCS</i>	8941	9536	9533	6367	4056	2482
<i>LC-R1 GS</i>	8941	9460	9253	6470	4234	2632
<i>CAN</i>	8941	8421	7520	5638	3874	2567
<i>CAN No retrofit</i>	8941	8435	7592	5725	3953	2630
<i>SWE CCS</i>	8941	8658	9502	6939	4610	2953
<i>SWE GS</i>	8941	8561	8767	6762	4631	3022
<i>SWE REN</i>	8941	8736	7269	5181	3520	2446
<i>A2 REN</i>	8941	8576	7665	5633	3814	2492
<i>LC REN</i>	8941	9249	7522	5181	3452	2214

A2+GS+CCS						
<i>ParCom No retro +CCS</i>	8941	9454	12618	9726	6463	4148
<i>ParCom No retro +GS</i>	8941	9060	8664	6510	4530	3114
<i>temperature</i>	8941	8475	7607	5660	3862	2548
<i>RT2005+GS</i>	8941	8408	9974	7840	5446	3588
<i>RT 2005 + CCS</i>	8941	8404	9684	7197	4833	3113

DR=12%	2005	2010	2015	2020	2025	2030
<i>TJ-2004</i>	8941	7714	6395	4427	2800	1702
<i>RT2005</i>	8941	7680	6134	4145	2578	1552
<i>SWE</i>	8941	7817	5950	3907	2382	1418
<i>A1</i>	8941	7714	6322	4263	2643	1571
<i>A2</i>	8941	7714	6322	4257	2621	1544
<i>A2 CCS</i>	8941	7825	8672	5847	3545	2047
<i>A2 GS 70%</i>	8941	7726	7990	5728	3604	2132
<i>A3</i>	8941	8713	6533	3985	2346	1335
<i>ParCom with Re</i>	8941	8154	7028	4813	3060	1927
<i>ParCom without Re</i>	8941	8493	7280	5081	3131	1887
<i>Applmp</i>	8941	7714	6395	4427	2800	1702
<i>LC-R1</i>	8941	8713	6512	3963	2325	1323
<i>LC-R2004</i>	8941	8722	6516	3980	2337	1333
<i>Ref No retrofit</i>	8941	7760	6516	4545	2881	1751
<i>SWE-No retrofit</i>	8941	8547	7195	5205	3494	2287
<i>RT2005 No retrofit</i>	8941	7677	6193	4211	2633	1593
<i>Ref CCS</i>	8941	7705	8718	6110	3818	2268
<i>Ref GS</i>	8941	7746	8183	6132	4002	2456
<i>A1 No Retrofit</i>	8941	7727	6382	4330	2698	1609
<i>A2 No Retrofit</i>	8941	7727	6382	4323	2674	1581
<i>LC-R1 CCS</i>	8941	8714	7961	4859	2828	1582
<i>LC-R1 GS</i>	8941	8645	7728	4937	2953	1677
<i>CAN</i>	8941	7696	6280	4302	2702	1636
<i>CAN No retrofit</i>	8941	7709	6340	4369	2757	1676
<i>SWE CCS</i>	8941	7912	7936	5295	3215	1882
<i>SWE GS</i>	8941	7824	7322	5160	3230	1926
<i>SWE REN</i>	8941	7984	6071	3954	2455	1559
<i>A2 REN</i>	8941	7837	6401	4299	2660	1588
<i>LC REN</i>	8941	8452	6281	3954	2408	1411
A2+GS+CCS						
<i>ParCom No retro +CCS</i>	8941	8639	10538	7423	4507	2644
<i>ParCom No retro +GS</i>	8941	8280	7235	4968	3159	1985
<i>temperature</i>	8941	7744	6353	4319	2694	1624
<i>RT2005+GS</i>	8941	7684	8330	5983	3798	2287
<i>RT 2005 + CCS</i>	8941	7680	8087	5492	3370	1984

Table A- 5 Cumulative costs

						In million yuan
DR=0%	2010	2015	2020	2025	2030	
<i>TJ-2004</i>	65840	153884	261914	387878	527278	
<i>RT2005</i>	66790	152531	254223	370561	497989	
<i>SWE</i>	68749	153820	250423	358402	475205	
<i>A1</i>	65840	154353	259162	379421	509018	

A2	65840	154353	260110	380031	507826
A2 CCS	66006	162978	308046	471033	641873
A2 GS	65753	159607	297254	459925	636057
A3	75268	170866	272800	381392	493405
ParCom with Re	66983	162188	281643	418473	570771
ParCom without Re	69823	169023	293273	435225	590437
Applmp	65810	153854	261884	387847	527247
LC-R1	75268	170679	272201	380116	491126
LC-R2004	75213	170530	272296	380436	492131
Ref No retrofit	65751	155019	265727	395328	538796
SWE-No retrofit	68502	153915	251929	362186	482028
RT2005 No retrofit	66549	152866	255991	374631	505177
Ref CCS	65793	160978	309548	482456	669993
Ref GS	65769	159738	304038	481545	681983
A1 No Retrofit	65628	154724	260973	383538	516149
A2 No Retrofit	65628	154724	261917	384075	514778
LC-R1 CCS	75253	175193	299189	430678	564287
LC-R1 GS	75043	173513	296559	431948	572819
CAN	66284	153331	258576	380289	514404
CAN No retrofit	66073	153701	260386	384411	521653
SWE CCS	68895	161095	291288	437506	593585
SWE GS	68591	157909	281017	425546	584110
SWE REN	69195	156196	255011	366271	491843
A2 REN	66242	155798	262980	385056	516164
LC REN	73862	165650	264688	375789	493090
A2+GS+CCS					
ParCom No retro +CCS	70043	181254	362573	568707	788603
ParCom No retro +GS	67182	164543	287798	429072	586258
temperature	65933	153867	259906	381653	514997
RT2005+GS	66614	159206	302088	472095	660013
RT 2005 + CCS	66791	158749	293528	446832	611265

DR=4%	2010	2015	2020	2025	2030
TJ-2004	59375	123504	188250	250397	306975
RT2005	60264	122754	183720	241129	292855
SWE	62046	124099	182036	235333	282753
A1	59375	123890	186728	246091	298708
A2	59375	123890	187324	246533	298426
A2 CCS	59509	129815	216834	297328	366723
A2 GS	59297	127430	209913	290205	361723
A3	67810	137587	198785	252422	297927
ParCom with Re	60319	129619	201234	268745	330523
ParCom without Re	62854	135069	209533	279586	342591
Applmp	59348	123477	188224	250370	306949
LC-R1	67810	137454	198407	251712	296808
LC-R2004	67759	137331	198426	251838	297213
Ref No retrofit	59283	124291	190636	254576	312806
SWE-No retrofit	61820	124113	182890	237305	285957
RT2005 No retrofit	60043	122945	184765	243305	296293
Ref CCS	59334	131858	237964	338334	426226
Ref GS	59308	127465	213851	301396	382740
A1 No Retrofit	59177	124109	187805	248301	302139
A2 No Retrofit	59177	124109	188400	248709	301779

<i>LC-R1 CCS</i>	67797	140503	214956	279918	334213
<i>LC-R1 GS</i>	67619	139283	213112	279974	337209
<i>CAN</i>	59791	123211	186296	246351	300787
<i>CAN No retrofit</i>	59594	123430	187373	248564	304266
<i>SWE CCS</i>	62165	129097	207174	279360	342745
<i>SWE GS</i>	61906	126829	200588	271905	336281
<i>SWE REN</i>	62423	125884	185155	240049	290965
<i>A2 REN</i>	59717	124994	189286	249555	302780
<i>LC REN</i>	66594	133600	193026	247875	295506
<i>A2+GS+CCS</i>					
<i>ParCom No retro +CCS</i>	63033	143482	252153	353921	443225
<i>ParCom No retro +GS</i>	60481	131334	205226	274930	338694
<i>temperature</i>	59454	123514	187084	247163	301290
<i>RT2005+GS</i>	60109	127230	212821	296700	372985
<i>RT 2005 + CCS</i>	60266	126964	207773	283449	350223

DR=8%	2010	2015	2020	2025	2030
<i>TJ-2004</i>	53986	101396	141074	172656	196484
<i>RT2005</i>	54823	101047	138419	167599	189387
<i>SWE</i>	56454	102392	137920	165016	184992
<i>A1</i>	53986	101712	140234	170417	192583
<i>A2</i>	53986	101712	140617	170728	192592
<i>A2 CCS</i>	54096	105848	159220	200167	229415
<i>A2 GS</i>	53916	104130	154671	195492	225625
<i>A3</i>	61589	113276	150842	178129	197311
<i>ParCom with Re</i>	54771	105970	149869	184180	210185
<i>ParCom without Re</i>	57051	110409	156040	191649	218187
<i>Applmp</i>	53962	101372	141050	172632	196460
<i>LC-R1</i>	61589	113180	150597	177716	196725
<i>LC-R2004</i>	61541	113076	150577	177750	196876
<i>Ref No retrofit</i>	53893	101943	142597	175090	199614
<i>SWE-No retrofit</i>	56246	102354	138394	166056	186550
<i>RT2005 No retrofit</i>	54619	101142	139035	168787	191105
<i>Ref CCS</i>	53951	107112	172148	223186	260227
<i>Ref GS</i>	53925	104114	156996	201470	235725
<i>A1 No Retrofit</i>	53802	101830	140875	171632	194311
<i>A2 No Retrofit</i>	53802	101830	141256	171925	194284
<i>LC-R1 CCS</i>	61577	115269	160978	194035	216927
<i>LC-R1 GS</i>	61425	114367	159661	193672	217800
<i>CAN</i>	54378	101275	139940	170462	193389
<i>CAN No retrofit</i>	54193	101392	140580	171677	195136
<i>SWE CCS</i>	56551	105881	153757	190463	217173
<i>SWE GS</i>	56328	104234	149422	185671	212791
<i>SWE REN</i>	56775	103755	140106	168003	189425
<i>A2 REN</i>	54281	102571	142003	172650	195071
<i>LC REN</i>	60529	110170	146630	174520	194588
<i>A2+GS+CCS</i>					
<i>ParCom No retro +CCS</i>	57197	116289	182885	234636	272268
<i>ParCom No retro +GS</i>	54904	107239	152534	187959	214800
<i>temperature</i>	54054	101420	140388	170926	193724
<i>RT2005+GS</i>	54684	104085	156514	199142	231275
<i>RT 2005 + CCS</i>	54824	103940	153481	191959	220094

DR=10%	2010	2015	2020	2025	2030
<i>TJ-2004</i>	51625	92601	123905	146654	162319
<i>RT2005</i>	52437	92399	121889	142909	157234
<i>SWE</i>	54001	93731	121771	141292	154427
<i>A1</i>	51625	92887	123285	145031	159606
<i>A2</i>	51625	92887	123593	145290	159667
<i>A2 CCS</i>	51724	96362	138488	167996	187232
<i>A2 GS</i>	51559	94895	134767	164177	183992
<i>A3</i>	58861	103576	133238	152903	165520
<i>ParCom with Re</i>	52342	96578	131218	155934	173025
<i>ParCom without Re</i>	54509	100614	136614	162267	179715
<i>Applmp</i>	51602	92578	123883	146632	162297
<i>LC-R1</i>	58861	103494	133039	152584	165086
<i>LC-R2004</i>	58814	103398	133008	152591	165171
<i>Ref No retrofit</i>	51532	93057	125130	148535	164658
<i>SWE-No retrofit</i>	53801	93675	122117	142046	155521
<i>RT2005 No retrofit</i>	52240	92459	122358	143791	158463
<i>Ref CCS</i>	51592	95313	138363	169614	190709
<i>Ref GS</i>	51566	94863	136563	168593	191112
<i>A1 No Retrofit</i>	51447	92968	123777	145936	160848
<i>A2 No Retrofit</i>	51447	92968	124084	146182	160884
<i>LC-R1 CCS</i>	58849	105232	141326	165152	180211
<i>LC-R1 GS</i>	58709	104451	140205	164715	180586
<i>CAN</i>	52005	92543	123050	145036	160109
<i>CAN No retrofit</i>	51826	92623	123541	145941	161364
<i>SWE CCS</i>	54089	96663	134446	160895	178459
<i>SWE GS</i>	53882	95250	130898	157010	174842
<i>SWE REN</i>	54298	94929	123619	143714	157791
<i>A2 REN</i>	51899	93650	124772	146855	161596
<i>LC REN</i>	57869	100817	129598	149693	162890
<i>A2+GS+CCS</i>					
<i>ParCom No retro +CCS</i>	54642	105558	158099	195388	220135
<i>ParCom No retro +GS</i>	52462	97677	133417	158935	176577
<i>temperature</i>	51688	92629	123378	145376	160365
<i>RT2005+GS</i>	52305	94913	136268	166974	188102
<i>RT 2005 + CCS</i>	52438	94810	133904	161626	180128

DR=12%	2010	2015	2020	2025	2030
<i>TJ-2004</i>	49455	84986	109806	126301	136684
<i>RT2005</i>	50243	84905	108290	123533	133028
<i>SWE</i>	51745	86219	108457	122614	131322
<i>A1</i>	49455	85246	109351	125122	134784
<i>A2</i>	49455	85246	109600	125337	134869
<i>A2 CCS</i>	49545	88176	121590	142995	155750
<i>A2 GS</i>	49392	86918	118529	139858	152994
<i>A3</i>	56352	95162	118698	132964	141331
<i>ParCom with Re</i>	50110	88457	115925	133846	145173
<i>ParCom without Re</i>	52174	92143	120685	139287	150853
<i>Applmp</i>	49433	84965	109785	126279	136663
<i>LC-R1</i>	56352	95092	118536	132714	141005
<i>LC-R2004</i>	56307	95003	118498	132704	141045
<i>Ref No retrofit</i>	49362	85366	110794	127764	138451
<i>SWE-No retrofit</i>	53801	93675	122117	142046	155521

RT2005 No retrofit	50054	84936	108645	124185	133911
Ref CCS	49424	87246	121379	144041	158026
Ref GS	49398	86874	119920	143140	158066
A1 No Retrofit	49282	85296	109726	125796	135681
A2 No Retrofit	49282	85296	109974	126002	135749
LC-R1 CCS	56341	96542	125184	142471	152458
LC-R1 GS	56211	95864	124227	142006	152531
CAN	49824	84979	109169	125111	135102
CAN No retrofit	49651	85029	109544	125785	136008
SWE CCS	51825	88692	118657	137839	149485
SWE GS	51633	87474	115734	134669	146491
SWE REN	52021	87276	110032	124602	133929
A2 REN	49710	85925	110610	126626	136398
LC REN	55422	92701	115533	130107	138856
A2+GS+CCS					
ParCom No retro +CCS	52294	96314	137972	165017	181425
ParCom No retro +GS	50220	89411	117751	136254	147945
temperature	49513	85018	109400	125352	135288
RT2005+GS	50119	86991	119773	142037	156043
RT 2005 + CCS	50244	86922	117923	138029	150295

DR=16%	2010	2015	2020	2025	2030
TJ-2004	45612	72579	88402	97238	101908
RT2005	46357	72678	87591	95757	100029
SWE	47748	73945	88131	95717	99635
A1	45612	72792	88165	96616	100964
A2	45612	72792	88330	96765	101054
A2 CCS	45686	74897	96216	107692	113434
A2 GS	45555	73961	94112	105541	111452
A3	51907	81415	96443	104092	107858
ParCom with Re	46161	75248	92764	102364	107456
ParCom without Re	48042	78361	96557	106523	111726
Applmp	45593	72559	88383	97218	101889
LC-R1	51907	81363	96332	103935	107667
LC-R2004	51864	81285	96287	103903	107658
Ref No retrofit	45520	72841	89050	98140	102947
SWE-No retrofit	51553	86149	108706	123157	132090
RT2005 No retrofit	46181	72667	87784	96110	100484
Ref CCS	45585	74162	95922	108065	114358
Ref GS	45559	73905	94953	107387	114100
A1 No Retrofit	45450	72796	88375	96986	101433
A2 No Retrofit	45450	72796	88539	97130	101515
LC-R1 CCS	51897	82383	100673	109944	114441
LC-R1 GS	51784	81864	99964	109496	114234
CAN	45960	72649	88072	96612	101106
CAN No retrofit	45798	72652	88282	96982	101579
SWE CCS	47814	75722	94836	105118	110358
SWE GS	47646	74806	92819	102963	108282
SWE REN	47986	74777	89294	97099	101290
A2 REN	45834	73338	89087	97671	102067
LC REN	51085	79433	94005	101815	105752
A2+GS+CCS					
ParCom No retro +CCS	48141	81362	107920	122415	129800

<i>ParCom No retro +GS</i>	46252	75973	94045	103957	109213
<i>temperature</i>	45662	72613	88161	96707	101177
<i>RT2005+GS</i>	46245	74124	95015	106941	113242
<i>RT 2005 + CCS</i>	46358	74102	93873	104648	110168

Inclusion of carbon price

Hypothesis 1. low carbon price prospect

Table A- 6

DR=0%	2010	2015	2020	2025	2030
<i>TJ-2004</i>	66.66	161.54	281.58	424.26	583.73
<i>RT2005</i>	67.57	159.71	272.41	403.92	549.46
<i>SWE</i>	69.52	160.57	266.96	388.12	520.41
<i>A1</i>	66.66	161.86	278.15	413.98	561.84
<i>A2</i>	66.66	161.83	278.77	413.61	558.79
<i>A2+CCS</i>	66.82	169.44	318.92	487.25	663.97
<i>A2+Gas Switching</i>	66.55	166.63	313.44	488.41	679.09
<i>A3</i>	75.96	176.51	285.60	403.32	525.82
<i>ParCom with Re</i>	67.89	170.94	304.24	459.62	633.85
<i>ParCom without Re</i>	70.75	177.98	316.65	478.36	656.96
<i>Applmp</i>	66.63	161.54	281.68	424.51	584.21
<i>LC-R1</i>	75.96	176.31	284.94	401.79	522.97
<i>LC-R2004</i>	75.91	176.22	285.19	402.25	524.10
<i>Ref No retrofit</i>	66.58	162.84	285.88	432.47	596.53
<i>SWE-No retrofit</i>	69.28	160.74	268.92	393.01	529.23
<i>RT2005 No retrofit</i>	67.34	160.19	274.65	409.00	558.39
<i>Ref CCS</i>	66.62	167.74	321.55	501.11	696.24
<i>Ref GS</i>	66.57	166.92	321.05	512.33	729.63
<i>A1 No Retrofit</i>	66.46	162.38	280.43	419.11	570.72
<i>A2 No Retrofit</i>	66.46	162.38	281.16	418.92	567.94
<i>LC-R1 CCS</i>	75.95	180.23	307.43	442.77	580.64
<i>LC-R1 GS</i>	75.74	179.02	307.98	450.83	600.43
<i>CAN</i>	67.08	160.63	277.09	414.15	566.88
<i>CAN No retrofit</i>	66.89	161.30	279.90	420.53	577.77
<i>SWE CCS</i>	69.66	166.94	301.20	452.25	613.55
<i>SWE GS</i>	69.36	164.36	295.67	451.18	622.73
<i>SWE REN</i>	69.92	162.26	268.65	388.86	524.38
<i>A2 REN</i>	66.99	162.11	277.48	409.18	550.41
<i>LC REN</i>	74.54	171.12	276.62	395.32	520.90
<i>A2+GS+CCS</i>					
<i>ParCom No retro +CCS</i>	70.96	188.68	374.21	585.11	810.11
<i>ParCom No retro +GS</i>	68.08	173.11	309.76	468.92	647.18
<i>temperature</i>	66.76	161.50	278.98	416.06	567.37
<i>RT2005+GS</i>	67.39	165.93	317.35	499.11	701.17
<i>RT 2005 + CCS</i>	67.58	164.96	303.91	462.15	631.92
Min	66.46	159.71	266.96	388.12	520.41
DR=4%	2010	2015	2020	2025	2030
<i>TJ-2004</i>	60.05	129.12	201.05	271.42	336.14
<i>RT2005</i>	60.91	128.02	195.57	260.45	319.52
<i>SWE</i>	62.68	129.07	192.85	252.64	306.35

A1	60.05	129.40	199.10	266.14	326.16
A2	60.05	129.38	199.50	266.06	325.01
A2+CCS	60.18	134.62	224.28	307.41	379.20
A2+Gas Switching	59.95	132.61	220.57	306.92	384.34
A3	68.38	141.76	207.24	265.37	315.13
ParCom with Re	61.07	136.04	215.93	292.58	363.25
ParCom without Re	63.61	141.63	224.71	304.50	376.99
Applmp	60.02	129.12	201.10	271.55	336.36
LC-R1	68.38	141.61	206.82	264.53	313.75
LC-R2004	68.33	141.53	206.94	264.75	314.24
Ref No retrofit	59.97	130.03	203.74	276.05	342.62
SWE-No retrofit	62.46	129.13	193.99	255.21	310.51
RT2005 No retrofit	60.70	128.32	196.92	263.19	323.82
Ref CCS	60.01	136.88	246.12	349.77	440.74
Ref GS	59.97	132.75	225.01	319.34	407.52
A1 No Retrofit	59.86	129.73	200.48	268.91	330.46
A2 No Retrofit	59.86	129.73	200.95	268.94	329.44
LC-R1 CCS	68.37	144.26	220.64	287.49	343.52
LC-R1 GS	68.19	143.36	220.73	291.27	352.04
CAN	60.44	128.57	198.36	265.97	327.95
CAN No retrofit	60.26	129.01	200.07	269.44	333.25
SWE CCS	62.79	133.45	213.96	288.53	354.04
SWE GS	62.54	131.59	210.25	286.98	356.62
SWE REN	63.02	130.36	194.17	253.48	308.43
A2 REN	60.33	129.64	198.85	263.86	321.20
LC REN	67.15	137.64	200.95	259.54	310.53
A2+GS+CCS					
ParCom No retro +CCS	63.79	149.01	260.20	364.33	455.70
ParCom No retro +GS	61.22	137.61	219.51	298.03	370.34
temperature	60.14	129.12	199.53	267.16	328.58
RT2005+GS	60.75	132.19	222.88	312.55	394.57
RT 2005 + CCS	60.91	131.59	214.89	293.00	361.95
Min	59.86	128.02	192.85	252.64	306.35

DR=8%	2010	2015	2020	2025	2030
TJ-2004	54.54	105.58	149.65	185.41	212.66
RT2005	55.36	104.98	146.37	179.34	204.22
SWE	56.98	106.11	145.21	175.60	198.22
A1	54.55	105.83	148.54	182.62	207.90
A2	54.54	105.81	148.80	182.64	207.48
A2+CCS	54.65	109.48	164.47	206.75	237.01
A2+Gas Switching	54.46	108.00	161.89	205.79	238.41
A3	62.06	116.40	156.59	186.16	207.13
ParCom with Re	55.39	110.75	159.71	198.66	228.40
ParCom without Re	57.68	115.30	166.19	206.74	237.27
Applmp	54.52	105.58	149.67	185.47	212.76
LC-R1	62.06	116.30	156.32	185.67	206.42
LC-R2004	62.02	116.22	156.37	185.77	206.63
Ref No retrofit	54.46	106.22	151.37	188.11	216.15
SWE-No retrofit	56.77	106.10	145.86	176.98	200.27
RT2005 No retrofit	55.16	105.15	147.18	180.86	206.39
Ref CCS	54.51	110.90	177.85	230.55	268.89
Ref GS	54.47	108.07	164.54	212.45	249.58
A1 No Retrofit	54.37	106.02	149.38	184.16	210.09

<i>A2 No Retrofit</i>	54.37	106.02	149.68	184.25	209.74
<i>LC-R1 CCS</i>	62.05	118.11	165.00	199.02	222.64
<i>LC-R1 GS</i>	61.90	117.44	164.89	200.77	226.39
<i>CAN</i>	54.92	105.27	148.03	182.39	208.49
<i>CAN No retrofit</i>	54.75	105.55	149.09	184.33	211.20
<i>SWE CCS</i>	57.07	109.17	158.54	196.46	224.06
<i>SWE GS</i>	56.85	107.80	155.99	194.98	224.32
<i>SWE REN</i>	57.27	107.11	146.24	176.38	199.50
<i>A2 REN</i>	54.79	106.05	148.49	181.55	205.70
<i>LC REN</i>	60.99	113.21	152.04	181.84	203.32
<i>A2+GS+CCS</i>					
<i>ParCom No retro +CCS</i>	57.82	120.46	188.60	241.55	280.06
<i>ParCom No retro +GS</i>	55.51	111.92	162.11	202.00	232.44
<i>temperature</i>	54.62	105.60	148.75	183.12	208.99
<i>RT2005+GS</i>	55.21	107.80	163.34	208.91	243.46
<i>RT 2005 + CCS</i>	55.36	107.43	158.50	198.22	227.26
Min	54.37	104.98	145.21	175.60	198.22

DR=10%	2010	2015	2020	2025	2030
<i>TJ-2004</i>	51625	92601	123905	146654	162319
<i>RT2005</i>	52437	92399	121889	142909	157234
<i>SWE</i>	54001	93731	121771	141292	154427
<i>A1</i>	51625	92887	123285	145031	159606
<i>A2</i>	51625	92887	123593	145290	159667
<i>A2 CCS</i>	51724	96362	138488	167996	187232
<i>A2 GS</i>	51559	94895	134767	164177	183992
<i>A3</i>	58861	103576	133238	152903	165520
<i>ParCom with Re</i>	52342	96578	131218	155934	173025
<i>ParCom without Re</i>	54509	100614	136614	162267	179715
<i>Applmp</i>	51602	92578	123883	146632	162297
<i>LC-R1</i>	58861	103494	133039	152584	165086
<i>LC-R2004</i>	58814	103398	133008	152591	165171
<i>Ref No retrofit</i>	51532	93057	125130	148535	164658
<i>SWE-No retrofit</i>	53801	93675	122117	142046	155521
<i>RT2005 No retrofit</i>	52240	92459	122358	143791	158463
<i>Ref CCS</i>	51592	95313	138363	169614	190709
<i>Ref GS</i>	51566	94863	136563	168593	191112
<i>A1 No Retrofit</i>	51447	92968	123777	145936	160848
<i>A2 No Retrofit</i>	51447	92968	124084	146182	160884
<i>LC-R1 CCS</i>	58849	105232	141326	165152	180211
<i>LC-R1 GS</i>	58709	104451	140205	164715	180586
<i>CAN</i>	52005	92543	123050	145036	160109
<i>CAN No retrofit</i>	51826	92623	123541	145941	161364
<i>SWE CCS</i>	54089	96663	134446	160895	178459
<i>SWE GS</i>	53882	95250	130898	157010	174842
<i>SWE REN</i>	54298	94929	123619	143714	157791
<i>A2 REN</i>	51899	93650	124772	146855	161596
<i>LC REN</i>	57869	100817	129598	149693	162890
<i>A2+GS+CCS</i>					
<i>ParCom No retro +CCS</i>	54642	105558	158099	195388	220135
<i>ParCom No retro +GS</i>	52462	97677	133417	158935	176577
<i>temperature</i>	51688	92629	123378	145376	160365
<i>RT2005+GS</i>	52305	94913	136268	166974	188102
<i>RT 2005 + CCS</i>	52438	94810	133904	161626	180128

min	51447	92399	121771	141292	154427

DR=12%	2010	2015	2020	2025	2030
TJ-2004	49455	84986	109806	126301	136684
RT2005	50243	84905	108290	123533	133028
SWE	51745	86219	108457	122614	131322
A1	49455	85246	109351	125122	134784
A2	49455	85246	109600	125337	134869
A2 CCS	49545	88176	121590	142995	155750
A2 GS	49392	86918	118529	139858	152994
A3	56352	95162	118698	132964	141331
ParCom with Re	50110	88457	115925	133846	145173
ParCom without Re	52174	92143	120685	139287	150853
Applmp	49433	84965	109785	126279	136663
LC-R1	56352	95092	118536	132714	141005
LC-R2004	56307	95003	118498	132704	141045
Ref No retrofit	49362	85366	110794	127764	138451
SWE-No retrofit	53801	93675	122117	142046	155521
RT2005 No retrofit	50054	84936	108645	124185	133911
Ref CCS	49424	87246	121379	144041	158026
Ref GS	49398	86874	119920	143140	158066
A1 No Retrofit	49282	85296	109726	125796	135681
A2 No Retrofit	49282	85296	109974	126002	135749
LC-R1 CCS	56341	96542	125184	142471	152458
LC-R1 GS	56211	95864	124227	142006	152531
CAN	49824	84979	109169	125111	135102
CAN No retrofit	49651	85029	109544	125785	136008
SWE CCS	51825	88692	118657	137839	149485
SWE GS	51633	87474	115734	134669	146491
SWE REN	52021	87276	110032	124602	133929
A2 REN	49710	85925	110610	126626	136398
LC REN	55422	92701	115533	130107	138856
A2+GS+CCS					
ParCom No retro +CCS	52294	96314	137972	165017	181425
ParCom No retro +GS	50220	89411	117751	136254	147945
temperature	49513	85018	109400	125352	135288
RT2005+GS	50119	86991	119773	142037	156043
RT 2005 + CCS	50244	86922	117923	138029	150295
min	49282	84905	108290	122614	131322

DR=16%	2010	2015	2020	2025	2030
TJ-2004	45612	72579	88402	97238	101908
RT2005	46357	72678	87591	95757	100029
SWE	47748	73945	88131	95717	99635
A1	45612	72792	88165	96616	100964
A2	45612	72792	88330	96765	101054
A2 CCS	45686	74897	96216	107692	113434
A2 GS	45555	73961	94112	105541	111452
A3	51907	81415	96443	104092	107858
ParCom with Re	46161	75248	92764	102364	107456
ParCom without Re	48042	78361	96557	106523	111726
Applmp	45593	72559	88383	97218	101889
LC-R1	51907	81363	96332	103935	107667
LC-R2004	51864	81285	96287	103903	107658

<i>Ref No retrofit</i>	45520	72841	89050	98140	102947
<i>SWE-No retrofit</i>	51553	86149	108706	123157	132090
<i>RT2005 No retrofit</i>	46181	72667	87784	96110	100484
<i>Ref CCS</i>	45585	74162	95922	108065	114358
<i>Ref GS</i>	45559	73905	94953	107387	114100
<i>A1 No Retrofit</i>	45450	72796	88375	96986	101433
<i>A2 No Retrofit</i>	45450	72796	88539	97130	101515
<i>LC-R1 CCS</i>	51897	82383	100673	109944	114441
<i>LC-R1 GS</i>	51784	81864	99964	109496	114234
<i>CAN</i>	45960	72649	88072	96612	101106
<i>CAN No retrofit</i>	45798	72652	88282	96982	101579
<i>SWE CCS</i>	47814	75722	94836	105118	110358
<i>SWE GS</i>	47646	74806	92819	102963	108282
<i>SWE REN</i>	47986	74777	89294	97099	101290
<i>A2 REN</i>	45834	73338	89087	97671	102067
<i>LC REN</i>	51085	79433	94005	101815	105752
<i>A2+GS+CCS</i>					
<i>ParCom No retro +CCS</i>	48141	81362	107920	122415	129800
<i>ParCom No retro +GS</i>	46252	75973	94045	103957	109213
<i>temperature</i>	45662	72613	88161	96707	101177
<i>RT2005+GS</i>	46245	74124	95015	106941	113242
<i>RT 2005 + CCS</i>	46358	74102	93873	104648	110168
<i>min</i>	45450	72559	87591	95717	99635

Hypothesis 2. medium carbon price prospect

Table A- 7

DR=0%	In million RMB				
	2010	2015	2020	2025	2030
<i>TJ-2004</i>	66659	165853	299013	463738	652447
<i>RT2005</i>	67572	163730	288459	439976	611894
<i>SWE</i>	69522	164310	281363	419902	574757
<i>A1</i>	66661	166070	294878	451240	625708
<i>A2</i>	66659	166015	295145	449667	620167
<i>A2+CCS</i>	66824	172769	327038	502416	687702
<i>A2+Gas Switching</i>	66553	170485	327287	518466	730355
<i>A3</i>	75961	179562	296439	426191	563963
<i>ParCom with Re</i>	67892	175912	324315	504154	710349
<i>ParCom without Re</i>	70745	183070	337477	525246	737944
<i>Applmp</i>	66631	165881	299222	464315	653597
<i>LC-R1</i>	75961	179345	295704	424338	560348
<i>LC-R2004</i>	75910	179294	296098	424920	561563
<i>Ref No retrofit</i>	66582	167253	303744	472744	666817
<i>SWE-No retrofit</i>	69276	164536	283803	426121	586225
<i>RT2005 No retrofit</i>	67343	164303	291141	446205	623052
<i>Ref CCS</i>	66621	171266	330773	519103	725294
<i>Ref GS</i>	66569	170883	335736	545188	787067
<i>A1 No Retrofit</i>	66461	166679	297608	457525	636820
<i>A2 No Retrofit</i>	66461	166679	298091	456420	632130
<i>LC-R1 CCS</i>	75948	182748	313446	453846	597932
<i>LC-R1 GS</i>	75743	181930	317315	469997	632322
<i>CAN</i>	67077	164731	293427	450720	630577
<i>CAN No retrofit</i>	66887	165581	297189	459723	646101

<i>SWE CCS</i>	69661	169925	308607	466019	634928
<i>SWE GS</i>	69357	167854	308103	478113	668568
<i>SWE REN</i>	69923	165548	280177	412172	562190
<i>A2 REN</i>	66986	165570	289843	434203	590186
<i>LC REN</i>	74544	174061	286573	415286	552931
<i>A2+GS+CCS</i>					
<i>ParCom No retro +CCS</i>	70958	192495	382586	599782	832206
<i>ParCom No retro +GS</i>	68079	177955	329221	511963	720951
<i>temperature</i>	66765	165781	295727	453031	630515
<i>RT2005+GS</i>	67393	169590	330323	527592	750261
<i>RT 2005 + CCS</i>	67580	168157	311623	476370	653925

DR=4%	2010	2015	2020	2025	2030
<i>TJ-2004</i>	60048	132187	211910	293125	369686
<i>RT2005</i>	60907	130884	205582	280299	350056
<i>SWE</i>	62682	131728	201860	270196	333041
<i>A1</i>	60050	132396	209541	286672	357478
<i>A2</i>	60048	132356	209731	285972	355177
<i>A2+CCS</i>	60181	137017	229536	316135	391390
<i>A2+Gas Switching</i>	59955	135354	229261	323583	409592
<i>A3</i>	68380	143931	214051	278105	334056
<i>ParCom with Re</i>	61067	139567	228441	317119	400737
<i>ParCom without Re</i>	63612	145249	237685	330284	416589
<i>Applmp</i>	60023	132202	212032	293428	370220
<i>LC-R1</i>	68380	143777	213590	277096	332332
<i>LC-R2004</i>	68332	143723	213802	277397	332889
<i>Ref No retrofit</i>	59966	133165	214878	298198	376928
<i>SWE-No retrofit</i>	62456	131831	203280	273472	338442
<i>RT2005 No retrofit</i>	60696	131245	207199	283659	355410
<i>Ref CCS</i>	60014	139414	252051	360015	455469
<i>Ref GS</i>	59966	135578	234212	337469	435600
<i>A1 No Retrofit</i>	59862	132787	211194	290072	362832
<i>A2 No Retrofit</i>	59862	132787	211519	289631	360945
<i>LC-R1 CCS</i>	68368	146075	224537	293890	352433
<i>LC-R1 GS</i>	68195	145445	226642	302017	367948
<i>CAN</i>	60443	131485	208553	286109	359075
<i>CAN No retrofit</i>	60263	132049	210845	290980	366593
<i>SWE CCS</i>	62795	135598	218750	296453	365044
<i>SWE GS</i>	62536	134082	218065	301923	379224
<i>SWE REN</i>	63022	132703	201430	266544	327363
<i>A2 REN</i>	60329	132108	206618	277876	341194
<i>LC REN</i>	67155	139740	207229	270755	326636
<i>A2+GS+CCS</i>					
<i>ParCom No retro +CCS</i>	63785	151760	265679	372901	467287
<i>ParCom No retro +GS</i>	61218	141059	231653	321766	406522
<i>temperature</i>	60137	132164	209992	287571	359591
<i>RT2005+GS</i>	60749	134801	231034	328326	418691
<i>RT 2005 + CCS</i>	60914	133887	219891	301206	373303

DR=8%	2010	2015	2020	2025	2030
<i>TJ-2004</i>	54544	107796	156602	197847	230078
<i>RT2005</i>	55355	107042	152786	190738	220108
<i>SWE</i>	56980	108027	150993	185714	212178

A1	54545	107986	155230	194421	224238
A2	54544	107957	155364	194110	223257
A2+CCS	54652	111226	167959	212004	243718
A2+Gas Switching	54461	109993	167501	215435	251662
A3	62061	117977	160990	193560	217137
ParCom with Re	55390	113296	167719	212760	247948
ParCom without Re	57679	117904	174488	221526	257864
Applmp	54522	107802	156673	198010	230338
LC-R1	62061	117866	160693	192986	216262
LC-R2004	62015	117812	160801	193138	216521
Ref No retrofit	54459	108482	158504	200818	233959
SWE-No retrofit	56772	108051	151819	187478	214835
RT2005 No retrofit	55159	107262	153770	192604	222811
Ref CCS	54514	112745	181769	236659	276881
Ref GS	54469	110112	170459	222894	264205
A1 No Retrofit	54369	108229	156242	196316	226955
A2 No Retrofit	54369	108229	156463	196156	226189
LC-R1 CCS	62050	119441	167601	202886	227567
LC-R1 GS	61902	118948	168741	207068	234855
CAN	54917	107375	154566	193957	224673
CAN No retrofit	54747	107745	155986	196683	228514
SWE CCS	57072	110739	161717	201225	230126
SWE GS	56850	109608	161032	203638	236194
SWE REN	57270	108804	150937	184023	209608
A2 REN	54787	107833	153511	189740	216409
LC REN	60993	114724	156116	188410	211949
A2+GS+CCS					
ParCom No retro +CCS	57820	122474	192281	246802	286573
ParCom No retro +GS	55514	114403	169882	215654	251322
temperature	54620	107800	155463	194874	225198
RT2005+GS	55214	109693	168609	218034	256088
RT 2005 + CCS	55360	109111	161827	203168	233544

DR=10%	2010	2015	2020	2025	2030
TJ-2004	52133	98125	136612	166312	187498
RT2005	52922	97576	133654	160985	180291
SWE	54481	98602	132495	157502	174900
A1	52135	98305	135566	163794	183396
A2	52133	98280	135678	163589	182751
A2+CCS	52232	101033	145807	177546	198403
A2+Gas Switching	52055	99965	145322	179849	203667
A3	59291	107645	141597	165063	180568
ParCom with Re	52906	102900	145822	178257	201382
ParCom without Re	55082	107081	151699	185574	209461
Applmp	52112	98129	136667	166433	187681
LC-R1	59291	107550	141355	164624	179931
LC-R2004	59247	107497	141430	164729	180106
Ref No retrofit	52048	98701	138146	168615	190398
SWE-No retrofit	54281	98598	133122	158804	176787
RT2005 No retrofit	52733	97743	134422	162387	182242
Ref CCS	52106	100203	146392	180416	203601
Ref GS	52062	100048	147623	185378	212532
A1 No Retrofit	51964	98493	136359	165222	185363

A2 No Retrofit	51964	98493	136541	165133	184877
LC-R1 CCS	59281	108861	146886	172317	188551
LC-R1 GS	59143	108422	147720	175336	193610
CAN	52497	97810	135028	163393	183582
CAN No retrofit	52332	98107	136149	165454	186376
SWE CCS	54565	100884	141112	169577	188582
SWE GS	54358	99901	140457	171143	192547
SWE REN	54750	99299	132545	156376	173187
A2 REN	52360	98199	134244	160346	177880
LC REN	58292	104760	137429	160694	176172
A2+GS+CCS					
ParCom No retro +CCS	55210	110932	166005	205288	231441
ParCom No retro +GS	53019	103859	147614	180577	204018
temperature	52204	98139	135731	164114	184048
RT2005+GS	52789	99765	146226	181821	206838
RT 2005 + CCS	52927	99302	140898	170682	190656

DR=12%	2010	2015	2020	2025	2030
TJ-2004	49919	89772	120272	141800	155839
RT2005	50687	89391	117986	137798	150594
SWE	52184	90443	117312	135442	146974
A1	49921	89940	119474	139939	152932
A2	49919	89919	119568	139805	152507
A2+CCS	50009	92247	127757	150778	164607
A2+Gas Switching	49846	91318	127268	152302	168091
A3	56746	98696	125628	142647	152927
ParCom with Re	50626	93932	127950	151462	166785
ParCom without Re	52698	97742	133099	157656	173487
Applmp	49900	89773	120313	141888	155970
LC-R1	56746	98615	125431	142307	152456
LC-R2004	56702	98563	125480	142378	152573
Ref No retrofit	49833	90255	121514	143598	158034
SWE-No retrofit	54240	97943	131196	155291	171752
RT2005 No retrofit	50504	89515	118585	138855	152015
Ref CCS	49893	91504	128122	152792	168163
Ref GS	49851	91373	129064	156430	174425
A1 No Retrofit	49755	90084	120095	141019	154369
A2 No Retrofit	49755	90084	120246	140975	154063
LC-R1 CCS	56736	99710	129881	148330	159096
LC-R1 GS	56608	99318	130486	150515	162631
CAN	50273	89544	119041	139601	152981
CAN No retrofit	50113	89780	119928	141169	155035
SWE CCS	52260	92372	124273	144917	157517
SWE GS	52067	91513	123656	145903	160091
SWE REN	52434	91070	117434	134711	145849
A2 REN	50132	89873	118456	137385	149009
LC REN	55809	96127	122039	138910	149170
A2+GS+CCS					
ParCom No retro +CCS	52814	100999	144663	173153	190493
ParCom No retro +GS	50728	94765	129445	153339	168872
temperature	49985	89792	119588	140163	153375
RT2005+GS	50561	91204	128023	153828	170410
RT 2005 + CCS	50692	90837	123819	145419	158661

DR=16%	2010	2015	2020	2025	2030
TJ-2004	46002	76207	95633	107157	113470
RT2005	46730	76081	94299	104906	110660
SWE	48116	77154	94279	103989	109175
A1	46003	76353	95170	106130	111974
A2	46002	76337	95235	106076	111789
A2+CCS	46075	78019	100670	113011	119235
A2+Gas Switching	45935	77308	100213	113623	120725
A3	52237	84108	101292	110413	115040
ParCom with Re	46594	79394	101066	113654	120541
ParCom without Re	48481	82601	105119	118267	125386
Applmp	45984	76204	95656	107205	113537
LC-R1	52237	84048	101159	110204	114771
LC-R2004	52196	83998	101174	110230	114818
Ref No retrofit	45915	76546	96454	108276	114766
SWE-No retrofit	51921	89390	114999	131677	141951
RT2005 No retrofit	46559	76139	94657	105510	111427
Ref CCS	45979	77422	100761	113978	120892
Ref GS	45940	77325	101319	115967	124058
A1 No Retrofit	45846	76427	95546	106752	112756
A2 No Retrofit	45846	76427	95650	106754	112640
LC-R1 CCS	52228	84817	104081	113973	118820
LC-R1 GS	52117	84503	104386	115120	120573
CAN	46338	76110	94901	105909	111924
CAN No retrofit	46186	76254	95456	106827	113061
SWE CCS	48178	78546	98892	109955	115625
SWE GS	48011	77883	98360	110274	116655
SWE REN	48333	77666	94478	103732	108736
A2 REN	46188	76340	94568	104712	109941
LC REN	51409	82046	98577	107616	112232
A2+GS+CCS					
ParCom No retro +CCS	48577	84956	112790	128059	135862
ParCom No retro +GS	46679	80030	102124	114918	121900
temperature	46058	76235	95219	106236	112177
RT2005+GS	46616	77331	100784	114602	122059
RT 2005 + CCS	46734	77104	98136	109710	115668

Hypothesis 3. High carbon price

Table A- 8

DR=0%	2010	2015	2020	2025	2030
TJ-2004	67805	176790	327594	517106	735806
RT2005	68667	173980	314888	488902	687880
SWE	70604	173958	305376	463460	641459
A1	67811	176797	322459	501912	703673
A2	67805	176692	322243	498896	695372
A2+CCS	67969	181989	342730	526035	720111
A2+Gas Switching	67673	180516	350775	560186	793824
A3	76931	187624	315006	458293	611734
ParCom with Re	69166	188423	357157	564503	803480
ParCom without Re	72037	195866	371447	588519	836183
Applmp	67781	176869	327981	518097	737718

LC-R1	76931	187382	314172	456059	607277
LC-R2004	76885	187416	314795	456847	608666
Ref No retrofit	67745	178426	333021	527216	752066
SWE-No retrofit	70359	174288	308483	471305	655898
RT2005 No retrofit	68454	174764	318255	496612	701619
Ref CCS	67779	180914	348110	546305	763844
Ref GS	67689	181140	360423	590303	857386
A1 No Retrofit	67627	177619	325879	509684	717375
A2 No Retrofit	67627	177619	326043	507506	710592
LC-R1 CCS	76920	189921	325337	471438	621898
LC-R1 GS	76724	189791	333851	497594	672969
CAN	68187	175160	320328	500373	708050
CAN No retrofit	68028	176438	325546	512705	728969
SWE CCS	70733	178262	322918	487493	664208
SWE GS	70429	177060	329351	515658	725510
SWE REN	70942	174202	299959	445223	610107
A2 REN	68027	174583	310883	469504	640620
LC REN	75498	181873	303871	443852	593872
A2+GS+CCS					
ParCom No retro +CCS	72239	203087	399354	623628	863674
ParCom No retro +GS	69334	190190	361130	570395	810890
temperature	67928	176688	323427	503474	707806
RT2005+GS	68482	179187	352457	567161	810966
RT 2005 + CCS	68684	177021	326601	498669	684206

DR=4%	2010	2015	2020	2025	2030
TJ-2004	60990	140207	230467	323889	412611
RT2005	61808	138405	222768	308565	389295
SWE	63571	138820	217537	295502	367735
A1	60995	140268	227481	315988	397866
A2	60990	140192	227381	314527	394269
A2+CCS	61122	143869	240263	330773	409595
A2+Gas Switching	60875	142739	244689	347993	442822
A3	69178	149877	226283	297007	359317
ParCom with Re	62113	148732	249753	351982	448893
ParCom without Re	64674	154621	259701	366736	467222
Applmp	60968	140259	230702	324420	413514
LC-R1	69178	149706	225760	295799	357207
LC-R2004	69133	149713	226123	296238	357888
Ref No retrofit	60922	141355	233883	329609	420815
SWE-No retrofit	63347	138995	219364	299657	374558
RT2005 No retrofit	61609	138920	224820	312751	395921
Ref CCS	60966	146572	263809	376637	476694
Ref GS	60887	143123	250376	363690	472036
A1 No Retrofit	60820	140813	229573	320219	404496
A2 No Retrofit	60820	140813	229712	319221	401639
LC-R1 CCS	69168	151423	232711	304875	366005
LC-R1 GS	69001	151262	237651	318476	389700
CAN	61355	139137	226046	314806	399048
CAN No retrofit	61201	140010	229258	321520	409250
SWE CCS	63676	141800	228530	309767	381526
SWE GS	63417	140870	232051	323937	409105
SWE REN	63859	139081	214477	286138	352983
A2 REN	61184	138743	220457	298755	368217

<i>LC REN</i>	67939	145508	218684	287768	348670
<i>A2+GS+CCS</i>					
<i>ParCom No retro +CCS</i>	64838	159635	277257	387973	485453
<i>ParCom No retro +GS</i>	62250	150025	252375	355555	453086
<i>temperature</i>	61093	140168	228032	316816	399726
<i>RT2005+GS</i>	61644	141875	245596	351474	450409
<i>RT 2005 + CCS</i>	61821	140476	230142	315070	390407

DR=8%	2010	2015	2020	2025	2030
<i>TJ-2004</i>	55324	113770	169011	216449	253797
<i>RT2005</i>	56101	112648	164296	207869	241857
<i>SWE</i>	57717	113324	161536	201143	231559
<i>A1</i>	55328	113854	167249	212213	246691
<i>A2</i>	55324	113799	167204	211485	245068
<i>A2+CCS</i>	55432	116393	175499	221531	254747
<i>A2+Gas Switching</i>	55223	115515	177939	230431	270369
<i>A3</i>	62721	122432	169291	205247	231501
<i>ParCom with Re</i>	56257	120117	181961	233879	274660
<i>ParCom without Re</i>	58558	124877	189183	243546	285851
<i>Applmp</i>	55304	113803	169156	216744	254247
<i>LC-R1</i>	62721	122309	168954	204565	230440
<i>LC-R2004</i>	62679	122300	169164	204811	230787
<i>Ref No retrofit</i>	55250	114581	171211	219816	258205
<i>SWE-No retrofit</i>	57509	113398	162616	203400	234937
<i>RT2005 No retrofit</i>	55915	112981	165565	210218	245230
<i>Ref CCS</i>	55303	118135	189974	247333	289492
<i>Ref GS</i>	55231	115750	181360	238896	284503
<i>A1 No Retrofit</i>	55162	114212	168548	214594	250080
<i>A2 No Retrofit</i>	55162	114212	168658	214135	248842
<i>LC-R1 CCS</i>	62712	123487	173377	210091	235861
<i>LC-R1 GS</i>	62569	123320	176290	217383	247397
<i>CAN</i>	55673	113079	166283	211356	246814
<i>CAN No retrofit</i>	55524	113676	168300	215148	252078
<i>SWE CCS</i>	57802	115420	168590	209894	240130
<i>SWE GS</i>	57580	114691	170515	217195	253061
<i>SWE REN</i>	57964	113580	159798	196211	224331
<i>A2 REN</i>	55496	112794	162885	202693	231951
<i>LC REN</i>	61642	119049	163927	199044	224698
<i>A2+GS+CCS</i>					
<i>ParCom No retro +CCS</i>	58692	128416	200493	256790	297864
<i>ParCom No retro +GS</i>	56369	121078	183740	236144	277187
<i>temperature</i>	55411	113767	167564	212661	247569
<i>RT2005+GS</i>	55955	114987	178478	232259	273918
<i>RT 2005 + CCS</i>	56112	114081	169041	212217	243958

DR=10%	2010	2015	2020	2025	2030
<i>TJ-2004</i>	52845	103310	146866	181023	205570
<i>RT2005</i>	53603	102443	143172	174548	196889
<i>SWE</i>	55153	103204	141232	169756	189750
<i>A1</i>	52849	103400	145507	177890	200555
<i>A2</i>	52845	103352	145476	177371	199449
<i>A2+CCS</i>	52943	105544	152189	185359	207203
<i>A2+Gas Switching</i>	52751	104767	153996	191805	218061
<i>A3</i>	59894	111522	148505	174410	191675

<i>ParCom with Re</i>	53697	108818	157585	194971	221771
<i>ParCom without Re</i>	55884	113129	163830	202977	230785
<i>Applmp</i>	52827	103337	146980	181244	205895
<i>LC-R1</i>	59894	111417	148233	173890	190905
<i>LC-R2004</i>	59852	111402	148391	174073	191154
<i>Ref No retrofit</i>	52770	103994	148644	183640	208871
<i>SWE-No retrofit</i>	54954	103243	142060	171431	192162
<i>RT2005 No retrofit</i>	53423	102708	144172	176325	199338
<i>Ref CCS</i>	52825	104904	153313	189114	213573
<i>Ref GS</i>	52758	104948	156668	198095	228071
<i>A1 No Retrofit</i>	52687	103687	146534	179695	203022
<i>A2 No Retrofit</i>	52687	103687	146630	179384	202200
<i>LC-R1 CCS</i>	59885	112398	151788	178248	195198
<i>LC-R1 GS</i>	59752	112233	154035	183642	203380
<i>CAN</i>	53186	102761	144716	177170	200476
<i>CAN No retrofit</i>	53040	103255	146324	180056	204329
<i>SWE CCS</i>	55230	104973	146930	176688	196571
<i>SWE GS</i>	55024	104324	148346	181965	205544
<i>SWE REN</i>	55383	103453	139923	166150	184626
<i>A2 REN</i>	53007	102513	142038	170719	189955
<i>LC REN</i>	58884	108526	143945	169244	186111
<i>A2+GS+CCS</i>					
<i>ParCom No retro +CCS</i>	56005	116119	172983	213546	240555
<i>ParCom No retro +GS</i>	53799	109651	159064	196801	223774
<i>temperature</i>	52926	103319	145744	178220	201167
<i>RT2005+GS</i>	53466	104371	154435	193165	220551
<i>RT 2005 + CCS</i>	53613	103641	147006	178112	198984

DR=12%	2010	2015	2020	2025	2030
<i>TJ-2004</i>	50570	94288	128800	153556	169824
<i>RT2005</i>	51309	93632	125908	148651	163457
<i>SWE</i>	52798	94456	124599	145277	158529
<i>A1</i>	50573	94380	127749	151225	166247
<i>A2</i>	50570	94338	127729	150854	165488
<i>A2+CCS</i>	50658	96197	133190	157249	171733
<i>A2+Gas Switching</i>	50481	95507	134523	161935	179339
<i>A3</i>	57296	102083	131415	150201	161648
<i>ParCom with Re</i>	51348	99083	137730	164828	182586
<i>ParCom without Re</i>	53431	103006	143178	171554	189984
<i>Applmp</i>	50552	94309	128890	153724	170059
<i>LC-R1</i>	57296	101992	131193	149800	161081
<i>LC-R2004</i>	57256	101973	131312	149936	161261
<i>Ref No retrofit</i>	50493	94865	130243	155607	172327
<i>SWE-No retrofit</i>	54854	101992	138644	165412	183694
<i>RT2005 No retrofit</i>	51135	93840	126698	150002	165254
<i>Ref CCS</i>	50551	95619	133995	159953	176167
<i>Ref GS</i>	50487	95647	136619	166643	186508
<i>A1 No Retrofit</i>	50416	94608	128562	152601	168062
<i>A2 No Retrofit</i>	50416	94608	128645	152392	167515
<i>LC-R1 CCS</i>	57287	102811	134065	153260	164500
<i>LC-R1 GS</i>	57164	102650	135802	157274	170361
<i>CAN</i>	50903	93857	127104	150627	166071
<i>CAN No retrofit</i>	50760	94264	128391	152839	168924

<i>SWE CCS</i>	52868	95954	129226	150808	163990
<i>SWE GS</i>	52676	95375	130262	154634	170263
<i>SWE REN</i>	53012	94697	123616	142631	154872
<i>A2 REN</i>	50723	93636	124979	145778	158530
<i>LC REN</i>	56350	99417	127510	145854	157036
<i>A2+GS+CCS</i>					
<i>ParCom No retro +CCS</i>	53541	105543	150626	180044	197952
<i>ParCom No retro +GS</i>	51441	99808	138967	166321	184194
<i>temperature</i>	50645	94305	127928	151469	166678
<i>RT2005+GS</i>	51179	95224	134896	162972	181123
<i>RT 2005 + CCS</i>	51318	94637	129023	151580	165418

DR=16%	2010	2015	2020	2025	2030
<i>TJ-2004</i>	46547	79666	101642	114892	122206
<i>RT2005</i>	47251	79331	99889	112064	118722
<i>SWE</i>	48631	80236	99442	110515	116475
<i>A1</i>	46551	79757	101012	113583	120338
<i>A2</i>	46547	79725	101003	113388	119970
<i>A2+CCS</i>	46620	81076	104673	117569	124087
<i>A2+Gas Switching</i>	46469	80527	105382	120064	127892
<i>A3</i>	52699	86716	105429	115495	120646
<i>ParCom with Re</i>	47200	83337	107951	122457	130439
<i>ParCom without Re</i>	49096	86629	112207	127398	135685
<i>Applmp</i>	46531	79679	101698	114990	122335
<i>LC-R1</i>	52699	86649	105279	115250	120326
<i>LC-R2004</i>	52660	86624	105342	115322	120418
<i>Ref No retrofit</i>	46469	80076	102603	116179	123695
<i>SWE-No retrofit</i>	52437	92497	120268	138375	149468
<i>RT2005 No retrofit</i>	47088	79453	100380	112854	119711
<i>Ref CCS</i>	46530	80603	105061	118967	126261
<i>Ref GS</i>	46473	80607	106686	122756	131687
<i>A1 No Retrofit</i>	46401	79895	101521	114392	121345
<i>A2 No Retrofit</i>	46401	79895	101582	114300	121101
<i>LC-R1 CCS</i>	52691	87225	107178	117470	122530
<i>LC-R1 GS</i>	52584	87076	108222	119728	125617
<i>CAN</i>	46866	79416	100591	113183	120126
<i>CAN No retrofit</i>	46729	79689	101420	114506	121737
<i>SWE CCS</i>	48689	81321	102540	114106	120037
<i>SWE GS</i>	48521	80855	103077	116128	123158
<i>SWE REN</i>	48818	80457	98898	109082	114582
<i>A2 REN</i>	46684	79233	99220	110366	116102
<i>LC REN</i>	51864	84581	102503	112331	117361
<i>A2+GS+CCS</i>					
<i>ParCom No retro +CCS</i>	49187	88473	117213	132979	141037
<i>ParCom No retro +GS</i>	47277	83891	108833	123477	131510
<i>temperature</i>	46612	79694	101112	113716	120555
<i>RT2005+GS</i>	47135	80423	105689	120722	128884
<i>RT 2005 + CCS</i>	47259	80047	101972	114059	120285

Case B : inclusion of electricity surplus in the large heat plants

Exhibit 1 : CO₂ emission costs are excluded

Table A- 9 cumulative cost (million yuan , 2005 price)

DR =0%	Price escalation 1% per year				
	2010	2015	2020	2025	2030
TJ-2004	65611	149166	245436	354257	474518
RT2005	66790	150557	244794	349642	464458
SWE	68749	153719	248955	352238	460067
A1	65611	150598	246174	353686	470331
A2	65611	150598	247936	356811	473757
A2+CCS	65743	158875	294932	446128	605313
A2+Gas Switching	65585	155962	284221	434213	596830
A3	75268	170866	272676	380819	492259
ParCom with Re	66122	151561	251507	364293	489405
ParCom without Re	68879	157435	259875	373183	497628
AppImp	65540	148665	244028	351414	469690
LC-R1	75268	170679	271845	378137	487089
LC-R2004	75213	170530	272182	379926	491150
Ref No retrofit	65444	149499	247255	358988	480146
SWE-No retrofit	68502	153406	248003	352732	464509
RT2005 No retrofit	66549	150695	246172	353581	469063
Ref CCS	65538	155980	292325	447514	615298
Ref GS	65600	155157	286831	445586	624124
A1 No Retrofit	65368	150746	247594	357701	474903
A2 No Retrofit	65368	150746	249333	360678	478031
LC-R1 CCS	75253	175193	299147	430472	564009
LC-R1 GS	75043	173513	296320	430759	570206
CAN	66223	150364	246845	356049	473853
CAN No retrofit	65901	149533	245234	353027	472036
SWE CCS	68895	160564	287041	426948	576634
SWE GS	68591	157343	276491	414319	565661
SWE REN	69195	156196	255011	366146	491479
A2 REN	66242	155045	259642	379289	509854
LC REN	73862	165582	264126	375107	492369
ParCom No retro +CCS	69067	169332	328449	505543	694286
ParCom No retro +GS	66321	153890	257562	374658	504462
temperature	65643	149326	245733	354624	474764
RT2005+GS	66614	156961	291245	448182	621195
RT 2005 + CCS	66791	156531	283390	424603	575743
min			244028	349642	460067

DR =0%	Price escalation 2% per year				
	2010	2015	2020	2025	2030
TJ-2004	65609	149148	245345	354100	474246
RT2005	66790	150551	244741	349545	464286
SWE	68749	153719	248944	352213	459983
A1	65609	150584	246101	353566	470133
A2	65609	150584	247869	356702	473582

A2+CCS	65741	158859	294859	446011	605126
A2+Gas Switching	65583	155949	284150	434093	596629
A3	75268	170866	272675	380817	492253
ParCom with Re	66114	151516	251344	364038	488983
ParCom without Re	68870	157386	259693	372888	497149
Applmp	65537	148645	243930	351243	469393
LC-R1	75268	170679	271842	378129	487068
LC-R2004	75213	170530	272181	379925	491145
Ref No retrofit	65441	149478	247154	358821	479840
SWE-No retrofit	68502	153406	247981	352691	464415
RT2005 No retrofit	66549	150688	246118	353486	468873
Ref CCS	65536	155961	292230	447351	615016
Ref GS	65598	155140	286736	445419	623825
A1 No Retrofit	65365	150731	247522	357582	474687
A2 No Retrofit	65365	150731	249265	360570	477839
LC-R1 CCS	75253	175193	299147	430472	564008
LC-R1 GS	75043	173513	296318	430754	570192
CAN	66223	150354	246781	355939	473641
CAN No retrofit	65899	149517	245150	352881	471780
SWE CCS	68895	160564	287016	426900	576547
SWE GS	68591	157343	276465	414268	565566
SWE REN	69195	156196	255011	366146	491477
A2 REN	66242	155044	259623	379262	509824
LC REN	73862	165582	264123	375104	492366
ParCom No retro +CCS	69057	169281	328263	505244	693800
ParCom No retro +GS	66312	153845	257398	374402	504037
temperature	65641	149308	245655	354497	474557
RT2005+GS	66614	156955	291185	448072	620995
RT 2005 + CCS	66791	156524	283333	424500	575560

DR =0%	Price escalation 3% per year				
	2010	2015	2020	2025	2030
TJ-2004	65607	149130	245254	353943	473974
RT2005	66790	150546	244688	349449	464113
SWE	68749	153719	248933	352188	459899
A1	65607	150570	246029	353445	469934
A2	65607	150570	247802	356593	473407
A2+CCS	65738	158844	294787	445894	604938
A2+Gas Switching	65581	155936	284078	433973	596427
A3	75268	170866	272674	380816	492248
ParCom with Re	66105	151471	251181	363783	488560
ParCom without Re	68861	157337	259510	372594	496670
Applmp	65534	148625	243831	351073	469096
LC-R1	75268	170679	271838	378121	487047
LC-R2004	75213	170530	272180	379923	491140
Ref No retrofit	65438	149457	247053	358653	479534
SWE-No retrofit	68502	153406	247959	352650	464322
RT2005 No retrofit	66549	150682	246065	353391	468684

Ref CCS	65533	155942	292135	447187	614734
Ref GS	65597	155124	286641	445252	623526
A1 No Retrofit	65363	150716	247449	357463	474471
A2 No Retrofit	65363	150716	249197	360463	477647
LC-R1 CCS	75253	175193	299146	430471	564007
LC-R1 GS	75043	173513	296315	430750	570178
CAN	66222	150344	246717	355829	473428
CAN No retrofit	65897	149502	245066	352735	471524
SWE CCS	68895	160564	286991	426852	576460
SWE GS	68591	157343	276439	414217	565471
SWE REN	69195	156196	255011	366145	491475
A2 REN	66242	155043	259605	379235	509794
LC REN	73862	165582	264120	375101	492363
ParCom No retro +CCS	69048	169230	328076	504944	693313
ParCom No retro +GS	66304	153800	257234	374146	503613
temperature	65638	149290	245577	354370	474350
RT2005+GS	66614	156949	291124	447962	620795
RT 2005 + CCS	66791	156518	283277	424397	575377

DR =4%	Price escalation 1% per year				
	2010	2015	2020	2025	2030
TJ-2004	59187	120121	177860	231557	280356
RT2005	60264	121377	177911	229655	276251
SWE	62046	124032	181180	232194	275994
A1	59187	121192	178529	231599	278942
A2	59187	121192	179602	233356	280826
A2+CCS	59293	126862	208503	283174	347820
A2+Gas Switching	59158	124828	201711	275744	341766
A3	67810	137587	198716	252139	297405
ParCom with Re	59612	121898	181849	237502	288254
ParCom without Re	62079	126648	188091	244008	294510
Applmp	59126	119751		229941	277938
LC-R1	67810	137454	198210	250721	294974
LC-R2004	67759	137331	198363	251588	296763
Ref No retrofit	59030	120322	178934	234081	283274
SWE-No retrofit	61820	123769	180515	232220	277612
RT2005 No retrofit	60043	121425	178686	231707	278600
Ref CCS	59125	128270	227092	318726	398590
Ref GS	59170	124196	203062	281366	353819
A1 No Retrofit	58964	121246	179331	233693	281290
A2 No Retrofit	58964	121246	180390	235375	283039
LC-R1 CCS	67797	140503	214933	279820	334083
LC-R1 GS	67619	139283	212979	279379	336029
CAN	59741	121109	178967	232870	280704
CAN No retrofit	59452	120450		231042	279333
SWE CCS	62165	128739	204615	273688	334465
SWE GS	61906	126447	197860	265872	327308
SWE REN	62423	125884	185155	239991	290806
A2 REN	59717	124479	187224	246279	299269

LC REN	66594	133554	192685	247469	295086
ParCom No retro +CCS	62231	134815	230229	317667	394310
ParCom No retro +GS	59773	123595	185778	243560	296217
temperature	59215	120240	178062	231794	280547
RT2005+GS	60109	125664	206140	283576	353805
RT 2005 + CCS	60266	125411	201510	271225	332592

DR =4%	Price escalation 2% per year				
	2010	2015	2020	2025	2030
TJ-2004	59185	120108	177804	231468	280220
RT2005	60264	121373	177879	229602	276166
SWE	62046	124032	181174	232181	275957
A1	59185	121182	178484	231530	278841
A2	59185	121182	179560	233293	280736
A2+CCS	59291	126851	208458	283107	347724
A2+Gas Switching	59157	124819	201666	275676	341664
A3	67810	137587	198716	252139	297402
ParCom with Re	59605	121864	181745	237353	288036
ParCom without Re	62071	126611	187974	243837	294263
Applmp	59124	119736		229844	277789
LC-R1	67810	137454	198208	250717	294964
LC-R2004	67759	137331	198362	251587	296761
Ref No retrofit	59028	120306	178872	233985	283122
SWE-No retrofit	61820	123769	180502	232198	277569
RT2005 No retrofit	60043	121421	178653	231654	278509
Ref CCS	59123	128256	227032	318634	398449
Ref GS	59168	124184	203003	281272	353671
A1 No Retrofit	58961	121235	179285	233625	281183
A2 No Retrofit	58961	121235	180347	235313	282943
LC-R1 CCS	67797	140503	214932	279820	334082
LC-R1 GS	67619	139283	212978	279377	336023
CAN	59740	121102	178927	232808	280601
CAN No retrofit	59451	120439		230959	279206
SWE CCS	62165	128739	204601	273662	334423
SWE GS	61906	126447	197845	265845	327263
SWE REN	62423	125884	185155	239990	290805
A2 REN	59717	124479	187213	246264	299252
LC REN	66594	133554	192684	247468	295084
ParCom No retro +CCS	62223	134777	230111	317492	394059
ParCom No retro +GS	59766	123562	185674	243410	295999
temperature	59213	120227	178013	231721	280441
RT2005+GS	60109	125659	206103	283515	353707
RT 2005 + CCS	60266	125406	201475	271168	332502

DR =4%	Price escalation 3% per year				
	2010	2015	2020	2025	2030
TJ-2004	59183	120094	177747	231378	280084

RT2005	60264	121369	177846	229548	276082
SWE	62046	124032	181168	232168	275921
A1	59183	121171	178439	231461	278740
A2	59183	121171	179518	233230	280647
A2+CCS	59289	126839	208413	283039	347628
A2+Gas Switching	59156	124810	201622	275608	341563
A3	67810	137587	198715	252138	297399
ParCom with Re	59598	121831	181641	237204	287819
ParCom without Re	62063	126575	187858	243666	294017
Applmp	59122	119722		229747	277641
LC-R1	67810	137454	198206	250713	294954
LC-R2004	67759	137331	198362	251587	296759
Ref No retrofit	59025	120291	178809	233889	282970
SWE-No retrofit	61820	123769	180489	232175	277525
RT2005 No retrofit	60043	121416	178621	231601	278417
Ref CCS	59121	128242	226973	318541	398308
Ref GS	59167	124172	202945	281178	353523
A1 No Retrofit	58959	121224	179239	233556	281075
A2 No Retrofit	58959	121224	180304	235251	282847
LC-R1 CCS	67797	140503	214932	279820	334082
LC-R1 GS	67619	139283	212977	279374	336017
CAN	59740	121094	178888	232746	280497
CAN No retrofit	59450	120427		230876	279079
SWE CCS	62165	128739	204586	273636	334381
SWE GS	61906	126447	197829	265817	327217
SWE REN	62423	125884	185155	239990	290804
A2 REN	59717	124478	187201	246248	299235
LC REN	66594	133554	192682	247466	295082
ParCom No retro +CCS	62215	134739	229992	317318	393809
ParCom No retro +GS	59759	123528	185570	243260	295780
temperature	59211	120214	177964	231648	280335
RT2005+GS	60109	125655	206066	283454	353609
RT 2005 + CCS	60266	125402	201441	271111	332412

DR =8%	Price escalation 2% per year				
	2010	2015	2020	2025	2030
TJ-2004	53829	98921	134302	161577	182105
RT2005	54823	100069	134728	161021	180629
SWE	56454	102345	137405	163353	181804
A1	53829	99734	134883	161853	181778
A2	53829	99734	135552	162877	182860
A2+CCS	53915	103680	153749	191721	218950
A2+Gas Switching	53800	102236	149338	186964	214763
A3	61589	113276	150802	177985	197061
ParCom with Re	54179	100245	136970	165233	186568
ParCom without Re	56402	104163	141795	170191	191424
Applmp	53777	98641			180797
LC-R1	61589	113180	150484	177202	195849
LC-R2004	61541	113076	150541	177622	196661
Ref No retrofit	53682	99031	134936	162954	183654

SWE-No retrofit	56246	102118	136916	163203	182321
RT2005 No retrofit	54619	100058	135154	162102	181843
Ref CCS	53776	104485	165053	211638	245273
Ref GS	53809	101734	150007	189772	220258
A1 No Retrofit	53623	99728	135326	162959	182999
A2 No Retrofit	53623	99728	135987	163944	184017
LC-R1 CCS	61577	115269	160964	193986	216864
LC-R1 GS	61425	114367	159585	193363	217241
CAN	54336	99756	135213	162606	182742
CAN No retrofit	54075	99219	134397	161416	181731
SWE CCS	56551	105635	152169	187288	212887
SWE GS	56328	103972	147730	182293	208163
SWE REN	56775	103755	140106	167974	189353
A2 REN	54281	102214	140691	170712	193027
LC REN	60529	110139	146417	174272	194334
ParCom No retro +CCS	56526	109858	168310	212748	245009
ParCom No retro +GS	54312	101501	139594	168939	191076
temperature	53855	99012	134449	161747	182261
RT2005+GS	54684	102973	152268	191612	221177
RT 2005 + CCS	54824	102832	149489	184928	210768

DR =10%	Price escalation 2% per year				
	2010	2015	2020	2025	2030
TJ-2004	51482	90476	118400	138047	151541
RT2005	52437	91571	118928	137870	150760
SWE	54001	93693	121369	140069	152203
A1	51482	91187	118930	138362	151461
A2	51482	91187	119462	139151	152289
A2+CCS	51560	94497	134022	161386	179292
A2+Gas Switching	51453	93272	130437	157545	175824
A3	58861	103576	133208	152799	165345
ParCom with Re	51802	91631	120617	140977	154999
ParCom without Re	53918	95216	124916	145373	159331
AppImp	51433	90232			
LC-R1	58861	103494	132953	152210	164473
LC-R2004	58814	103398	132981	152499	165020
Ref No retrofit	51339	90554	118886	139071	152683
SWE-No retrofit	53801	93479	120944	139885	152457
RT2005 No retrofit	52240	91540	119238	138653	151635
Ref CCS	51432	93056	132590	160635	179490
Ref GS	51460	92825	130899	159539	179580
A1 No Retrofit	51283	91160	119253	139165	152343
A2 No Retrofit	51283	91160	119779	139926	153126
LC-R1 CCS	58849	105232	141316	165118	180167
LC-R1 GS	58709	104451	140148	164491	180196
CAN	51966	91247	119228	138964	152204

CAN No retrofit	51718	90760	118524	137987	151341
SWE CCS	54089	96459	133189	158494	175326
SWE GS	53882	95032	129557	154455	171464
SWE REN	54298	94929	123619	143694	157742
A2 REN	51899	93350	123720	145348	160018
LC REN	57869	100791	129429	149498	162691
ParCom No retro +CCS	54030	99999	146127	178147	199361
ParCom No retro +GS	51922	92718	122783	143922	158472
temperature	51506	90556	118523	138188	151673
RT2005+GS	52305	93972	132863	161205	180642
RT 2005 + CCS	52438	93871	130697	156231	173223

DR =12%	Price escalation 2% per year				
	2010	2015	2020	2025	2030
TJ-2004	49324	83155	105302	119548	128492
RT2005	50243	84202	105902	119637	128181
SWE	51745	86187	108142	121708	129754
A1	49324	83779	105785	119877	128560
A2	49324	83779	106210	120490	129198
A2+CCS	49394	86566	117920	137771	149642
A2+Gas Switching	49295	85522	114991	134650	146768
A3	56352	95162	118675	132889	141207
ParCom with Re	49617	84167	107157	121921	131213
ParCom without Re	51634	87461	111017	125851	135103
Applmp	49279	82942			
LC-R1	56352	95092	118470	132441	140572
LC-R2004	56307	95003	118477	132637	140939
Ref No retrofit	49186	83206	105674	120312	129335
SWE-No retrofit	53801	93511	121182	140396	153273
RT2005 No retrofit	50054	84155	106122	120202	128809
Ref CCS	49278	85301	116653	136991	149490
Ref GS	49301	85123	115302	136065	149348
A1 No Retrofit	49133	83734	106016	120457	129194
A2 No Retrofit	49133	83734	106435	121049	129801
LC-R1 CCS	56341	96542	125177	142446	152427
LC-R1 GS	56211	95864	124183	141842	152256
CAN	49788	83870	106061	120374	129151
CAN No retrofit	49552	83427	105447	119560	128411
SWE CCS	51825	88521	117656	136009	147169
SWE GS	51633	87292	114667	132721	143996
SWE REN	52021	87276	110032	124588	133895
A2 REN	49710	85674	109762	125446	135170
LC REN	55422	92679	115398	129952	138699
ParCom No retro +CCS	51735	91493	128074	151298	165363
ParCom No retro +GS	49726	85111	108956	124284	133927
temperature	49347	83226	105407	119666	128604
RT2005+GS	50119	86192	117027	137577	150462
RT 2005 + CCS	50244	86123	115332	133851	145116

DR =16%	Price escalation 2% per year				
	2010	2015	2020	2025	2030
TJ-2004	45502	71206	85333	92965	96987
RT2005	46357	72167	86012	93371	97214
SWE	47748	73922	87934	95208	98829
A1	45502	71689	85730	93282	97187
A2	45502	71689	86005	93658	97576
A2+CCS	45560	73685	93696	104338	109680
A2+Gas Switching	45473	72918	91709	102243	107695
A3	51907	81415	96429	104051	107795
ParCom with Re	45747	71989	86656	94565	98743
ParCom without Re	47589	74804	89831	97779	101939
Applmp	45463	71040			
LC-R1	51907	81363	96293	103785	107445
LC-R2004	51864	81285	96274	103867	107604
Ref No retrofit	45372	71216	85545	93388	97448
SWE-No retrofit	51553	86033	108102	122172	130837
RT2005 No retrofit	46181	72095	86108	93654	97526
Ref CCS	45462	72702	92698	103596	109220
Ref GS	45477	72599	91828	102947	108921
A1 No Retrofit	45324	71620	85833	93574	97505
A2 No Retrofit	45324	71620	86105	93939	97877
LC-R1 CCS	51897	82383	100668	109931	114425
LC-R1 GS	51784	81864	99938	109406	114094
CAN	45931	71827	85982	93651	97600
CAN No retrofit	45715	71454	85502	93062	97042
SWE CCS	47814	75602	94192	104029	109050
SWE GS	47646	74678	92132	101804	106876
SWE REN	47986	74777	89294	97092	101274
A2 REN	45834	73158	88527	96931	101304
LC REN	51085	79418	93918	101717	105652
ParCom No retro +CCS	47672	77698	101030	113478	119806
ParCom No retro +GS	45838	72707	87919	96131	100466
temperature	45523	71262	85412	93050	97070
RT2005+GS	46245	73542	93199	104208	110004
RT 2005 + CCS	46358	73518	92154	102080	107148

Exhibit II. Inclusion of CO2 emission cost (million yuan , 2005 price)

Case I. Low carbon price expectation

Table A- 10

DR =0%	Price escalation 2% per year				
	2010	2015	2020	2025	2030
TJ-2004	66428	156802	265015	390484	530697
RT2005	67572	157726	262933	382907	515753

SWE	69522	160475	265482	381930	505187
A1	66430	158093	265088	388122	522951
A2	66428	158058	266526	390282	524543
A2+CCS	66559	165324	305732	462230	627225
A2+Gas Switching	66383	162973	300338	462576	639664
A3	75961	176514	285478	402747	524668
ParCom with Re	67023	160271	273944	405186	552065
ParCom without Re	69792	166340	283066	416020	563676
Applmp	66358	156335	263722	387908	526358
LC-R1	75961	176309	284577	399802	518916
LC-R2004	75910	176221	285075	401739	523114
Ref No retrofit	66271	157297	267303	395958	537569
SWE-No retrofit	69276	160234	264975	383511	511621
RT2005 No retrofit	67343	158011	264781	387855	522084
Ref CCS	66363	162724	304230	466003	641260
Ref GS	66398	162322	303745	476202	671471
A1 No Retrofit	66198	158388	266981	393150	529254
A2 No Retrofit	66198	158388	268508	395413	530999
LC-R1 CCS	75948	180226	307393	442562	580363
LC-R1 GS	75743	179023	307736	449631	597800
CAN	67016	157654	265299	389798	526113
CAN No retrofit	66714	157116	264666	389001	527896
SWE CCS	69661	166411	296931	441646	596516
SWE GS	69357	163792	291115	439906	604184
SWE REN	69923	162258	268653	388735	524014
A2 REN	66986	161356	274128	403384	544072
LC REN	74544	171057	276059	394638	520181
ParCom No retro +CCS	69973	176707	339895	521650	715306
ParCom No retro +GS	67209	162408	279359	414247	564963
temperature	66472	156943	264727	388903	526928
RT2005+GS	67393	163677	306444	475087	662152
RT 2005 + CCS	67580	162739	293713	439816	596218
	66198	156335	262933	381930	505187

DR =4%	Price escalation 2% per year				
	2010	2015	2020	2025	2030
TJ-2004	59858	125725	190599	252495	309385
RT2005	60907	126642	189730	248926	302833
SWE	62682	129002	191992	249493	299551
A1	59860	126696	190857	251575	306294
A2	59858	126671	191735	252822	307317
A2+CCS	59963	131658	215906	293192	360197
A2+Gas Switching	59814	129995	212321	292388	364278
A3	68380	141757	207167	265089	314607
ParCom with Re	60352	128283	196438	261185	320763
ParCom without Re	62829	133174	203151	268748	328663
Applmp	59799	125379	189761	251026	307203
LC-R1	68380	141611	206617	263532	311909
LC-R2004	68332	141531	206876	264498	313793
Ref No retrofit	59711	126043	191975	255455	312940

SWE-No retrofit	62456	128789	191598	250105	302122
RT2005 No retrofit	60696	126797	190804	251541	306037
Ref CCS	59803	133277	235188	330069	412964
Ref GS	59826	129472	214161	299212	378447
A1 No Retrofit	59646	126858	191959	254235	309500
A2 No Retrofit	59646	126858	192895	255547	310607
LC-R1 CCS	68368	144257	220613	287397	343390
LC-R1 GS	68195	143364	220596	290670	350858
CAN	60392	126462	190991	252427	307765
CAN No retrofit	60121	126016	190495	251832	308188
SWE CCS	62795	133092	211391	282836	345718
SWE GS	62536	131205	207507	280921	347602
SWE REN	63022	130356	194171	253421	308268
A2 REN	60329	129129	196772	260571	317671
LC REN	67155	137598	200603	259136	310112
ParCom No retro +CCS	62975	140302	238159	327897	406534
ParCom No retro +GS	60503	129841	199961	266509	327647
temperature	59896	125834	190457	251722	307728
RT2005+GS	60749	130617	216162	299364	375291
RT 2005 + CCS	60914	130030	208594	280723	344225
	59646	125379	189730	248926	299551

DR =8%	Price escalation 2% per year				
	2010	2015	2020	2025	2030
TJ-2004	54386	103108	142875	174326	198278
RT2005	55355	103999	142681	172765	195463
SWE	56980	106060	144694	173939	195033
A1	54388	103849	143188	174052	197095
A2	54386	103830	143735	174793	197744
A2+CCS	54472	107308	158994	198306	226540
A2+Gas Switching	54345	106109	156560	197261	227544
A3	62061	116402	156549	186015	206883
ParCom with Re	54798	105025	146807	179709	204786
ParCom without Re	57030	109049	151943	185279	210506
Applmp	54336	102848		173447	197099
LC-R1	62061	116298	156204	185159	205546
LC-R2004	62015	116225	156331	185645	206418
Ref No retrofit	54247	103307	143713	175975	200187
SWE-No retrofit	56772	105867	144379	174123	196037
RT2005 No retrofit	55159	104068	143303	174175	197132
Ref CCS	54339	108268	170755	219005	253937
Ref GS	54353	105688	157547	200752	234114
A1 No Retrofit	54190	103922	143828	175490	198773
A2 No Retrofit	54190	103922	144414	176273	199473
LC-R1 CCS	62050	118111	164987	198972	222579
LC-R1 GS	61902	117436	164818	200463	225831
CAN	54875	103755	143308	174534	197844
CAN No retrofit	54629	103377	142904	174072	197798
SWE CCS	57072	108923	156951	193282	219774
SWE GS	56850	107538	154294	191605	219690

SWE REN	57270	107106	146241	176354	199428
A2 REN	54787	105694	147179	179614	203661
LC REN	60993	113174	151828	181587	203065
ParCom No retro +CCS	57149	114030	174029	219665	252798
ParCom No retro +GS	54922	106180	149166	182984	208719
temperature	54420	103195	142811	173945	197526
RT2005+GS	55214	106687	159099	201381	233358
RT 2005 + CCS	55360	106322	154508	191185	217939
	54190	102848	142681	172765	195033

DR =10%	Price escalation 2% per year				
	2010	2015	2020	2025	2030
TJ-2004	51990	94112	125489	148143	163887
RT2005	52922	94985	125511	147181	162102
SWE	54481	96922	127415	148488	162360
A1	51992	94761	125806	148040	163189
A2	51990	94745	126240	148617	163705
A2+CCS	52067	97666	138465	166795	185362
A2+Gas Switching	51949	96641	136445	165766	185677
A3	59291	106298	137996	159231	172955
ParCom with Re	52367	95780	128750	152448	168930
ParCom without Re	54491	99456	133301	157314	173897
Applmp	51943	93885		147450	162998
LC-R1	59291	106209	137719	158587	171994
LC-R2004	59247	106139	137805	158931	172592
Ref No retrofit	51855	94266	126144	149383	165302
SWE-No retrofit	54281	96737	127129	148558	162967
RT2005 No retrofit	52733	95022	125981	148221	163315
Ref CCS	51946	96358	137404	166648	186355
Ref GS	51956	96263	137161	168277	190207
A1 No Retrofit	51800	94802	126290	149101	164411
A2 No Retrofit	51800	94802	126757	149712	164968
LC-R1 CCS	59281	107717	144732	169229	184757
LC-R1 GS	59143	107127	144530	170217	186901
CAN	52459	94719	125928	148423	163748
CAN No retrofit	52224	94370	125559	148009	163605
SWE CCS	54565	99331	137240	163417	180837
SWE GS	54358	98136	135023	161900	180365
SWE REN	54750	97846	128732	150424	165586
A2 REN	52360	96377	129119	152487	168296
LC REN	58292	103434	133948	155388	169511
ParCom No retro +CCS	54598	103643	150991	183874	205661
ParCom No retro +GS	52479	96779	130699	155058	171973
temperature	52022	94189		147875	163377
RT2005+GS	52789	97204	138551	169007	190030
RT 2005 + CCS	52927	96919	134951	161377	178969

DR =12%	Price escalation 2% per year				
	2010	2015	2020	2025	2030
TJ-2004	49788	86323	111204	127628	138063
RT2005	50687	87178	111386	127098	136988
SWE	52184	89004	113190	128475	137672
A1	49790	86894	111514	127637	137678
A2	49788	86880	111861	128088	138090
A2+CCS	49858	89342	121707	142257	154567
A2+Gas Switching	49749	88462	120021	141284	154483
A3	56746	97540	122690	138095	147194
ParCom with Re	50133	87780	113925	131107	142029
ParCom without Re	52157	91153	117990	135401	146392
Applmp	49745	86124			137380
LC-R1	56746	97464	122467	137606	146495
LC-R2004	56702	97398	122522	137847	146905
Ref No retrofit	49657	86440	111715	128566	139118
SWE-No retrofit	54240	96353	126340	147357	161452
RT2005 No retrofit	50504	87189	111738	127865	137871
Ref CCS	49747	88191	120741	141949	155013
Ref GS	49755	88122	120537	143094	157628
A1 No Retrofit	49605	86909	111877	128419	138569
A2 No Retrofit	49605	86909	112251	128900	139014
LC-R1 CCS	56736	98723	128096	145868	156166
LC-R1 GS	56608	98205	127876	146508	157572
CAN	50238	86896	111643	127954	138113
CAN No retrofit	50014	86572	111304	127580	137917
SWE CCS	52260	91039	121108	140094	151643
SWE GS	52067	90003	119248	138736	150976
SWE REN	52434	89823	114320	130048	140094
A2 REN	50132	88316	114285	131231	141710
LC REN	55809	94990	119195	134744	144107
ParCom No retro +CCS	52254	94685	132234	156084	170529
ParCom No retro +GS	50235	88648	115546	133207	144416
temperature	49818	86393		127442	137716
RT2005+GS	50561	89014	121793	143875	157810
RT 2005 + CCS	50692	88793	118959	138125	149787

DR =16%	Price escalation 2% per year				
	2010	2015	2020	2025	2030
TJ-2004	45892	73634	89500	98296	102988
RT2005	46730	74449	89889	98306	102753
SWE	48116	76087	91518	99711	103849
A1	45893	74079	89782	98420	102936
A2	45892	74068	90006	98702	103200
A2+CCS	45949	75836	96490	107507	113046
A2+Gas Switching	45854	75180	95299	106692	112630
A3	52237	83248	99304	107563	111659
ParCom with Re	46180	74757	91429	100632	105542

ParCom without Re	48028	77631	94743	104069	109012
Applmp	45854	73480			
LC-R1	52237	83191	99156	107273	111274
LC-R2004	52196	83131	99171	107387	111464
Ref No retrofit	45767	73695	89809	98835	103581
SWE-No retrofit	51921	88216	111758	126793	136005
RT2005 No retrofit	46559	74423	90077	98716	103218
Ref CCS	45856	74938	95697	107060	112937
Ref GS	45858	74904	95554	107633	114168
A1 No Retrofit	45721	74055	89977	98841	103407
A2 No Retrofit	45721	74055	90219	99142	103693
LC-R1 CCS	52228	84077	102833	112365	117001
LC-R1 GS	52117	83672	102608	112597	117577
CAN	46308	74148	89928	98666	103236
CAN No retrofit	46103	73866	89637	98355	103002
SWE CCS	48178	77554	96740	106916	112112
SWE GS	48011	76767	95410	105849	111355
SWE REN	48333	76738	92366	100791	105305
A2 REN	46188	75191	91758	100839	105551
LC REN	51409	81200	96648	104979	109192
ParCom No retro +CCS	48108	80171	104120	116904	123403
ParCom No retro +GS	46265	75417	92570	102030	107070
temperature	45918	73691			102829
RT2005+GS	46616	75714	96607	108436	114703
RT 2005 + CCS	46734	75587	94832	105104	110352
	45721	73480	89500	98296	102753

Case II. Medium carbon price expectation

Table A- 11

DR =0%	Electricity Price escalation 1% per year				
	2010	2015	2020	2025	2030
TJ-2004	70163	169241	296411	449880	628209
RT2005	71054	168835	291359	436982	605015
SWE	72874	170445	289915	429705	589657
A1	70163	169959	295297	444846	614930
A2	70163	170116	296296	445751	614975
A3	78960	184512	305026	436307	574041
ParCom with Re	71043	174630	310443	473591	659844
ParCom without Re	70654	174198	310709	475903	665949
	70098	168732	294891	446690	622613
LC-R1	78960	184273	304338	434900	571571
LC-R2004	78851	183814	303669	433889	570468
Ref No retrofit	70045	169831	298897	455201	636868
SWE-No retrofit	72624	170533	291061	432706	595111
RT2005 No retrofit	70805	168913	292418	439815	610346
Ref CCS					
Ref GS					

A1 No Retrofit	69914	169914	296297	447696	620259
A2 No Retrofit	69914	170770	298531	448474	616911
LC-R1 CCS					
LC-R1 CS					
CAN	70616	169230	294414	444461	618264
CAN No retrofit	70367	169264	295414	447213	623540

DR =0%		Electricity Price escalation 2% per year			
	2010	2015	2020	2025	2030
TJ-2004	70163	169045	294658	444286	615258
RT2005	71054	168758	290356	433391	596108
SWE	72874	170434	289675	428370	585527
A1	70163	169829	294069	440898	605635
A2	70163	170000	295181	442303	607039
A3	78960	184495	304904	435818	572125
ParCom with Re	71031	174058	307376	465427	642920
ParCom without Re	70638	173491	306976	465845	645043
	70098	168499	292961	440590	608541
LC-R1	78960	184264	304247	434533	570076
LC-R2004	78851	183803	303566	433462	568718
Ref No retrofit	70045	169544	296714	448520	621845
SWE-No retrofit	72624	170506	290645	430837	589746
RT2005 No retrofit	70805	168819	291222	435645	600154
Ref CCS					
Ref GS					
A1 No Retrofit	69914	169740	294856	443162	609675
A2 No Retrofit	69914	170676	297336	444304	606719
LC-R1 CCS					
LC-R1 CS					
CAN	70616	169106	293025	439822	607249
CAN No retrofit	70367	169100	293806	441961	611194

DR =0%		Electricity Price escalation 3% per year			
	2010	2015	2020	2025	2030
TJ-2004	70163	168831	292685	437759	599582
RT2005	71054	168675	289225	429190	585293
SWE	72874	170422	289403	426797	580472
A1	70163	169688	292686	436289	594376
A2	70163	169875	293925	438282	597436
A3	78960	184477	304765	435243	569770
ParCom with Re	71019	173440	303941	455953	622556
ParCom without Re	70621	172727	302795	454170	619882
	70098	168246	290788	433476	591512
LC-R1	78960	184254	304143	434099	568236
LC-R2004	78851	183792	303448	432958	566564
Ref No retrofit	70045	169233	294259	440735	603686
SWE-No retrofit	72624	170475	290175	428639	583200
RT2005 No retrofit	70805	168715	289873	430768	587787
Ref CCS					
Ref GS					

A1 No Retrofit	69914	169550	293235	437873	596861
A2 No Retrofit	69914	170572	295986	439428	594352
LC-R1 CCS					
LC-R1 CS					
CAN	70616	168969	291459	434402	593899
CAN No retrofit	70367	168921	291995	435830	596240

DR =4%		Electricity Price escalation 1% per year			
	2010	2015	2020	2025	2030
TJ-2004	63289	135420	211600	287254	359563
RT2005	64118	135331	208747	280544	348682
SWE	65774	136866	208468	277400	342268
A1	63289	135979	211077	284833	353816
A2	63289	136089	211722	285438	354074
A3	71171	148141	220448	285282	341205
ParCom with Re	64024	139399	220753	301202	376744
ParCom without Re	63663	139001	220767	302216	379288
LC-R1	71171	147972	220012	284493	339985
LC-R2004	71074	147617	219528	283839	339292
Ref No retrofit	63174	135812	213122	290172	363835
SWE-No retrofit	65545	136878	209108	278952	344813
RT2005 No retrofit	63889	135335	209334	282001	351151
Ref CCS					
Ref GS					
A1 No Retrofit	63061	135892	211611	286275	356262
A2 No Retrofit	63061	136493	213083	287050	355375
LC-R1 CCS					
LC-R1 CS					
CAN	63708	135513	210512	284483	354960
CAN No retrofit	63480	135486	211058	285890	357387

DR =4%		Electricity Price escalation 2% per year			
	2010	2015	2020	2025	2030
TJ-2004	63289	135286	210547	284327	353675
RT2005	64118	135279	208151	278688	344688
SWE	65774	136859	208330	276733	340479
A1	63289	135891	210342	282772	349603
A2	63289	136011	211054	283633	350462
A3	71171	148130	220377	285036	340389
ParCom with Re	64014	138995	218873	296827	368838
ParCom without Re	63650	138501	218476	296830	369528
LC-R1	71171	147966	219960	284310	339353
LC-R2004	71074	147610	219469	283626	338552
Ref No retrofit	63174	135614	211804	286658	356961
SWE-No retrofit	65545	136859	208864	278003	342461
RT2005 No retrofit	63889	135271	208622	279841	346568
Ref CCS					
Ref GS					
A1 No Retrofit	63061	135772	210744	283900	351452

A2 No Retrofit	63061	136429	212371	284890	350791
LC-R1 CCS					
LC-R1 CS					
CAN	63708	135428	209683	282070	349980
CAN No retrofit	63480	135374	210095	283150	351792

DR =4%		Electricity Price escalation 3% per year			
	2010	2015	2020	2025	2030
TJ-2004	63289	135139	209364	280924	346590
RT2005	64118	135222	207480	276524	339864
SWE	65774	136851	208172	275948	338297
A1	63289	135795	209514	280374	344531
A2	63289	135926	210302	281534	346119
A3	71171	148118	220297	284748	339392
ParCom with Re	64005	138559	216770	291772	359396
ParCom without Re	63636	137960	215915	290606	357870
LC-R1	71171	147959	219901	284095	338578
LC-R2004	71074	147602	219402	283375	337644
Ref No retrofit	63174	135399	210324	282578	348705
SWE-No retrofit	65545	136838	208588	276891	339604
RT2005 No retrofit	63889	135202	207820	277323	341037
Ref CCS					
Ref GS					
A1 No Retrofit	63061	135642	209770	281140	345666
A2 No Retrofit	63061	136359	211569	282371	345261
LC-R1 CCS					
LC-R1 CS					
CAN	63708	135336	208749	279259	343979
CAN No retrofit	63480	135252	209012	279962	345054

DR =8%		Electricity Price escalation 1% per year			
	2010	2015	2020	2025	2030
TJ-2004	57564	110863	157525	195940	226365
RT2005	58338	110977	155958	192420	221091
SWE	59856	112428	156306	191319	218617
A1	57564	111302	157310	194778	223811
A2	57564	111381	157733	195185	224072
A3	64676	121641	165996	198975	222535
ParCom with Re	58181	113850	163679	204541	236334
ParCom without Re	57844	113482	163559	204925	237358
LC-R1	64676	121518	165713	198513	221891
LC-R2004	64590	121239	165353	198065	221427
Ref No retrofit	57452	111121	158470	197594	228589
SWE-No retrofit	59645	112391	156650	192125	219840
RT2005 No retrofit	58128	110935	156269	193171	222268
Ref CCS					
Ref GS					
A1 No Retrofit	57354	111190	157576	195503	224958
A2 No Retrofit	57354	111619	158564	196149	224908
LC-R1 CCS					
LC-R1 CS					

CAN	57954	111020	156963	194527	224181
CAN No retrofit	57743	110955	157246	195245	225328

DR =8% Electricity Price escalation 2% per year					
	2010	2015	2020	2025	2030
TJ-2004	57564	110770	156877	194350	223537
RT2005	58338	110942	155595	191425	219204
SWE	59856	112423	156224	190974	217804
A1	57564	111241	156859	193661	221794
A2	57564	111327	157324	194204	222336
A3	64676	121633	165954	198847	222171
ParCom with Re	58174	113560	162495	202099	232415
ParCom without Re	57833	113121	162115	201920	232523
LC-R1	64676	121514	165683	198419	221611
LC-R2004	64590	121234	165318	197955	221098
Ref No retrofit	57452	110981	157655	195674	225263
SWE-No retrofit	59645	112378	156503	191626	218756
RT2005 No retrofit	58128	110891	155836	192011	220095
Ref CCS					
Ref GS					
A1 No Retrofit	57354	111107	157041	194212	222648
A2 No Retrofit	57354	111576	158131	194988	222735
LC-R1 CCS					
LC-R1 CS					
CAN	57954	110962	156456	193224	221806
CAN No retrofit	57743	110877	156656	193761	222651

DR =8% Electricity Price escalation 3% per year					
	2010	2015	2020	2025	2030
TJ-2004	57564	110668	156150	192508	220157
RT2005	58338	110903	155187	190269	216937
SWE	59856	112417	156131	190568	216817
A1	57564	111175	156352	192366	219383
A2	57564	111269	156863	193067	220262
A3	64676	121625	165907	198697	221727
ParCom with Re	58165	113247	161174	199290	227771
ParCom without Re	57821	112733	160504	198464	226794
LC-R1	64676	121510	165648	198308	221269
LC-R2004	64590	121229	165279	197826	220697
Ref No retrofit	57452	110830	156740	193453	221297
SWE-No retrofit	59645	112364	156338	191043	217446
RT2005 No retrofit	58128	110843	155348	190662	217489
Ref CCS					
Ref GS					
A1 No Retrofit	57354	111016	156442	192715	219889
A2 No Retrofit	57354	111528	157643	193639	220128
LC-R1 CCS					
LC-R1 CS					
CAN	57954	110898	155886	191711	218961
CAN No retrofit	57743	110793	155992	192040	219448

DR =10%		Electricity Price escalation 1% per year			
	2010	2015	2020	2025	2030
TJ-2004	55057	101111	137916	165576	185570
RT2005	55806	101298	136781	163037	181879
SWE	57262	102706	137323	162537	180477
A1	55057	101501	137794	164778	183859
A2	55057	101568	138140	165113	184098
A3	61829	111089	146100	169866	185357
ParCom with Re	55623	103714	143017	172443	193338
ParCom without Re	55296	103359	142855	172643	193957
	55011				
LC-R1	61829	110984	145869	169506	184879
LC-R2004	61747	110735	145555	169129	184490
Ref No retrofit	54947	101318	138664	166834	187202
SWE-No retrofit	57059	102651	137568	163114	181328
RT2005 No retrofit	55603	101240	137001	163572	182693
Ref CCS					
Ref GS					
A1 No Retrofit	54854	101382	137971	165286	184643
A2 No Retrofit	54854	101746	138787	165858	184760
LC-R1 CCS					
LC-R1 CS					
CAN	55433	101290	137530	164578	184065
CAN No retrofit	55230	101211	137725	165086	184854

DR =10%		Electricity Price escalation 2% per year			
	2010	2015	2020	2025	2030
TJ-2004	55057	101033	137404	164389	183571
RT2005	55806	101269	136497	162299	180556
SWE	57262	102701	137259	162285	179919
A1	55057	101450	137438	163945	182436
A2	55057	101524	137816	164380	182871
A3	61829	111082	146067	169772	185109
ParCom with Re	55616	103467	142069	170592	190518
ParCom without Re	55286	103052	141698	170366	190480
	55011				
LC-R1	61829	110981	145846	169438	184689
LC-R2004	61747	110731	145529	169049	184267
Ref No retrofit	54947	101201	138017	165395	184842
SWE-No retrofit	57059	102640	137453	162747	180579
RT2005 No retrofit	55603	101203	136659	162710	181168
Ref CCS					
Ref GS					
A1 No Retrofit	54854	101312	137548	164320	183011
A2 No Retrofit	54854	101710	138446	164996	183235
LC-R1 CCS					
LC-R1 CS					
CAN	55433	101241	137130	163608	182393
CAN No retrofit	55230	101147	137259	163979	182966

Electricity Price escalation 3% per year

DR =10%

	2010	2015	2020	2025	2030
TJ-2004	55057	100948	136829	163016	181191
RT2005	55806	101236	136176	161443	178973
SWE	57262	102697	137187	161990	179244
A1	55057	101395	137038	162981	180741
A2	55057	101475	137453	163532	181409
A3	61829	111075	146030	169662	184808
ParCom with Re	55609	103201	141012	168468	187192
ParCom without Re	55275	102720	140409	167753	186378
	55011				
LC-R1	61829	110977	145820	169358	184458
LC-R2004	61747	110726	145498	168955	183996
Ref No retrofit	54947	101074	137292	163734	182038
SWE-No retrofit	57059	102628	137323	162320	179676
RT2005 No retrofit	55603	101163	136275	161710	179345
Ref CCS					
Ref GS					
A1 No Retrofit	54854	101236	137074	163203	181067
A2 No Retrofit	54854	101670	138062	163995	181412
LC-R1 CCS					
LC-R1 CS					
CAN	55433	101188	136681	162484	180396
CAN No retrofit	55230	101076	136735	162698	180715

DR =12%**Electricity Price escalation 1% per year**

	2010	2015	2020	2025	2030
TJ-2004	52753	92679	121852	141900	155147
RT2005	53479	92924	121053	140084	152568
SWE	54877	94288	121734	140011	151898
A1	52753	93026	121797	141358	154002
A2	52753	93083	122080	141634	154215
A3	59212	101948	129720	146959	157229
ParCom with Re	53274	94955	126109	147438	161284
ParCom without Re	52956	94612	125918	147508	161631
LC-R1	59212	101858	129531	146676	156868
LC-R2004	59134	101634	129255	146355	156539
Ref No retrofit	52645	92843	122444	142861	156356
SWE-No retrofit	54682	94220	121902	140419	152488
RT2005 No retrofit	53284	92852	121201	140460	153129
Ref CCS					
Ref GS					
A1 No Retrofit	52558	92901	121906	141706	154533
A2 No Retrofit	52558	93212	122582	142209	154735
LC-R1 CCS					
LC-R1 CS					
CAN	53117	92874	121602	141206	154117
CAN No retrofit	52922	92785	121729	141559	154657

DR =12%**Electricity Price escalation 2% per year**

	2010	2015	2020	2025	2030

TJ-2004	52753	92613	121445	141005	153717
RT2005	53479	92899	120828	139532	151630
SWE	54877	94284	121684	139827	151512
A1	52753	92983	121514	140731	152986
A2	52753	93046	121823	141082	153336
A3	59212	101943	129694	146889	157058
ParCom with Re	53267	94744	125345	146022	159228
ParCom without Re	52947	94349	124985	145767	159097
LC-R1	59212	101855	129513	146626	156738
LC-R2004	59134	101631	129234	146296	156386
Ref No retrofit	52645	92744	121928	141774	154660
SWE-No retrofit	54682	94211	121812	140148	151965
RT2005 No retrofit	53284	92822	120931	139815	152046
Ref CCS					
Ref GS					
A1 No Retrofit	52558	92842	121569	140978	153365
A2 No Retrofit	52558	93181	122312	141563	153651
LC-R1 CCS					
LC-R1 CS					
CAN	53117	92833	121285	140478	152925
CAN No retrofit	52922	92731	121359	140727	153309

DR =12% Electricity Price escalation 3% per year					
	2010	2015	2020	2025	2030
TJ-2004	52753	92541	120988	139973	152019
RT2005	53479	92872	120575	138893	150511
SWE	54877	94281	121628	139610	151045
A1	52753	92937	121196	140007	151779
A2	52753	93005	121534	140444	152293
A3	59212	101937	129665	146809	156851
ParCom with Re	53261	94516	124494	144401	156813
ParCom without Re	52937	94065	123946	143773	156119
LC-R1	59212	101852	129492	146568	156580
LC-R2004	59134	101627	129211	146227	156200
Ref No retrofit	52645	92636	121351	140520	152652
SWE-No retrofit	54682	94201	121710	139832	151335
RT2005 No retrofit	53284	92788	120627	139067	150755
Ref CCS					
Ref GS					
A1 No Retrofit	52558	92778	121192	140138	151978
A2 No Retrofit	52558	93148	122009	140815	152360
LC-R1 CCS					
LC-R1 CS					
CAN	53117	92789	120929	139635	151507
CAN No retrofit	52922	92672	120943	139766	151707

Case III. High carbon price expectation

Table A- 12

DR =0%	Electricity Price escalation 1% per year				
	2010	2015	2020	2025	2030
TJ-2004	71295	179710	323472	500257	707586
RT2005	72166	178850	316492	483091	677045
SWE	73963	180065	313072	471284	653713
A1	71295	180225	321319	492405	688631
A2	71295	180381	322030	492332	686744
A3	79921	192576	323272	467150	619649
ParCom with Re	72244	186230	340401	528384	744793
ParCom without Re	71880	186295	342525	534946	758271
LC-R1	79921	192297	322473	465459	616487
LC-R2004	79812	191849	321849	464592	615799
Ref No retrofit	71189	180659	327195	508082	720206
SWE-No retrofit	73720	180265	314759	475547	661454
RT2005 No retrofit	71924	179040	318099	487203	684691
Ref CCS					
Ref GS					
A1 No Retrofit	71052	180338	322916	496587	696328
A2 No Retrofit	71052	181195	324861	496383	691043
LC-R1 CCS					
LC-R1 CS					
CAN	71738	179447	320530	492785	694124
CAN No retrofit	71496	179639	322128	496871	701773

DR =0%	Electricity Price escalation 2% per year				
	2010	2015	2020	2025	2030
TJ-2004	71295	179514	321719	494662	694635
RT2005	72166	178773	315489	479500	668137
SWE	73963	180054	312833	469949	649582
A1	71295	180095	320091	488457	679336
A2	71295	180266	320914	488884	678808
A3	79921	192560	323149	466661	617733
ParCom with Re	72233	185658	337335	520220	727869
ParCom without Re	71864	185588	338792	524887	737365
LC-R1	79921	192288	322381	465092	614992
LC-R2004	79812	191838	321745	464166	614049
Ref No retrofit	71189	180372	325011	501402	705183
SWE-No retrofit	73720	180237	314343	473677	656089
RT2005 No retrofit	71924	178945	316903	483033	674499
Ref CCS					
Ref GS					
A1 No Retrofit	71052	180164	321475	492053	685744
A2 No Retrofit	71052	181100	323665	492213	680851
LC-R1 CCS					
LC-R1 CS					
CAN	71738	179322	319141	488146	683109

CAN No retrofit	71496	179474	320520	491620	689428

DR =0%	Electricity Price escalation 3% per year				
	2010	2015	2020	2025	2030
TJ-2004	71295	179300	319745	488135	678959
RT2005	72166	178689	314358	475299	657322
SWE	73963	180042	312560	468376	644528
A1	71295	179954	318708	483847	668077
A2	71295	180141	319658	484863	669205
A3	79921	192541	323010	466086	615378
ParCom with Re	72221	185040	333899	510746	707504
ParCom without Re	71847	184824	334611	513213	712204
LC-R1	79921	192278	322277	464658	613152
LC-R2004	79812	191826	321627	463662	611895
Ref No retrofit	71189	180060	322556	493617	687024
SWE-No retrofit	73720	180207	313873	471480	649543
RT2005 No retrofit	71924	178842	315554	478157	662132
Ref CCS					
Ref GS					
A1 No Retrofit	71052	179974	319854	486763	672931
A2 No Retrofit	71052	180996	322316	487337	668484
LC-R1 CCS					
LC-R1 CS					
CAN	71738	179186	317575	482727	669760
CAN No retrofit	71496	179295	318709	485488	674473

DR =4%	Electricity Price escalation 1% per year				
	2010	2015	2020	2025	2030
TJ-2004	64219	143103	229194	316327	400387
RT2005	65032	142691	225141	307266	385908
SWE	66669	143946	223640	301645	375623
A1	64219	143520	228033	312397	391976
A2	64219	143630	228509	312495	391341
A3	71960	154090	232490	303536	365442
ParCom with Re	65011	147902	240228	332911	420675
ParCom without Re	64670	147863	241408	336267	426825
	64158	142717	228206	314518	397606
LC-R1	71960	153892	231985	302592	363903
LC-R2004	71864	153545	231529	302014	363396
Ref No retrofit	64114	143752	231496	320650	406655
SWE-No retrofit	66446	144037	224615	303885	379271
RT2005 No retrofit	64809	142776	226068	309423	389495
Ref CCS					
Ref GS					
A1 No Retrofit	63996	143546	228941	314574	395576
A2 No Retrofit	63996	144147	230244	314840	393793
LC-R1 CCS					
LC-R1 CS					
CAN	64630	143017	227514	312420	394054
CAN No retrofit	64407	143102	228435	314563	397638

DR =4%	Electricity Price escalation 2% per year				
	2010	2015	2020	2025	2030

TJ-2004	64219	142969	228141	313400	394498
RT2005	65032	142640	224546	305411	381914
SWE	66669	143939	223502	300978	373833
A1	64219	143432	227298	310336	387763
A2	64219	143552	227841	310690	387729
A3	71960	154079	232419	303290	364627
ParCom with Re	65002	147498	238347	328536	412768
ParCom without Re	64657	147362	239117	330881	417065
	64158	142557	227044	311322	391199
LC-R1	71960	153886	231933	302409	363271
LC-R2004	71864	153537	231470	301801	362656
Ref No retrofit	64114	143554	230178	317137	399781
SWE-No retrofit	66446	144018	224371	302937	376919
RT2005 No retrofit	64809	142712	225356	307262	384911
Ref CCS					
Ref GS					
A1 No Retrofit	63996	143426	228074	312199	390766
A2 No Retrofit	63996	144083	229532	312680	389209
LC-R1 CCS					
LC-R1 CS					
CAN	64630	142932	226685	310007	389074
CAN No retrofit	64407	142990	227472	311823	392042

DR =4%		Electricity Price escalation 3% per year			
	2010	2015	2020	2025	2030
TJ-2004	64219	142822	226958	309997	387414
RT2005	65032	142583	223874	303246	377090
SWE	66669	143930	223344	300193	371652
A1	64219	143336	226470	307938	382690
A2	64219	143467	227090	308591	383385
A3	71960	154066	232339	303002	363629
ParCom with Re	64992	147062	236245	323481	403326
ParCom without Re	64643	146822	236556	324656	405408
	64158	142383	225739	307607	383495
LC-R1	71960	153879	231874	302194	362497
LC-R2004	71864	153530	231403	301551	361748
Ref No retrofit	64114	143339	228698	313057	391525
SWE-No retrofit	66446	143998	224095	301825	374062
RT2005 No retrofit	64809	142642	224554	304744	379381
Ref CCS					
Ref GS					
A1 No Retrofit	63996	143296	227100	309439	384980
A2 No Retrofit	63996	144013	228730	310161	383679
LC-R1 CCS					
LC-R1 CS					
CAN	64630	142839	225751	307196	383074
CAN No retrofit	64407	142868	226389	308635	385305

DR =8%		Electricity Price escalation 1% per year			
	2010	2015	2020	2025	2030
TJ-2004	58334	116591	169307	213543	248909

RT2005	59095	116473	166973	208674	241762
SWE	60597	117721	166545	206161	237290
A1	58334	116929	168691	211541	245030
A2	58334	117008	169013	211676	244857
A3	65330	126097	174183	210316	236393
ParCom with Re	58999	120183	176717	223787	260720
ParCom without Re	58678	120077	177349	225518	263623
	58282	116302	168650	212472	247430
LC-R1	65330	125954	173854	209766	235592
LC-R2004	65244	125681	173511	209360	235215
Ref No retrofit	58231	117035	170758	216021	252205
SWE-No retrofit	60391	117741	167102	207359	239080
RT2005 No retrofit	58889	116489	167500	209823	243512
Ref CCS					
Ref GS					
A1 No Retrofit	58128	116899	169197	212689	246776
A2 No Retrofit	58128	117329	170085	213062	246291
LC-R1 CCS					
LC-R1 CS					
CAN	58717	116618	168365	211474	245820
CAN No retrofit	58511	116634	168889	212616	247567

DR =8%	Electricity Price escalation 2% per year				
	2010	2015	2020	2025	2030
TJ-2004	58334	116498	168659	211954	246082
RT2005	59095	116438	166611	207679	239874
SWE	60597	117716	166463	205816	236477
A1	58334	116868	168239	210424	243014
A2	58334	116955	168604	210695	243121
A3	65330	126089	174141	210188	236028
ParCom with Re	58991	119893	175533	221345	256800
ParCom without Re	58667	119717	175905	222514	258788
LC-R1	65330	125950	173824	209672	235312
LC-R2004	65244	125676	173477	209250	234887
Ref No retrofit	58231	116896	169943	214101	248880
SWE-No retrofit	60391	117728	166956	206860	237996
RT2005 No retrofit	58889	116445	167067	208662	241339
Ref CCS					
Ref GS					
A1 No Retrofit	58128	116816	168663	211398	244467
A2 No Retrofit	58128	117285	169651	211901	244118
LC-R1 CCS					
LC-R1 CS					
CAN	58717	116560	167858	210171	243444
CAN No retrofit	58511	116557	168298	211132	244890

DR =8%	Electricity Price escalation 3% per year				
	2010	2015	2020	2025	2030
TJ-2004	58334	116396	167932	210112	242702
RT2005	59095	116399	166203	206523	237608
SWE	60597	117710	166370	205410	235490

A1	58334	116802	167732	209129	240602
A2	58334	116896	168143	209558	241047
A3	65330	126081	174093	210038	235584
ParCom with Re	58983	119580	174211	218536	252157
ParCom without Re	58655	119328	174294	219057	253060
LC-R1	65330	125946	173790	209561	234970
LC-R2004	65244	125670	173438	209121	234486
Ref No retrofit	58231	116745	169029	211879	244914
SWE-No retrofit	60391	117714	166790	206277	236686
RT2005 No retrofit	58889	116397	166579	207313	238733
Ref CCS					
Ref GS					
A1 No Retrofit	58128	116725	168063	209901	241707
A2 No Retrofit	58128	117237	169163	210552	241511
LC-R1 CCS					
LC-R1 CS					
CAN	58717	116496	167288	208658	240600
CAN No retrofit	58511	116472	167634	209411	241687

DR =10%	Electricity Price escalation 1% per year				
	2010	2015	2020	2025	2030
TJ-2004	55759	106085	147658	179507	202747
RT2005	56497	106073	145905	175930	197674
SWE	57938	107307	145822	174349	194806
A1	55759	106389	147215	178073	200081
A2	55759	106457	147482	178206	200013
A3	62426	114967	152919	178957	196102
ParCom with Re	56369	109209	153795	187689	211961
ParCom without Re	56057	109080	154245	188928	213969
	55710				
LC-R1	62426	114845	152652	178530	195510
LC-R2004	62344	114600	152352	178184	195183
Ref No retrofit	55657	106452	148818	181405	205182
SWE-No retrofit	57739	107302	146238	175226	196071
RT2005 No retrofit	56298	106064	146298	176770	198908
Ref CCS					
Ref GS					
A1 No Retrofit	55561	106340	147587	178906	201308
A2 No Retrofit	55561	106704	148324	179276	201115
LC-R1 CCS					
LC-R1 CS					
CAN	56130	106152	146964	178002	200572
CAN No retrofit	55931	106144	147354	178837	201804

DR =10%	Electricity Price escalation 2% per year				
	2010	2015	2020	2025	2030
TJ-2004	55759	106006	147146	178320	200748
RT2005	56497	106044	145620	175193	196351
SWE	57938	107303	145758	174097	194248
A1	55759	106338	146859	177239	198659
A2	55759	106412	147158	177473	198785
A3	62426	114961	152887	178863	195854

ParCom with Re	56362	108962	152846	185838	209141
ParCom without Re	56047	108773	153087	186651	210492
	55710				
LC-R1	62426	114842	152629	178461	195321
LC-R2004	62344	114596	152325	178104	194961
Ref No retrofit	55657	106334	148171	179966	202823
SWE-No retrofit	57739	107291	146124	174859	195322
RT2005 No retrofit	56298	106027	145957	175908	197383
Ref CCS					
Ref GS					
A1 No Retrofit	55561	106270	147164	177941	199675
A2 No Retrofit	55561	106668	147983	178414	199590
LC-R1 CCS					
LC-R1 CS					
CAN	56130	106104	146564	177032	198899
CAN No retrofit	55931	106079	146888	177731	199915

DR =10%		Electricity Price escalation 3% per year			
	2010	2015	2020	2025	2030
TJ-2004	55759	105921	146572	176947	198368
RT2005	56497	106011	145299	174336	194768
SWE	57938	107298	145686	173802	193573
A1	55759	106283	146458	176275	196963
A2	55759	106363	146795	176625	197323
A3	62426	114954	152850	178753	195552
ParCom with Re	56355	108696	151789	183714	205815
ParCom without Re	56036	108441	151798	184038	206390
	55710				
LC-R1	62426	114838	152603	178381	195090
LC-R2004	62344	114592	152295	178010	194689
Ref No retrofit	55657	106207	147446	178305	200018
SWE-No retrofit	57739	107279	145994	174432	194419
RT2005 No retrofit	56298	105988	145573	174908	195560
Ref CCS					
Ref GS					
A1 No Retrofit	55561	106194	146690	176824	197732
A2 No Retrofit	55561	106628	147599	177414	197767
LC-R1 CCS					
LC-R1 CS					
CAN	56130	106051	146115	175908	196903
CAN No retrofit	55931	106008	146364	176450	197664

DR =10%		Electricity Price escalation 5% per year			
	2010	2015	2020	2025	2030
TJ-2004	55759	105728	145205	173523	192155
RT2005	56497	105938	144533	172189	190608
SWE	57938	107287	145512	173052	191768
A1	55759	106157	145506	173869	192531
A2	55759	106252	145930	174512	193509

A3	62426	114938	152761	178475	194742
ParCom with Re	56339	108099	149300	178480	197253
ParCom without Re	56014	107700	148763	177598	195827
	55710				
LC-R1	62426	114829	152538	178177	194466
LC-R2004	62344	114582	152222	177771	193957
Ref No retrofit	55657	105920	145727	174174	192722
SWE-No retrofit	57739	107252	145683	173352	192020
RT2005 No retrofit	56298	105897	144656	172403	190774
Ref CCS					
Ref GS					
A1 No Retrofit	55561	106021	145563	174043	192658
A2 No Retrofit	55561	106537	146683	174909	192981
LC-R1 CCS					
LC-R1 CS					
CAN	56130	105930	145044	173099	191677
CAN No retrofit	55931	105848	145117	173253	191778

DR =12%		Electricity Price escalation 1% per year			
	2010	2015	2020	2025	2030
TJ-2004	53395	97012	129961	153042	168439
RT2005	54110	97087	128659	150421	164827
SWE	55495	98302	128834	149512	163066
A1	53395	97286	129646	152014	166597
A2	53395	97344	129868	152140	166590
A3	59758	105335	135437	154322	165688
ParCom with Re	53956	99740	135076	159644	175727
ParCom without Re	53652	99592	135385	160523	177114
LC-R1	59758	105230	135218	153988	165245
LC-R2004	59679	105010	134954	153690	164959
Ref No retrofit	53294	97314	130890	154506	170259
SWE-No retrofit	55304	98276	129142	150152	163964
RT2005 No retrofit	53919	97058	128948	151033	165700
Ref CCS					
Ref GS					
A1 No Retrofit	53204	97222	129914	152616	167459
A2 No Retrofit	53204	97532	130529	152967	167439
LC-R1 CCS					
LC-R1 CS					
CAN	53753	97112	129459	151953	166907
CAN No retrofit	53562	97083	129745	152561	167777

DR =12%		Electricity Price escalation 2% per year			
	2010	2015	2020	2025	2030
TJ-2004	53395	96946	129554	152148	167009
RT2005	54110	97062	128434	149869	163889
SWE	55495	98299	128785	149327	162680
A1	53395	97244	129363	151387	165581
A2	53395	97307	129611	151588	165711
A3	59758	105329	135411	154253	165517
ParCom with Re	53949	99529	134312	158228	173670
ParCom without Re	53642	99329	134452	158781	174579

LC-R1	59758	105227	135200	153938	165115
LC-R2004	59679	105007	134933	153631	164806
Ref No retrofit	53294	97215	130373	153418	168563
SWE-No retrofit	55304	98267	129051	149881	163440
RT2005 No retrofit	53919	97027	128678	150387	164616
Ref CCS					
Ref GS					
A1 No Retrofit	53204	97163	129578	151888	166291
A2 No Retrofit	53204	97502	130259	152322	166356
LC-R1 CCS					
LC-R1 CS					
CAN	53753	97071	129142	151226	165715
CAN No retrofit	53562	97029	129375	151729	166429

DR =12%		Electricity Price escalation 3% per year			
	2010	2015	2020	2025	2030
TJ-2004	53395	96874	129097	151115	165311
RT2005	54110	97035	128181	149230	162770
SWE	55495	98295	128728	149111	162213
A1	53395	97197	129046	150663	164374
A2	53395	97266	129323	150950	164668
A3	59758	105323	135383	154172	165310
ParCom with Re	53942	99301	133461	156606	171255
ParCom without Re	53633	99046	133413	156787	171601
LC-R1	59758	105224	135180	153879	164957
LC-R2004	59679	105003	134910	153562	164621
Ref No retrofit	53294	97107	129796	152165	166555
SWE-No retrofit	55304	98257	128949	149565	162810
RT2005 No retrofit	53919	96994	128374	149639	163325
Ref CCS					
Ref GS					
A1 No Retrofit	53204	97099	129200	151048	164904
A2 No Retrofit	53204	97469	129955	151574	165065
LC-R1 CCS					
LC-R1 CS					
CAN	53753	97027	128786	150383	164297
CAN No retrofit	53562	96969	128959	150768	164827

DR =12%		Electricity Price escalation 5% per year			
	2010	2015	2020	2025	2030
TJ-2004	53395	96712	128012	148548	160903
RT2005	54110	96974	127576	147631	159843
SWE	55495	98286	128593	148562	160969
A1	53395	97092	128290	148860	161235
A2	53395	97173	128637	149365	161960
A3	59758	105310	135313	153968	164756
ParCom with Re	53928	98791	131461	152625	165076
ParCom without Re	53612	98412	130973	151889	163981

LC-R1	59758	105217	135130	153730	164532
LC-R2004	59679	104995	134853	153388	164122
Ref No retrofit	53294	96865	128426	149057	161358
SWE-No retrofit	55304	98235	128705	148768	161144
RT2005 No retrofit	53919	96918	127650	147771	159952
Ref CCS					
Ref GS					
A1 No Retrofit	53204	96954	128304	148960	161304
A2 No Retrofit	53204	97393	129231	149706	161692
LC-R1 CCS					
LC-R1 CS					
CAN	53753	96926	127938	148283	160602
CAN No retrofit	53562	96835	127970	148374	160658

II. SYS3 Supply option (municipal plan follow-up)

Table A- 13. Primary energy demand (1000 toe)

	2010	2015	2020	2025	2030
TJ-2004	5,607	7,503	9,291	9,943	10,285
RT2005	5,522	6,912	8,391	8,921	9,173
SWE	5,415	6,296	7,406	7,784	7,922
A1	5,607	7,217	8,683	9,074	9,182
A2	5,607	7,217	8,420	8,757	8,823
A3	5,170	5,757	6,067	6,085	6,106
AppImp	5,594	7,533	9,329	9,980	10,320
LC-R1	5,170	5,719	6,026	6,031	6,013
LC-R2004	5,170	5,730	6,049	6,064	6,086
Ref No retrofit	5,671	7,860	9,815	10,481	10,782
SWE-No retrofit	5,448	6,453	7,680	8,113	8,305
RT2005 No retrofit	5,554	7,084	8,668	9,254	9,559
A1 No Retrofit	5,639	7,389	8,962	9,407	9,568
A2 No Retrofit	5,639	7,389	8,697	9,089	9,209
CAN	5,565	7,226	8,866	9,456	9,755
CAN No retrofit	5,613	7,428	9,183	9,827	10,178
ParCom with Re	6,092	8,655	10,317	10,829	11,244
ParCom without Re	6,180	8,903	10,968	11,499	11,711
CCS and GS scenario					
A2+CCS	5,597	8,789	10,339	10,766	10,904
A2+Gas Switching	5,607	6,351	7,441	7,786	7,834
Ref CCS	5,597	9,209	11,528	12,444	13,000
Ref GS	5,607	6,663	8,257	8,848	9,115
LC-R1 CCS	5,159	6,778	7,272	7,366	7,333
LC-R1 GS	5,170	5,165	5,422	5,415	5,422
SWE CCS	5,349	7,616	9,046	9,529	9,753
SWE GS	5,415	5,586	6,594	6,942	7,043
ParCom No retro +CCS	6,074	10,969	13,644	14,315	14,655
ParCom No retro +GS	6,180	7,899	9,737	10,219	10,359

Temperature	5,659	7,355	8,638	9,027	9,163
RT2005+GS	5,522	6,082	7,415	7,931	8,142
RT 2005 + CCS	5,513	8,394	10,301	10,975	11,349

Table A- 14 Year-by-year Variation of primary energy demand in comparison with the baseline scenario

Scenario	2010	2015	2020	2025	2030
TJ-2004					
RT2005	-1.5%	-7.9%	-9.4%	-10.3%	-10.8%
CAN	-0.7%	-3.7%	-4.4%	-4.9%	-5.2%
SWE	-3.4%	-16.1%	-19.7%	-21.7%	-23.0%
A1	0.0%	-3.8%	-5.8%	-8.7%	-10.7%
A2	0.0%	-3.8%	-8.5%	-11.9%	-14.2%
A3	-7.8%	-23.3%	-34.0%	-38.8%	-40.6%
LC-R1	-7.8%	-23.8%	-34.4%	-39.3%	-41.5%
LC-R2004	-7.8%	-23.6%	-34.1%	-39.0%	-40.8%
Temperature	0.9%	-2.0%	-6.4%	-9.2%	-10.9%
Applmp	-0.2%	0.4%	0.4%	0.4%	0.3%
ParCom with Re	8.6%	15.4%	12.2%	8.9%	9.3%
ParCom without Re	10.2%	18.7%	18.8%	15.6%	13.9%
Ref No retrofit	1.1%	4.8%	5.6%	5.4%	4.8%
SWE-No retrofit	-2.8%	-14.0%	-16.9%	-18.4%	-19.3%
RT2005 No retrofit	-0.9%	-5.6%	-6.5%	-6.9%	-7.1%
A1 No Retrofit	0.6%	-1.5%	-2.9%	-5.4%	-7.0%
A2 No Retrofit	0.6%	-1.5%	-5.6%	-8.6%	-10.5%
CAN No retrofit	0.1%	-1.0%	-1.2%	-1.2%	-1.0%
A2+CCS	-0.2%	17.1%	12.2%	8.3%	6.0%
Ref CCS	-0.2%	19.1%	18.3%	17.6%	16.8%
LC-R1 CCS	-8.0%	-9.7%	-20.8%	-25.9%	-28.7%
SWE CCS	-4.6%	1.5%	-2.1%	-4.2%	-5.2%
ParCom No retro +CCS	8.3%	46.2%	47.7%	44.0%	42.5%
RT 2005 + CCS	-1.7%	11.9%	11.1%	10.4%	10.3%
A2+Gas Switching	0.0%	-15.4%	-19.2%	-21.7%	-23.8%
LC-R1 GS	-7.8%	-31.2%	-41.0%	-45.5%	-47.3%
SWE GS	-3.4%	-25.5%	-28.6%	-30.2%	-31.5%
RT2005+GS	-1.5%	-18.9%	-20.0%	-20.2%	-20.8%
ParCom No retro +GS	10.2%	5.3%	5.5%	2.8%	0.7%
Ref GS	0.0%	-11.2%	-11.1%	-11.0%	-11.4%

Table A- 15 scenarios of year-by-year CO2 emission

Emission in Mt	2010	2015	2020	2025	2030
TJ-2004	21.5	28.0	33.7	35.7	35.9
RT2005	21.1	25.8	30.4	31.8	31.9
SWE	20.8	23.5	26.9	27.8	27.4
A1	21.5	27.0	31.7	32.5	32.0
A2	21.4	26.9	30.7	31.3	30.6
A2+CCS	21.4	12.1	13.2	11.6	10.7
A2+Gas Switching	21.4	23.1	26.8	27.4	27.2
A3	19.1	20.0	20.6	20.4	20.2

PartCom with Re	23.3	32.2	37.7	38.8	39.3
PartCom without Re	23.6	33.1	39.9	41.2	41.0
Applmp	21.4	28.0	33.7	35.7	35.9
LC-R1	19.1	19.9	20.5	20.3	19.8
LC-R2004	19.1	19.9	20.6	20.3	20.1
Ref No retrofit	21.7	29.4	35.6	37.6	37.7
SWE-No retrofit	20.9	24.1	27.9	28.9	28.8
<i>RT2005 No retrofit</i>	21.3	26.5	31.5	33.2	33.3
Ref CCS	21.4	11.1	12.5	12.6	10.8
Ref GS	20.8	23.1	27.3	29.2	29.9
A1 No Retrofit	21.6	27.6	32.7	33.7	33.4
A2 No Retrofit	21.6	27.5	31.7	32.4	32.0
LC-R1 CCS	19.1	9.3	8.8	8.2	7.3
LC-R1 GS	19.1	17.0	17.8	17.7	17.8
CAN	21.4	27.0	32.2	33.9	34.0
CAN No retrofit	21.5	27.7	33.2	35.1	35.4
SWE CCS	20.5	10.3	10.9	10.7	9.1
SWE GS	20.8	19.8	23.3	24.2	24.2
SWE REN	N.A	N.A	N.A	N.A	N.A
A2 REN	N.A	N.A	N.A	N.A	N.A
LC REN	N.A	N.A	N.A	N.A	N.A
A2+GS+CCS	N.A	N.A	N.A	N.A	N.A
ParCom No retro +CCS	23.2	13.7	15.8	13.9	13.2
ParCom No retro +GS	23.6	28.2	34.8	36.1	36.3
temperature	21.7	27.5	31.5	32.3	31.9
RT2005+GS	21.1	21.8	26.3	27.7	28.1
RT 2005 + CCS	21.1	10.7	11.8	11.8	10.1

Table A- 16 Year-by-year emission variation compared to baseline scenario

	2010	2015	2020	2025	2030
<i>RT2005</i>	-1.7%	-8.1%	-9.8%	-10.7%	-11.3%
SWE	-3.5%	-16.2%	-20.0%	-22.1%	-23.7%
A1	0.0%	-3.8%	-5.8%	-8.8%	-10.9%
A2	-0.3%	-4.1%	-8.9%	-12.3%	-14.8%
A2+CCS	-0.5%	-56.8%	-60.7%	-67.4%	-70.3%
A2+Gas Switching	-0.3%	-17.7%	-20.5%	-23.1%	-24.4%
A3	-11.0%	-28.7%	-38.7%	-42.8%	-43.8%
PartCom with Re	8.1%	14.7%	11.9%	8.8%	9.4%
PartCom without Re	9.6%	18.0%	18.5%	15.6%	14.1%
Applmp	-0.5%	0.0%	0.0%	0.0%	0.0%
LC-R1	-11.0%	-29.1%	-39.1%	-43.2%	-44.9%
LC-R2004	-11.0%	-29.0%	-38.9%	-42.9%	-44.0%
Ref No retrofit	1.1%	4.7%	5.6%	5.4%	4.9%
SWE-No retrofit	-2.9%	-14.1%	-17.2%	-18.8%	-19.9%
<i>RT2005 No retrofit</i>	-0.9%	-5.5%	-6.5%	-6.9%	-7.2%
Ref CCS	-0.5%	-60.7%	-63.5%	-65.5%	-70.6%
Ref GS	-3.1%	-17.7%	-19.1%	-18.2%	-16.8%
A1 No Retrofit	0.5%	-1.5%	-2.9%	-5.4%	-7.1%
A2 No Retrofit	0.3%	-1.9%	-6.0%	-9.0%	-11.0%
LC-R1 CCS	-11.2%	-66.7%	-73.8%	-77.1%	-79.7%
LC-R1 GS	-11.0%	-39.3%	-47.2%	-50.4%	-50.5%

CAN	-0.7%	-3.6%	-4.4%	-4.9%	-5.2%
CAN No retrofit	-0.2%	-1.4%	-1.5%	-1.5%	-1.4%
SWE CCS	-4.6%	-63.2%	-67.6%	-70.0%	-74.7%
SWE GS	-3.5%	-29.4%	-30.9%	-32.3%	-32.7%
SWE REN	N.A	N.A	N.A	N.A	N.A
A2 REN	N.A	N.A	N.A	N.A	N.A
LC REN	N.A	N.A	N.A	N.A	N.A
A2+GS+CCS	N.A	N.A	N.A	N.A	N.A
ParCom No retro +CCS	7.8%	-51.2%	-53.2%	-60.9%	-63.3%
ParCom No retro +GS	9.6%	0.7%	3.3%	1.2%	1.0%
temperature		-1.9%	-6.4%	-9.3%	-11.2%
RT2005+GS	-1.7%	-22.3%	-21.9%	-22.2%	-21.8%
RT 2005 + CCS	-1.8%	-61.7%	-65.0%	-67.0%	-72.0%

Cost analysis in SYS3

A. No electricity sale benefits are taken into account

Table A- 17. year-by-year cost without considering CO2 emission cost

DR=0%	2010	2015	2020	2025	2030
<i>TJ-2004</i>	13.56	21.38	25.57	28.58	30.26
<i>RT2005</i>	13.89	21.19	24.88	27.46	28.87
<i>SWE</i>	14.33	21.08	24.19	26.29	27.40
<i>A1</i>	13.56	21.49	25.26	27.96	29.14
<i>A2</i>	13.56	21.49	25.41	28.05	29.04
<i>A2 CCS</i>	13.56	29.27	34.12	37.06	37.78
<i>A2 GS</i>	13.56	28.47	32.76	35.14	36.22
<i>A3</i>	15.95	23.47	25.44	26.52	26.58
<i>ParCom with Re</i>	13.83	22.46	26.83	29.89	31.76
<i>ParCom without Re</i>	14.37	23.13	27.78	30.40	31.98
<i>Applmp</i>	13.54	21.38	25.57	28.58	30.26
<i>LC-R1</i>	15.95	23.40	25.36	26.39	26.68
<i>LC-R2004</i>	15.93	23.32	25.31	26.30	26.35
<i>TJ2004 No retrofit</i>	13.53	21.64	26.06	29.16	30.83
<i>SWE-No retrofit</i>	14.27	21.14	24.39	26.60	27.81
<i>RT2005 No retrofit</i>	13.82	21.26	25.08	27.77	29.29
<i>Ref CCS</i>	13.59	30.49	36.37	40.43	42.47
<i>Ref GS</i>	13.56	28.61	33.73	36.87	38.99
<i>A1 No Retrofit</i>	13.49	21.56	25.46	28.28	29.55
<i>A2 No Retrofit</i>	13.49	21.56	25.60	28.37	29.45
<i>LC-R1 CCS</i>	15.98	29.56	32.12	33.23	33.32
<i>LC-R1 GS</i>	15.95	27.41	28.86	29.90	30.02
<i>CAN</i>	13.70	21.28	25.24	28.05	29.61
<i>CAN No retrofit</i>	13.64	21.35	25.44	28.36	30.02
<i>SWE CCS</i>	14.45	28.89	33.14	35.46	36.65
<i>SWE GS</i>	14.29	26.57	29.95	32.34	33.85
<i>SWE REN</i>	N.A	N.A	N.A	N.A	N.A
<i>A2 REN</i>	N.A	N.A	N.A	N.A	N.A
<i>LC REN</i>	N.A	N.A	N.A	N.A	N.A
<i>A2+GS+CCS</i>	N.A	N.A	N.A	N.A	N.A
<i>ParCom No retro +CCS</i>	14.48	33.34	39.54	42.41	43.46
<i>ParCom No retro +GS</i>	14.37	31.05	37.17	40.36	42.66

<i>temperature</i>	13.60	21.26	24.94	27.44	28.76
<i>RT2005+GS</i>	13.89	27.89	32.16	34.71	36.42
<i>RT 2005 + CCS</i>	14.05	29.81	34.97	37.90	39.48

DR=4%	2010	2015	2020	2025	2030
<i>TJ-2004</i>	11.14	14.44	14.20	13.04	11.35
<i>RT2005</i>	11.41	14.32	13.81	12.53	10.83
<i>SWE</i>	11.78	14.24	13.43	12.00	10.28
<i>A1</i>	11.14	14.52	14.02	12.76	10.93
<i>A2</i>	11.14	14.52	14.11	12.80	10.89
<i>A2 CCS</i>	11.14	19.77	18.95	16.91	14.17
<i>A2 GS</i>	11.14	18.62	17.76	15.76	13.42
<i>A3</i>	13.11	15.85	14.12	12.10	9.97
<i>ParCom with Re</i>	11.36	15.17	14.90	13.64	11.91
<i>ParCom without Re</i>	11.81	15.63	15.43	13.87	12.00
<i>Applmp</i>	11.12	14.44	14.20	13.04	11.35
<i>LC-R1</i>	13.11	15.81	14.08	12.04	10.01
<i>LC-R2004</i>	13.09	15.76	14.05	12.00	9.89
<i>TJ2004 No retrofit</i>	11.12	14.62	14.47	13.31	11.56
<i>SWE-No retrofit</i>	11.73	14.28	13.54	12.14	10.43
<i>RT2005 No retrofit</i>	11.12	12.99	12.80	11.59	10.16
<i>Ref CCS</i>	11.17	24.75	24.10	21.68	18.57
<i>Ref GS</i>	11.14	19.33	18.73	16.83	14.63
<i>A1 No Retrofit</i>	11.09	14.57	14.14	12.91	11.09
<i>A2 No Retrofit</i>	11.09	14.57	14.22	12.95	11.05
<i>LC-R1 CCS</i>	13.13	19.97	17.84	15.17	12.50
<i>LC-R1 GS</i>	13.11	18.51	16.02	13.64	11.26
<i>CAN</i>	11.26	14.37	14.01	12.80	11.11
<i>CAN No retrofit</i>	11.21	14.42	14.13	12.94	11.26
<i>SWE CCS</i>	11.88	19.52	18.40	16.18	13.75
<i>SWE GS</i>	11.75	17.95	16.63	14.76	12.70
<i>SWE REN</i>	N.A	N.A	N.A	N.A	N.A
<i>A2 REN</i>	N.A	N.A	N.A	N.A	N.A
<i>LC REN</i>	N.A	N.A	N.A	N.A	N.A
<i>A2+GS+CCS</i>	N.A	N.A	N.A	N.A	N.A
<i>ParCom No retro +CCS</i>	11.90	22.52	21.96	19.36	16.30
<i>ParCom No retro +GS</i>	11.81	20.97	20.64	18.42	16.00
<i>temperature</i>	11.17	14.36	13.85	12.52	10.79
<i>RT2005+GS</i>	11.41	18.84	17.86	15.84	13.66
<i>RT 2005 + CCS</i>	11.54	20.14	19.42	17.30	14.81

DR=8%	2010	2015	2020	2025	2030
<i>TJ-2004</i>	9.23	9.90	8.06	6.13	4.42
<i>RT2005</i>	9.45	9.82	7.84	5.89	4.22
<i>SWE</i>	9.76	9.76	7.63	5.64	4.00
<i>A1</i>	9.23	9.95	7.96	6.00	4.25
<i>A2</i>	9.23	9.95	8.01	6.02	4.24
<i>A2 CCS</i>	9.23	13.56	10.76	7.95	5.52
<i>A2 GS</i>	9.23	12.77	10.08	7.41	5.22
<i>A3</i>	10.86	10.87	8.02	5.69	3.88
<i>ParCom with Re</i>	9.41	10.40	8.46	6.41	4.64
<i>ParCom without Re</i>	9.78	10.71	8.76	6.52	4.67
<i>Applmp</i>	9.21	9.90	8.06	6.13	4.42
<i>LC-R1</i>	10.86	10.84	7.99	5.66	3.90

LC-R2004	10.84	10.80	7.98	5.64	3.85
TJ2004 No retrofit	9.21	10.02	8.22	6.26	4.50
SWE-No retrofit	9.71	9.79	7.69	5.71	4.06
RT2005 No retrofit	9.21	8.91	7.27	5.45	3.95
Ref CCS	9.25	16.97	13.69	10.19	7.23
Ref GS	9.23	13.25	10.63	7.91	5.69
A1 No Retrofit	9.18	9.99	8.03	6.07	4.32
A2 No Retrofit	9.18	9.99	8.07	6.09	4.30
LC-R1 CCS	10.88	13.69	10.13	7.13	4.87
LC-R1 GS	10.86	12.69	9.10	6.41	4.38
CAN	9.32	9.86	7.96	6.02	4.32
CAN No retrofit	9.28	9.89	8.02	6.09	4.38
SWE CCS	9.84	13.38	10.45	7.61	5.35
SWE GS	9.73	12.31	9.44	6.94	4.94
SWE REN	N.A	N.A	N.A	N.A	N.A
A2 REN	N.A	N.A	N.A	N.A	N.A
LC REN	N.A	N.A	N.A	N.A	N.A
A2+GS+CCS	N.A	N.A	N.A	N.A	N.A
ParCom No retro +CCS	9.86	15.44	12.47	9.10	6.35
ParCom No retro +GS	9.78	14.38	11.72	8.66	6.23
temperature	9.25	9.85	7.86	5.89	4.20
RT2005+GS	9.45	12.92	10.14	7.45	5.32
RT 2005 + CCS	9.56	13.81	11.02	8.13	5.76

I. cumulative cost internalising CO2 emission cost

All numbers are expressed in million yuan (2005 price)

-Low carbon price assumption

Table A- 18

DR=0%	2010	2015	2020	2025	2030
TJ-2004	64980	157857	283235	431704	598090
RT2005	66865	159853	281746	423846	581811
SWE	69444	163552	281911	417098	565681
CAN	65809	158474	281845	426650	588541
LC-R2004	76167	180875	305304	439700	580137
A1	64973	159233	283297	428813	588723
A2	64971	159198	284486	430318	589194
ParCom with Re	64870	162316	295820	452395	626454
Ref No retrofit	64682	158458	286121	437566	607349
Ref CCS	65031	166120	334480	528130	741532
ParCom No retro +CCS	67872	177937	361203	567619	786312
RT 2005 + CCS	67289	168528	330488	513826	712025
A2+CCS	64970	165883	325819	505892	697337
Ref GS	64952	164611	328543	516451	721708
ParCom No retro +GS	67545	176266	358475	565894	792718

RT2005+GS	66862	166103	322659	498777	689327
A2+Gas Switching	64952	165731	326948	507209	698365

DR=4%	2010	2015	2020	2025	2030
TJ-2004	58547	126068	201208	274441	341976
RT2005	60247	127893	200964	271066	335190
SWE	62568	131079	202056	268762	329086
CAN	59296	126683	200632	272062	337773
LC-R2004	68515	144791	219479	285851	342901
A1	58541	127101	201473	273276	338199
A2	58539	127076	202206	274177	338686
ParCom with Re	58402	129210	209229	286475	357121
Ref No retrofit	58276	126437	202942	277641	346554
Ref CCS	58591	131670	232622	328178	414828
ParCom No retro +CCS	61081	140631	250541	352462	441288
RT 2005 + CCS	60616	133881	231019	321519	402006
A2+CCS	58538	131588	227546	316453	394215
Ref GS	58524	130618	228915	321647	404965
ParCom No retro +GS	60796	139408	248642	351002	443078
RT2005+GS	60244	132110	226016	312944	390303
A2+Gas Switching	58524	130870	224868	312055	388567

DR=8%	2010	2015	2020	2025	2030
TJ-2004	53194	103024	149070	186279	214723
RT2005	54737	104691	149481	185104	212114
SWE	56841	107469	150990	184894	210307
CAN	53875	103621	148944	185239	212914
LC-R2004	62142	118541	164378	198139	222186
A1	53189	103810	149397	185892	213242
A2	53187	103791	149857	186443	213622
ParCom with Re	53025	105255	154297	193551	223303
Ref No retrofit	52946	103239	150118	188071	217095
Ref CCS	53231	106880	168775	217343	253850
ParCom No retro +CCS	55432	113817	181216	233051	270486
RT 2005 + CCS	55061	108900	168471	214485	248400
A2+CCS	53186	106882	165748	210961	243735
Ref GS	53174	106134	166400	213537	248630
ParCom No retro +GS	55182	112902	179860	231891	270675

RT2005+GS	54734	107579	165170	209365	241953
A2+Gas Switching	53174	106385	164044	208382	240618

DR=10%	2010	2015	2020	2025	2030
TJ-2004	50851	93883	130212	157011	175711
RT2005	52324	95477	130819	156479	174237
SWE	54333	98082	132428	156851	173561
CAN	51501	94467	130228	156370	174565
LC-R2004	59350	108100	144289	168619	184435
A1	50845	94571	130542	156832	174815
A2	50844	94555	130910	157267	175138
ParCom with Re	50672	95766	134460	162736	182296
Ref No retrofit	50612	94041	131026	158361	177442
Ref CCS	50885	97100	145944	180930	204936
ParCom No retro +CCS	52961	103249	156440	193792	218411
RT 2005 + CCS	52629	99030	146045	179198	201500
A2+CCS	50843	97126	143593	176172	197726
Ref GS	50832	96467	144025	177982	201055
ParCom No retro +GS	52725	102450	155284	192767	218267
RT2005+GS	52322	97880	143334	175174	196601
A2+Gas Switching	50832	97059	143903	176522	198030

DR=12%	2010	2015	2020	2025	2030
TJ-2004	48699	85984	114788	134217	146613
RT2005	50108	87510	115534	134138	145910
SWE	52028	89958	117197	134907	145985
CAN	49321	86555	114910	133863	145924
LC-R2004	56784	99062	127775	145423	155911
A1	48693	86589	115112	134175	146097
A2	48692	86575	115406	134520	146368
ParCom with Re	48512	87575	118255	138757	151722
Ref No retrofit	48470	86095	115418	135236	147884
Ref CCS	48730	88677	127412	152781	168696
ParCom No retro +CCS	50691	94153	136340	163431	179755
RT 2005 + CCS	50395	90522	127811	151854	166641
A2+CCS	48692	88721	125581	149211	163503

Ref GS	48681	88138	125853	150477	165771
ParCom No retro +GS	50470	93452	135347	162528	179432
RT2005+GS	50106	89514	125566	148657	162861
A2+Gas Switching	48681	88372	124473	147644	161698

DR=16%	2010	2015	2020	2025	2030
TJ-2004	44892	73149	91512	101918	107493
RT2005	46186	74548	92419	102384	107680
SWE	47948	76729	94104	103592	108576
CAN	45464	73690	91770	101921	107346
LC-R2004	52243	84338	102669	112130	116851
A1	44887	73618	91807	102020	107384
A2	44885	73608	91999	102240	107571
ParCom with Re	44693	74284	93845	104827	110659
Ref No retrofit	44680	73190	91883	102496	108185
Ref CCS	44919	75054	99760	113351	120512
ParCom No retro +CCS	46678	79457	106368	120890	128237
RT 2005 + CCS	46442	76741	100530	113415	120068
A2+CCS	44885	75117	98639	111305	117738
Ref GS	44876	74659	98713	111905	118785
ParCom No retro +GS	46480	78909	105624	120187	127791
RT2005+GS	46185	75958	98957	111331	117721
A2+Gas Switching	44876	74869	97904	110324	116647

DR=10%	2010	2015	2020	2025	2030
TJ-2004	8.42	8.24	6.12	4.25	2.79
RT2005	8.62	8.17	5.96	4.08	2.66
SWE	8.90	8.13	5.79	3.91	2.53
A1	8.42	8.28	6.05	4.16	2.69
A2	8.42	8.28	6.08	4.17	2.68
A2 CCS	8.42	11.28	8.17	5.51	3.49
A2 GS	8.42	10.98	7.84	5.22	3.34
A3	9.90	9.05	6.09	3.94	2.45
ParCom with Re	8.58	8.66	6.42	4.44	2.93
ParCom without Re	8.92	8.92	6.65	4.52	2.95
Applmp	8.40	8.24	6.12	4.25	2.79
LC-R1	9.90	9.02	6.07	3.92	2.46
LC-R2004	9.89	8.99	6.06	3.91	2.43
TJ2004 No retrofit	8.40	8.34	6.24	4.33	2.85
SWE-No retrofit	8.86	8.15	5.84	3.95	2.57
RT2005 No retrofit	8.58	8.20	6.00	4.13	2.70
Ref CCS	8.44	11.76	8.71	6.01	3.92
Ref GS	8.42	11.03	8.07	5.48	3.60
A1 No Retrofit	8.38	8.31	6.09	4.20	2.73
A2 No Retrofit	8.38	8.31	6.13	4.22	2.72

<i>LC-R1 CCS</i>	9.92	11.40	7.69	4.94	3.08
<i>LC-R1 GS</i>	9.90	10.57	6.91	4.44	2.77
<i>CAN</i>	8.51	8.20	6.04	4.17	2.73
<i>CAN No retrofit</i>	8.47	8.23	6.09	4.22	2.77
<i>SWE CCS</i>	8.97	11.14	7.93	5.27	3.38
<i>SWE GS</i>	8.87	10.24	7.17	4.81	3.12
<i>SWE REN</i>	N.A	N.A	N.A	N.A	N.A
<i>A2 REN</i>	N.A	N.A	N.A	N.A	N.A
<i>LC REN</i>	N.A	N.A	N.A	N.A	N.A
<i>A2+GS+CCS</i>	0.00	0.00	0.00	0.00	0.00
<i>ParCom No retro +CCS</i>	8.99	12.85	9.47	6.30	4.01
<i>ParCom No retro +GS</i>	8.92	11.97	8.90	6.00	3.94
<i>temperature</i>	8.44	8.20	5.97	4.08	2.65
<i>RT2005+GS</i>	8.62	10.75	7.70	5.16	3.36
<i>RT 2005 + CCS</i>	8.72	11.49	8.37	5.63	3.64

DR=12%	2010	2015	2020	2025	2030
<i>TJ-2004</i>	7.69	6.88	4.67	2.96	1.78
<i>RT2005</i>	7.88	6.82	4.55	2.85	1.70
<i>SWE</i>	8.13	6.79	4.42	2.73	1.61
<i>A1</i>	7.69	6.92	4.61	2.90	1.71
<i>A2</i>	7.69	6.92	4.64	2.91	1.71
<i>A2 CCS</i>	7.69	9.42	6.23	3.84	2.22
<i>A2 GS</i>	7.69	8.88	5.84	3.58	2.10
<i>A3</i>	9.05	7.56	4.65	2.75	1.56
<i>ParCom with Re</i>	7.84	7.23	4.90	3.10	1.87
<i>ParCom without Re</i>	8.15	7.45	5.08	3.15	1.88
<i>Applmp</i>	7.68	6.88	4.67	2.96	1.78
<i>LC-R1</i>	9.05	7.53	4.63	2.74	1.57
<i>LC-R2004</i>	9.04	7.51	4.62	2.73	1.55
<i>TJ2004 No retrofit</i>	7.68	6.97	4.76	3.02	1.81
<i>SWE-No retrofit</i>	8.86	8.15	5.84	3.95	2.57
<i>RT2005 No retrofit</i>	7.68	6.19	4.21	2.63	1.59
<i>Ref CCS</i>	7.71	9.82	6.64	4.19	2.50
<i>Ref GS</i>	7.69	9.21	6.16	3.82	2.29
<i>A1 No Retrofit</i>	7.65	6.94	4.65	2.93	1.74
<i>A2 No Retrofit</i>	7.65	6.94	4.68	2.94	1.73
<i>LC-R1 CCS</i>	9.92	11.40	7.69	4.94	3.08
<i>LC-R1 GS</i>	9.05	8.82	5.27	3.10	1.77
<i>CAN</i>	7.77	6.85	4.61	2.91	1.74
<i>CAN No retrofit</i>	7.74	6.87	4.65	2.94	1.77
<i>SWE CCS</i>	8.20	9.30	6.06	3.68	2.16
<i>SWE GS</i>	8.11	8.55	5.47	3.35	1.99
<i>SWE REN</i>	N.A	N.A	N.A	N.A	N.A
<i>A2 REN</i>	N.A	N.A	N.A	N.A	N.A
<i>LC REN</i>	N.A	N.A	N.A	N.A	N.A
<i>A2+GS+CCS</i>	N.A	N.A	N.A	N.A	N.A
<i>ParCom No retro +CCS</i>	8.22	10.73	7.22	4.40	2.56
<i>ParCom No retro +GS</i>	8.15	10.00	6.79	4.18	2.51
<i>temperature</i>	7.71	6.85	4.56	2.84	1.69
<i>RT2005+GS</i>	7.88	8.98	5.88	3.60	2.14
<i>RT 2005 + CCS</i>	7.97	9.60	6.39	3.93	2.32

DR=16%	2010	2015	2020	2025	2030
TJ-2004	6.45	4.85	2.76	1.47	0.74
RT2005	6.61	4.80	2.69	1.41	0.71
SWE	6.82	4.78	2.61	1.35	0.67
A1	6.45	4.87	2.73	1.44	0.71
A2	6.45	4.87	2.74	1.44	0.71
A2 CCS	6.46	6.63	3.68	1.90	0.92
A2 GS	6.45	6.25	3.45	1.77	0.88
A3	7.59	5.32	2.75	1.36	0.65
ParCom with Re	6.58	5.09	2.90	1.54	0.78
ParCom without Re	6.84	5.24	3.00	1.56	0.78
Applmp	6.44	4.85	2.76	1.47	0.74
LC-R1	7.59	5.30	2.74	1.36	0.65
LC-R2004	7.58	5.29	2.73	1.35	0.64
TJ2004 No retrofit	6.44	4.91	2.81	1.50	0.75
SWE-No retrofit	8.10	6.81	4.46	2.76	1.64
RT2005 No retrofit	6.44	4.36	2.49	1.31	0.66
Ref CCS	6.47	6.91	3.92	2.08	1.04
Ref GS	6.45	6.49	3.64	1.89	0.95
A1 No Retrofit	6.42	4.89	2.75	1.45	0.72
A2 No Retrofit	6.42	4.89	2.76	1.46	0.72
LC-R1 CCS	9.07	9.52	5.87	3.45	1.96
LC-R1 GS	7.59	6.21	3.11	1.54	0.73
CAN	6.52	4.82	2.72	1.44	0.72
CAN No retrofit	6.49	4.84	2.75	1.46	0.73
SWE CCS	6.88	6.55	3.58	1.82	0.90
SWE GS	6.80	6.02	3.23	1.66	0.83
SWE REN	N.A	N.A	N.A	N.A	N.A
A2 REN	N.A	N.A	N.A	N.A	N.A
LC REN	N.A	N.A	N.A	N.A	N.A
A2+GS+CCS	N.A	N.A	N.A	N.A	N.A
ParCom No retro +CCS	6.90	7.56	4.27	2.18	1.06
ParCom No retro +GS	6.84	7.04	4.01	2.07	1.04
temperature	6.47	4.82	2.69	1.41	0.70
RT2005+GS	6.61	6.32	3.47	1.78	0.89
RT 2005 + CCS	6.69	6.76	3.77	1.95	0.97

Medium carbon price assumption

Table A- 19

DR=0%	2010	2015	2020	2025	2030
TJ-2004	65143	162336	300827	471344	666972
RT2005	67022	164034	297947	460056	644404
SWE	69599	167442	296468	449036	620183
CAN	65967	162732	298337	463380	652400
LC-R2004	76306	184088	316351	462510	617740
A1	65138	163605	300190	466240	652758
A2	65134	163549	301028	466538	650737
ParCom with Re	65051	167467	316074	497109	703132

Ref No retrofit	64848	163039	304155	478011	677806
	2010	2015	2020	2025	2030
Ref CCS	65197	169743	343203	544533	767486
ParCom No retro +CCS	68055	181935	369766	582470	808592
RT 2005 + CCS	67446	171878	338362	528205	734185
A2+CCS	65133	169374	334101	521219	721231
	2010	2015	2020	2025	2030
Ref GS	65112	168734	343392	549472	779307
ParCom No retro +GS	67724	181295	378116	609120	866665
RT2005+GS	67017	169920	335791	527415	738574
A2+Gas Switching	65112	169745	340952	537427	749788
DR=8%	2010	2015	2020	2025	2030
TJ-2004	53306	105348	156137	198832	232254
RT2005	54843	106862	156002	196606	228108
SWE	56946	109495	156878	195112	224368
CAN	53983	105831	155583	196914	229204
LC-R2004	62237	120223	168907	205600	232169
A1	53300	106080	156199	197808	229691
A2	53298	106051	156533	198021	229515
ParCom with Re	53148	107924	162433	207779	242973
Ref No retrofit	53059	105615	157362	200891	235021
Ref CCS	53344	108811	172559	223043	261177
ParCom No retro +CCS	55557	115955	185018	238425	277127
RT 2005 + CCS	55168	110688	171905	219544	254786
A2+CCS	53298	108743	169352	216324	250559
Ref GS	53283	108287	172432	224089	263363
ParCom No retro +GS	55304	115509	187757	245663	289677
RT2005+GS	54840	109579	170540	218595	254690
A2+Gas Switching	53283	108483	169761	218137	253984
DR=16%	2010	2015	2020	2025	2030
TJ-2004	44970	74427	94654	106584	113132
RT2005	46261	75743	95324	106673	112846
SWE	48022	77847	96742	107434	113168
CAN	45540	74906	94728	106278	112604
LC-R2004	52310	85272	104725	115003	120217
A1	44965	74868	94839	106474	112723
A2	44963	74852	94981	106585	112759
ParCom with Re	44779	75750	97461	110136	117031
Ref No retrofit	44759	74496	95103	107265	113951

Ref CCS	44998	76142	101579	115703	123182
ParCom No retro +CCS	46765	80665	108234	123194	130789
RT 2005 + CCS	46517	77750	102189	115527	122440
A2+CCS	44963	76166	100377	113532	120251
Ref GS	44953	75850	101428	115876	123572
ParCom No retro +GS	46566	80342	109138	125334	133959
RT2005+GS	46259	77067	101392	114837	121913
A2+Gas Switching	44953	76030	100490	114032	121061

-High carbon price assumption

Table A- 20

DR=0%	2010	2015	2020	2025	2030
TJ-2004	66126	173109	329244	524549	750168
RT2005	67961	174128	324219	508825	720233
SWE	70526	176935	320326	492438	686731
CAN	66919	173003	325080	512875	729714
LC-R2004	77142	192071	334909	494297	664703
A1	66123	174167	327607	516747	730559
A2	66117	174062	327962	515603	725779
ParCom with Re	66143	179795	348734	557277	796081
Ref No retrofit	65844	174046	333266	532316	762889
Ref CCS	66190	179112	359455	569427	802176
ParCom No retro +CCS	69153	192345	386350	606133	839878
RT 2005 + CCS	68393	180585	353182	550346	764308
A2+CCS	66115	178430	349630	544675	753476
Ref GS	66072	178831	367919	594427	849465
ParCom No retro +GS	68800	193351	409846	667372	956424
RT2005+GS	67951	179362	357769	566828	799123
A2+Gas Switching	66072	179616	364279	578987	813097
DR=8%	2010	2015	2020	2025	2030
TJ-2004	53974	111210	168435	217323	255862
RT2005	55482	112362	167405	213630	249750
SWE	57578	114686	167316	210436	243644
CAN	54630	111426	167192	214205	251238
LC-R2004	62806	124615	177175	217177	246340
A1	53971	111837	168107	215489	252032
A2	53967	111781	168262	215285	251214
ParCom with Re	53891	114621	176551	228774	269561
Ref No retrofit	53737	111601	169955	219776	259154
Ref CCS	54019	114035	180306	232953	272761

ParCom No retro +CCS	56304	121772	193105	248288	288293
RT 2005 + CCS	55812	115551	179011	228486	265093
A2+CCS	53966	113799	176781	225740	261477

Ref GS	53936	113816	183224	239982	283553
ParCom No retro +GS	56036	122062	201493	266030	315419
RT2005+GS	55476	114767	180304	232714	272414
A2+Gas Switching	53936	113896	180090	233024	272582

DR=16%	2010	2015	2020	2025	2030
TJ-2004	45438	77808	100585	114241	121790
RT2005	46708	78919	100840	113757	120833
SWE	48463	80855	101832	113886	120395
CAN	45993	78136	100343	113477	120730
LC-R2004	52708	87832	108827	120028	125750

A1	45434	78193	100602	113848	121009
A2	45431	78162	100671	113820	120863
ParCom with Re	45299	79606	104260	118853	126842
Ref No retrofit	45234	77947	101172	115088	122800

Ref CCS	45470	79218	105658	120387	128194
ParCom No retro +CCS	47288	84095	112570	128027	135877
RT 2005 + CCS	46968	80617	105950	119801	126982
A2+CCS	45431	79146	104302	118013	125025

Ref GS	45410	79056	106719	122589	131125
ParCom No retro +GS	47078	84117	115761	133808	143485
RT2005+GS	46703	80085	106223	120883	128664
A2+Gas Switching	45410	79174	105584	120397	128152

A. Electricity sale benefits are taken into account

- **Exclusion of carbon price**

Table A- 21

DR=0%	2010	2015	2020	2025	2030
TJ-2004	64.16	148.77	256.41	379.15	502.15
RT2005	66.08	152.10	258.33	376.94	507.61
SWE	68.67	156.80	264.74	384.31	515.25
A1	64.15	150.40	256.70	377.15	509.24
A2	64.15	150.40	258.96	381.92	515.78
A2+CCS	64.15	158.41	309.54	478.01	657.73
A2+Gas Switching	64.15	157.26	303.07	462.26	630.42
A3	75.59	175.90	293.68	419.79	550.63
ParCom with Re	63.76	149.90	261.70	389.69	530.40
ParCom without Re	66.40	155.68	270.16	398.84	540.87
AppImp	64.10	147.59			
LC-R1	75.59	175.71	292.88	417.27	546.42

LC-R2004	75.47	175.19	292.30	417.38	547.19
Ref No retrofit	63.85	147.43	252.05	370.26	501.42
SWE-No retrofit	68.28	156.16	263.67	382.59	512.93
RT2005 No retrofit	65.68	151.39	257.24	375.59	506.15
Ref CCS	64.20	157.52	313.15	488.14	679.79
Ref GS	64.15	155.15	299.91	459.55	631.76
A1 No Retrofit	63.75	149.57	255.49	375.68	507.67
A2 No Retrofit	63.75	149.57	257.75	380.46	514.21
LC-R1 CCS	75.64	182.05	331.17	490.76	655.64
LC-R1 GS	75.60	179.72	317.50	460.86	608.47
CAN	65.02	149.89	255.27	373.65	504.55
CAN No retrofit	64.44	146.68	248.60	363.20	490.20
SWE CCS	69.00	164.69	310.50	469.91	640.66
SWE GS	68.64	162.00	299.30	447.47	607.69
SWE REN					
A2 REN					
LC REN					
A2+GS+CCS					
ParCom No retro +CCS	66.96	169.96	344.44	538.21	743.18
ParCom No retro +GS	66.17	159.36	309.38	473.47	651.89
temperature	64.27	148.38			
RT2005+GS	66.08	158.69	301.38	456.58	622.96
RT 2005 + CCS	66.50	161.76	314.98	485.51	669.74

DR=4%	2010	2015	2020	2025	2030
TJ-2004	57.87	118.96	181.82	240.15	293.36
RT2005	59.60	122.24	185.97	244.50	297.54
SWE	61.93	126.11	190.88	249.89	303.05
A1	57.87	120.67	184.46	243.90	297.52
A2	57.87	120.67	185.82	246.51	300.85
A2+CCS	57.87	126.08	216.79	299.97	372.96
A2+Gas Switching	57.87	124.70	209.50	286.29	353.46
A3	68.05	141.13	211.84	274.14	327.29
ParCom with Re	57.49	120.16	187.20	250.36	307.48
ParCom without Re	59.85	124.82	193.47	256.97	314.63
Applmp	57.82	118.61	180.93	238.56	
LC-R1	68.05	140.99	211.35	272.80	325.25
LC-R2004	67.94	140.59	210.90	272.69	325.42
Ref No retrofit	57.59	118.45	181.21	239.53	292.77
SWE-No retrofit	61.58	125.58	190.09	248.78	301.69
RT2005 No retrofit	60.04	122.37	180.78	234.45	282.89
Ref CCS	57.91	125.37	218.74	305.10	382.92
Ref GS	57.87	123.75	210.62	289.43	359.33
A1 No Retrofit	57.50	120.00	183.56	242.87	296.44
A2 No Retrofit	57.50	120.00	184.92	245.48	299.78
LC-R1 CCS	68.09	145.30	234.83	313.67	380.66
LC-R1 GS	68.06	143.71	226.47	297.29	357.26
CAN	58.64	120.44	183.67	242.08	295.21
CAN No retrofit	58.14	118.03	179.18	235.73	
SWE CCS	62.22	131.53	219.04	297.75	367.09
SWE GS	61.91	129.61	212.04	285.18	350.22
SWE REN	62.42	125.88	185.16	239.99	
A2 REN	59.75	124.51	187.26	246.32	299.31

LC REN	66.59	133.55	192.69	247.47	295.09
A2+GS+CCS					
ParCom No retro +CCS	60.33	134.73	239.41	335.09	418.34
ParCom No retro +GS	59.66	127.11	217.14	298.13	370.55
temperature	57.96	119.20	182.06	240.13	
RT2005+GS	59.60	126.68	212.33	288.95	356.50
RT 2005 + CCS	59.97	128.88	220.81	305.00	379.81

DR=8%	2010	2015	2020	2025	2030
TJ-2004	52.64	97.78	136.34	165.99	188.40
RT2005	54.20	100.49	139.60	169.35	191.69
SWE	56.31	103.75	143.50	173.49	195.89
A1	52.63	99.06	138.19	168.40	190.99
A2	52.63	99.06	139.03	169.88	192.78
A2+CCS	52.63	102.77	158.43	200.73	231.49
A2+Gas Switching	52.63	101.81	153.86	192.92	221.21
A3	61.76	115.80	159.21	190.91	213.31
ParCom with Re	52.27	98.54	139.66	171.76	195.82
ParCom without Re	54.40	102.38	144.48	176.76	201.04
Applmp	52.59	97.52	135.75	165.04	
LC-R1	61.76	115.71	158.90	190.17	212.27
LC-R2004	61.67	115.39	158.55	189.99	212.22
Ref No retrofit	52.38	97.35	135.85	165.49	187.91
SWE-No retrofit	56.00	103.30	142.89	172.72	195.01
RT2005 No retrofit	54.62	100.75	136.57	163.85	184.25
Ref CCS	52.67	102.19	159.46	203.37	236.15
Ref GS	52.63	101.06	154.36	194.43	223.88
A1 No Retrofit	52.30	98.50	137.49	167.64	190.21
A2 No Retrofit	52.30	98.50	138.33	169.12	191.99
LC-R1 CCS	61.80	118.67	173.63	213.75	241.99
LC-R1 GS	61.77	117.57	168.40	204.43	229.71
CAN	53.34	99.01	137.80	167.48	189.86
CAN No retrofit	52.89	97.16	134.67	163.41	
SWE CCS	56.57	107.54	161.25	201.28	230.50
SWE GS	56.29	106.14	156.74	193.92	221.32
SWE REN	56.77	103.75	140.11	167.97	189.35
A2 REN	54.31	102.24	140.73	170.75	193.07
LC REN	60.53	110.14	146.42	174.27	194.34
A2+GS+CCS					
ParCom No retro +CCS	54.81	109.39	173.60	222.26	257.35
ParCom No retro +GS	54.25	103.82	159.05	200.23	230.73
temperature	52.71	97.97	136.54	166.05	
RT2005+GS	54.20	103.54	156.10	195.07	223.52
RT 2005 + CCS	54.52	105.15	161.55	204.36	235.88

DR=10%	2010	2015	2020	2025	2030
TJ-2004	50.34	89.36	119.79	141.15	155.88
RT2005	51.84	91.84	122.71	144.14	158.83
SWE	53.85	94.85	126.23	147.84	162.56
A1	50.34	90.46	121.35	143.12	157.97
A2	50.34	90.46	122.02	144.25	159.30
A2+CCS	50.34	93.55	137.49	167.97	188.20
A2+Gas Switching	50.34	93.10	135.53	164.34	183.26

A3	59.01	105.72	140.00	162.84	177.58
ParCom with Re	49.98	89.96	122.41	145.53	161.35
ParCom without Re	52.01	93.47	126.69	149.94	165.91
AppImp	50.30	89.13	119.31	140.41	
LC-R1	59.01	105.64	139.75	162.28	176.82
LC-R2004	58.92	105.36	139.44	162.10	176.71
Ref No retrofit	50.10	88.96	119.35	140.70	
SWE-No retrofit	53.55	94.44	125.68	147.18	161.83
RT2005 No retrofit	51.53	91.39	122.14	143.53	158.20
Ref CCS	50.37	93.03	138.24	169.87	191.43
Ref GS	50.34	92.09	134.16	163.03	182.39
A1 No Retrofit	50.02	89.95	120.73	142.45	157.29
A2 No Retrofit	50.02	89.95	121.40	143.58	158.62
LC-R1 CCS	59.04	108.11	151.51	180.43	199.00
LC-R1 GS	59.01	107.19	147.34	173.31	189.93
CAN	51.01	90.48	121.10	142.48	157.20
CAN No retrofit	50.59	88.85	118.46	139.16	
SWE CCS	54.09	98.04	140.44	169.29	188.50
SWE GS	53.83	96.84	136.78	163.58	181.59
SWE REN	54.30	94.93	123.62	143.69	157.74
A2 REN	51.93	93.38	123.76	145.39	160.06
LC REN	57.87	100.79	129.43	149.50	162.69
A2+GS+CCS					
ParCom No retro +CCS	52.39	99.39	150.07	185.14	208.21
ParCom No retro +GS	51.87	94.60	138.20	167.86	187.92
temperature	50.41	89.53	119.97	141.23	
RT2005+GS	51.84	94.38	135.88	163.95	182.66
RT 2005 + CCS	52.14	95.77	140.29	171.13	191.86

DR=16%	2010	2015	2020	2025	2030
TJ-2004	44.50	70.17	85.58	93.87	98.27
RT2005	45.81	72.14	87.76	96.09	100.47
SWE	47.58	74.56	90.45	98.85	103.24
A1	44.50	70.90	86.54	95.00	99.43
A2	44.50	70.90	86.88	95.52	100.01
A2+CCS	44.50	72.72	94.97	106.82	112.86
A2+Gas Switching	44.50	72.25	93.07	104.01	109.56
A3	51.99	82.75	100.12	109.00	113.40
ParCom with Re	44.16	70.44	86.85	95.84	100.56
ParCom without Re	45.93	73.18	90.00	99.03	103.79
AppImp	44.47	70.02	85.29	93.49	97.82
LC-R1	51.99	82.70	99.98	108.75	113.09
LC-R2004	51.91	82.49	99.76	108.57	112.94
Ref No retrofit	44.28	69.86	85.24	93.53	97.92
SWE-No retrofit	51.30	86.77	111.70	127.55	137.46
RT2005 No retrofit	46.18	72.47	86.78	94.42	98.41
Ref CCS	44.52	72.35	95.23	107.52	113.95
Ref GS	44.50	71.78	93.08	104.30	110.07
A1 No Retrofit	44.22	70.50	86.08	94.52	98.95
A2 No Retrofit	44.22	70.50	86.42	95.04	99.53
LC-R1 CCS	56.51	98.99	133.43	154.41	166.72
LC-R1 GS	52.00	83.61	103.97	114.07	119.03
CAN	45.09	71.06	86.56	94.86	99.25
CAN No retrofit	44.73	69.91	84.90	92.94	97.20

SWE CCS	47.78	76.52	97.99	109.20	114.94
SWE GS	47.57	75.72	95.96	106.37	111.74
SWE REN	47.99	74.78	89.29	97.09	101.27
A2 REN	45.86	73.19	88.56	96.97	101.34
LC REN	51.08	79.42	93.92	101.72	105.65
A2+GS+CCS					
ParCom No retro +CCS	46.24	76.86	102.51	116.15	123.03
ParCom No retro +GS	45.83	73.73	95.81	107.33	113.31
temperature	44.56	70.30	85.71	93.96	98.32
RT2005+GS	45.81	73.63	94.64	105.56	111.14
RT 2005 + CCS	46.07	74.55	97.08	109.07	115.26

- inclusion of carbon price

B.1-low carbon price

Table A- 22

in million					
DR=4%	2010	2015	2020	2025	2030
TJ-2004	58547	124577	194615	261180	322525
RT2005	60247	127505	197823	263826	324211
SWE	62568	131079	201700	267205	326645
A1	58541	126188	196829	263942	324972
A2	58539	126163	197995	266040	327434
A2+CCS	58538	130892	224238	310054	385431
A2+Gas Switching	58524	129872	220154	303004	376073
A3	68617	145297	220293	287088	344494
ParCom with Re	58236	126574	201895	274193	340208
ParCom without Re	60611	131381	208649	281877	349027
Applmp	58498	124255	193806	259744	320383
LC-R1	68617	145150	219761	285615	342198
LC-R2004	68515	144791	219416	285601	342453
Ref No retrofit	58276	124183	194313	261001	322587
SWE-No retrofit	62214	130600	201188	266690	326248
RT2005 No retrofit	60696	127746	192936	254332	310415
Ref CCS	58591	130337	226512	315745	396226
Ref GS	58524	129036	221775	307365	384103
A1 No Retrofit	58187	125628	196230	263478	324762
A2 No Retrofit	58187	125628	197468	265717	327447
LC-R1 CCS	68661	149051	240509	321246	389964
LC-R1 GS	68631	147790	234089	308584	372096
CAN	59296	125802	195733	261700	322378
CAN No retrofit	58810	123605	191874	256599	316251
SWE CCS	62847	135881	225833	306928	378389
SWE GS	62537	134369	221697	300252	370559
SWE REN	63022	130356	194171	253422	308269
A2 REN	60358	129159	196818	260623	317726
LC REN	67155	137598	200606	259138	310115
A2+GS+CCS					
ParCom No retro +CCS	61081	140256	247455	345496	430814
ParCom No retro +GS	60402	133393	231424	321228	402198
temperature	58647	124810	194508	260131	320161
RT2005+GS	60244	131642	222389	304805	378083

RT 2005 + CCS	60616	133506	227933	314554	391532

DR=10%	2010	2015	2020	2025	2030
<i>TJ-2004</i>	50851	92993	126884	151246	168229
<i>RT2005</i>	52324	95256	129291	153452	170171
<i>SWE</i>	54333	98082	132272	156256	172716
<i>A1</i>	50845	94034	128224	152795	169695
<i>A2</i>	50844	94018	128793	153711	170714
<i>A2+CCS</i>	50843	96718	141935	173380	194269
<i>A2+Gas Switching</i>	50832	96473	141537	172565	193114
<i>A3</i>	59437	108444	144786	169275	185187
<i>ParCom with Re</i>	50546	94106	130539	157005	175284
<i>ParCom without Re</i>	52584	97706	135078	161881	180474
<i>Applmp</i>	50811	92782	126439	150572	167361
<i>LC-R1</i>	59437	108354	144517	168662	184341
<i>LC-R2004</i>	59350	108100	144262	168527	184285
<i>Ref No retrofit</i>	50612	92673	126607	151013	168061
<i>SWE-No retrofit</i>	54029	97695	131869	155850	172342
<i>RT2005 No retrofit</i>	52020	94872	128887	153096	169885
<i>Ref CCS</i>	50885	96305	142867	175545	197842
<i>Ref GS</i>	50832	95526	140425	171771	193018
<i>A1 No Retrofit</i>	50540	93596	127765	152384	169353
<i>A2 No Retrofit</i>	50540	93596	128373	153363	170458
<i>LC-R1 CCS</i>	59472	110599	154930	184538	203591
<i>LC-R1 GS</i>	59449	109868	151719	179033	196640
<i>CAN</i>	51501	93952	127797	151942	168740
<i>CAN No retrofit</i>	51096	92460	125496	149185	165698
<i>SWE CCS</i>	54565	100916	144494	174211	194013
<i>SWE GS</i>	54310	99941	142249	171021	190491
<i>SWE REN</i>	54750	97846	128732	150424	165586
<i>A2 REN</i>	52390	96407	129157	152527	168337
<i>LC REN</i>	58292	103434	133949	155389	169512
<i>A2+GS+CCS</i>					
<i>ParCom No retro +CCS</i>	52961	103035	154937	190871	214515
<i>ParCom No retro +GS</i>	52428	98661	146114	179000	201419
<i>temperature</i>	50931	93161	126894	150916	167537
<i>RT2005+GS</i>	52322	97612	141564	171755	192047
<i>RT 2005 + CCS</i>	52629	98817	144542	176277	197605

DR=16%	2010	2015	2020	2025	2030
<i>TJ-2004</i>	44892	72602	89745	99206	104268
<i>RT2005</i>	46186	74418	91639	101023	106008
<i>SWE</i>	47948	76729	94032	103349	108258
<i>A1</i>	44887	73293	90592	100136	105175
<i>A2</i>	44885	73282	90882	100563	105633
<i>A2+CCS</i>	44885	74870	97767	109991	116224
<i>A2+Gas Switching</i>	44876	74515	96657	108457	114493
<i>A3</i>	52319	84583	102992	112517	117265
<i>ParCom with Re</i>	44596	73204	91628	101907	107357
<i>ParCom without Re</i>	46371	76011	94908	105317	110861
<i>Applmp</i>	44858	72458	89484	98856	103861
<i>LC-R1</i>	52319	84526	102847	112239	116917
<i>LC-R2004</i>	52243	84338	102656	112094	116797
<i>Ref No retrofit</i>	44680	72334	89499	98976	104058

SWE-No retrofit	51667	88949	115353	132170	142623
<i>RT2005 No retrofit</i>	46559	74798	90749	99478	104105
Ref CCS	44919	74566	98130	110827	117478
Ref GS	44876	74081	96804	108984	115319
A1 No Retrofit	44619	72938	90225	99788	104847
A2 No Retrofit	44619	72938	90537	100246	105343
LC-R1 CCS	56836	100685	135594	156840	169300
LC-R1 GS	52329	85422	106635	117260	122515
CAN	45464	73380	90503	99880	104887
CAN No retrofit	45121	72324	89037	98236	103158
SWE CCS	48145	78469	100538	112091	117999
SWE GS	47932	77809	99235	110415	116221
SWE REN	48333	76738	92366	100791	105305
A2 REN	46218	75221	91792	100873	105586
LC REN	51409	81200	96648	104980	109193
A2+GS+CCS					
ParCom No retro +CCS	46678	79332	105600	119572	126628
ParCom No retro +GS	46252	76445	100457	113233	119917
temperature	44957	72726	89793	99123	104078
RT2005+GS	46185	75800	98052	109785	115836
RT 2005 + CCS	46442	76616	99762	112097	118460

B2 -medium carbon price

Table A- 23

DR=4%	2010	2015	2020	2025	2030
<i>TJ-2004</i>	58682	127777	205615	283016	356205
<i>RT2005</i>	60376	130494	207962	283801	354873
SWE	62695	133865	210833	284884	353467
A1	58676	129314	207403	284613	356425
A2	58674	129274	208361	286083	357740
A2+CCS	58673	133422	229626	318910	397760
A2+Gas Switching	58655	132751	228980	319802	401460
A3	68731	147586	227221	299935	363532
ParCom with Re	58385	130253	214559	298884	377846
ParCom without Re	60763	135150	221777	307817	388777
Applmp	58633	127472	204877	281755	354376
LC-R1	68731	147430	226648	298298	360891
LC-R2004	68630	147098	226393	298363	361211
Ref No retrofit	58412	127456	205589	283290	357028
SWE-No retrofit	62342	133425	210609	285077	354307
<i>RT2005 No retrofit</i>	60826	130800	203350	274930	342134
Ref CCS	58727	132963	232178	325191	409542
Ref GS	58655	131993	231109	325630	412318
A1 No Retrofit	58324	128819	207081	284774	357274
A2 No Retrofit	58324	128819	208177	286542	359085
LC-R1 CCS	68775	150983	244524	327755	398992
LC-R1 GS	68747	149986	240116	319448	388115
CAN	59426	128846	206056	281969	353631
CAN No retrofit	58944	126781	202785	278276	349730
SWE CCS	62973	138155	230744	314973	389519

SWE GS	62663	136990	229639	315320	393288
SWE REN	63141	132822	201550	266606	327324
A2 REN	60480	131746	204713	274759	337843
LC REN	67267	139807	207001	270463	326329
A2+GS+CCS					
ParCom No retro +CCS	61231	143158	253083	354222	442552
ParCom No retro +GS	60549	136986	243711	345112	438525
temperature	58783	127989	205108	280676	351311
RT2005+GS	60372	134384	230671	320709	402333
RT 2005 + CCS	60745	135935	233061	322885	403019

DR=8%	2010	2015	2020	2025	2030
<i>TJ-2004</i>	53306	104294	151982	191292	222103
<i>RT2005</i>	54843	106596	154069	192592	222516
SWE	56946	109495	156674	194297	223177
A1	53300	105441	153293	192517	222755
A2	53298	105412	153886	193377	223553
A2+CCS	53298	108256	167277	212676	245901
A2+Gas Switching	53283	107785	166801	212969	247360
A3	62328	120599	169455	206434	233232
ParCom with Re	53010	105994	157633	200466	233711
ParCom without Re	55154	110004	163058	206759	240846
Applmp	53263	104064	151488	190533	221106
LC-R1	62328	120487	169094	205534	231904
LC-R2004	62237	120223	168871	205472	231955
Ref No retrofit	53059	104005	151872	191333	222373
SWE-No retrofit	56627	109108	156418	194250	223401
<i>RT2005 No retrofit</i>	55267	106973	151417	187775	216064
Ref CCS	53344	107870	168714	215991	251526
Ref GS	53283	107171	167935	215966	252466
A1 No Retrofit	52981	105015	152969	192437	222963
A2 No Retrofit	52981	105015	153651	193466	224013
LC-R1 CCS	62365	122939	180352	222696	252723
LC-R1 GS	62341	122247	177576	217925	246863
CAN	53983	105217	152530	191087	221254
CAN No retrofit	53556	103622	150188	188527	218607
SWE CCS	57192	112506	169314	212145	243555
SWE GS	56921	111621	168450	211996	244830
SWE REN	57369	108903	151036	184094	209635
A2 REN	54917	107607	152340	187945	214510
LC REN	61086	114786	155998	188256	211790
A2+GS+CCS					
ParCom No retro +CCS	55557	115698	183118	234556	271777
ParCom No retro +GS	54978	111105	176519	228043	267373
temperature	53393	104466	151724	190111	219852
RT2005+GS	54840	109258	168305	214068	248440
RT 2005 + CCS	55168	110431	170005	215675	249436

DR=10%	2010	2015	2020	2025	2030
TJ-2004	50953	94984	132603	160910	181162
RT2005	52421	97116	134570	162313	181983
SWE	54429	99819	137046	164143	183129
A1	50947	95980	133732	161981	181859
A2	50945	95955	134202	162646	182483
A2+CCS	50945	98323	144912	177622	199471
A2+Gas Switching	50931	98274	146183	180115	203035
A3	59523	109877	148443	175089	192711
ParCom with Re	50659	96392	137123	167969	189823
ParCom without Re	52699	100047	141892	173362	195769
AppImp	50913	94783	132194	160310	180406
LC-R1	59523	109782	148153	174411	191751
LC-R2004	59436	109544	147947	174321	191735
Ref No retrofit	50716	94708	132469	160884	181286
SWE-No retrofit	54125	99455	136785	164032	183195
RT2005 No retrofit	52118	96772	134306	162223	182082
Ref CCS	50988	97970	145990	180047	203412
Ref GS	50931	97373	145321	179918	203910
A1 No Retrofit	50643	95582	133414	161837	181904
A2 No Retrofit	50643	95582	133956	162631	182713
LC-R1 CCS	59558	111829	157160	187678	207427
LC-R1 GS	59536	111250	154938	184014	203045
CAN	51600	95846	133173	160939	180767
CAN No retrofit	51197	94435	131169	158777	178548
SWE CCS	54660	102360	147204	178065	198720
SWE GS	54406	101582	146437	177805	199390
SWE REN	54841	99389	132635	156446	173229
A2 REN	52482	98022	133321	158971	176435
LC REN	58376	104819	137346	160585	176059
A2+GS+CCS					
ParCom No retro +CCS	53074	104880	158093	195157	219634
ParCom No retro +GS	52539	100894	152507	189617	215471
temperature	51034	95140	132424	160069	179619
RT2005+GS	52419	99329	145931	178896	201493
RT 2005 + CCS	52727	100359	147380	180284	202484

DR=16%	2010	2015	2020	2025	2030
TJ-2004	44970	73879	92887	103872	109907
RT2005	46261	75613	94544	105312	111174
SWE	48022	77847	96671	107191	112850
A1	44965	74543	93624	104590	110515
A2	44963	74526	93864	104908	110822
A2+CCS	44963	75920	99504	112219	118737
A2+Gas Switching	44953	75676	99243	112166	118907
A3	52385	85509	105033	115392	120649
ParCom with Re	44683	74670	95244	107216	113729
ParCom without Re	46459	77511	98645	110858	117536
AppImp	44936	73742	92646	103556	109544
LC-R1	52385	85448	104877	115086	120258
LC-R2004	52310	85272	104713	114967	120163
Ref No retrofit	44759	73640	92719	103745	109823

SWE-No retrofit	51741	90081	118065	136143	147390
<i>RT2005 No retrofit</i>	46634	76018	93730	103891	109430
Ref CCS	44998	75654	99949	113180	120149
Ref GS	44953	75272	99520	112955	120106
A1 No Retrofit	44699	74213	93333	104366	110347
A2 No Retrofit	44699	74213	93613	104746	110732
LC-R1 CCS	56903	101492	136903	158502	171169
LC-R1 GS	52396	86319	108453	119759	125439
CAN	45540	74596	93462	104237	110145
CAN No retrofit	45199	73592	92154	102867	108758
SWE CCS	48218	79413	102118	114114	120276
SWE GS	48005	78870	101570	113754	120189
SWE REN	48402	77735	94548	103794	108789
A2 REN	46288	76262	94113	104078	109284
LC REN	51474	82095	98555	107583	112198
A2+GS+CCS					
ParCom No retro +CCS	46765	80539	107467	121877	129180
ParCom No retro +GS	46338	77877	103970	118380	126085
temperature	45036	73997	92842	103572	109399
RT2005+GS	46259	76910	100487	113292	120028
RT 2005 + CCS	46517	77624	101421	114209	120831

B3. high carbon price

Table A- 24

DR=4%	2010	2015	2020	2025	2030
<i>TJ-2004</i>	59489	135662	224037	313645	398996
<i>RT2005</i>	61147	137887	225018	311938	393983
SWE	63458	140830	226383	310063	388034
A1	59486	137051	225209	313795	396677
A2	59481	136975	225876	314504	396698
A2+CCS	59480	140139	240219	333413	415830
A2+Gas Switching	59444	140004	244276	344080	434558
A3	69415	153418	239339	318723	388679
ParCom with Re	59282	139269	235722	333598	425852
ParCom without Re	61672	144370	243642	344117	439257
Applmp	59443	135394	223412	312612	397535
LC-R1	69415	153245	238704	316888	385652
LC-R2004	69317	152974	238600	317090	386096
Ref No retrofit	59231	135510	224457	314564	400778
SWE-No retrofit	63105	140462	226566	311134	390296
<i>RT2005 No retrofit</i>	61609	138344	220840	303891	382515
Ref CCS	59543	139908	243243	340517	428843
Ref GS	59444	139407	247142	351719	448624
A1 No Retrofit	59145	136709	225323	314784	398801
A2 No Retrofit	59145	136709	226233	315995	399642
LC-R1 CCS	69460	156217	252583	338626	412449
LC-R1 GS	69437	155688	251010	335792	409752
CAN	60208	136367	223419	310536	393473
CAN No retrofit	59747	134609	221064	308681	392253
SWE CCS	63728	144231	240398	328162	405876
SWE GS	63418	143652	243498	337209	423043

SWE REN	63859	139081	214477	286080	352824
A2 REN	61214	138258	218430	295516	364744
LC REN	67939	145462	218344	287364	348251
A2+GS+CCS					
ParCom No retro +CCS	62134	150883	264511	369144	460567
ParCom No retro +GS	61434	145805	264285	378753	484942
temperature	59603	135856	223012	309784	391310
RT2005+GS	61140	141329	245106	343730	433923
RT 2005 + CCS	61523	142395	243182	336619	419993

DR=8%	2010	2015	2020	2025	2030
TJ-2004	53974	110157	164280	209782	245711
RT2005	55482	112096	165472	209617	244158
SWE	57578	114686	167112	209621	242453
A1	53971	111198	165201	210198	245096
A2	53967	111143	165615	210641	245252
A2+CCS	53966	113312	174706	222091	256818
A2+Gas Switching	53936	113199	177129	227856	265958
A3	62894	124960	177662	218027	247502
ParCom with Re	53753	112692	171751	221461	260299
ParCom without Re	55907	116851	177628	228653	268708
Applmp	53934	109953	163859	209154	244903
LC-R1	62894	124835	177261	217018	245987
LC-R2004	62806	124615	177139	217050	246126
Ref No retrofit	53737	109991	164466	210219	246506
SWE-No retrofit	57259	114349	167110	210067	243397
RT2005 No retrofit	55915	112585	163104	205281	238374
Ref CCS	54019	113095	176461	225901	263110
Ref GS	53936	112701	178727	231859	272655
A1 No Retrofit	53661	110884	165162	210601	245975
A2 No Retrofit	53661	110884	165733	211332	246552
LC-R1 CCS	62933	126889	186034	229807	260923
LC-R1 GS	62913	126524	185029	228145	259311
CAN	54630	110812	164138	208378	243288
CAN No retrofit	54221	109443	162391	206882	242060
SWE CCS	57817	117084	176083	220710	253454
SWE GS	57546	116600	177828	225448	261592
SWE REN	57964	113580	159798	196183	224259
A2 REN	55525	112466	161613	200798	229951
LC REN	61642	119017	163716	198798	224446
A2+GS+CCS					
ParCom No retro +CCS	56304	121516	191205	244419	282943
ParCom No retro +GS	55710	117658	190255	248410	293116
temperature	54072	110320	163712	207785	242109
RT2005+GS	55476	114446	178068	228187	266165
RT 2005 + CCS	55812	115294	177111	224617	259743

DR=10%	2010	2015	2020	2025	2030
TJ-2004	51563	100067	142755	175518	199133
RT2005	53004	101887	143991	175779	198484
SWE	55005	104326	145687	176301	197883
A1	51559	100973	143570	175975	198915
A2	51555	100925	143899	176327	199079
A2+CCS	51554	102732	151192	185334	208170

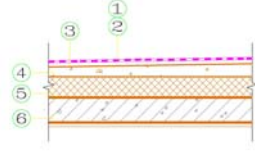
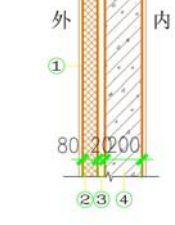
A2+Gas Switching	51527	102976	154758	191971	217330
A3	60039	113669	155266	184350	203732
ParCom with Re	51337	102197	148774	184570	210099
ParCom without Re	53386	105980	153908	190650	216979
AppImp	51525	99889	142406	175020	198517
LC-R1	60039	113562	154945	183591	202639
LC-R2004	59955	113363	154821	183578	202697
Ref No retrofit	51335	99899	142863	175806	199656
SWE-No retrofit	54701	104004	145627	176563	198473
RT2005 No retrofit	52709	101639	143958	176063	199079
Ref CCS	51604	102525	152533	188148	212614
Ref GS	51527	102174	154267	192534	219350
A1 No Retrofit	51264	100672	143485	176207	199459
A2 No Retrofit	51264	100672	143941	176780	199933
LC-R1 CCS	60076	115280	161976	193523	213988
LC-R1 GS	60058	114974	161166	192233	212729
CAN	52191	100699	142763	174618	197563
CAN No retrofit	51804	99482	141243	173278	196400
SWE CCS	55231	106353	152926	185081	206613
SWE GS	54976	105910	154231	188532	212292
SWE REN	55383	103453	139923	166130	184578
A2 REN	53036	102243	141023	169252	188418
LC REN	58884	108499	143778	169050	185913
A2+GS+CCS					
ParCom No retro +CCS	53756	109954	164957	203302	228635
ParCom No retro +GS	53207	106574	163846	205729	235116
temperature	51653	100217	142334	174072	196635
RT2005+GS	52999	103838	154043	190144	215109
RT 2005 + CCS	53314	104600	153391	187617	210714

DR=12%	2010	2015	2020	2025	2030
TJ-2004	45438	77260	98818	111529	118565
RT2005	46708	78789	100060	112396	119161
SWE	48463	80855	101760	113644	120077
A1	45434	77868	99387	111964	118801
A2	45431	77837	99554	112143	118925
A2+CCS	45431	78899	103429	116699	123511
A2+Gas Switching	45410	78820	104337	118531	125998
A3	52781	88051	109103	120407	126189
ParCom with Re	45202	78526	102042	115933	123540
ParCom without Re	46986	81452	105645	119901	127747
AppImp	45406	77138	98610	111263	118264
LC-R1	52781	87983	108931	120066	125747
LC-R2004	52708	87832	108815	119992	125696
Ref No retrofit	45234	77091	98789	111568	118673
SWE-No retrofit	52183	93115	123260	142768	154833
RT2005 No retrofit	47088	79257	99376	111160	117639
Ref CCS	45470	78730	104029	117864	125161
Ref GS	45410	78478	104811	119668	127658
A1 No Retrofit	45174	77602	99228	111927	118856
A2 No Retrofit	45174	77602	99466	112213	119113
LC-R1 CCS	57299	103834	139935	161933	174813
LC-R1 GS	52796	88825	112222	124300	130416

Appendix IV. Technical recommendation of current BEE standard implementation

Example of envelope insulation in HXJD 6-stoery apartment buildings project

Table A- 25. Technical specification for TJ-2004 implementation

component		modus operandi		d	λ	a	R	K
Built-up Roofing (flat)		1	Membrane Waterproof sheet					
		2	SBS waterproof	10	0.17	1.0	0.059	
		3	1 : 3 mortar leveling course (20mm)	20	0.93	1.0	0.022	
		4	Mixture of cement and residual slags (1 :6) with 2% slope	70	0.29	1.5	0.161	
		5	EPS 110mm	110	0.042	1.5	1.746	
		6	Concrete slab	120	1.74	1.0	0.069	
		7	Overall K value					0.45
Exterior wall		1	Paintings&coating					
		2	EPS 80mm	80	0.042	1.2	1.587	
		3	mortar leveling course (20mm)	20	0.93	1.0	0.022	
		4	Reinforced concrete	200	1.74	1.0	0.115	
		5	Overall K value					0.53

Staircase : insulating mortar 30mm

Window : heat insulation aluminium double-glazed window

Door : Steel security door

Source: Credit Du, J. Tianjin Building Energy Efficiency Monitoring and Evaluation Centre

Buildings illustration and energy efficiency monitoring measures in the HXJD programme



Figure 8-1 Completed medium-rise residential buildings in HXJD project

-Energy efficiency Monitoring



Figure 8-2 heat metres in a completed house



Figure 8-3 air tightness check

Source: Photos were taken by author during performance monitoring in Huaxiajindian project

Appendix V. Registered BEE materials commercialisation in Tianjin buildings construction market in 2007

Supplier	Quantity
Beijing Beipaojun Co.ltd	4200
Beijing Beipeng bldg Mat Ltd	15754
Beijing Bofa	350
Beijing Danrunya SciTech Co.	90
Beijing Derun Jiaye bldg Mat Manufacturing	6304.95
Beijing Fangyeda Co.	8000
Beijing Hangyu Insulation Co.	4100
Beijing Hongbo Fengye	6630
Beijing Hongyunjia	10
Beijing JingYeDa	18900
Beijing Pengyang	1101
Beijing QingTian Sci-Tech	230
Beijing Beipao Qinggang	900
Beijing Solite	4300
Beijing Taishenglong	23013
Beijing Yanchang Rongxin	1000
Beijing Yingxin	450
Beijing Zhenli	530
Beijing Zhongtao Weiye	1620
Chang County Huayu	13551
Dacheng County Guangan Xinjia	1000
Dalian Huaneng Fire-proof Mater	600
Hebei Haoyeda	3427.5
Hebei Hongxin	3922
Hebei Huamei Group	16332.09
Hebei jingwang	100
Hebei Nanyang Chemcial Eng.	10474
Henan Anxinda Waterproof	1480
Knife Insulating Mat.	3145
Lafarge	150
Langfang Dadong	11031
Langfang Jinjiang	5508
Langfang Jinke	500
Langfang Jinmei	3300
Langfang Huaneng	30006.981
Langfang Zhongan	15752.333
Langfang Zhonghuan Chemical Eng.	220
Langfang Tianda	29646.25
Langfang Xiangfa	350
Langfang New Times	3260
Langfang Xinda	7416
Langfang Yida	6200
Ninghe County Hengtong	10361
Qingdao Ox	2218
Qingdao Hongyun	2800
Qingdao Century Huayu	400
Qiangxian Tiantong	2800
Shangxi Huihuang	4255

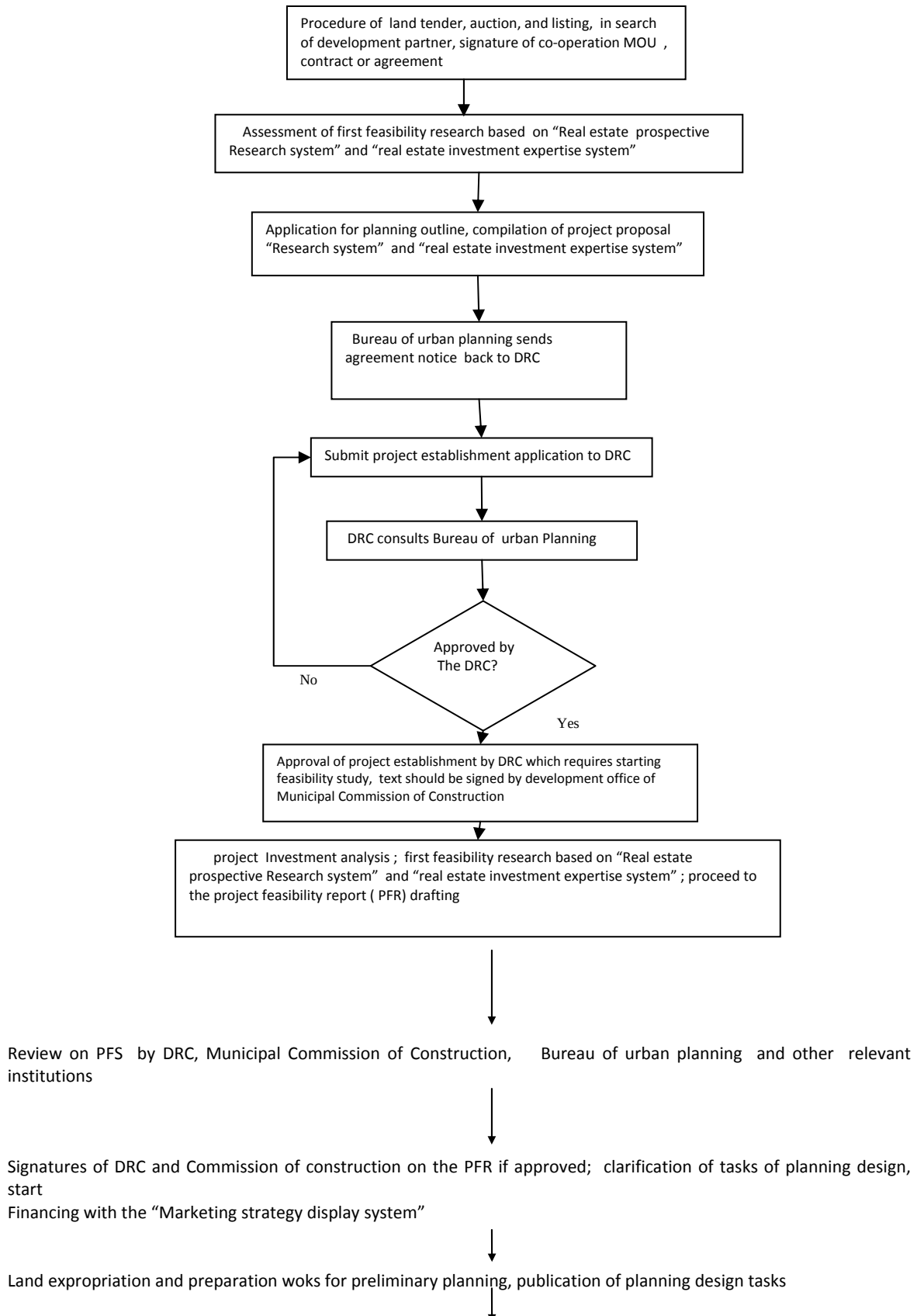
Yutian Caitingqiao	10954
OwenScorning China (Tianjin)	8850
Tanggu Shuntong	25024
Tianjin Boao	3108
Tianjin ChangheChang	12996
Tianjin Fubang	40
Tianjin Gangsheng Huaneng	2682
Tianjin Hongtailai	4462
Tianjin hongyu	3990
Tianjin Hualida	5724
Tianjin Jinniu	2536
Tianjin Jinshunda	900
Tianjin Shengjie	680
Tianjin Aoxinhai	1000
Tianjin Aolin	4280
Tianjin Chenxing	6164
Tianjin Sanxing	14898
Tianjin Fuda	2100
Tianjin Guojun	10477.3
Tianjin Hongsheng	11565
Tianjin Huaqiang	11854
Tianjin Jifa	2945
Tianjin Jiemei	2760
Tianjin Jinan	710
Tianjin Chaoen	1179
Tianjin Qiangsheng	4683
Tianjin Jinsheng	4385
Tianjin Jinma	4664
Tianjin Longshengxiang	4739
Tianjin Xinda	9456
Tianjin Junli	18300
Tianjin Kaichi	500
Tianjin kunshen	9120
Tianjun Linlong	3100
Tianjin Lubao	236
Tianjin Meihua	2861
Tianjin Meiri	1980
Tianjin Ouyisi	32270
Tianjin Paomo	750
Tianjin Pengcheng Weiye	3735
Tianjin Sanhe	4627
Tianjin Sanxing Yangguang	56803.9
Tianjin Shengli	1936
Tianjin Shengdi	20853
Tianjin Shengqiang	50
Tianjin Tiande	2796
Tianjin Shuanglong Shuangsheng	24734
Tianjin Tianyu	4715
Tianjin tudasi	600
Tianjin Wanteng	24573
Tianjin Hongguang	400
Tiangjin hongrun	7754
Tianjin Liangxing	4820
Tianjin Mingxing	1510
Tianjin Quanyuan	14181.94

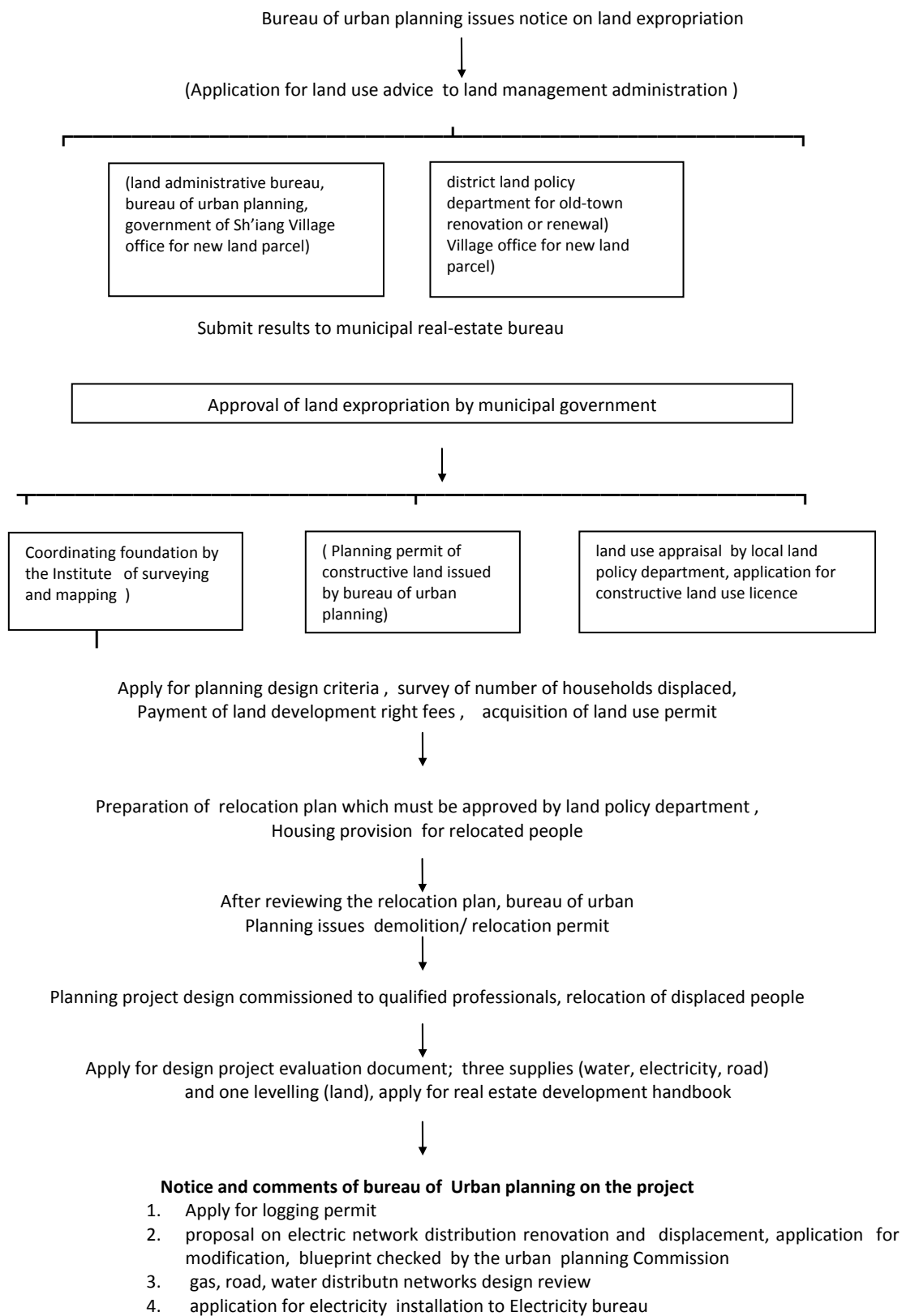
Tianjin Chaosite	25990
Tianjin Xinfengye Petrochemical	300
Tianjin Xinrui	4300
Tianjin Xinle	192
Tianjin Yajin	31113.2
Tianjin Yulin	2697
Tianjin Zhaoyuan	16689
Tianjin Shuangxinxin	20333
Tianjin Taoshide	280
Tianjin Tianneng	2120
Tianjin Tianyutong XPS	23960.9555
Tianjin Weiye	5270
Tianjin Xishite	39962.29
Tianjin Xinyu	8623
Tianjin Yantong	2623
Tianjin Youjingfumu	205
Tianjin Zhuyijian	1300
total	896658.6895

Source: Tianjin Buildings Materials Association (Courtesy of Secretary Yang)

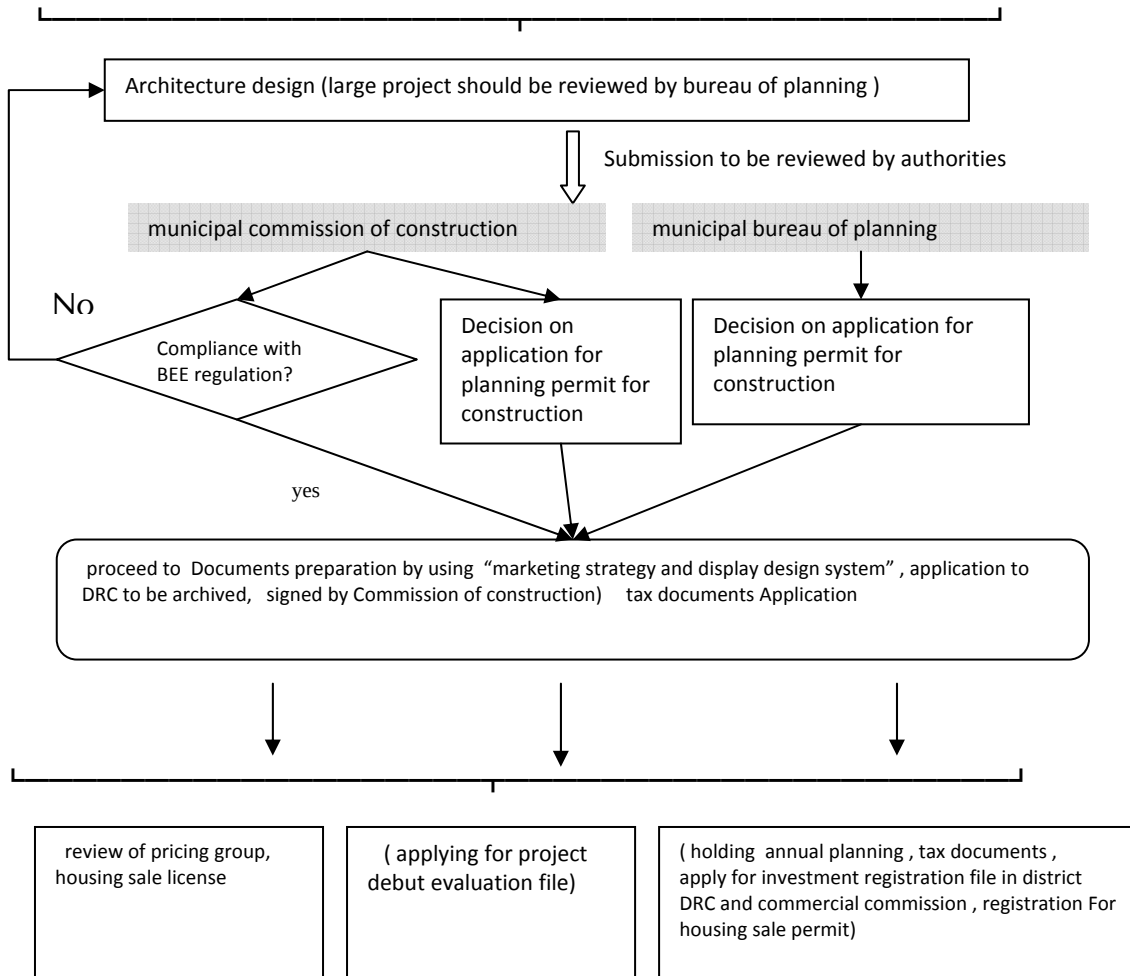
Appendix VI. Property development process in Chinese cities

The diagram below illustrates the general process by specifying the different steps.

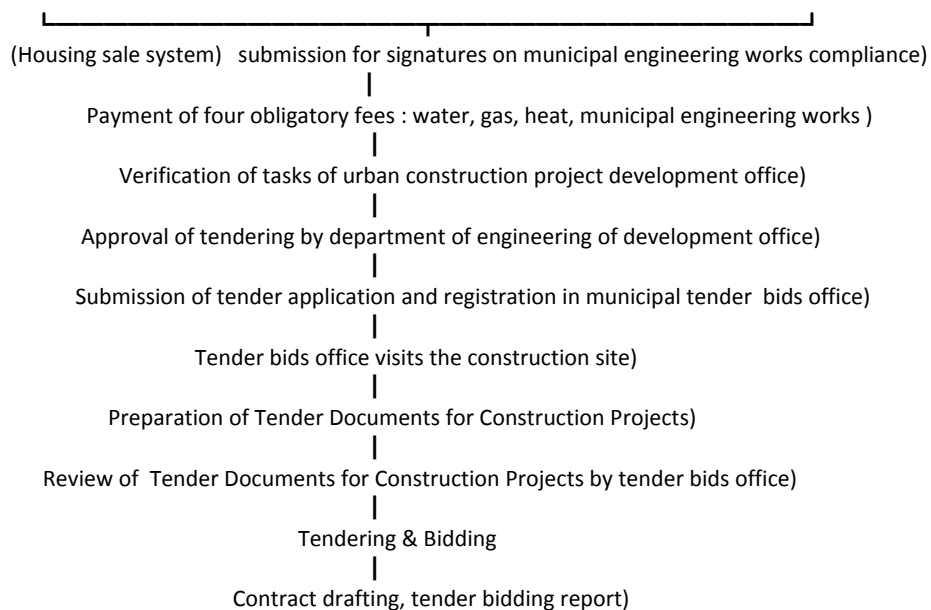


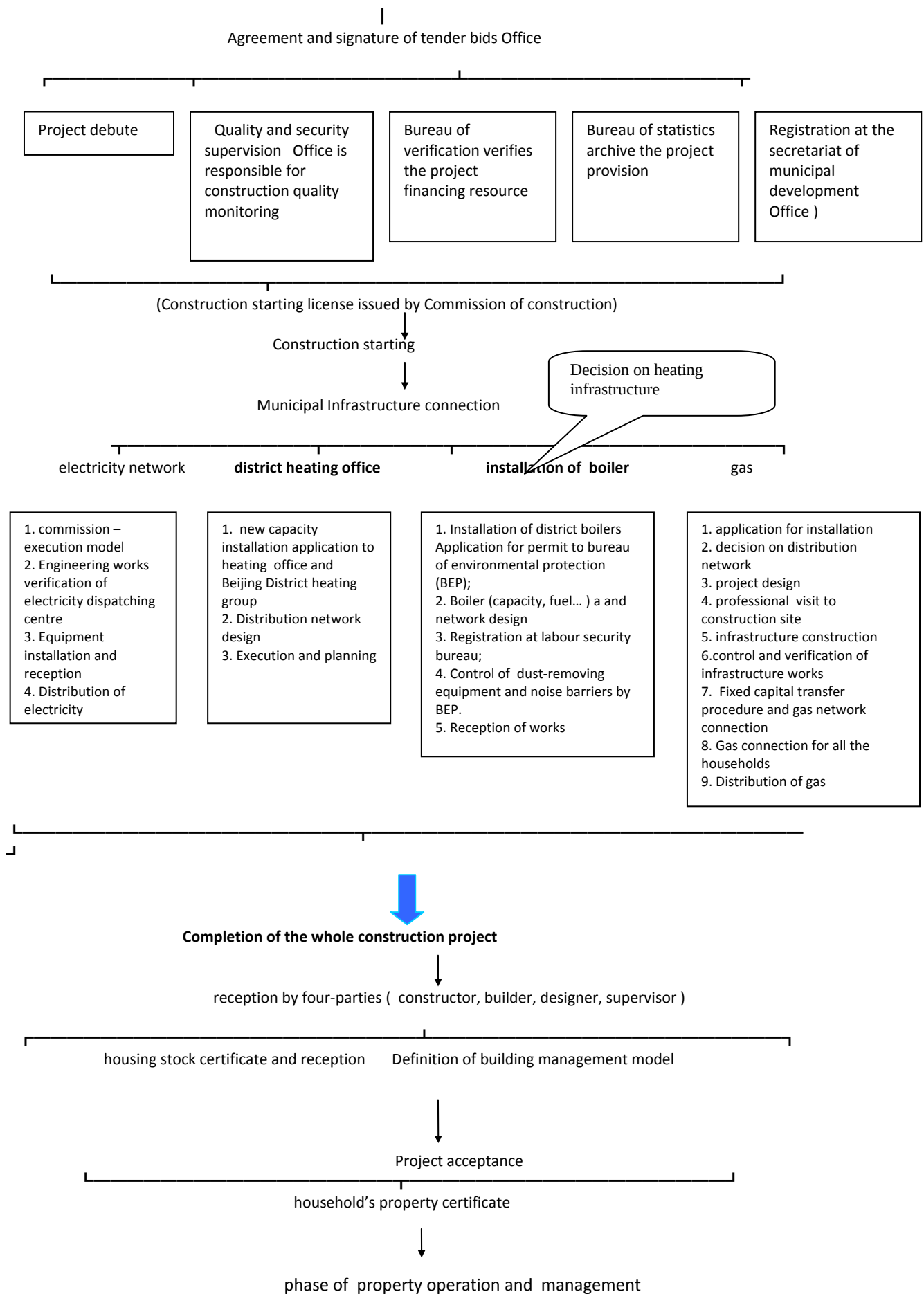


Report on municipal engineering meeting



Pricing approved by Commission of Construction and Municipal bureau of price





Appendix VII

Rebound effect

1 Economic theory of energy consumption in residential buildings- in the search of the rebound effect of energy consumption

A large number of academic research in energy economy states that improving energy efficiency releases an economic reaction that partially offsets the original energy saving. As the energy efficiency of some process improves, the process becomes cheaper, thereby providing an incentive to increase its use (**Haas et al.2000**). In this review, we attempt to supply some insightful analysis of economics of building energy efficiency improvement and its economic

1.1 Model of (**Hass et al.1998, Haas et al.2000**): the European Case

According to the microeconomic theory in order to obtain any service ,it is necessary for a final consumer to mobilize an effort to get it either through work or money. As far as the energy services are concerned, this effort is therefore energy consumption. models of (**Hass et al.1998, Haas et al.2000**) specified the energy demand for space heating in the residential buildings. In fact, several factors exert influence on demand for space heating : building energy performance (insulation, thermal inertia...), efficiencies of heating system and appliances, energy prices, outdoor temperature, and most importantly the behavior of final consumer. In general, the demand for energy in heating is determined essentially by four factors determinants: 1.building energy performance, 2. consumer's behavior ; 3 climatic condition in terms of heating degree day ; 4 type of heating appliance. In practice, a consumer confronts permanently un trade-off between building performance quality and energy cost and performance of the energy system in order to maximize his utility of service S, the problem is to resolve the programme 1.1

$$Max \quad U(s) - PE_{Sh} \quad (1.1)$$

where

$U(s)$ is the utility of energy service

P is the energy price to meet comfort requirement

E_{Sh} is the real energy consumption in space heating

In fact, the consumer acquires energy service S_{pr} by consuming E_{Sh} , the quality of energy acquired service is dependent on heating appliance's energy efficiency but also the building's energy performance, represented by equation 1.2

$$E_{Sh} = S_{pr}/\eta \quad (1.2)$$

where

$$\eta = \eta_{HS}/g$$

S_{pr} is the actual service supplied by consumption, η represents the efficiency of heating system and building's energy performance, η_{HS} is the efficiency of heating system. g reflects the building's thermal performance; e.g. the higher is building's insulating quality or heating system's efficiency, the less one requires energy E_{Sh} for supply the same service S_{pr} . It is to note that building's performance g is correlated negatively with the coefficient of thermal transfer U .

secondly, to take account of consumer's behavior in analysis, it is desirable to define a theoretical comfort requirement in terms of S_{th} (e.g. indoor temperature is maintained at $20^\circ C$, 1V/h for air exchange etc. . .) which can be estimated by technical model as follows.

$$S_{Th} = 24q \cdot HDD \cdot A/1000$$

where A is the heating area. Consequently, the factor $f_{service}$ is introduced to take into account the consumer's behavior to estimate heating consumption. We define then $S_{pr} = S_{Th}$, $\rightarrow f_{service} = 1$ for any service S_i ,

$$f_{service} = \frac{\eta E_{Sh}}{S_{Th}} = \frac{E_{Sh}}{E_{Th}} \quad (1.3)$$

the real E_{Sh} and theoretical E_{Th} energy consumption are calculated by equations 1.4 and 1.5.

$$E_{Th} = C_0 \frac{q \cdot HDD \cdot A}{\eta_{HS}} \quad (1.4)$$

$$E_{Sh} = C_0 \frac{q \cdot HDD \cdot A}{\eta_{HS}} \times f_{service} \quad (1.5)$$

where

- C_0 : constant of conversion factor
- E_{Sh} : real consumption of for space heating
- E_{Th} : theoretical energy demand for space heating
- HDD : heating degree day
- A : heating area
- q : specified heating consumption in W/m^2
- η_{HS} : heating system efficiency

Equation 1.3 shows more the factor $f_{service}$ is important, more the real energy consumption approaches the theoretical energy need for heating, and higher is the comfort level(e.g. indoor temperature increases from 16°C to 20°C). Likewise, the demand for service S_{pr} supplied by energy consumption converges to theoretical value S_{Th} . The factor $f_{service}$ is taken as proxy to describe the relation between the real consumption and theoretical calculation value is a function F depending on variables such as building types, energy performance of buildings and heating equipment, energy service price, energy sources, preset indoor temperature, consumer's behavior etc.

More generally, the problem for the consumer can be expressed by the programme 1.6

$$Max_s U(S) - pE \quad (1.6)$$

where

$U(s)$ is the utility of energy service

P is the energy price supplied by the energy consumption per KWh

E is the energy consumption

and

$$s = E\eta \quad (1.7)$$

hence the solution of the programme 1.6 is

$$U'(s) = P/\eta = P_s \quad (1.8)$$

P_s is price of service, $U'(s)$ is the marginal utility of consuming one more unit of energy service. we can see immediately from this equation that the service price P_s is more important than energy price P for $\eta < 1$ regardless of building's energy performance¹, thus the consumer is always required to arbitrage between the choice of energy sources and the quality of services. e.g. the price of natural gas is more expensive than coal, but gas fired boiler is far more efficient than a coal oven with small capacity let alone the environmental pollution concerns. The price of service is dependent upon the efficiency of heating system and building energy performance, as well as the factor of consumption behavior $f_{service}$, so the final energy demand for energy varies with these parameters. Based on the empirical observations, (Hass et al.1998) regresses the energy consumption E_{Sh} on different variables underlying the characteristics in the function F , the results can be illustrated by the figure Figure 1.1.

One can see that the factor of service is positively correlated with the performance of building, designated by the value q , in other words, the value of $f_{service}$, the residents living in a low-performing house is inferior to the theoretical value predicted by the theoretical calculation². The requirement of service increases while the building energy performance is ameliorated. It can be

¹the case of condensing boiler or heating pump are excluded here since their COP can be well above 1

²this implies that the price of service is higher than what the consumer is affordable to pay to obtain this service

Figure 1.1: Service demand function $f_{service}$ according to building energy performance

derived from this dynamics that there is an arbitrage between the price of service and the demanded comfort in heating service for a *rational* consumers.

Figure 1.2: Rebound effect of demand for services (**Haas et al.2000**)

This short-term rebound effect of demand for energy service can often be observed after housing thermal retrofitting program whose dynamics can be shown by figure Figure 1.2. When building energy performance improves, the consumption curve moves from η_0 towards η_1 , should rebound effect did not exist, the energy demand would be lowered from E_0 to E_{1th} , but this is not the case in the real life. According to equation 1.8, as buildings becomes more energy efficient, say η increases, the consumer finds the price of service is lower than before and will not remain the previous level S_0 but strives to move to upper level S_1 according to fundamental microeconomic theories .

Consequently, the real energy conservation given by building efficiency improvement seems be less important than theoretical value,calculated using standard methodology which does not take into account the factor of consumer's behavior varying according to performance quality. This seems to be quite intuitive, yet the the quantification of the order of magnitude of this effect is quite subtle,since several factors can influence the real consumption, 1. upgrade of building's envelope thermal insulation, 2. Amelioration of heating system efficiency, 3. energy sources c change (for example, from coal to gas or electricity), 4. change of heating system (individual heating equipment to district heating) . The consumer's behavior is far from negligible in evaluation of building efficiency operations.

on the other hand, the evidence of existence of rebound effect reveals the fact the economic benefits could also be overestimated in the program of building energy efficiency improvement.

imperfection persisting in the estimate of energy conservation can be significantly minimized if the relationship between $f_{service}$ of building energy performance and heating system, thus a more reasonable vision can be achieved regarding the order of magnitude of energy saving potentials

offered by energy demand management in buildings. the elasticities of price and income can be estimated by employing technic-econometric approach to relating energy demand to several determinant variables, a simplified model can be represented as 1.9, a series of relevant data during the modelling period will be required to run the simulation.

$$\ln E_t = C + \beta_1 \ln P_t + \beta_2 \ln Y_t + \beta_3 \ln HDD_t \quad (1.9)$$

where P_t et Y_t is energy price and households disposable incomes during the period t respectively. However, as mentioned previously, the determinant factor influencing the heating consumption are more complexes, it is required to include in the model the factors such as heating system efficiency and type of housing. (**Haas et al.2000**) proposed evaluating the magnitude of rebound effect in residential heating consumption comprising several variables

$$E_{Sh} = K \times q^\alpha \times \eta_{HS}^{\beta_1} \times P^{\beta_2} \times Y^{\beta_3} \times Z^{\beta_4} \times A^{\beta_5} \times e^{\beta_6} \quad (1.10)$$

The model 1.10 can be easily transformed into *log – log* scale

$$\ln E_{hs} = \ln K + \alpha \ln q + \beta_1 \ln \eta_{HS} + \beta_2 \ln P + \beta_3 \ln Y + \beta_4 \ln Z + \beta_5 \ln A + \beta_6 \ln e \quad (1.11)$$

where

- K is a constant
- q is the thermal performance coefficient
- η_{HS} is the energy system efficiency
- P is energy price
- Y is household income
- Z number of houses in a building
- A heating space area
- e dummy variable
 - 1 for central heating
 - 0 for non central(individual)

This model allows to estimate different parameters and coefficients of variables, β_2 measures the elasticity of price, thus rebound effect relating to energy price; and rebound effect owing to amelioration of building performance and heating system efficiency can be quantified by the difference between the absolute value of coefficients α and β_1 . a sample of 500 Austrian households were observed in (**Haas et al.2000**), the simulation results show an increase by 20 to 30% of energy consumption compared with theoretical demand . This confirms the thesis that heating energy saving does not follow linearly the building's energy performance but in a more complicated way.

1.2 The model of Dubin- Miedema-Chandran(1986), the case for USA

The phenomenon of rebound effect of energy consumption for heating and cooling of American households were analyzed in an empirical study paper (Durbin et al.1986), the author specified a technico-econometric model to test la significance of consumer's behavior in response to housing energy efficiency upgrade combining building thermal quality and equipment efficiency improvement. Three categories of efficiency packages were assessed to be compared to the baseline case (housing without any efficiency amelioration intervention in Florida where energy demand for both space heating and cooling are quite important). Their main conclusion is that actual energy conservation is systematically below theoretical engineering estimates, as much as 13% for heating and 8 – 12% below for space cooling, due mainly to increased requirement of thermal comfort of consumer. More interestingly, customers who conserve electricity are also persistent; their houses are comparatively warmer in Summer and cooler in Winter. A log-log model was derived from utility function to estimate demand elasticity of price and household revenue, then the rebound effect relating to real energy service price was quantified accordingly.

1.2.1 Model

Let $U(\tau, G)$ represent the utility of consumption of a vector of goods G in an environment with temperature noted as τ , and τ^* indicates the degree of comfortable temperature for the resident, it is assumed the consumer's utility follows a a linear function $U[(\tau^* - \tau), G]$, and also $\tau^* > \tau$, he needs a certain type of effort to reach the level τ^* , i.e. energy consumption. The consumer has to trade off between the comfort requirement(ambient temperature of heated or cooled area) and energy price. Consume's question can be expressed mathematically

$$Max \quad U[(\tau^* - \tau), G]$$

subject to

$$(p/\eta)C(\tau, T) + G \leq W \quad (1.1)$$

where p is energy price, T is outdoor temperature, η is the efficiency of equipment, $C(\tau, T)$ is the consumption of heating and cooling. Using Lagrangien with multiplier λ ,

$$L = U[(\tau^* - \tau), G] + \lambda[W - G - (p/\eta)C(\tau, T)] \quad (1.2)$$

the first order condition is

$$L_\tau = -U_\tau - \lambda(p/\eta)C_\tau(\tau, T) = 0 \quad (1.3)$$

$$L_G = U_G - \lambda = 0 \quad (1.4)$$

rewrite the equation differently

$$-U_\tau/U_G = pC(\tau, T)/\eta \quad (1.5)$$

the equation 1.5 implies that marginal rate of substitution between the indoor comfort and other consumption goods depend on *price of comfort* which in turn is a function of comfort level. the thermal consumption of consumer i is assumed as a quadratic function to the temperature difference $\tau - T$,

$$C^i(\tau, T) = W_{i0} + W_{i1}(\tau - T) + W_{i2}(\tau - T)^2 \quad (1.6)$$

In fact, the comfort price is calculated by approximation of rated utilization changed during the billing period with a degree change on the thermostats.

The model for estimation of conditional electricity consumption is written as

$$Y_{ij}^e = \sum_{j=i}^J UEC_{it}^j \psi_i^j(F_{it}^j \beta^j) + E_i \gamma + \epsilon_{it} \quad (1.7)$$

where

Y_{ij}^e electricity demand of household i over the period t

UEC_{it}^j unitary consumption of electricity of household i over the period t

ψ_i^j indicator of equipment j owned by household i ,

F_{it}^j vector of socioeconomic variables influencing equipment j of household i over the period t ,

β parameters related to F_{it}^j

E_i vector of socioeconomic variables influencing electricity consumption not respect with time

γ vector of parameters related to E

ϵ_{it} non observable random disturbance for household i over the period t , assumed to be homoscedastic and non correlated

The energy consumption is then decomposed into tow principal usages: heating and cooling, referred to as Y_{it}^{SH} and Y_{it}^{AC} respectively,

$$Y_{it}^{SH} = UEC_{it}^{SH} \psi_{it}^{SH}(F_{it}^{SH} \beta^{SH}) + \epsilon_{it}^{SH} \quad (1.8)$$

$$Y_{it}^{AC} = UEC_{it}^{AC} \psi_{it}^{AC}(F_{it}^{AC} \beta^{AC}) + \epsilon_{it}^{AC} \quad (1.9)$$

$$Y_{it}^e = Y_{it}^{SH} + Y_{it}^{AC} + E_i \gamma \quad (1.10)$$

By dividing the tow sides of the equations 1.8 and 1.9 by the estimator UEC , the models of estimation for the month t can be transformed as follows

$$UH_t = \alpha_0 + \alpha_1 PHEAT_t + \alpha_2 Income + \alpha_3 Noccupt + \epsilon H_t \quad (1.11)$$

$$UAC_t = \beta_0 + \beta_1 PCOOL_t + \beta_2 Income + \beta_3 Noccupt + \epsilon AC_t \quad (1.12)$$

where

$$UH_t = Y_{it}^{SH} / UEC_{it}^{SH} \quad (1.13a)$$

$$UAC_t = Y_{it}^{AC} / UEC_{it}^{AC} \quad (1.13b)$$

$$PHEAT_t = P_t(\Delta UEC_t^{SH} / \Delta \tau) = P_t \lambda^{SH} \quad (1.13c)$$

$$PCOOL_t = P_t(\Delta UEC_t^{AC} / \Delta \tau) = P_t \lambda^{AC} \quad (1.13d)$$

P_t electricity tariff,

λ^{SH} et λ^{AC} KWh consumed in response to every degree change of thermostat for heating and cooling respectively

Income revenue of households divided into category 1-6

Noccupt number of resident in the house

α et β coefficients to estimate in the models

$\epsilon H_t, \epsilon AC_t$ error terms.

The data of input for econometric simulation derived from a sample of survey of consumption conducted by electricity company.

1.2.2 measurement

This model is quite convenient by the fact that the elasticities of energy demand with respect to energy price and households revenue can be derived from equations 1.11 et 1.12 straightforward.

for

$$\partial Y^{SH} / \partial P = \alpha_1 \lambda^{SH} UEC_{it}^{SH}$$

Price elasticity of heating

$$\epsilon_{Y^{SH}, P} = \partial \ln Y^{SH} / \partial \ln P = \alpha_1 UH^{-1} PHEAT$$

In a simplified way, elasticity with respect to revenue and to number of resident in the house. It is found by simulation that price elasticity is relatively high during the heating period varying from -0.52 to -0.81 , that is to say the consumers are likely to consume more energy if the price of comfort

decreases in an effective way. On the other hand, elasticity is far less important during peak period of heating and cooling since the consumers can hardly adjust their demand quickly because of lack of substitution services.

1.2.3 quantification of rebound effect in the model

The main objective is to quantify the degree of consumption rebound following to energy performance improvement (in plain words, how a consumer reacts when the real comfort price falls, the demand curve of energy will be shifted in this case). The main findings in their paper is that engineer's calculation often overestimate energy saving potentials in the building energy efficiency operations. Classical method assumes $l\%$ of building performance improvement- say a percentage of change in the UEC value will lead to the same percentage de reduction of energy demand, mathematically saying, i.e.

$$\partial \ln Y / \partial \ln UEC = 1$$

However, it is straightfoward to derive from equations 1.11 and 1.12 by assuming that only P and λ vary according to the function.

$$\epsilon_{Y,UEC} = 1 + \epsilon_{Y,P} \epsilon_{\lambda,UEC} \quad (1.14)$$

The results of estimation show that $0 < \epsilon_{\lambda,UEC}$. By combining the coefficients price elasticity and λ with respect to UEC , one can obtain the elasticity energy demand with respect to building thermal performance improvement from the simulation results. The value varies between 0.1 et 0.16. Therefore the percentage energy conservation is not the same degree of performance improvement, e.g. energy demand elasticity of cooling in February is $-.84$, $\epsilon_{\lambda,UEC}$ is 0.16, the real energy saving is thus -0.87 instead of -1 as presumed frequently by classical engineering estimate model.

1.3 Does this economic theory holds in long-term energy demand analysis?

A question is thus raised about the applicability of this economic theory of rebound effect for the case of residential buildings in China how this effect should be considered in the scenario analysis of energy demand development in the years ahead. Because the aforementioned econometric models are suitable for measuring the short-term price and income elasticities. However, the confidence of their consistency arises when we need to analyze the energy demand for the longer term, say up to 2030 or 2050. Indeed, this "rule" can not be reapplied mechanically without consideration of specific socioeconomic characteristics, the types of buildings, the climatic condition, also bear in mind that the consumer's behaviors main differ significantly from that of households living in European countries or in the US. More specifically, it would be very difficult to capture all the consistent parameters in terms of magnitude of contribution to generating rebound effect in their energy consumption for two main reasons

1. In china, the energy price is so far heavily administrated by the central and local authorities although coal price is partly deregulated since the middle of 1990 (but the electric price is

still regulated by the NDRC or DRC); in terms of price of energy goods and services, the price paid by the end users does not reflect the real cost of production, in particular the heating and electricity price in residential prices are heavily subsidized either directly by the government or by cross-subsidies ³. As far as the urban district heating is concerned, the households are not required to pay the real consumption of heat, they pay instead a seasonal fee to heat delivery companies (mostly operated by the local government runned enterprises), the heating price is calculated based on living area, or floor space of occupancy instead of real consumption over the period of heating. Moreover, a lot of end-users working in state-owned companies or government agencies don't pay heating services at all in some cases where heating service is included in the employee's welfare. Many heating companies keep running by receiving subsidies from local governments or overly bad bank loans at the expense of profits of taxpayers. In general, the heating prices vary according to fuel sources (coal, gas, oil . . .), ranging between 15 – 30 *yuan/m*²

2. In China, in most of existing residential buildings, heat is supplied by centralized heating system (large-scale heat plants or CHPs, the final regulation is hardly developed, the consumers are not allowed to adjust the indoor temperature accordingly when outside climatic conditions change, the terminal regulating appliances have been installed recently in the new built houses in some cities as the central government issued a guideline urging all northern municipalities to proceed to urban heating system reform by moving progressively from old-style welfare delivery to market-oriented services. So far, the individual billing and pricing initiatives have hardly developed, some social concerns arise while the heating bill goes through directly to customers, particularly for the urban low-income and laid-off households. Any radical attempt to changing the whole system will harm the social stability over this economic-transitional period. Consequently, the rebound effect of heating energy consumption relating to building energy efficiency is not straightforward in this context. The FFEM projects ⁴ carried out in Beijing, Harbin confirm this thesis.

A priori, it seems more feasible to measure the rebound effect in the buildings situated in the transition area of China, the so-called *Hot-Summer and Cold-Winter climatic zone* (for example, the city of Shanghai) where most of households use reversible heat-pump electric air-conditioner to meet the heating and cooling requirements, electricity is paid individually by the households themselves unlike the urban district in the North, like the case studied in (Durbin et al. 1986) for the household electric consumption.

However, this zone is characterised by a long hot summer and a relatively short and mild winter time, cooling related electricity consumption in buildings is much higher than heating consumption,

³for example, in China, electricity price for industrial and commercial sectors are much higher than residential, so the residential consumers are unevenly subsidized by the other sectors

⁴A Sino-French building efficiency enhancement collaboration project financed by the French government's global environment aid fund, several pilot projects have been completed including construction of new efficient houses and thermal rehabilitation of existing dwellings in North and central China, a couple of Chinese and French building experts involved in these projects

which make the economic analysis more complex since the parameter q in equation 1.5 to estimate the cooling energy consumption seems to be less plausible ⁵.

On the other hand, the revenue or price elasticity coefficient are always pertinent in the parameter calibration in the previous models. Empirical study in different housing types in this area would be helpful to give insightful output in terms of consumer's behavior in heating and cooling. The difficulty of lack of consistent time series data persists systematically in the energy statistics in China's residential sector.

References

- [Durbin et al.1986] Durbin, J., Miedema,A. and Chandran, R.1986.*Price effects of energy-efficient technologies : a study of residential demand for heating and cooling*. Rand Journal of Economics. Vol 17(3).
- [Hass et al.1998] Haas, R., Auer, H., Biermayr, P., 1998.*The impact of consumer behavior on residential energy demand for space heating*. Energy and Buildings 27(2), 195-205.
- [Haas et al.2000] Haas, R.,Biermayr,P.2000 *The rebound effect for space heating Empirical evidence from Austria*. Energy Policy 28;403-410.
- [Quigley 1984] Quigley, J.1984. *The Production of housing service and the derived demand for residential energy*.Rand Journal of Economics(The).Vol.15(4).

⁵for the residential housings in this area , the main source of cooling load are more likely to be related to solar irradiation instead of direct heat transfer through envelope in lack of solar protection. U-value of building envelope is no longer a consistent parameter to relate energy demand to building's energy performance. the marginal effect of decreasing U value of wall or roof by upgrading insulation decreases sharply beyond certain threshold value. Low U-value of walls(good insulation) might even render the house less efficient during cooling season without well-designed natural ventilation system

Appendix XIII

Theoretical Model of Barriers to BEE Technology Adoption

The aforementioned market and non market barriers have been addressed extensively in energy economic literature. Jaffe and Stavins(1994) developed an theoretical model to explain different market and non-market barriers to uptake the energy-conservation technology and to investigate the efficiency of policy instruments. The model is derived from the construction builder's perspective. It gives a quite comprehensive overview on the economic theory of building energy efficiency policies. We present here their model very briefly to give some insights into the theoretical framework of BEE policy making for the Chinese policy makers.

Assuming now there is a builder in time T in a jurisdiction i has potentially consideration of incorporation of a new technology (e.g. the state-of-the-art building efficiency improvement measures such as enhanced insulation, passive heating or cooling etc) into construction of residential building j . Assume also that the builder designs the house to maximise the expected profits. the builder needs to tradeoff the incremental cost of the new technology against the expected increase in selling price associated a more energy-efficiency house ¹

It is also assumed that houses are heterogenous in the energy use and the house market may discount energy savings because builder cannot represent them credibly. The possible effect incremental costs of the prevalence of practice among builders in the area and the builder's experiences of technology are considered possible. Regulation can affect the decision by modifying the costs of adopting new technology. For example, some incentives measures like tax credits or subsidy are allowed to encourage uptake of efficiency technologies. The builder's decision can be modelled as an attempt to maximise the sum of base selling price of house (without this new energy-saving technology) and the present discounted value of the expected energy savings if the technology is adopted minus the cost of adoption. By assuming that builder recognizes the uncertainty embodied in all variables. The problem of decision making is to maximise his profits, formally

¹the commodity housing market is addressed here whereas the social house market in which sell price ceiling is regulated by the local government is excluded from the analysis here. In other words, the property developer (builders) can pass on parts of the incremental costs to the house buyers which is consistent with actual building efficiency market

$$\begin{aligned} \max \pi_{ijT} = & Y + [I \cdot \delta \cdot (1 - \psi) \cdot \int_T^\infty f(m_{ijt}, \xi_{ijt}) \cdot e^{-rt} dt] \\ & - I \cdot [L(C_{iT}, S_{ijT}, v_{iT}) - \phi D_{iT} - W_{iT} + E_{iT}] \end{aligned} \quad (1)$$

where upper case letters represent stocks or present values, lower case letters represent flows;

π_{ijT}	profit associated with adoption of technology in building house j in area i at time T
Y	the base selling price of house
I	the indicator of adopting technology ($I=1$ if technology is adopted and 0 otherwise)
δ	discount rate applied by market to value of energy savings
ψ	average quantify of energy used by technology relative to energy consumption in absence of new technology ($0 < \psi \leq 1$)
m_{ijt}	vector of present and future values of observable characteristics of house(size),and geographic zone(price of fuel ,climate etc)
ξ_{ijt}	unobservable factors that affect energy use
$f(\cdot)$	function that relates elements of m_{ijt} to annual fuel expenditure
r	real market rate of interest
C_{iT}	engineering estimate of adopting technology
S_{ijT}	cumulative stock of houses built previously by builder j that incorporated technology
v_{iT}	fraction of newly constructed homes in jurisdiction i that incorporated technology
$L(\cdot)$	a function that generates the “effective cost”of adopting technology from engineering cost and prevalence of technology
D_{iT}	dummy variable set to unity if jurisdiction i has regulation in year T requiring that technology be installed
ϕ	parameter that captures the average perceived monetary equivalent cost of ignoring regulation , a function of the nature of regulations,the magnitude of penalties, perceived probabilities of enforcement, and likely stigma
W_{iT}	subsidy or tax credits in jurisdiction i for adopting technology
E_{iT}	tax on externality in jurisdiction i relevant to energy performance(e.g.carbon emission)

The $L(\cdot)$ function represent an “epidemic effect”that is related to the prevalence of technology.The knowledge of existence of prevalence and probability are increasing functions of prevalence of use of a new technology.The technology is diffused like a disease (diffusion by contact). The idea that information spreads by contact with previous adopters is captured by allowing the cost of adoption to depend on the “regional”prevalence of use.It

is natural to allow the builder's own experience with technology (S_{ijt}) to reduce effective cost.

Denoting the expected discounted present value of the function $f(\cdot)$ as $G(\cdot)$, the condition for adoption is that the technology should be employed if :

$$\delta \cdot (1 - \psi) \cdot \mathbf{G}(m_{ijt}, \xi_{ijt}) + \phi D_{iT} > L(C_{iT}, S_{iT}, v_{iT}) - W_{iT} + E_{iT} \quad (2)$$

Equation 2 says that the builder will use the technology if the valuations placed by market on energy savings in expected energy costs plus the implicit or explicit value of complying with regulations exceed the cost of adoption. The cost of adoption include learning of technology , appliance purchase , time consuming and the tax relevant to BEE, and may be reduced by government subsidy.

Now we need to specify the functional forms. For simplicity, let the function $\mathbf{G}(\cdot)$ be Cobb-Douglas. Let m_{jt} denote k^{th} element of $1 \times K$ vector $\mathbf{m}_{ijt}$, and specifically, let $m_{ijt}^1 = P_{ijt}$ the price of fuel to house j in region i in year t , let other elements of m_{ijt} be constant ($m_{jt}^k = m_{jT}^k$ for all $t > T$, $k=2,3... K$). The function from equation 2 can be written as:

$$G(\cdot) = [\int_T^\infty (P_{ijt})e^{-rt} dt]^{\alpha_1} \cdot [\Pi(m_{ijT}^k)^{\alpha_k}] \cdot \xi_{iT} \quad (3)$$

The cost/learning function $L(\cdot)$ can be based on proportionate reductions in the cost of installation as either builder's own experience or prevalence of the technology being installed increase:

$$L(\cdot) = (C_{iT})^{\beta_1} \cdot (v_{iT})^{\beta_2} \cdot (\frac{S_{iT}}{\beta_3})^{\beta_4} \quad (4)$$

Finally, overall cost is the product of three factors that depend respectively on :the engineering cost estimate, C_{iT} ; the prevalence of installation of the technology within the region, v_{iT} ; and builder's own cumulative experience with technology, S_{iT} .

The engineering cost C_{iT} will be the actual cost if everyone is currently adopting the technology ($v_{iT} = 1$), and builder has a typical experience parameterised by β_3 . However, when installation of the technology is less prevalent ($v_{iT} < 1$), the cost is higher, since the sensitivity parameter β_2 is assumed to be less than 0. For builder has with more or less experiences than typical level β_3 , cost will be higher or lower, with own experience senility parameterised by β_4 .

Rearranging equation 2 in the form of benefit/ratio :

$$\left[\frac{\delta \cdot (1 - \psi) \cdot \mathbf{G}(m_{ijt}, \xi_{ijt})}{L(C_{iT}, S_{ijT}, v_{iT}) - W_{iT} + E_{iT}} \right] \geq 1 \quad (5)$$

Substituting eqs. 3 and 4 into equation 5, and taking natural logarithm of both sides yields as follows:

$$\begin{aligned} & \log(\delta) + \log(1 - \psi) + \alpha_1 \log\left(\int_T^\infty (P_{ijt} e^{-rt} dt)\right) + \sum_{k=2}^k [\alpha_k \log(m_{ijT^k})] \\ & - \log((C_{iT})^{\beta_1} \cdot (v_{iT}) \cdot (\frac{S_{ijT}}{\beta_3}) - \phi D_{iT} - W_{iT} + E_{iT}) + \log(v_{iT}) \geq 0 \end{aligned} \quad (6)$$

The equation 6 illustrates the main factors that can affect the BEE technology diffusion and adoption. First of all, the principal-agent problem associated with the builder/ownership will have a negative effect on the rate of adoption. The parameter δ will be greater than 0 but less than 1, so $\log(\delta)$ in equation 6 will be negative. Individuals have uncertainty about future energy price; the likelihood of energy-saving will be reduced. And if the energy price P_{ijt} is artificially low (this is the case in the district heating price in China), adoption will also be slower than it would otherwise be. From equation 6, we can also see that if decision makers hold high discount rates r , the anticipated energy savings and therefore the tendency of adopt new energy-conservation technologies will be less than otherwise.

Turning to the second line of eq 6, we can see the decreases in adoption costs will accelerate technology diffusion and adoption, this may be results of changes in the direct costs of “physical” or engineering costs (C_{iT}), but also the changes in “effective costs” associated with learning, inversely related with the prevalence of installation of technology in the model, v_{iT} ; and builder’s own cumulative experience with the technology, S_{ijT} . So depending on the magnitude of parameter β_2 , there may be dynamics of externality by which adoption increased today will foster future diffusion by increasing v_{it} . Most importantly, regulations on energy efficiency such as mandatory building codes have direct, positive effect on adoption by decreasing the expected cost of adopting (ϕ). Government fiscal policy such as tax credits, subsidy and tax on energy-related carbon emissions can all contribute to reduce the cost of adoption and hence increase the probability of technology diffusion. This has significant policy implications. Institutional aspect is of the importance as technological innovation. In order to accelerate the diffusion of BEE technology, the public policy should not hold an artificially low energy price that will slow the prevalence of newly efficiency technologies.

References

- [1] Jaffe,A.and Stavins,R.1994.*The Energy-paradox and Diffusion of Conservation Technology*. Resource and Energy Economics. 16 (2), pp.91-122.