Integration of Social Life Cycle Assessment as a tool for evaluation and decision-making in the design phase of offshore wind farm projects in France

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Integration of Social Life Cycle Assessment as a tool for the evaluation and decision-making in the design phase of offshore wind farm projects in France

Intégration de l'Analyse Sociale de Cycle de Vie comme outil d'évaluation et d'aide à la prise de décision dans la phase de conception des projets de parcs éoliens en mer en France

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Résumé étendu

La production d'énergie joue un rôle essentiel dans la réalisation des activités économiques. Actuellement, une part significative de l'énergie primaire consommée à l'échelle mondiale provient de sources fossiles. Or, l'exploitation de ces énergies fossiles peut engendrer d'importants dommages environnementaux notamment sur le climat, la biodiversité et la santé humaine. Face à une demande énergétique croissante, il est impératif d'entreprendre une transition énergétique vers des sources présentant un moindre impact environnemental.

Les technologies éoliennes font partie des principales solutions émergentes de production d'énergie renouvelable. En particulier, l'éolien en mer présente plusieurs avantages liés aux spécificités de la zone d'implantation par rapport à leurs équivalents terrestres. En effet, l'environnement marin offre de grandes surfaces et, généralement, un vent moyen plus fort et plus régulier que les sites terrestres. La capacité installée de l'éolien en mer en Europe était de près de 15 GW en 2021, et elle pourrait atteindre plus de 300 GW d'ici 2050. Cet objectif ambitieux est dû, en partie, au grand potentiel du littoral atlantique européen. En France, dans le cadre de la stratégie nationale de transition énergétique, les parcs éoliens offshore (PEO) font l'objet d'un développement important avec un objectif annoncé jusqu'à 45 GW de capacité installée d'ici 2050. Actuellement, la France compte une douzaine de projets de PEO en cours de développement, dont un parc en service, le PEO de Saint-Nazaire, depuis fin 2022 ; et deux autres mis en service de manière progressive depuis l'été 2023 : les PEO de Fécamp et Saint-Brieuc

Ces projets de PEO présentent actuellement une diversité de paramètres, en termes de :

- Capacité installée des parcs, allant de 25 à 30 MW pour des parcs pilotes jusqu'à des parcs commerciaux de 250 MW à 1,5 GW[1] ;
- Technologie des turbines et des fondations (fixes ou flottantes) ;
- Territoire d'implantation et façades maritimes (Atlantique Sud, Atlantique Nord, Manche Ouest, Manche Est - mer du Nord, Méditerranée) ;
- Stade de développement : consultation publique, développement, construction ou exploitation.

En France, le secteur éolien en mer est en pleine émergence. Toutefois, au cours du cycle de vie d'un PEO, des activités en amont et en aval peuvent ne pas être exemptes d'impacts environnementaux et socio-économiques. Ainsi, les implications du développement de ces systèmes doivent être analysées objectivement afin de garantir leur adéquation aux objectifs de la transition énergétique. Les impacts

[1] Un exercice de planification est en cours en France depuis novembre 2023, visant notamment la définition des zones d'accélération de l'éolien offshore sur l'ensemble des façades métropolitaines. Dans ce contexte, certaines projections de puissance intègrent des projets de parcs commerciaux jusqu'à 2GW, notamment en Méditerranée.

environnementaux potentiels des filières énergétiques sont typiquement quantifiés grâce à la méthode d'Analyse de Cycle de Vie (ACV), reconnue à l'international comme l'une des méthodes les plus pertinentes à cet égard. Néanmoins, le paradigme du développement durable, défini par les Nations Unies comme celui *« qui répond aux besoins du présent sans compromettre la capacité des générations futures de répondre aux leurs »*, nécessite d'intégrer aussi des critères socio-économiques à l'évaluation des impacts.

A l'instar des impacts environnementaux, les impacts sociaux et socio-économiques peuvent être générés à différentes stades du cycle de vie d'un système, allant de l'extraction des matières premières au démantèlement. Ces impacts peuvent concerner différentes catégories de parties prenantes tels que les travailleurs présents au sein de la chaîne de valeur ou les communautés locales, sur le site d'exploitation mais aussi dans d'autres régions du monde impliquées dans le cycle de vie. En fonction de leurs intérêts, les parties prenantes présentent souvent des opinions différentes sur les PEO. D'une part, certaines parties prenantes soulignent les impacts favorables potentiels tels que les retombées économiques à l'échelle locale, qui se traduisent par exemple par la création d'emplois. Cependant, d'autres parties prenantes affirment qu'ils peuvent également avoir des impacts défavorables, liés par exemple à l'influence potentielle de leur exploitation sur les activités et aménagements maritimes existants. D'autres préoccupations concernent également les activités en amont, telles que les conditions de travail liées à la fabrication de certains composants, ou en aval, qui comprennent, par exemple, le traitement des composants à la fin du cycle de vie. Certaines de ces activités peuvent se dérouler dans d'autres pays que la France. Pour tendre vers la durabilité sociale, les décideurs doivent donc avoir une vue d'ensemble du cycle de vie du système considéré, être en mesure d'identifier les potentiels points problématiques (ou « hotspots ») sociaux ainsi que d'anticiper les réponses à apporter. A ces fins, l'ACV sociale se révèle être un outil approprié.

Classiquement, et conformément aux recommandations formulées par la norme ISO14040, une ACV est conduite à travers différentes phases de travail : définition de l'objectif et du périmètre de l'étude, collecte de l'inventaire des données à utiliser, évaluation des impacts, et interprétation des résultats obtenus. Depuis la fin des années 2000, le cadre de l'ACV a commencé à être adapté pour l'évaluation des impacts sociaux. A ce jour, l'un des principaux cadres est proposé par les lignes directrices pour l'ACV sociale du Programme des Nations Unies pour l'Environnement (UNEP), publiées pour la première fois en 2009 et mises à jour en 2020. Les lignes directrices de l'UNEP pour l'ACV sociale proposent un certain nombre de notions fondamentales largement reprises par les études en ACV sociale. Notamment, les lignes directrices de l'UNEP proposent une liste de catégories de parties prenantes et des sous-catégories d'impact correspondantes pouvant être intégrées pour la conduite d'une étude d'ACV sociale. Avec 6 catégories de parties prenantes (e.g., travailleurs, communautés locales)

rassemblant 40 sous-catégories d'impact (e.g., santé et sécurité, héritage culturel) à évaluer, le champ d'application potentiel pour une étude d'ACV sociale est large.

En pratique, les lignes directrices de l'UNEP ne sont pas appliquées littéralement dans leur intégralité mais adaptée au cas par cas, en fonction des systèmes analysés. En effet, l'UNEP, les praticiens, ainsi que les auteurs d'études eux-mêmes, recommandent d'adapter le cadre proposé à chaque contexte ou étude de cas. Comme évoqué, il existe un grand nombre de sous-catégories d'impact potentiellement à intégrer. Adapter ce cadre implique d'identifier lesquelles de ces sous-catégories sont les plus pertinentes à considérer, voire à ajouter, au regard des spécificités sectorielles du système étudié. D'où la nécessité d'une étape de hiérarchisation des sous-catégories d'impact social, permettant d'identifier les sous-catégories prioritaires pour le système en question. Toutefois, il existe encore une grande variété de façons d'adapter les lignes directrices à un contexte spécifique. Cette disparité peut traduire un manque de transparence quant à la méthodologie utilisée pour retenir ou exclure les sous-catégories d'impact en début d'étude d'ACV sociale.

Le début d'une étude d'ACV sociale peut se résumer à l'adaptation de la liste des parties prenantes et des sous-catégories d'impact proposées par les lignes directrices de l'UNEP en une liste finale spécifiquement adaptée au contexte sectoriel de l'étude. Historiquement, la plupart des travaux ont délimité le périmètre d'application en fondant leur choix exclusivement sur une revue de littérature. Cette revue de littérature peut se fonder sur des articles scientifiques, mais aussi sur diverses sources de littérature grise, tels que les cahiers des charges d'un produit et/ou les rapports de maîtres d'ouvrage dans le cas de projets d'aménagement. Les préoccupations formulées par les parties prenantes, par exemple lors débats publics, peuvent également constituer une source d'information pertinente pour identifier quels pourraient être a priori les points problématiques sociaux à considérer au sein d'une ACV sociale. Bien que nécessaire, une revue de littérature seule peut cependant être insuffisante pour refléter ce que les parties prenantes perçoivent sur les différents impacts potentiels d'un système, en particulier dans le contexte d'un secteur émergent tel que l'éolien en mer en France pour lequel il y a encore peu de retour d'information scientifique et une recherche sur les enjeux sociaux encore peu avancée.

Compte-tenu de ces éléments, plusieurs experts en ACV sociale recommandent d'impliquer les parties prenantes elles-mêmes dans la définition du périmètre d'application au début d'une étude d'ACV sociale. C'est ce qui se traduit par l'utilisation d'approches participatives, également dites « bottom-up » par opposition aux approches « top-down » qui se focalisent davantage sur la prise en compte des besoins des commanditaires de l'étude. Généralement, les approches participatives nécessitent un certain investissement pour être mises en place, en particulier en temps. Aussi, la nature même de l'approche participative suggère de s'intéresser à la pertinence des profils de parties prenantes qui vont influencer la définition du périmètre au début d'une étude d'ACV Sociale. Dans cette idée, l'une des propositions de la présente thèse consiste à ajouter un élément méthodologique à la consultation des

parties prenantes, qui porte précisément sur la systématisation de l'accès aux parties prenantes afin d'améliorer la représentativité des réponses obtenues par rapport au profil des répondants.

Compte tenu des aspects précités liés à la consultation des parties prenantes en ACV sociale, cette thèse pose pour première question scientifique : **comment développer une approche systématique pour l'identification et la hiérarchisation des sous-catégories d'impact pertinentes sur la base de la consultation des parties prenantes ?**

Comme évoqué, même lorsque les approches participatives sont déployées, une revue de littérature spécifique au secteur reste nécessaire.

Dans le contexte de l'implantation des PEO en France, la revue de littérature révèle que les préoccupations sociales peuvent être liées à des questions telles que la sécurité maritime, l'économie des secteurs du tourisme ou de la pêche professionnelle. Au sein du processus décisionnel actuel de l'implantation des PEO, la prise en compte des préoccupations sociales est principalement axée sur la zone d'implantation du PEO en question, se concentrant donc sur les étapes de construction et d'exploitation du cycle de vie. Toutefois, comme évoqué précédemment, dans le contexte de la durabilité sociale, il est essentiel d'analyser les conséquences d'un système vis-à-vis des parties prenantes en considérant l'intégralité de son cycle de vie. Ainsi, des impacts potentiels peuvent se produire selon différentes échelles géographiques. Il s'agit d'identifier une échelle correspondant aux secteurs et pays impliqués dans le cycle de vie du système, soit une échelle globale, mais aussi une échelle locale impliquant les territoires d'implantation, ou encore l'échelle nationale du pays impliqué dans le développement de la filière. En pratique également, dans le contexte d'un secteur émergent, considérer l'ensemble du cycle de vie d'un système implique de traiter avec une difficulté d'accès aux données, voire un manque de données.

Aussi, considérant les éléments précités liés à l'évaluation multi-échelle des impacts sociaux dans le secteur éolien en mer en France, cette thèse pose pour deuxième question scientifique : **comment adapter le cadre actuel de l'ACV sociale pour coupler la vision holistique de l'ACV et les aspects locaux d'une étape donnée du cycle de vie tout en considérant les difficultés d'accès aux données ?**

L'objectif des deux questions scientifiques ainsi énoncées est de contribuer à améliorer l'application des phases d'ACV sociale normée par l'ISO 14040. Les innovations méthodologiques sous-jacentes à la première question scientifique visent à améliorer la définition du périmètre au début d'une étude d'ACV sociale. La proposition méthodologique inhérente à la seconde question scientifique cible quant à elle des verrous identifiés dans les phases d'inventaire des données et d'évaluation des impacts.

Eléments de réponses à la première question scientifique : approche systématique pour hiérarchiser les sous-catégories d'impact en ACV sociale

La sélection des sous-catégories d'impact à évaluer est un enjeu méthodologique et opérationnel essentiel lors de la phase de définition du périmètre d'une étude en ACV Sociale. En effet, du fait d'un grand nombre de parties prenantes et de sous-catégories d'impact qui peuvent être évaluées, une évaluation complète suggère un déploiement conséquent de temps et de ressources. Dans la pratique, les sous-catégories d'impact social sont souvent sélectionnées de manière arbitraire et sont limitées à une liste réduite ne comprenant que certaines d'entre elles, parfois sans justification vis-à-vis de l'inclusion ou de l'exclusion d'une sous-catégorie donnée. Pour surmonter cette difficulté lors de la phase initiale de définition du périmètre de l'étude, des méthodes pour hiérarchiser (ou prioriser) les sous-catégories d'impact selon le niveau de pertinence ont été proposées dans des travaux antérieurs. En aidant à définir l'objectif et le périmètre d'application de l'étude, le travail de hiérarchisation vise à mettre l'accent sur les sous-catégories d'impact sociaux qui devraient être considérées comme prioritaires à traiter pour les phases ultérieures d'inventaire et d'évaluation d'impact.

Pour améliorer la démarche de hiérarchisation des sous-catégories d'impact social, deux approches ont été mises en place dans cette thèse.

La première approche vise à classer les sous-catégories d'impact selon le point de vue d'entreprises directement impliquées dans l'exploitation des PEO en France, c'est-à-dire selon le point de vue de décideurs industriels du secteur énergétique. Cette approche consiste à demander aux participants des entreprises concernées de classer directement les sous-catégories d'impact, c'est-à-dire de les ordonner directement par niveau d'importance, de la plus importante à la moins importante à considérer au sein de l'étude d'ACV sociale. Au-delà l'objectif principal de classement des sous-catégories, l'implication des entreprises dans les discussions dès le démarrage de l'étude présente l'intérêt de pouvoir également fournir une expertise sur certaines questions sectorielles et alimenter la réflexion pour les autres phases de l'étude.

Dans le cadre de l'application de cette première approche, sept développeurs de parcs éoliens et un opérateur du raccordement électrique en mer ont été consultés. La méthodologie a permis d'obtenir un classement de sous-catégories d'impact social hiérarchisées sur la base du critère d'importance. Toutefois, la petite taille du panel finalement impliqué dans cette approche est à noter. Aussi, la forte dispersion dans les rangs attribués par les répondants pour les différentes catégories d'impacts révèle un manque de consensus sur ce qui est important à évaluer ou moins important. Pour ces raisons, ce classement peut ne pas refléter les préoccupations des parties prenantes externes, c'est-à-dire celles qui sont extérieures aux développeurs éoliens. Dans l'ensemble, les résultats obtenus dans cette première

approche renforcent la nécessité de consulter les parties prenantes externes pour obtenir des résultats de hiérarchisation qui reflètent davantage leurs préoccupations.

C'est pourquoi a été conduite une seconde approche participative, à savoir la consultation des parties prenantes externes aux entreprises assurant directement l'exploitation des PEO en France. Pour cette seconde approche, un besoin de développement méthodologique spécifique a été identifié dans le démarrage de la thèse, notamment par rapport à l'accès systématisé aux parties prenantes et la mesure du niveau de représentativité des répondants en tenant compte de la diversité des sous-groupes (ou profils) de parties prenantes.

Pour ce faire, les sous-catégories d'impact ont été soumises à la consultation des parties prenantes afin de les classer et de définir celles qui sont les plus pertinentes à inclure dans les phases ultérieures de l'ACV sociale, tout en prenant soin de caractériser les répondants à cette approche participative. Sur la base des travaux existants en matière d'ACV sociale, une démarche de sondage est proposée, reposant sur une notation des catégories d'impact consistante à mesurer la différence entre un niveau d'attente et un niveau de perception attribués par les parties prenantes au moyen d'une enquête en ligne. Pour ce faire, chaque sous-catégorie d'impact identifiée à partir de la liste des lignes directrices de l'UNEP, ou adaptée à partir d'un travail d'analyse sectorielle, a été notée de 1 à 5 selon deux critères, à savoir le critère *Attente* et le critère *Perception*. Le critère *Attente* se réfère à la mesure dans laquelle une bonne performance est souhaitable ou importante pour une sous-catégorie d'impact à l'avenir. En d'autres termes il évalue le niveau d'intérêt d'un répondant pour une sous-catégorie d'impact donnée. Le critère *Perception* reflète le niveau actuel de performance atteinte selon le point de vue du répondant, c'est-à-dire un niveau de satisfaction actuellement ressenti par le répondant. La différence entre les notes attribuées pour chacun de ces deux critères permet d'obtenir une note d'écart (ou « gap score ») pour chaque sous-catégorie d'impact. Plus l'écart est élevé, plus la différence entre ce que la partie prenante attend idéalement et ce qu'elle observe actuellement est grande, traduisant un potentiel point problématique à considérer pour les phases ultérieures de l'ACV sociale. Par exemple, un écart négatif pour une sous-catégorie d'impact implique un niveau d'importance élevé mais un niveau de perception bas, c'est-à-dire que le système étudié ne répond pas aux attentes.

Afin d'améliorer l'utilisation de cette approche de notation des sous-catégories d'impact par deux critères, la proposition de cette thèse est d'intégrer un protocole de représentativité pour être en mesure de questionner la légitimité du panel de parties prenantes répondant aux enquêtes. La thèse a conçu un protocole méthodologique qui permet de caractériser le profil des parties prenantes à l'aide de variables qualitatives telles que l'activité professionnelle du répondant. Cette proposition vise à contribuer au besoin de transparence et de meilleure représentativité des approches participatives en ACV sociale, notamment en procédant à un échantillonnage des parties prenantes.

Appliquée par exemple à la catégorie de parties prenantes des Communautés locales, l'échantillonnage consiste à identifier les communautés locales des zones d'implantation de parcs éoliens en mer en France. Dans cet exemple, il est supposé que cette catégorie de parties prenantes n'est pas une catégorie homogène et qu'elle doit être plus détaillée, ou désagrégée, en différent sous-groupes à considérer. L'hypothèse sous-jacente à cette désagrégation est que l'appartenance à un sous-groupe de parties prenantes plutôt qu'à un autre exerce une influence sur l'attribution des notes aux critères (*Attente* et *Perception*) d'évaluation des sous-catégories d'impact. Pour l'exemple des Communautés locales, l'hypothèse mentionnée précédemment peut suggérer, par exemple, que le sous-groupe des administrations publiques locales ait, en général, un niveau de perception différent sur les projets d'éoliennes en mer que le sous-groupe des professionnels de la mer (e.g., pêcheurs, aquaculteurs). En se basant sur cette hypothèse, il est donc nécessaire de définir un échantillon de référence, qui est utilisé pour effectuer une comparaison avec l'échantillon d'enquête circonscrit dans ce travail. Dans le cas de la catégorie de parties prenantes Communautés locales, la thèse considère que l'échantillon de référence correspond au nombre de participants aux différents débats publics organisés par la CNDP (Commission Nationale du Débat Public) sur l'éolien en mer en France. Pour avoir accès à cet échantillon de référence, un sondage a ligne a été conçu. Le sondage a été adressé à un panel qu'il a été nécessaire de constituer préalablement sous la forme d'une mailing-list de personnes susceptibles d'être pertinentes pour répondre à l'enquête de notation des sous-catégories d'impact. En pratique, la méthode mise en place par la thèse pour constituer ce panel consiste à assembler des contacts publics à partir de sites web de clusters sectoriels, relatifs au secteur de l'énergie ou à divers secteurs d'activités maritimes, de façon automatisée grâce à un outil de webscrapping. Une fois le panel constitué, l'enquête est envoyée, puis les réponses collectées.

Du fait d'avoir collecté une variable qualitative « sous-groupe », l'échantillon d'enquête comprend différents sous-groupes de répondants. La répartition des sous-groupes de notre échantillon est comparée avec les sous-groupes de participants aux différents débats publics sur l'éolien en mer en France (i.e., l'échantillon de référence). Cette comparaison est réalisée au moyen d'un test de khi-deux et, dans le cas où une différence significative est observée entre les deux échantillons, un ajustement des notes que les répondants ont attribué est réalisé. L'ajustement correspond à une sous-pondération des notes attribuées par les sous-groupes sur-représentés dans l'échantillon d'enquête par rapport à l'échantillon de référence, et inversement pour les sous-groupes sous-représentés.

En tant que résultat intermédiaire, la prise en compte des résultats désagrégés permet d'illustrer la nécessité de considérer la répartition des sous-groupes de parties prenantes répondant à une enquête. En effet, les résultats désagrégés sont déterminants en ce qu'ils mettent en évidence la note du critère *Perception* attribuée en fonction des sous-groupes de parties prenantes aux différentes sous-catégories d'impact. Dans le cas des réponses obtenues dans l'enquête destinée aux Communautés locales, les

différents sous-groupes recensés dans cette thèse sont : les administrations publiques locales, les associations locales, les acteurs de la navigation maritime/aérienne/du nautisme, et les professionnels de la mer. Les résultats intermédiaires de l'enquête révèlent que les administrations publiques locales ont, en général, attribué une note plus élevée au critère *Perception* par rapport au sous-groupe des professionnels de la mer (e.g., pêcheurs, aquaculteurs). Ces résultats confortent l'hypothèse selon laquelle le premier sous-groupe mentionné tend à avoir une meilleure perception des systèmes éoliens en mer que le deuxième sous-groupe. Par extension, ces résultats renforcent la nécessité de prendre en compte la proportion des différents sous-groupes de répondants dans une enquête.

Pour résumer, compte tenu des éléments discutés précédemment, le cadre proposé dans la thèse pour hiérarchiser les sous-catégories d'impact consiste à relier la notation par écart (i.e., en considérant les critères *Attente* et *Perception*) au test de représentativité des répondants à une enquête. Ainsi, le format de l'enquête permet d'obtenir deux types de données. Les données quantitatives sont les notes des *Attente* et *Perception* attribuées aux catégories d'impacts, sur la base desquelles sont calculés les écarts entre les deux. Les données qualitatives correspondent aux variables qui qualifient le répondant, incluant la variable qualitative « sous-groupe ». La collecte de cette variable qualitative permet d'évaluer si l'échantillon d'enquête représente ou non l'échantillon de référence supposé. Dans le cas où l'échantillon d'enquête ne représente pas l'échantillon de référence, le rapport entre les valeurs de cette variable observées dans l'échantillon d'enquête et les valeurs de cette même variable caractérisant l'échantillon de référence est calculé pour obtenir des coefficients d'ajustement.

L'ajustement des données quantitatives au moyen d'un coefficient calculé grâce à la variable qualitative est une opération que la thèse détaille pour la rendre duplicable aisément. Par exemple, dans l'échantillon d'enquête, les répondants du sous-groupe des acteurs de la navigation maritime/aérienne/du nautisme sont surreprésentés par rapport à ceux de l'échantillon de référence, et inversement pour les répondants du sous-groupe des administrations publiques qui sont sous-représentés dans l'échantillon d'enquête. Le test de khi-deux révèle que cette différence de répartition entre l'échantillon d'enquête et l'échantillon de référence est significative. Ainsi, sur la base des valeurs obtenues, les coefficients d'ajustement sont calculés pour diminuer le poids des répondants du sous-groupe des acteurs de la navigation maritime/aérienne/du nautisme, et inversement pour le sous-groupe des administrations publiques. Une fois ces étapes appliquées, l'écart calculé pour les différentes sous-catégories d'impact est ajusté et peut-être observé à l'échelle agrégée de l'ensemble de la catégorie de partie prenante.

Cette méthodologie a été appliquée pour l'intégralité des catégories de parties prenantes des Communautés locales ainsi que des Acteurs de la chaîne de valeur. Pour ces deux catégories de parties prenantes, des réponses ont été obtenues permettant de hiérarchiser les sous-catégories d'impact respectives. Un ajustement de ces réponses a pu être conduit en considérant des échantillons de référence. Toutefois, les résultats agrégés de la hiérarchisation, après ajustement, révèle dans l'ensemble

des différences de notes relativement faibles selon les sous-catégories d'impact. De plus, il est important de noter que les écarts-types présentent des valeurs élevées et révèlent donc que les opinions des répondants varient fortement dans l'attribution des notes. Cette variation d'opinions dans les notes attribuées aux sous-catégories d'impact en fonction des répondants représente un verrou scientifique qui devrait être davantage étudié dans des travaux ultérieurs.

Pour conclure, le travail mené en lien avec la première question scientifique de la présente thèse a consisté à développer une méthode pour systématiser l'accès aux parties prenantes et questionner la représentativité des répondants à une approche participative par enquête. La méthode a été testée dans le secteur éolien en mer en France et est transférable à d'autres secteurs. Les résultats obtenus ouvrent différentes perspectives. L'une de ces perspectives concerne l'aspect opérationnel des résultats de la hiérarchisation des sous-catégories d'impact du point de vue du praticien et la suite des phases à mener en ACV sociale (i.e., phases d'inventaire, d'évaluation des impacts et d'interprétation). En supposant que le praticien de l'ACV sociale ne peut pas considérer de façon exhaustive l'ensemble des sous-catégories soumises en enquête pour notation auprès des parties prenantes, il est amené à sélectionner un nombre de sous-catégories à traiter. Il s'agit de s'interroger sur ce qui pourrait être la règle de sélection optimale du nombre de sous-catégories d'impact à considérer. Cela implique de définir une solution pour répondre au compromis entre maintenir un nombre de sous-catégories restreint pour les évaluer en profondeur, ou préférer un plus grand nombre de sous-catégories à évaluer mais en assumant potentiellement davantage de contraintes en temps pour les couvrir lors des phases ultérieures du travail. Par ailleurs, analyser davantage le niveau de désagrégation des données collectées est une perspective amenant à des travaux ultérieurs. Comme mentionné précédemment, il existe une relation entre le sous-groupe des parties prenantes et la note de perception attribuée aux sous-catégories d'impact. L'utilisation de méthode de traitements statistiques développée dans la présente thèse mériterait approfondissement pour étudier plus précisément l'influence des variables qualitatives qui caractérisent les répondants sur les notes qu'ils attribuent aux sous-catégories d'impact. Par exemple, il est probable que la fonction exercée par les répondants au sein de son organisation influence la perception des sous-catégories d'impact social.

Eléments de réponses à la deuxième question scientifique : inventaire et évaluation d'impact multi-échelle appliqués aux systèmes de parcs éoliens offshore en France

Pour rappel, cette deuxième question scientifique de la thèse découle du constat selon lequel le processus de décision actuelle concernant l'implantation des parcs éolien en mer devrait tenir compte des préoccupations sociales principalement relatives aux étapes de construction et opération d'un PEO. Toutefois, dans une perspective de durabilité sociale les impacts potentiels doivent être considérés aussi sur l'ensemble du cycle de vie d'un système.

Après l'identification des parties prenantes et la hiérarchisation des sous-catégories d'impact présentées conduite en réponse à la précédente question scientifique, cette deuxième question se concentre sur les phases d'inventaire, d'évaluation d'impact et d'interprétation d'ACV sociale appliquées à l'éolien en mer en France. Les résultats de la hiérarchisation sont utilisés pour identifier un ordre de traitement des sous-catégories d'impact. La phase d'analyse de l'inventaire consiste à collecter les données nécessaires à la mesure des indicateurs identifiés ainsi qu'à la modélisation du système sur son cycle de vie. La phase d'évaluation des impacts consiste à mesurer les risques sociaux sectoriels et/ou à mesurer la performance sociale du système par rapport aux sous-catégories d'impact considérées et les indicateurs relatifs identifiés.

La littérature conduite sur les impacts sociaux sectoriels de l'éolien en mer amène à identifier des préoccupations particulières au niveau la zone d'implantation d'un PEO. Ces préoccupations sont, par exemple, liées à la cohabitation de l'installation d'un PEO avec les emplois locaux déjà existants sur le territoire. Selon les territoires considérés, la pêche professionnelle peut être une activité importante pour l'économie locale. Par conséquent, les parties prenantes liées aux activités de pêche sont fréquemment consultées en raison de leur lien étroit avec l'espace maritime. Dans ce cas, les principales préoccupations sont liées à l'impact potentiel des PEO sur les espèces de poissons commerciales ainsi qu'aux contraintes en termes de zone de navigation. Mais aussi, dans certains cas, il est avancé par des experts que les PEO peuvent générer un « effet de réserve » ou à un « effet de débordement » influençant le comportement des ressources halieutiques. Ainsi, la fermeture de zones à la navigation pourrait entraîner une augmentation de la productivité en termes de ressources halieutiques, en raison de la réduction de la pression de pêche. Pour atteindre un niveau de détail qui intègre les différentes particularités locales d'un PEO dans le cadre d'une étude d'ACV Sociale, définir un périmètre d'application local est nécessaire.

Par ailleurs, la littérature révèle aussi des impacts d'un PEO au niveau national, par exemple liés aux conséquences du développement d'un nouveau secteur et des retombées économiques qui en découlent à l'échelle du pays. Pour toute étude ACV sociale, un périmètre national doit donc aussi être défini. Au-delà des périmètres locaux et nationaux évoqués, et dans le but d'intégrer les différentes activités du

cycle de vie d'un PEO, les impacts et les risques sociaux sectoriels de la chaîne d'approvisionnement doivent être considérés selon un périmètre global. Au total donc, la présente thèse propose de conduire les phases d'application de l'ACV sociale selon une approche multi-échelle.

L'approche multi-échelle conduit à réutiliser les outils existants en ACV sociale en fonction des différents périmètres géographiques définis. Les phases d'inventaire et d'évaluation des impacts pour les périmètres national et local sont couvertes par l'approche des « points de référence de performance » (PRP). L'approche PRP consiste à attribuer un score de performance (par exemple, entre -2 et +2) à un indicateur selon la valeur mesurée. Les scores sont définis selon un ensemble de valeurs de référence qu'il implique d'identifier au préalable. La flexibilité de l'approche PRP permet d'inclure des indicateurs supplémentaires autres que ceux proposés dans les lignes directrices de l'UNEP, et par ce biais d'intégrer certaines spécificités sectorielles. Quant au périmètre global, il est abordé selon une application conventionnelle de l'utilisation d'une base de données de risques sociaux à l'échelle des différents secteurs et pays impliqués dans la chaîne d'approvisionnement. L'application est réalisée sur différents scénarios technologiques de PEO afin d'identifier de manière comparative les activités et les composants potentiellement liés à des points problématiques sociaux. Ainsi, de manière classique, les coûts de main-d'œuvre sont estimés pour toutes les activités et les étapes du cycle de vie du système, et les heures de risques sont obtenues pour différents indicateurs d'impacts. Des logiciels et des bases de données spécifiques d'ACV sociale permettent de développer cette modélisation et d'obtenir les résultats d'impacts sociaux.

Pour la collecte de données, deux grandes catégories de données sont mobilisées : les données primaires et les données secondaires. Les données primaires impliquent, par définition, que le praticien collecte directement les données. Si l'on suit cette définition, la réalisation d'une ACV sociale exclusivement sur la base de données primaires implique soit un processus de collecte de données très long, conditionné par l'existence de ces données, soit une évaluation partielle portant sur un nombre limité d'indicateurs. Pour compléter les informations, et afin de garantir un plus grand nombre d'indicateurs à évaluer, les données sur les projets existants dans la littérature peuvent être utilisées pour couvrir davantage d'indicateurs et de sous-catégories d'impact. Ces données sont dites secondaires.

Dans le cas de l'approche pour couvrir le périmètre global, c'est-à-dire pour couvrir les risques sociaux liés à la chaîne d'approvisionnement, il est nécessaire d'assembler certaines données préliminaires. Les données d'inventaire nécessaires correspondent aux données relatives aux matériaux et aux composants du système évalué, ainsi qu'au coût des matériaux, au coût de la main-d'œuvre et à l'origine géographique de ces matériaux et main d'œuvre. En l'absence d'informations exhaustives sur les coûts spécifiquement liés au système, des hypothèses sont utilisées. Les hypothèses peuvent consister à identifier les prix des matières premières et/ou le coût de la main-d'œuvre dans chaque secteur à partir de sources génériques (e.g., prix communiqués par des grossistes).

Outre l'estimation du coût des activités, les différents secteurs industriels impliqués doivent être identifiés, ainsi que le pays où les activités sont réalisées. En l'absence d'informations sur l'origine géographique des matériaux utilisés, il est possible d'utiliser pour hypothèse les informations par défaut correspondant aux flux commerciaux fournis renseignés dans une base de données. Dans cette thèse, la base de données utilisée est Product Social Impact Life Cycle Assessment (PSILCA), avec le logiciel openLCA. Par exemple, un processus industriel générique « Fabrication de métaux de base en France » implique des pays fournisseurs en amont tels que la Belgique, l'Italie, l'Allemagne, l'Espagne et les Pays-Bas. Par défaut, la base de données propose un grand nombre d'indicateurs. Dans cette thèse, les indicateurs retenus pour l'évaluation des impacts au périmètre global ont été sélectionnés sur la base de travaux similaires en ACV sociale appliqués à l'éolien en mer.

L'évaluation des impacts sur le périmètre global est testée sur deux parcs éoliens hypothétiques, définis sur la base des choix de conception technologique observés parmi les projets de parcs éoliens émergents en France. Deux types principales configurations technologiques de PEO sont en effet identifiées : les systèmes équipés de fondations flottantes et les systèmes reposant sur des fondations fixes. Les PEO fixes correspondent aux premiers parcs éoliens offshore développés en France. Les technologies de PEO flottantes sont néanmoins appelées à se développer progressivement, compte tenu des prévisions de la stratégie politique de déploiement de l'éolien en mer en France, et considérant les avantages qu'elles offrent par rapport aux technologies fixes. Les fondations flottantes permettent en effet d'installer des éoliennes offshores plus loin de la côte, avec des gains potentiels en matière de ressource en vents et une réduction de certaines préoccupations sociales, telles que les impacts visuels ou les conflits de cohabitation avec les activités maritimes s'exerçant en priorité près des côtes. Les paramètres différenciant des deux scénarios technologiques (fixe et flottant) sont notamment la distance à la côte, la technologie des fondations, ainsi que la puissance et le nombre de turbines.

Dans le cas de l'approche pour couvrir les périmètres national et local, la thèse propose le déploiement de nouveaux indicateurs d'impact qui impliquent la définition d'une échelle de performance. La définition d'une échelle de performance est réalisée en établissant des seuils pour chaque score de performance. Dans le processus méthodologique de définition de l'échelle de performance, une importante collecte de données est nécessaire, mais représente un verrou auquel la thèse répond.

Afin de favoriser une collecte de données spécifiques, différents projets de PEO ont été sélectionnés en cohérence avec les scénarios technologiques préalablement définis. Pour des raisons de fiabilité des résultats, les données spécifiques au site sont utilisées dans la mesure du possible. Toutefois, pour un certain nombre d'indicateurs identifiés, une contrainte d'accès aux données empêche la construction d'échelles de référence uniquement à partir des données issues des cas d'études observés en France. Malgré l'analyse documentaire approfondie, il peut rester impossible d'identifier des valeurs spécifiques aux sites liés aux études de cas évaluées pour certains des indicateurs identifiés. Par ailleurs, au moment

de la collecte des données réalisée dans la présente thèse, aucun PEO en France n'était en phase opérationnelle. Cette contrainte implique une évaluation d'impacts anticipés (ou potentiels) pour la phase d'opération d'un PEO, et donc une approche particulière pour la collecte des données. En outre, afin de compléter les informations collectées et d'aider à l'interprétation, des consultations individuelles avec les parties prenantes sont conduites.

Dans le cas où les valeurs spécifiques ne peuvent être obtenues, des données génériques peuvent être nécessaires pour compléter les informations manquantes. Une valeur générique désigne toute donnée qui ne correspond pas précisément à l'un des cas d'étude considéré. Cependant, malgré cette limite, une donnée générique peut fournir des informations utiles pour une estimation préliminaire de l'impact potentiel. Cette estimation peut servir de valeur de référence jusqu'à ce qu'une évaluation plus précise soit possible, lorsque des valeurs spécifiques au site deviennent disponibles. En fonction des indicateurs, le choix des valeurs génériques peut être large. Toutes les valeurs génériques n'ont pas le même niveau de résolution ou de proximité avec le système évalué. Il en résulte différents niveaux d'incertitude.

La méthode utilisée pour l'attribution des seuils nécessaires à la définition des scores de performance dans l'approche PRP dépend donc de la disponibilité en donnée. Pour adresser ce verrou spécifique, la présente thèse identifie plusieurs façons d'attribuer des seuils en fonction de la disponibilité des données. L'ordre préférentiel établi par la thèse est le suivant : utiliser les seuils tels qu'ils sont définis dans la littérature lorsqu'ils sont disponibles, déduire des seuils des observations de l'étude de cas, ce qui conduit à considérer un minimum et un maximum et à diviser en autant de parties égales ; et dans la situation la plus incertaine il s'agit d'estimer les seuils sur la base des valeurs que l'indicateur pourrait prendre. Dans cette dernière configuration, l'avis d'un expert est sollicité. En pratique, la définition de l'échelle de référence est conduite itérativement avec la collecte des données.

Pour les résultats liés au périmètre global, les risques sociaux sont calculés au moyen de la base de données PSILCA pour les deux scénarios de base fixe et flottant définis précédemment. Les résultats révèlent que les valeurs d'indicateurs mesurées en « heures de risque moyen » varient fortement d'un indicateur à l'autre. Les valeurs les plus élevées identifiées concernent les indicateurs *Salaire équitable* et *Epuisement des ressources eaux*, suivis par *Mesures de sécurité*. A l'inverse, les indicateurs *DALYs* (ou « EVCI » pour « espérance de vie corrigée de l'incapacité ») et *Fréquence du travail* ont les valeurs en heures de risque moyen les plus faibles parmi l'ensemble des indicateurs calculés. Pour 10 indicateurs sur 12 sélectionnés sur la base de travaux similaire en ACV sociale, le scénario de PEO flottant générerait un nombre d'heures de travail à risque plus élevé que le scénario de PEO fixe. Le scénario de PEO fixe génèrerait davantage d'heures de risque moyen concernant les indicateurs *Droits d'association et de négociation concernant* et *Ecart salarial entre les hommes et les femmes*. En complément de ces résultats, les contributions relatives des différentes activités aux heures à risque moyen sont analysées afin d'identifier plus précisément les activités qui contribuent le plus aux heures de risque moyen.

Dans le cas du scénario de PEO flottant, la principale contribution aux heures à risque moyen serait due à la fabrication des flotteurs. Ce résultat s'explique par l'hypothèse utilisée lors de la phase d'inventaire, laquelle repose sur la considération d'une technologie de flotteur semi-submersible en acier, impliquant donc de manière significative le secteur de l'acier. Pour les deux scénarios définis et l'ensemble des indicateurs considérés, la fabrication des turbines représente moins de la moitié des contributions relatives aux heures de risques moyens. En reprenant les données sur lesquelles se base PSILCA, l'activité de fabrication de métaux de base en France serait liée à des activités amont qui comprennent notamment l'exploitation minière en Afrique du Sud.

Pour les résultats liés aux périmètres national et local, les indicateurs identifiés lors de la phase d'inventaire sont évalués selon l'échelle de performance définie au préalable, pour chacune des sous-catégories d'impact et catégories de parties prenantes correspondantes. Les résultats obtenus sur plusieurs études de cas permettent d'identifier, pour certains indicateurs, des variations de performance sociale ainsi que certains paramètres expliquant ces variations.

A titre d'illustration, il est possible de discuter des résultats de l'indicateur de contenu local (ou « local content »), à savoir la part du coût du projet dont va bénéficier les acteurs de la chaîne de valeur régionaux. L'interprétation des résultats obtenus pour cet indicateur révèle que l'écart de performance mesuré est relativement élevé parmi les cas d'étude considérés. La prise en compte de plusieurs cas d'étude permet d'identifier certains paramètres susceptibles d'influencer la performance sociale de cet indicateur et d'expliquer l'écart mesuré entre les différents cas d'étude de PEO. En effet, l'écart peut s'expliquer notamment par la dépendance au contexte territorial. Les projets de PEO installés au sein un contexte industriel local développé sont susceptibles de recourir davantage à des contrats avec des entreprises locales. Plus particulièrement, la nécessité pour les territoires de développer leurs ports peut également favoriser la création de contrats locaux pour des travaux d'aménagement. Inversement, dans le cas de projets de PEO nécessitant des compétences spécialisées qui ne sont pas disponibles localement, il peut être difficile d'atteindre un niveau élevé de contenu local.

Pour résumer la contribution scientifique de la présente thèse relative à l'évaluation des indicateurs par l'approche PRP, différentes échelles de référence ont été définies et appliquées à l'évaluation de différents projets de PEO en France. La thèse propose et utilise une série d'indicateurs sectoriels qui considèrent les particularités de l'émergence de l'éolien en mer en France. Une proposition méthodologique a été faite pour systématiser l'accès aux données secondaires, sur lesquelles se base largement ce travail de définition des indicateurs. L'application de l'approche PRP dans la thèse met également en avant certaines limites quant aux échelles de référence définies dans leur forme actuelle. Certains indicateurs permettent d'évaluer spécifiquement les performances pour chaque étude de cas de PEO et de les comparer, grâce à la disponibilité des données. Dans d'autres cas, le manque de données spécifiques amène à l'utilisation d'informations génériques selon différents niveaux de résolution (e.g.,

des données génériques pour les entreprises, des données génériques pour l'ensemble du secteur éolien en mer). Toutefois, le choix fait par la thèse pour l'inclusion d'indicateurs évalués avec des données génériques demeure pertinent, pour permettre notamment d'orienter les recherches futures vers l'amélioration des indicateurs existants et l'identification d'informations spécifiques correspondantes pour combler le manque de données actuel.

Pour conclure sur les résultats découlant de la deuxième question scientifique de la thèse, l'une des contributions essentielles de ce travail repose sur la définition et l'application d'une approche multi-échelle dans la réalisation des étapes d'analyse d'inventaire et d'évaluation des impacts en ACV sociale. D'une part, des modèles d'ACV sociale utilisant une base de données générique et un logiciel ACV conventionnel ont été utilisés pour évaluer les risques sociaux des activités du secteur selon un périmètre global. Deux scénarios technologiques hypothétiques ont été définis pour mesurer les heures de risques moyens associées aux différentes technologies de PEO. D'autre part, pour couvrir les sous-catégories d'impact selon les périmètres national et local, l'évaluation est basée sur des sources de données secondaires et hétérogènes. Une hétérogénéité inhérente au contexte d'un secteur éolien en mer français caractérisé par une forte concurrence industrielle et un accès très restreint, voire inexistant dans certains cas, à des données primaires. Afin de pallier ces limitations, la thèse a développé une approche pour une méthode de collecte de données secondaires systématique et transparente, puis a défini, malgré les limites des données sus-évoquées, un ensemble d'indicateurs d'impact sociaux adaptés au secteur éolien en mer. Si certains indicateurs sont spécifiques au secteur éolien en mer, d'autres sont également transférables à d'autres systèmes. Il convient de souligner que la réalisation des phases d'inventaire et d'évaluation de l'impact nécessite un certain nombre d'hypothèses et est sujette à des incertitudes. En particulier, les hypothèses et les sources de données pour la définition des valeurs de référence et des seuils, essentiels pour évaluer la performance sociale, doivent être révisées et évoluer au fur et à mesure que de nouvelles données sont disponibles. D'autres travaux pourraient être menés pour étudier les protocoles de consultation d'experts pour la définition et/ou l'identification d'indicateurs. Notamment, la consultation d'experts pourrait être combinée à la définition des échelles de référence et des seuils associés afin de renforcer leur fiabilité.

En conclusion générale de la thèse, l'étude de la durabilité sociale d'un système tel qu'un PEO passe par la prise en compte des préoccupations des parties prenantes, étendues à l'ensemble du cycle de vie, et leur évaluation. L'ACV sociale est un cadre méthodologique qui peut être utilisé à cette fin. Le niveau actuel de développement de l'ACV sociale nécessite de renforcer la transparence des approches et la systématicité de la collecte de données afin d'accroître son utilisation et son appropriation par les décideurs. En outre, certaines particularités sectorielles du secteur de l'énergie éolienne en mer en France ont conduit à la nécessité d'adapter les cadres existants. Ce besoin d'adaptation a conduit à la formulation de deux questions de recherche dans le cadre de cette thèse.

Dans la travail de hiérarchisation des sous-catégories d'impacts, deux approches participatives ont été testées : l'une adressée aux développeurs de parcs éoliens et opérateur du raccordement électrique, et l'autre aux parties prenantes externes. Les résultats ont permis de dresser un ordre des sous-catégories d'impacts hiérarchisées selon les critères utilisés. Toutefois les résultats révèlent aussi une dispersion des scores dans les deux approches. La possibilité d'utiliser ces deux approches de manière plus complémentaire devrait être explorée, par exemple afin d'identifier les paramètres qui peuvent expliquer les divergences et les convergences de points de vue. Par ailleurs, il existe des similitudes entre l'étape de hiérarchisation et l'étape de pondération, qui consiste à attribuer plus d'importance à certains indicateurs et/ou sous-catégories d'impact. La pondération est généralement réalisée lorsque que les impacts ont été évalués. Dans cette thèse, aucune étape de pondération n'a été réalisée, ce qui suggère implicitement que le même poids a été attribué à toutes les sous-catégories d'impact. L'articulation entre ces deux étapes pourrait également être explorée lors de travaux ultérieurs.

Dans l'approche multi-échelle des impacts sociaux proposée dans la thèse, les périmètres national et local sont spécifiques à certaines étapes du cycle de vie d'un PEO. Ces périmètres ont été définis pour aider à focaliser les phases d'analyse de l'inventaire et d'évaluation des impacts pour tenir compte des spécificités du secteur éolien en mer en France. Pour rappel, la littérature a révélé de nombreuses spécificités liées aux stades de l'installation et de l'exploitation des systèmes de PEO. Cependant, pour être cohérent avec les principes fondamentaux de l'ACV, la collecte de données spécifiques au site doit également être encouragée pour les stades en amont et en aval de l'exploitation d'un PEO. Une étude approfondie serait en effet susceptible de conduire à l'identification d'autres spécificités relatives aux impacts sociaux au sein d'autres secteurs impliqués dans le cycle de vie d'un PEO. Dans ce cas, une approche PRP peut demeurer pertinente pour définir des indicateurs spécifiques en complément de ceux disponibles dans les bases de données utilisées en ACV sociales telle que PSILCA.

Par rapport à la viabilité des données utilisées, différents éléments pourraient contribuer à l'améliorer. Notamment, pour que l'évaluation de la base de données PSILCA soit fiable, le recours à des inventaires spécifiques impliquant des données primaires reste hautement privilégié. Ces inventaires spécifiques peuvent inclure les informations techniques et économiques propres aux composants et aux matières premières, ainsi que les coûts de main-d'œuvre, mais aussi les niveaux d'impact social eux-mêmes. Sur ce point, des visites effectuées sur les sites de fabrication de certains composants permettraient de collecter des informations plus précises sur les risques sociaux relatives à ces stades du cycle de vie par rapport aux informations génériques renseignées à défaut dans les bases de données. Une visite de site peut par exemple inclure l'utilisation d'enquêtes à remplir par les employés ou les cadres. Il est toutefois important de noter que ces méthodes d'accès aux données primaires prennent du temps et sont difficilement applicables à l'ensemble des stades du cycle de vie du système évalué.

Le besoin d’une méthode standardisée et fiable pour l’évaluation des questions de durabilité sociale se pose avec une acuité croissante, à la fois par les décideurs publics et industriels. Les travaux réalisés dans le cadre de cette thèse ont apporté une contribution méthodologique à l'intégration de la représentativité des parties prenantes et des spécificités territoriales dans le cadre de l'ACV sociale, y compris les phases de définition du périmètre, d'analyse de l'inventaire, d'évaluation de l'impact et d'interprétation. Ces développements sont considérés comme étant transférables à d'autres systèmes au sein du secteur de l'énergie, après une adaptation de l'approche, et, par extension, à d’autres projets d'infrastructure ou d’aménagement du territoire. Plus généralement, l'ACV sociale devrait continuer à se développer dans les années à venir dans un contexte en France où les autorités publiques et les différents appels d’offre tentent d’inclure de plus en plus de critères sociaux dans les processus de décision.

General table of contents

Acronyms

ADEME: Agency for the Environment and Energy Management
AER (Law): Acceleration of the production of renewable energy
ANCT: French National Agency for the Cohesion of Territories
CO2, MtCO2eq: carbon dioxide, million tons of CO2 equivalent
CRE: Energy Regulatory Commission
CSR: Corporate social responsibility
DALYs: Disability-adjusted life years
EEZ: Exclusive economic zone
EIA: Environmental impact assessment
E-LCA: Environmental life cycle assessment
FAD: Fish aggregating device
GBS: Gravity based foundation
GHG: Greenhouse gases
GRI: Global Reporting Initiative
IEA: International Energy Agency
ILO: International Labour Organisation
IPCC: Intergovernmental Panel on Climate Change
IRENA: International Renewable Energy Agency
ISO: International Organisation for Standardization
kV: Kilovolt
LCA: Life cycle assessment (analysis)
LCC: Life cycle costing
LCOE: Levelized cost of energy
LCSA: Life cycle sustainability assessment
MTE: Ministry of Ecology Transition (2020-2022)
MTES: Ministry of Ecology and Solidarity Transition (2022-)
MW, MWh: Megawatt, Megawatt hour
NGO: Non-governmental organisation
NIMBY: “Not in my back yard” syndrome
NOx / SOx: emissions: Nitrogen oxides (NOx), Sulphur oxides (SOx)
OECD: Organisation for Economic Co-operation and Development
OWF: Offshore wind farm
PMG-DD: Low speed direct drive permanent magnet generator
PMG-HS: High speed permanent magnet generator
PMG-MS: Medium speed permanent magnet generator
PPE: *Programmation pluriannuelle de l’Energie* (multi-annual energy plan)
PRP: Performance-reference-point
PSIA (Handbook): Handbook for product social impact assessment
PSILCA: Product social impact life cycle assessment
QALYs: Quality adjusted life years
SETAC: Society of Environmental Toxicology and Chemistry
SHDB: Social hotspot database
S-LCA: Social life cycle assessment
SMEs: Small and medium-sized enterprises
SNBC: *Stratégie nationale bas carbone* (national low-carbon strategy)
TOE: Ton of oil equivalent
UN: United Nations
UNDP: United Nations Development Program
UNEP: United Nations Environment Program
UNFCCC: United Nations Framework Convention on Climate Change
WBCSD: World Business Council for Sustainable Development
WCED: World Commission on Environment and Development
YOLL: Years of life lost

List of figures

List of tables

1. Introduction

1.1. Context

1.1.1. Ensuring a sustainable energy transition

1.1.1.1. Emergence of low-carbon technologies

Climate change can drive modifications in multiple physical climate conditions, increasing the frequency of natural disasters such as droughts or hurricanes, as well as causing changes in ecosystem structure, and species ranges in both terrestrial and ocean environments (IPCC, 2023). Consequences on human societies may result in political disorders, starvation or population displacement, among others (Berlie, 2018). Some of these impacts are already observable, such as increased risk of drought and effects on crop yields.

Among global net anthropogenic gas emissions causing greenhouse effects, CO_2 emissions are responsible for about two-thirds of the total emissions (IPCC, 2023). Regardless of the continent, almost half of CO_2 emissions were due to the energy production sector, including electricity and heat power generation (Papadis and Tsatsaronis, 2020, based on IEA 2019). CO_2 emissions are mainly the result of the combustion of coal, oil, and gas (IEA, 2019). Therefore, to mitigate climate change, decarbonising the world economy is necessary.

Although some countries have decoupled economic growth from energy consumption, the development of society through history has been largely correlated to fossil energy use (Carbonnier and Grinevald, 2011). Decarbonisation thus entails re-designing the industrial system (Falkner, 2016). Given the global scale of the energy system, the trajectory correction of the greenhouse gas (GHG) emissions through energy transition requires an international political concertation. In response, policymakers have engaged in several commitments. The well-known Paris Agreement, adopted in 2015, states the need for: "*holding the increase in the global average temperature to well below 2 °C above preindustrial levels and pursuing efforts to limit the temperature increase to 1.5 °C above pre-industrial levels* […]" (UNFCCC, 2016). By extension, the massive development of low-carbon energy production technologies is a major issue of the 21st century to fight against global warming. This observation leads to a challenge: ensuring this massive development of low-carbon technologies is aligned with the sustainable development paradigm.

1.1.1.2. Sustainability concept

The concept of sustainable development was defined by the World Commission on Environment and Development (WCED) in 1987 as: *"development that meets the needs of the present without compromising the ability of future generations to meet their own needs"* (WCED, 1987). Over the years, a paradigm has emerged representing sustainability as a central concept. Most studies agree to include three main dimensions when defining this concept, namely environmental, social and techno-economic dimensions. There are, however, different approaches to the formalisation of a methodological framework for its assessment (Purvis et al., 2019). To ensure that the energy transition aligns with the sustainability development principles, the development of new technologies and sectors has to consider their potential effects on these different dimensions. For this reason, private and public decision-makers must anticipate the impacts and changes the energy technologies may generate. An integrated framework that considers these aspects is, therefore, essential for ensuring optimal implementation of energy production projects (Lee et al., 2009). It should be noted that this energy transition entails the development of new plant installations and, therefore, environmental, socio-political and economic consequences, both at local and global levels (Jollivet, 2013). Although local consequences related to an energy system's operating phase may be the most visible, other effects are also generated upstream and downstream. Indeed, every industrial process, including those related to energy production, requires environmental and human resources. The assessment of the above-mentioned consequences should be addressed, ideally in a holistic way.

Life Cycle Thinking has been widely proposed as a relevant framework to consider the sustainability of products and services from a comprehensive perspective, from raw materials extraction and transformation to consumption and end-of-life (Sala et al., 2015). Life Cycle Assessment (LCA) is an evaluation method originally developed to assess the environmental dimension of sustainability by considering the entire life cycle of a product or service (ISO 14040, 2006). Following complementary frameworks developed by experts in the field, its application has been extended to also cover the other sustainability dimensions in holistic assessments known as Life Cycle Sustainability Assessments (LCSA) (Kloepffer, 2008). Regarding the environmental dimension, different categories of environmental impacts (e.g., global warming potential, freshwater toxicity, land use, etc.) exist and can be assessed to evaluate and compare the performance of different energy technologies. In contrast, the integration of social impacts into the assessment of processes through the whole life cycle is still underdeveloped. Though various social issues are often raised (e.g., social acceptability of local communities, working conditions of employees in the value chain, etc.), they are not systematically considered in available studies.

As mentioned in the previous section, by contributing to mitigate global warming, low-carbon technologies indirectly aim to be beneficial for individuals and society, thus, their social utility is indicated. It is, however, essential to ensure that they respect this paradigm and do not generate unexpected negative social effects during their life cycle. Enhancing the integration of social concerns into LCA energy assessment processes should help enhance the sustainability of the energy transition.

1.1.2. Emergence of offshore wind energy

1.1.2.1. Overview

Wind power technologies are among the main emerging renewable energy production technologies. Offshore wind power presents several technical advantages related to the specificities of the ocean sitting area compared to the onshore wind configuration. Indeed, the marine environment offers large surfaces and, generally, stronger and more regular average wind than onshore sites (Bilgili et al., 2011). Hence, it is expected that, for a given wind turbine (i.e., at equal rotor diameter and generator power), the average capacity factor (i.e., the number of kWh produced divided by its peak capacity) is higher for an offshore wind configuration than for an equivalent onshore one. At the same time, offshore wind faces physical constraints such as long distances to shore requiring the use of boats for installation and maintenance, as well as specialised skills and materials resistant to marine environments. The development of the offshore wind power sector involves, thus, significant investments (Xu et al., 2021). However, increasing industrialisation favouring economy of scale in the last years has led to considerable cost-savings and the levelized cost of energy (LCOE) has been almost halved between 2010 and 2020 (IRENA, 2021). For these reasons, and regarding its advantages compared to onshore wind power, offshore technology presents a strong potential development in the coming decades (Figure 1.1).

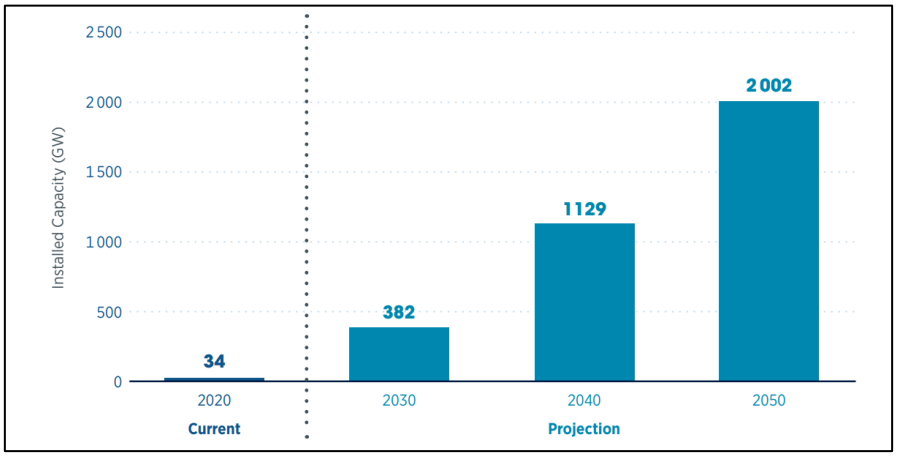

Figure 1.1. Offshore wind power current and projected capacity according to the IRENA 1.5°C Scenario, 2020-2050 (IRENA, 2021).

In 2020, the worldwide offshore wind installed capacity was approximately 34 GW. The main offshore wind markets were the United Kingdom, China and Germany, with respectively almost 10 GW, 10 GW and 8 GW of installed capacity (Bilgili and Alphan, 2022). According to IRENA's 1.5°C Scenario, the projected capacity could increase significantly over the next decades to reach up to 2,000 GW by 2050, as shown in Figure 1.1.

At the European level, the European Commission has promoted, through the Green Deal, offshore wind production as an essential contributor to the energy transition (EC, 2019). The European offshore wind installed capacity was almost 15 GW in 2021, but it is nowadays projected to increase to above 300 GW by 2050 (EC, 2020). This ambitious target is due, in part, to the great potential of the European Atlantic coastline.

1.1.2.2. Offshore wind deployment in France

In terms of marine area, France has the second largest economic exclusive zone (EEZ) in the world, which covers 10.2 million square kilometres, including both metropolitan and overseas regions. In particular, the metropolitan coastline includes almost 5,850 kilometres (GéoLittoral, 2022). In 2021, the French government announced that France had a significant delay in offshore wind deployment despite this great maritime potential (CGEDD, 2021a). To improve this situation, the government aims to accelerate the development of offshore wind power and simplify administrative procedures for its implementation (CGEDD, 2021), to become a major producer.

In 2020, the French production energy sector was responsible for 40.8 $MtCO_2eq$ emitted to the atmosphere, i.e., almost 10% of the total GHG emissions of the country (Citepa, 2022) The French law on energy transition and green growth, aims to reduce the impact of the energy sector by defining the main axes to mitigate climate change throughout a roadmap called the *"stratégie nationale bas carbone"* (SNBC). Among the axes are the commitments to reduce GHG emissions by 40% by 2030 compared to 1990 and to achieve carbon neutrality by 2050 (Law No. 2015-992 of August 17, 2015). The French government specifies the strategy for the development of the French energy mix in the multi-annual energy Plan, called the *"programmation pluriannuelle de l'énergie"* (PPE), a crucial document for anticipating industrial development.

The PPE is established over 10 years and formally updated every 5 years. In 2019, the maximum potential total capacity, considering both constraints due to physical parameters and existing maritime uses, was estimated at 49 GW (MTES, 2019). Depending on the future energy mix and consumption scenarios, such capacity could contribute between one and three quarters to the electricity needs by 2050.

Ambitions for offshore wind power in France have considerably evolved in recent years. In 2016, the PPE targeted a total installed capacity around 10 GW by 2028. In February 2022, the government

announced a target of 40 GW of offshore wind power, equivalent to 50 offshore wind farms in operation by 2050. The aim is to increase the share of offshore wind-generated electricity to one quarter of the total electricity of the country. A law adopted in March 2023 on the acceleration of the production of renewable energy from the sea (AER law) sets the framework to implement this ambition (AER law, 2023). The AER law, thus, outlines the procedures for defining future acceleration areas for offshore wind power and sets out a range of measures to support offshore wind power large-scale deployment, including the simplification of planning processes for offshore wind farms on the scale of maritime facades, the reduction of delays for obtaining administrative permits and for legal appeals.

In 2023, France has a dozen commercial offshore wind farms (OWF) under development. The first commercial OWF was completely operational at the end of 2022. The commissioning of a second commercial OWF is planned by the end 2023 (MTE, 2023).

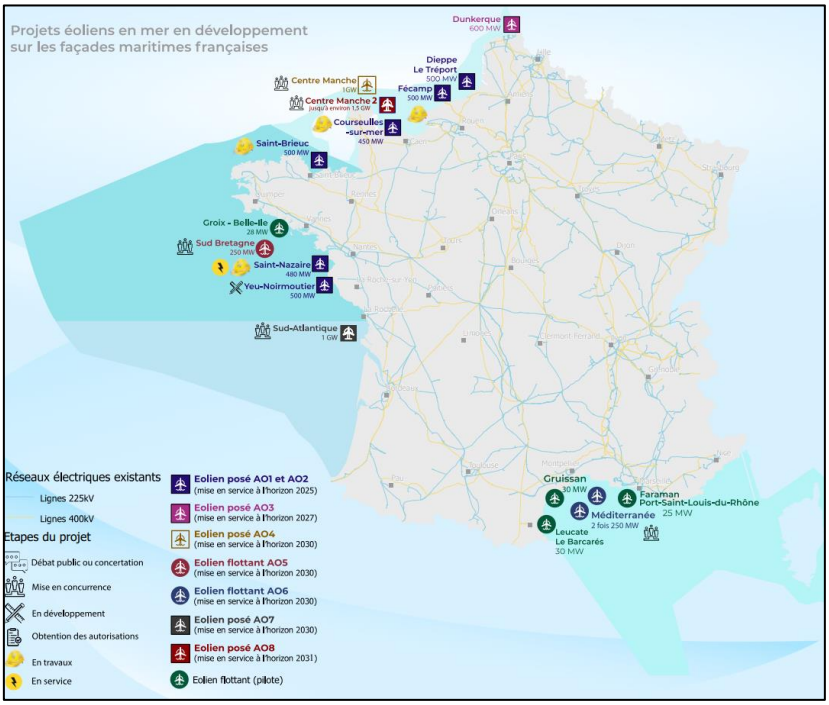

Figure 1.2. Expected progress of offshore wind energy development in France between 2020 and 2030 (Cerema, 2023).

Figure 1.2 introduces an overview of the various OWF projects under development. The reported elements include:

- the wind farms' installed capacity, from pilot projects between 25 and 30 MW to commercial farms from 250 MW up to 1.5 GW,
- the technology, either fixed or floating,
- the territorial installation areas: all maritime coasts are concerned, including South Atlantic, North Atlantic Western Channel, East Channel -North Sea, Mediterranean),
- and the current stage of development: public consultation, development, construction or operation.

The planning process intended by the French government for each maritime facade will lead to the depiction by 2024 of a new map of offshore wind farm siting areas.

1.1.3. Decision-making and social impacts: approach by LCA

1.1.3.1. Social concerns of stakeholders

Due to their multiple technological and economic dimensions, OWF projects involve many different people, referred to as stakeholders. A stakeholder can be defined as an *"individual or group that has an interest in any decision or activity of an organisation"* (ISO 26000, 2010). Depending on their interests, the stakeholders often present different opinions on OWF. On the one hand, some highlight the potential favourable impacts such as economic spin-offs at local scale, resulting for example in job creation. On the other hand, some stakeholders argue that OWFs may also lead to unfavourable impacts, for example related to the potential influence of their operation on previously existing maritime activities and amenities[2]. Other concerns are also related to upstream activities, such as the working conditions related to the manufacturing of certain components, or downstream ones, which include, for example, the treatment of components at the end of the cycle. Some of these activities can occur in countries other than France. Therefore, there is a need for social impact assessments regarding both national and international consequences of the OWF emergence.

In France, both an environmental impact assessment (EIA) and a public consultation are mandatory for the implantation of an OWF. The EIA assesses the potential effects on the biophysical, natural and socio-economic environment of a specific project over its lifetime. The EIA indicates measures to avoid, reduce or compensate for these effects. However, EIAs are mainly focused on both physical and environmental dimensions for the construction and operation stages. On the social dimension, information is often reduced to an initial state of the installation area and targeted impacts on key socio-economic sectors, such as fisheries, with a lack of consideration of up- and downstream stakeholders and activities. There is a persistent difficulty to articulate the social impact assessment in a holistic way and at different stages of the life cycle due, among others, to the large scope of such task and to the challenges to access such sensitive and often scarce data. While synthesising social information may be tricky, a social impact assessment all over the life cycle of OWF is necessary to identify the different social impacts and put them into perspective.

The public consultation related to OWF implementation, on the one hand, and the diversity of OWF projects, on the other hand, lead to the need for considering two main aspects within social impact assessments. Firstly, it is essential to consider representativeness of different local stakeholders on an

[2] Every aspect of the environment contributing to well-being

installation territory to define what the main social impacts may be related to. Secondly, articulating both local and global social impacts must be done through a systematic framework that covers the distinctive OWF parameters that can influence these social impacts. The need to provide a solution to deal with these two challenges has led to propose a methodology, in this PhD thesis, for assessing the social impacts of the life cycle of OWF by considering different stakeholders' perspectives and accounting for impacts both at the global and the local levels. This methodology has been tested in the French context and can be adapted and transferred to different energy systems.

1.1.3.2. Approach by Social Life Cycle Assessment

As previously mentioned, Life Cycle Assessment (LCA) approach was originally focused on the evaluation of the environmental dimension, which could be integrated in decision-making processes. Despite the valuable environmental information conventional LCA can provide, its exclusive use as a single tool in a decision-making process has limitations. In 2004, the World Energy Council stated that *"*[…] *LCA does not take into account technical performance, cost or political and social acceptance. Therefore, it is recommended that LCA be used in conjunction with these other parameters."* (World Energy Council, 2004).

Progressively, sustainability studies have looked to integrate the economic and social dimensions using an analogous life cycle perspective. Figure 1.3 presents one of the first conceptual frameworks of Social LCA (S-LCA) built upon E-LCA as a reference in 2006 (Dreyer et al, 2006). The main differences are highlighted in the figure. Thus, while E-LCA aims to explain how industrial processes impact the environment via the input and output flows exchanged by the two of them, S-LCA considers the social impacts generated by a company's activities on stakeholders (Dreyer et al., 2006).

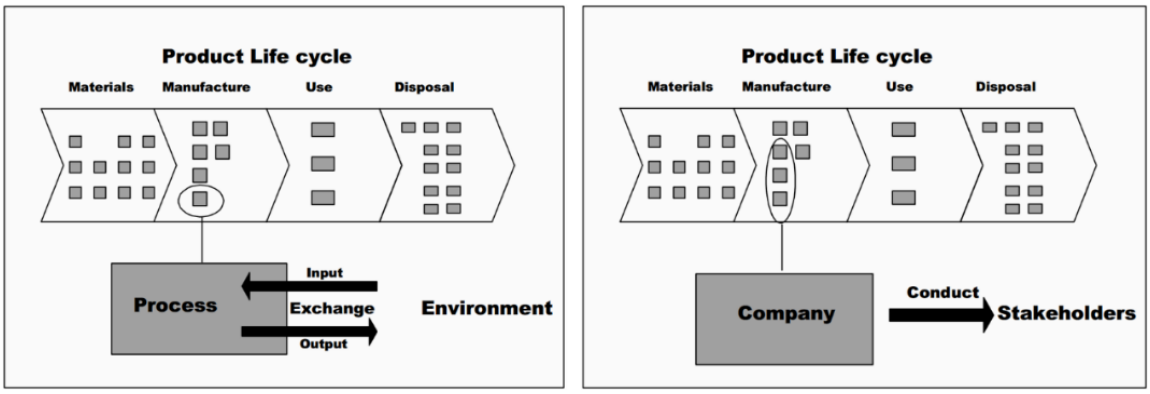

Figure 1.3. Conceptual understanding of the product system: environmental LCA VS social LCA (Dreyer et al., 2006).

Following the publication of several articles introducing the field, a well-known framework for S-LCA was established in 2009 and revised in 2020, namely the UNEP Guidelines (UNEP, 2020; UNEP/SETAC, 2009). UNEP Guidelines have greatly contributed to promoting S-LCA and paved the

way to extend the number of applications during the 2010s. Despite these efforts, S-LCA still has different methodological elements in development nowadays (Hannouf et al., 2021; Zheng et al., 2020). One of the key concepts of S-LCA that is widely used in available studies is the categorisation of stakeholders and their related impact categories and subcategories. A social impact category is defined by UNEP guidelines as "*a class that covers certain social issues of interest to stakeholders and decision-makers*", while an impact is a "*constituent of an impact category that is assigned to a stakeholder group*". Impact subcategories are typically evaluated based on one or several indicators. These concepts are deeply discussed in the Chapter 2.

Given the relevance of any energy plant system with respect to the territory it is attached to, the consideration of the territorial context and potential issues from a methodological perspective appears as a key feature to be integrated in an S-LCA framework. The implementation of OWFs in France provides a relevant set of case studies, currently at different levels of development, to build the methodological approach involving a wide range of socio-economic contexts of the French installation areas.

1.1.3.3. Multi-scale aspects of decision-making

In the context of energy planning, there are different levels of decision-making. While public policies and energy strategy are defined at the national level, the question of how these policies are implemented in local projects in installation areas is a constant challenge affecting the sustainability of energy systems (Laganier et al., 2002; Mocquet et al., 2018). However, in general, the local scale is not fully considered yet from the perspective of companies (Daudigeos and Ottaviani, 2021).

In addition, according to the principles of life cycle thinking, social impacts must be considered across all industrial processes related to a system. Complex systems such as energy plants include numerous industrial processes. For these systems, the S-LCA impact assessment would involve looking at the international level.

Frameworks for assessing the effects of companies' activities at different scales have been progressively introduced. In the early 2000s, the Global Reporting Initiative (GRI) formulated the relevance for considering both local and global social impacts in the assessment of companies' activities (GRI, 2002). This distinction between scales has been integrated into certain S-LCA frameworks (Finkbeiner et al., 2010; Peruzzini et al., 2017). Related to S-LCA for OWFs, some companies have already identified themselves methodological needs to better integrate local stakeholders and local impacts (Vattenfall AB, 2016). Global and local scales for Life Cycle Sustainability Assessment of OWF have been recently explored (Buchmayr et al., 2022). In Buchmayr et al. (2022), a global scale assessment was conducted, considering social risks thanks to the use of a sectoral database, while a local assessment was also

performed, involving the development of surveys and the use of their results to assess the possible effects of OWF in local life and landscape quality.

For a given life cycle stage (e.g., manufacturing of components), the different stakeholders to be considered are generally not located in the same place. Thus, some stakeholders can be around the installation area (e.g., workers who build the wind turbine foundations) while others may be spatially diffused (e.g. workers who build other components). In the case of stakeholders around the installation area, the collection of specific information related to this territory is possible, since the territory is identified. On the contrary, in the case of spatially diffused stakeholders and even stakeholders located in different countries, the specific data collection may be difficult. Therefore, average potential social impacts related to identified sectors and countries (i.e., generic data) may be needed. Data access may become even harder in cases of emerging technologies, for which commercial-size facilities do not exist or are rare.

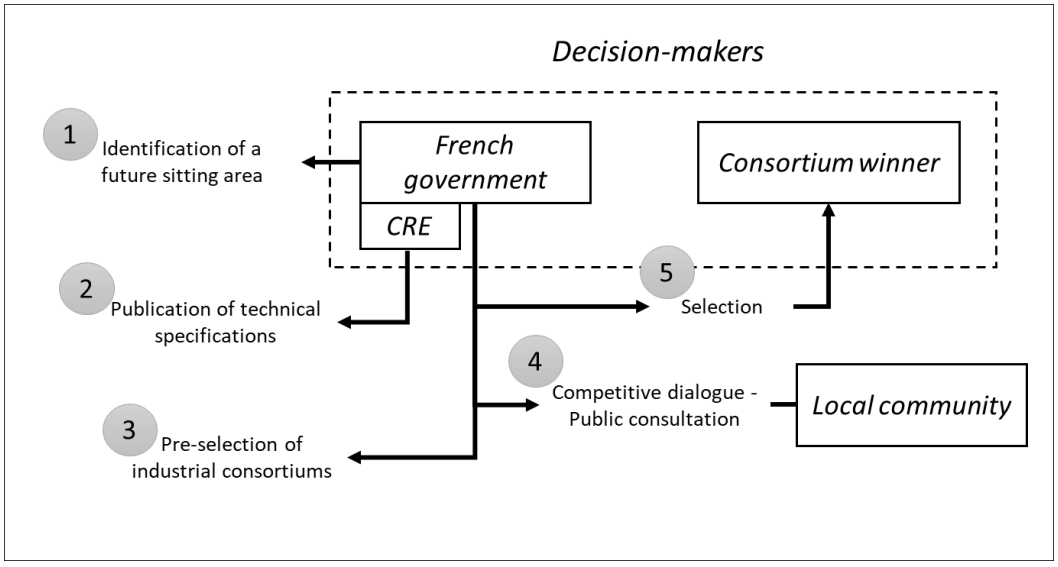

Figure 1.4. Decision-making process for the implementation of an offshore wind farm project before 2018 in France, prior to Essoc Law (adapted from www.ecologie.gouv.fr).

Figure 1.4 presents a simplified depiction of the decision-making process for the OWF sector in France up to 2018 prior to Essoc law and changes introduced in this process by the 2023 AER law. Among the main changes of the latter is the replacement of one public consultation per project by a single consultation of local communities within a larger area, which may concern several OWFs projects simultaneously. It should be noted that the most advanced OWF projects, on which this thesis has focused the data collection, correspond to projects prior to the Essoc law.

In the French context of OWF development, decision-makers are both public and private stakeholders. Among public decision-makers, are:

- the French government, which defines the direction of energy policy and allocates five-year budgets for the development of the sector. In the past, the government used to define future areas for OWF installations. This role is now shared with representatives of each maritime facade in the context of public consultations for the planning of offshore wind power acceleration. Both instances jointly organise these public consultations. Finally, the government selects the winner of the competitive dialogue.
- the Ministry of Ecology, which carries out the preliminary environmental studies before the winning candidate is selected following the competitive dialogue.
- the Energy Regulatory Commission (CRE) which oversees the tender procedure of the call for tenders that regulates the implementation of OWFs in France, including the technical specifications of OWF design to be provided (Cerema, 2023).

According to San Cristóbal (2011) on the definition of decision-makers in the energy sector, industrial consortiums and their related funding (i.e., investors) have to be considered as well. Within the OWF development framework, industrial consortium are indeed decision-makers, since they respond to the technical specifications that require them to account for technical, economic, environmental and social criteria in the development of OWF projects.

Technical specifications for the tender include criteria related to *"price"*, *"technical details"* and *"environmental and pre-existing activities"*. For the final decision, these dimensions have relative weights, of 40%, 40% and 20%, respectively. Social aspects are included among "environmental and pre-existing activities". Thus, they weigh less than 20% of the total sum of the evaluated criteria. For example, based on Dunkerque OWF project (i.e., call for tenders n°3 in 2016) social criteria relative to pre-existing activities were summarised in four points: employment, maritime safety, arrangements for professional fishing, and the consideration of the cultural heritage as touristic opportunities. Regarding employment considerations, candidates should promote the social inclusion of people currently outside of the labour force through sub-contractors, and to specify the share of contracts reserved for small and medium-sized enterprises (SMEs) (CRE, 2018). More recently, in the AO5 technical specifications, the criteria related to the professional inclusion of people encountering difficulties to find a job have been specified in greater detail. There are also criteria related to the amount of participative funding (DGEC, 2023).

These elements lead to discuss the way in which social criteria are integrated into these technical specifications. Firstly, the social dimension has little weight compared to the economic and technical dimensions, as previously indicated. Moreover, the absence of specific guidelines providing information on social criteria makes it difficult for consortiums of companies to design ambitious proposals with respect to these aspects. Finally, social criteria present in the call for tenders are focused on the local

effects around the installation area and exclude any reference to other activities within the life cycle that may affect other communities and even other countries.

Therefore, the development of the S-LCA approach in this thesis aims to contribute to a better identification and assessment of social criteria that can be considered in the future in the decision-making process related to new OWF development.

1.2. Scientific objectives

The implementation of offshore wind energy systems involves different stakeholders. The operation phase of an OWF ranges between 20 and 25 years, which may involve significant consequences for the territory around the installation site in the mid- to long-term. Potential social concerns are numerous and depend on the profile of the stakeholders involved. In this PhD, S-LCA is proposed as a useful method to identify and analyse these concerns systematically. S-LCA involves considering several subcategories of social impact within a coherent framework and analyse them via indicators allowing the performance of different systems with respect to those subcategories to be measured. Due to the large number of impact subcategories and associate social indicators, a hierarchisation is often required, to select the most relevant social impact subcategories to be assessed. To enhance this selection and justify it appropriately, it is important to define legitimate methods to rank the categories of impact to be assessed. This leads to the first scientific question addressed in this PhD thesis:

- **1st question:** How to develop a systematic approach for the identification and hierarchisation of relevant impact subcategories based on stakeholders' consultation?

Furthermore, in the current decision-making framework, the social issues surrounding OWF projects are mainly presented regarding the construction and operation stages. However, in the context of the emergence of a sector, a vision of the entire life cycle is necessary to address the social sustainability. This leads to the second scientific question which aims to explore to which extent the general framework of the life cycle perspective using S-LCA can be coupled with the social sectoral specificities related to the installation site. In addition, the proposed method should be adapted to the emerging nature of the sector. Indeed, due to the emergence of the sector, there may be a lack of feedback and constraints in terms of data accessibility. The second scientific question addressed in this PhD thesis is:

- **2nd question:** How to adapt the current S-LCA framework to couple LCA-holistic view and local aspects of for a given stage of the life cycle when data are scarce?

Scientific method

S-LCA is on its way to become a standardised approach through ISO 14075, currently in preparation. Considering this ISO standard not yet published, this PhD thesis uses available guidelines and standards, including the ISO 14040 on LCA principles and UNEP Guidelines for S-LCA (ISO 14040, 2006; UNEP, 2020). The manuscript is composed of the following chapters:

- **Chapter 2:** Literature review to explore and identify S-LCA approaches, including a sectoral focus related to energy production systems.

This chapter aims to review the main S-LCA methods developed since the 2000s and applied in published scientific literature and case studies of several companies in different sectors. The outcomes should lead to identify and adapt the methodological elements adopted for the application of the S-LCA methodology to the OWF sector in France. Furthermore, a holistic review is conducted to gather elements on social impacts related to the energy sector in general and offshore wind farms in particular, with a focus on the French context. Different disciplinary fields are also investigated, including sustainability assessment, S-LCA applications, social sciences applied to energy systems, and even coastal management.

- **Chapter 3:** Systematic methodological framework for a representative hierarchisation of social impact subcategories.

The first phase of an S-LCA is the goal and scope definition of study. Based on the outcome of the literature review presented in the chapter 2, S-LCA goal and scope definition requires the identification of relevant system boundaries, including the sub-systems, as well as of the associated stakeholders and their related social impact categories. As an intermediate result, a long list of social impacts of OWF is identified based on a literature review. A sub-step of hierarchisation is needed to classify these impacts subcategories from most to least relevant ones. For this purpose, the chapter 3 proposes a systematic approach for stakeholders' consultation through surveys. The approach points out the importance of the representativeness and transparency of the consulted stakeholders for S-LCA application and proposes a strategy to enhance current practices by adapting surveys' samples using a statistical adjustment.

- **Chapter 4:** Multi-scope inventory and impact assessment applied to offshore windfarm systems in France.

This chapter focuses on the two LCA phases following goal and scope definition, namely the inventory analysis and the impact assessment. In this PhD thesis, the inventory analysis and impact assessment phases are conducted by differentiating the geographical scope, including global, national, and local scopes.

For this purpose, two complementary approaches are used. The first approach is related to the use of a generic S-LCA database. Product Social Impact Life Cycle Assessment database (PSILCA) allows the identification of potential impacts (i.e., medium risks) occurring at the sectors and countries that are involved in the life cycle of the system. The second approach aims to assess impacts according to local and national scopes. This approach is conducted by using reference scales and performance reference points (PRP) as proposed by existing guidelines (Goedkoop et al., 2020; UNEP, 2020).

To address the global scope, the inventory consists in the identification of the main raw materials and industrial processes included in the life cycle of the system. These data are used to model the system, using the S-LCA database, in order to address social risks over countries and sectors involved in the value chain. For the generic evaluation, two baseline scenarios, representing the two foundation families currently available (i.e., fixed and floating foundations) are considered.

To address both national and local scopes, the inventory analysis phase consists of gathering social impact data based on a sectoral review from different studies. For national and local scopes, social impact indicators are identified by using the literature review conducted in Chapter 2 as a starting point. To complete the assessment of indicators proposed by S-LCA databases, the indicators identified in the local and national scope assessment aim to assess impacts that are specific to the offshore wind energy sector, with a focus on the installation and operation life cycle stages.

Significant variations in the potential social impacts within the different OWF projects are expected, considering both their different technical designs and contexts of the installation area. Moreover, the site characteristics may influence the technical design which can affect upstream and downstream social risks. To cover variations of social impact depending on OWF designed and territorial context, five case studies are investigated. Comparing these study cases should allow parameters having a substantial influence on social impacts to be identified. In accordance with ISO 14040 and UNEP guidelines (2020) principles, S-LCA is conducted iteratively. In particular, the interpretation phase occurs in parallel with both the inventory analysis and impact assessment phases.

- **Chapter 5:** Conclusion and perspectives

This chapter summarises the main outcomes of the PhD thesis, and then discusses on potential improvements related to different aspects of the methodology. The first improvement proposed in this PhD thesis is focused on the hierarchisation, related to the goal and scope definition LCA phase. Its ability and limitations to enhance the representativeness of stakeholders' when ranking the impact subcategories is discussed in the chapter. The second improvement is focused on the systematisation of S-LCA inventory and impact assessment related to different geographical scopes of the life cycle.

Further research hints to be conducted in the future are also discussed. For instance, additional indicators for the inventory analysis should be identified and or developed. Thus, the list of indicators and associate reference scales later used in the impact assessment phase are expected to evolve, as feedback on the massive deployment of OWF become more widely available.

The chapters of the PhD thesis are addressing the different S-LCA phases according to 14040 ISO standard. The global methodology is resumed in Figure 1.5.

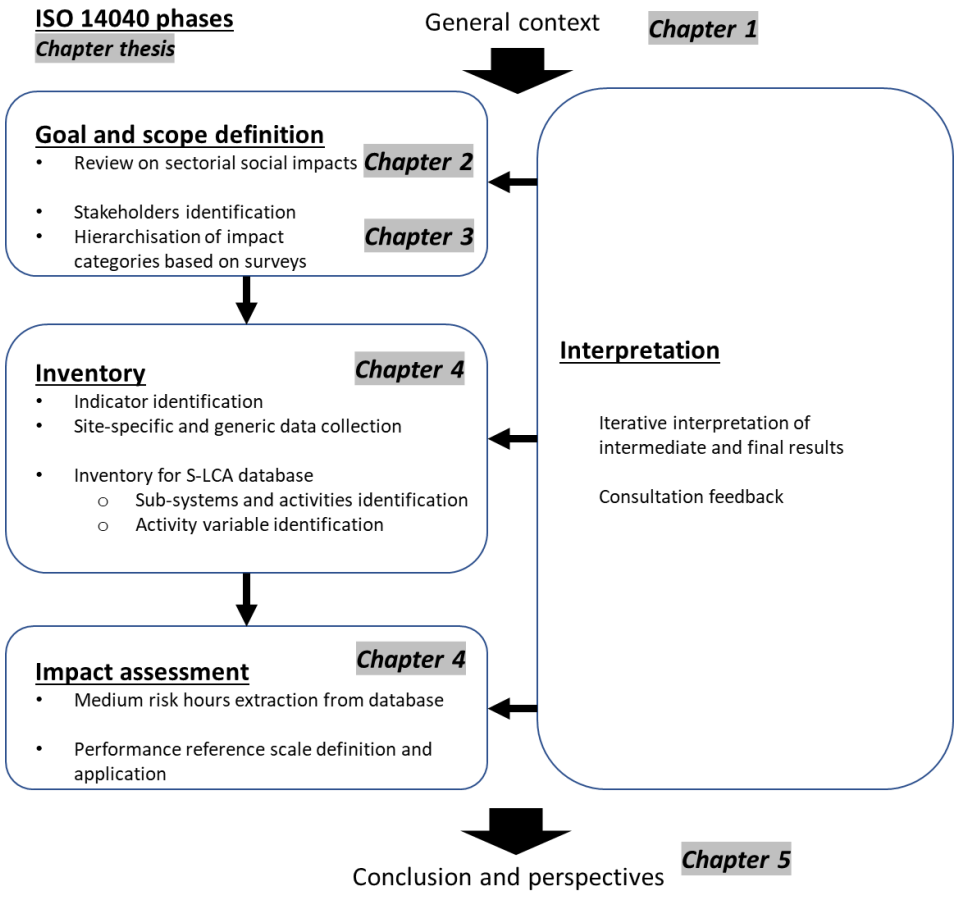

Figure 1.5. Main steps of the thesis (with respect to ISO14040 and UNEP, 2020).

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2. S-LCA framework applied to offshore wind

This chapter presents the initial development of S-LCA methodology that led to the publication, in 2009, of the first UNEP guidelines for social life cycle assessment of products, and its later update in 2020. After a general description and the definition of key concepts, some current challenges of the method and its application are discussed, with a focus on the context of energy systems, and, in particular, on emerging technologies. Thus, an overview of the current state of the art related to social aspects addressed in different studies in the literature, including S-LCA and LCSA studies but also other types of social impact assessment is provided. Special focus is given to offshore wind farm sector in France, though other studies related to different energy systems are also considered to identify a comprehensive set of relevant social impacts for the whole sector. At the end of the chapter, the main outcomes of the literature review are summarised, together with a brief introduction to the methodological improvements proposed in this PhD thesis and further developed in chapters 3 and 4.

2.1. Existing S-LCA frameworks

2.1.1. Brief historical background

Although social responsibility may be seen as a relatively recent concept, different studies highlight different examples of business' concerns for society since several centuries ago (Carroll, 2008; Latapí Agudelo et al., 2019) . Nevertheless, it was not until the 1950s that the social responsibility framework developed to become what we currently know. Since the mid-1970s, the principles defined by the Organisation for Economic Co-operation and Development (OECD) for multinational enterprises have paved the way towards the definition of social responsibility and its application within companies (OECD, 2011). In parallel, the "Protect, Respect and Remedy" framework from United Nations proposed a set of guiding principles (UNDP, 2011). This framework aims to guide organisations to ensure that human rights are respected within all their activities. However, by definition, these guiding principles remain general and do not represent a methodological standard. In the late 1990s, the first version of the guidelines by the Global Reporting Initiative (GRI) was published. Its further updates in

the 2010s constituted an operational turning point, as they consolidated the GRI Standards, aiming to address the sustainability performance of organisations, including, among others, the social dimension through a set of indicators (GRI, 2015, 2002). The notion of performance has been historically defined in terms of *"what contributes to the achievement of strategic objectives"* (Lorino, 1997). To improve the social performance of organisations, the G4 guidelines (GRI, 2015) propose to measure the social impacts upstream of their activities, which are defined as: *"Processes that help to identify substantial and potential negative impacts on society in the supply chain can enable the organisation to fight against them"*.

The interest in integrating social concerns into the activities of organisations has gradually led to the need for defining a certain number of concepts. One key concept for social assessments is that of "stakeholders". According to the International Organisation for Standardization (ISO) 26000:2010, a stakeholder is an *"individual or group that has an interest in any decision or activity of an organisation"* (ISO 26000, 2010). Historically, a distinction has been made between internal and external stakeholders. Internal stakeholders are mainly personnel employed by the company. External stakeholders are outside the company and have different profiles, including partners, suppliers, or society in general. All along the 2000s, the concept of Corporate Social Responsibility (CSR) was spread and became key for the definition of sustainability performance objectives of organisations. In France, the term "social" used in the context of CSR is generally restricted to the relationships between different subgroups of internal stakeholders, that is, between executives, investors and workers. In the United States, on the contrary, the use of the term "social" is used to described relationships between the company and the external partners and society surrounding it. Thus, in this context, the term "social" in CSR-related studies refers to concerns of both internal and external stakeholders (Mazuyer, 2013).

2.1.2. Origins of S-LCA

The first scientific publications on S-LCA emerged in the 2000s. The first publications in the field discussed the possibility to develop an assessment method to account for social impacts using environmental LCA methodology as well as other management tools as a basis (Arcese et al., 2016). They were mainly related to the corporate level, with an orientation towards a site-specific dimension. At the time, key notions such as the stakeholder identification and the relationships between different stakeholder groups and production stages were rarely addressed. The publication of the first version of UNEP./SETAC guidelines boosted the field and favoured articles testing their feasibility.

At the time, some work was conducted to define the fundamental motivations to develop S-LCA and the different purposes the new method could fulfil. Based on interviews with companies' representatives,

Jørgensen et al. (2009) was among the first studies to formulate the operational purposes of S-LCA applied to products or services. These purposes, as defined by Jørgensen et al. (2009), include:

- the identification of social hotspots or possibilities for improvement of the social performance all over the life cycle;
- the comparison of social impacts of alternative products or services providing the same function.

Other collaborative studies with large companies have been conducted since 2013, for example, by the Roundtable for Product Social Metrics. These collaborative studies resulted in the development and publication of the *Handbook for Product Social Impact Assessment* (PSIA Handbook) (Fontes et al., 2016; Goedkoop et al., 2020). Then, the *Social topics* report, recently updated, provides in more detail different indicators and corresponding definitions for assessing the social performance of companies(Harmens et al., 2022).

In parallel, the UNEP Guidelines for Social Product Life Cycle Assessment (UNEP Guidelines) were tested in different studies after their publication in 2009, then updated in 2020 (UNEP, 2020; UNEP/SETAC, 2009). The UNEP Guidelines propose a methodological framework for conducting S-LCAs. The framework relies on the same four phases commonly applied in environmental LCA, as required by ISO 14040:2006, namely goal and scope definition, inventory analysis, impact assessment and interpretation (ISO 14040, 2006). It should be noted that a specific standard for S-LCA on *"Principles and framework for social life cycle assessment"*, namely the ISO 14075, is currently under development, though not published yet.

Different S-LCA studies developed during the 2000s identified two main types of approaches (Parent et al., 2010; UNEP/SETAC, 2009). These approaches were the type I approach, also known as the Reference Scale approach, and the type II approach, also known as the impact pathway approach. The main features of each approach are discussed in the following section.

2.1.3. S-LCA type I and type II approaches

2.1.3.1. Definitions of type I and type II

The S-LCA type I approach aims to address the social performance of a product, service, or organisation by assigning a performance level for the assessed impact categories. Type I social impact assessment involves the consideration of social impacts for different stakeholder subcategories linked to the system, by dividing these impacts into impact subcategories. The approach is based on the definition of reference scales that establish levels of performance according to threshold values derived from international standards and other data sources. These values are called Performance Reference Points (PRP) (UNEP/SETAC, 2009). The type II approach is based on using causal relationships between the product

system activities and the resulting potential social impacts, analogously to impact characterisation conducted in environmental LCA. Type I can be seen as organisation-centred approach, limited to the identification of good practices or opportunities for improvement from a managerial perspective around performance reference points. Conversely, type II approach would be a long-term approach focusing on the ultimate impacts on humans as the health status or the well-being (Jørgensen et al., 2010). Figure 2.1 is a commonly used representation proposed by Neugebauer (2016) to differentiate these two approaches.

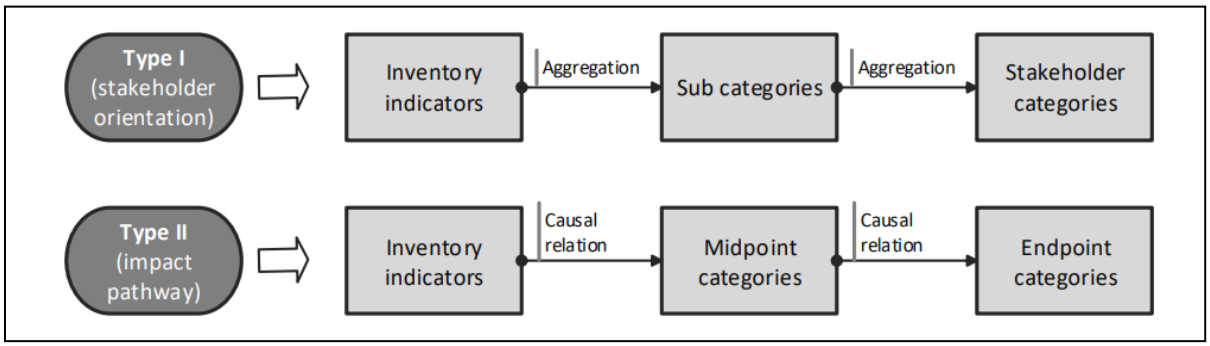


Figure 2.1. Type I and Type II assessment structure (Neugebauer, 2016; based on Parent et al., 2010; Wu et al., 2014).

2.1.3.2. Some nuances on type I and type II

Some nuances have been raised about type I approaches. Originally, performance-based approaches were mainly designed to assess the performance from an organisation's perspective, in the same way as a sustainability benchmark or comparison to compliance of managerial practices. Some authors claim that such applications should rather be called "CSR of the life cycle" instead of S-LCA and correspond, in a way, to a company's reporting exercise including numerous indicators, without really assessing the impact (Macombe et al., 2013). In this sense, an example of a reference scale based on an indicator that does not fully assess the impact is the one proposed in the *Social Topics for Product Social Impact Assessment* (Harmens et al., 2022). In particular, the "Health and Safety" social topic affecting "local communities" stakeholders is not addressed in the report by assessing the consequences of the product on life expectancy (i.e., an example of ultimate impact on humans), but instead, by identifying whether the company *"has a management system in place"* or not to address this social topic. In this case, the assessment can be done by identifying the existence of certifications and standards the company is compliant with (Harmens et al., 2022). According to the performance scale presented in the *Social Topics for Product Social Impact Assessment* and associated with this example, the existence of management system in place would be equivalent to a positive performance.

Despite these limitations, the use of type I approaches is widely present in the literature and aligned with the recommendations provided by the UNEP Guidelines (2020). In practice, studies have applied type I with some flexibility to adapt the approach to their case studies (Yu and Halog, 2015). Furthermore, a number of studies based on type I have progressively moved beyond the company's performance and a short-term view. Based on a type I S-LCA literature review, Russo Garrido et al. (2018), stated that *"not all type I S-LCA approaches focus solely on company activities and their immediate effects"*. Hybrid approaches are explored to consider impacts from different stakeholders' perspectives rather than restricting the analyses to organisation-centred performance assessments. The application of type I approach involves qualifying the data collected based on a scale. This can be a scale of performance (e.g., comparison with a target), but also a scale of risk (e.g., probability of an impact occurring), or other intermediate degrees between these two notions (Russo Garrido et al., 2018). The methodological development of this aspect of the PhD thesis is discussed in the section 2.1.4.3.

Regarding type II approaches, the study of impact pathways can be resumed as the investigation and/or the use of correlations between variables with times series or panel data (Sureau et al., 2020). To illustrate type II approach, different examples of impact pathways can be cited in the literature. Feschet et al., 2013, applied the Pathway Preston[3] (Preston, 1975) to S-LCA on banana product chain in Cameroun. This impact pathway aims to translate the influence that the economic growth generated by a system can have on the health status of the population of the country concerned (Feschet et al., 2013). In this work, indicators of *"potential capacity conditions"* are used to measure the effects of actions of companies on the related stakeholders. Another recent pathway consists of the translation of industrial activities into "*pressures*" on stakeholders by considering employment conditions and investment in health and well-being (Hannouf et al., 2021). In this work, health impacts are measured in QALYs (quality-adjusted life years). Moreover, assessing impacts on human health (e.g., using QALYs) and inducted health economic costs is presented as a way to encourage some responses to deal with them (e.g., working policies) (Hannouf et al., 2021). Looking among the studies based on type II, a distinction can be made depending on whether they aim to integrate several existing pathways, to explore new pathways, or only to apply pathways to case studies (Sureau et al., 2020).

Some limitations on the use of the type II approach can also be mentioned. To date, it appears that the type II approach has only been developed partially and is currently limited to social and socio-economic impacts for a single stakeholder category, namely workers, and very few impact subcategories (Bouillass et al., 2021). It seems, therefore, difficult to conduct an S-LCA in a holistic way, that is, covering the main stakeholder categories and social impact subcategories all over the life cycle by using type II exclusively.

[3] Neugebauer, 2016, classifies macroeconomic causal relationships as type III, although this typology seems to be rarely used nowadays.

To conclude this section, though the literature theoretically reveals only two S-LCA approaches, each of them, in practice, is applied in different ways depending on the study. In addition, the S-LCA method has been applied to a variety of sectors. Available studies reveal flexibility in the choice of impact subcategories, indicators and reference scales used for the assessment phase (Russo Garrido et al., 2018). The latter allows them to be adapted to their sectoral context and the goal of their studies. This diversity of approaches leads to the need for clear definitions of the main S-LCA concepts that a study intends to use, and for appropriate justifications, whenever necessary, of the different methodological adaptations done in the study.

2.1.4. Adapting S-LCA methodological framework

As introduced in chapter 1, the social sustainability of a system can only be assessed by considering its entire life cycle. The aim is to take a holistic view of the different risks, opportunities and social impacts that can be generated throughout the life cycle of an activity. In the energy context, this means looking beyond, without omitting, social concerns related to the site where the plant is located. Indeed, the different components and processes needed to build an energy plant, such as an offshore wind farm, are linked to several industrial sectors and geographical areas. Analysing social sustainability means looking at the social contexts of these sectors and geographical areas. This challenge requires the reuse and adaptation of several S-LCA methodological elements.

Overall, type I is a much more widespread methodological approach for S-LCA than type II. As mentioned in the previous section, type I approach is flexible and can be deployed in different ways to suit the context and the goal of the study. Moreover, it generally allows several stakeholders and impact subcategories to be addressed, whereas type II is generally limited to one or a few impact subcategories. Therefore, to address the S-LCA in a holistic way, considering a wide range of impacts and stakeholders, this PhD thesis focuses on type I approach and the framework proposed by the UNEP Guidelines (2020). In view of the elements discussed in the previous sections, it is important to clarify which concepts and methodological choices are reused and, if needed, adapted. The next sections provide some definitions of terms and concepts that are important to understand the methods proposed in this thesis and their link to previous work on S-LCA.

2.1.4.1. Phase 1: goal and scope definition

Considering both the UNEP Guidelines (2020) and the LCA framework compliant with ISO 14040:2006 standard, the first step to be conducted in an S-LCA is the goal and scope definition. In this phase, many methodological items must be defined. Some of them are similar to the elements required for an environmental LCA study, such as the definition of the system, the scope of the study and the system

boundaries. Other items are specific to S-LCA type I, such as the identification of the relevant stakeholder categories and associated social impact subcategories.

- **Stakeholder categories and associated impact subcategories**

The initial UNEP/SETAC Guidelines (2009) proposed a framework largely adopted by other S-LCA studies. Five stakeholder categories were defined in the Guidelines: Workers, Value Chain Actors, Local Communities, Society, and Consumers. The updated UNEP Guidelines (2020) proposed the addition of a sixth stakeholder category dedicated to Children. Each stakeholder category is addressed by different impact subcategories (UNEP, 2020; UNEP/SETAC, 2009). It should be noted that the terminology used in the guidelines is slightly different to that used in other reports, such as the *Handbook for product social impact assessment*. The latter is among the main sources presenting a framework for the application of the Reference scale approach and replaces the term "stakeholder categories", of UNEP guidelines, by the term "stakeholders groups", whereas the "social impact subcategories" defined in the guidelines correspond to "social topics" according to the Handbook's terminology (Harmens et al., 2022).

- **Indicators to assess social impact subcategories**

Each impact subcategory is assessed through one or several indicators that can be quantitative, semi-quantitative, or qualitative. Indeed, some indicators may need to be collected in a qualitative form, such as those related to internal policies, standards, or management strategies within an organisation (Finkbeiner et al., . UNEP Guidelines propose, through the *Methodological Sheets for Subcategories in Social Life Cycle Assessment* (UNEP, 2021), a baseline list of nearly 200 indicators related to 31 social impacts subcategories and examples of related sources for further data collection. However, the proposed indicators may not be all relevant for all industrial sectors. Moreover, additional indicators not included in the list may also be useful to evaluate a given sector. Selecting the relevant UNEP indicators for a given system is needed, but also identifying or building other relevant indicators specifics of the assessed system. Scientific and grey literature as standards and/or technical reports may serve identify other indicators in S-LCA (Lemeilleur and Vagneron, 2010). Companies' reports are also a useful source of information (GRI, 2015).

Indicators used in S-LCA can measure both favourable and unfavourable[4] impacts (Dreyer et al., 2010a, 2010b; Hauschild et al., 2008). It should be noted that defining what is favourable and unfavourable for the stakeholders can be a difficult or even arbitrary task. For example, there is a consensus in associating

[4] To avoid confusion with mathematical meaning, 'favourable' and 'unfavourable' are preferred rather than the original terms (i.e., 'positive' and 'negative')

child labour to an unfavourable effect. However, when analysing the potential transfer of impacts, the issue may become complex: eliminating child labour in a given position may lead children to go to school (favourable social consequence), but, in other cases, can force them to look for other work, potentially in worse conditions (unfavourable social consequence) (Macombe et al., 2013). If the assessment of final social impacts is one of the aims of the impact pathway approach, it is important to keep such nuances in mind for careful interpretations of the results.

In addition, the notion of "characterisation factor" should be mentioned. In S-LCA, they are mainly used to convert risk levels relative to impact subcategories (e.g., low, medium, high risks) into quantitative values. Considering, for example, the risk of forced labour in a country, the scale of risk is based on an equal distribution of values of the percentage of forced labour observed in the country. Then, a characterisation factor is assigned to each level of risk (Ciroth et al., 2015). PSILCA's characterisation factors are based on exponential relationships between impact factors ranging from 0.01 (very low risk) to 100 (very high risk). Obtaining quantitative results facilitates the comparison of social impacts between different alternatives, or between different life cycle stages. This approach will be presented in further detail in the section 2.1.4.3 related to the impact assessment phase.

- **Functional unit**

The functional unit is a *"quantified performance of a product system for use as a reference unit"* (ISO 14040, 2006). As stated by the UNEP guidelines published in 2020, the functional unit is "*particularly relevant in comparative studies, when two or more products are compared*", in a way that "*ensures that the product alternatives considered have been compared on an equivalent basis*", so as to guarantee a relevant and fair comparison (UNEP, 2020). The functional unit makes it possible to compare the impacts of different options in relation to the same unit of service (e.g., producing a MWh). The result of the assessment is generally expressed as a ratio: the numerator corresponds to the value of the impact, when it is quantifiable, and the denominator reflects the service provided, represented by the functional unit (Macombe et al., 2013).

In the case of S-LCA applied to energy systems in general, and to offshore wind power in particular, different functional units may be used. Two common functional units are the energy produced and supplied to the grid (MWh) and the installed capacity (MW). In general, the use of a functional unit involves the assumption of a linear relationship between the indicator and the parameter used to define the functional unit. For example, if a study identifies that an energy system generates 5 jobs/MW, it involves, by extension, that if the system has an installed capacity of 100 MW, it generates 500 jobs. However, some indicators may not be linearly dependent with respect to the functional unit. For

example, a study estimated the accidental risk[5] of offshore wind power projects with probabilities of $5.8 \cdot 10^{-4}$/year for a 350 MW farm project, $8.6 \cdot 10^{-3}$ for a 700 MW farm, and $1.4 \cdot 10^{-1}$/year for a 1400 MW farm (La compagnie du vent, 2010). In this example, the relationship between the farm installed capacity and the accident risk is not linear due to different parameters influencing these values non-linearly (e.g., proximity to shipping routes, density of maritime traffic, etc.) (La compagnie du vent, 2010; SSPA Sweden AB, 2008). Thus, there are scale effects that involve that above a certain OWF size, the risks increase significantly.

Another example of a non-linear scale effect is the spatial impact on the landscape. A study identified that an onshore wind power system can affect property values when the distance is very close, but fade sharply beyond a certain distance (Hoen et al., 2011). This example illustrates that it is not always possible to express the potential impacts of an energy system (e.g., price devaluation, accidental risk) in terms of a functional unit related to the service provided (e.g., MWh generation or MW of installed capacity), because, in some cases, there is no proportionality. A linear increase of the quantity of the service provided does not necessarily involve a simultaneous linear increase of the impact.

To conclude this section, this PhD thesis identifies the possibility of using indicators expressed in terms of a functional unit and indicators which can only be expressed at the level of the whole system or, eventually, the system at a particular phase of its life cycle (e.g., a commercial OWF during its operation phase). These elements lead to the need for a clarification of the notion of system boundaries.

- **System boundaries**

According to UNEP S-LCA framework, two perspectives for defining the system boundaries should be taken into account: the system boundaries based on technological processes and the system boundaries based on stakeholders involved in the life cycles (UNEP, 2020; Zanchi et al., 2018).

  - System boundaries based on processes or “physical perspective”

Defining system boundaries, or system limits, is fundamental to determine a space-time perimeter and levels of data collection regarding the subsequent S-LCA phases. To define the system to be assessed, it is necessary to identify the main process activities, that is, the industrial activities the system is composed of (Kolsch et al., 2008; UNEP/SETAC, 2009). Theoretically, in a holistic way, the system includes all the industrial processes that are carried out, from the extraction of raw materials, followed by the manufacturing, maintenance, and exploitation of the product, until the product decommissioning (Dreyer et al., 2006). Transport of materials between each stage of the life cycle may also be considered (Yu and Halog, 2015).

[5] As mentioned in 2.1.3.2 section, reference scale approach can address risks (or potential impacts)

An exhaustive S-LCA is limited from an operational point of view, as it would take an infinite amount of time (Grießhammer et al., 2006). Therefore, in a similar way as environmental LCA, applying a cut-off is necessary to weigh the elements of the system according to their relevance (Jørgensen et al., 2009). Some studies recommend considering the closest suppliers that the organisation can influence (Dreyer et al., 2006; Jørgensen et al., 2009). Following the same idea, other studies refer to organisations, and associated individuals, whose social behaviours are influenced by the organisation (Macombe et al., 2013).

As cut-off criteria, some approaches refer to the mass of the different components the assessed product is composed of. This means excluding the process activities which contribute to components that represent a relatively low mass compared to the total mass of the system. However, using mass cut-off criteria are not recommended: a component may have a low relative low mass compared to others (e.g., coltan in a mobile phone) and involve significant social impacts (Goedkoop et al., 2020). An alternative to mass cut-off criteria may be to consider the monetary cost of components. The costs may better reflect the intensity of the workers' presence in the different life cycle stages. The value added by an assessed process is also used (Benoît-Norris et al., 2012). In this case, the "added value" refers to the additional value given separately per activity that is considered: the activities generating the most added value are, thus, selected.

In relation to the system boundaries, the notion of "activity variable" is particularly useful to identify processes that are important. An activity variable is a measure of a process activity that can be related to the process output (UNEP, 2020). The activity variable "number of working hours", representing the working time of each of the process activities, is frequently used (Grießhammer et al., 2006; Jørgensen et al., 2009; UNEP/SETAC, 2009). Working time can be express with respect to a functional unit representing the service provided by the product (Dreyer et al., 2006) or to a monetary output (e.g., number of working hours for $1 of product output). On this basis, a cut-off threshold can be defined. For example, a 0.1% cut-off threshold applied to working time entails the exclusion of the upstream and downstream activities that contribute less than 0.1% to the total working time, assuming they do not contribute significantly to the social issues of the life cycle (Benoît-Norris et al., 2012). There is also a possibility to attribute gradual weighting of social issues according to different cut-off thresholds. For example, more weight can be allocated to processes that require more working hours (Benoît-Norris et al., 2012). Using working time as a cut-off criterion suggests that the process activities which require the highest number of working hours are also the ones that generate the highest potential impacts for value chain actors and workers. However, this assumption may be uncertain for other categories of stakeholders, such as local communities. Working time is a key concept, regularly used when conducting S-LCA with generic impact databases such as PSILCA.

It is important to note that defining the system boundaries, even if mandatory for feasibility reasons, entails a possibility of omitting certain stakeholders and certain social impacts. For these reasons, transparency on both the cut-off method and the part of the scope finally covered is crucial. Moreover, in practice, delimiting the system is a complex task. This may involve primarily defining which the main stakeholders and related social impacts to be considered are, or which the main stages of life cycle activities are, or both.

- System boundaries based on stakeholders' identification or "effect perspective"

Within a life cycle perspective, and similarly to environmental impacts, the social impacts shall be identified at a local and a global scale, while accounting for the diversity of involved stakeholders (Finkbeiner et al., 2010).

The selection of social impact subcategories (or "topics") is a key element of an S-LCA (WBCSD, 2016). The aim is to identify the relevant social impacts that ensure both the holistic nature and representativeness of the assessments, considering the stakeholders' perspectives, while maintaining a reasonable number of indicators to be evaluated (Yu and Halog, 2015). This task can be considered as resolving a trade-off between width of the scope (i.e., the number of impact subcategories considering their relevance) and depth of the assessment (i.e., the ability to identify, or create if needed, one or more robust indicators to assess the impact). To enhance representativeness of a social assessment, involving stakeholders through a participatory approach can be useful.

The relevance of stakeholders' roles in the frame of a social impact assessment has been emphasised since the first feedback from S-LCA studies (Benoît-Norris et al., 2011). For example, participatory approaches (e.g., "bottom-up" approaches) are relevant to prioritise (or hierarchise) the different impact categories or subcategories to be assessed in a study (Bouillass et al., 2021). It is also expected that stakeholders can provide local knowledge about the system. Therefore, including them in S-LCAs may allow the diversity of social representations of a given territory to be considered (Jouini et al., 2019). Moreover, involving stakeholders can help identify the indicators that make sense to measure the potential impacts they are affected by. Thus, involving stakeholders using participatory approaches is recognised as a method that enhances legitimacy of the selection of impact subcategories and indicators to be enhanced (Mathe, 2014).

It should be mentioned that participatory approaches involve challenges in terms of the time and resources consumed to put such strategies in place. Moreover, the quality of feedback from stakeholders and their representativeness is important the to ensure the credibility of the procedures and the quality of the results (Mathe, 2014). The chapter 3 of the thesis details the deployment of a participatory approach to hierarchise the social impact subcategories.

2.1.4.2. Phase 2: inventory analysis

The inventory analysis phase includes the collection of information required for the S-LCA. Some of this information is common to the application of environmental LCA (e.g., list of components and raw materials used by the system). However, other information must be collected, such as certain social data, in order to define relevant impact indicators to assess the identified and selected impact subcategories. Regarding this inventory analysis phase, it is important to explain the different types of data that can be used.

According to UNEP, 2020, three different levels of data can be distinguished :

- Company data is *"derived from a company but not allocated to a specific production site".*
- Site-specific data is *"collected for a specific production activity/ process, occurring in a specific organisation and facility, at a specific location".*
- Generic data is "*data that has not been collected for the specific process concerned*."

Whether it is a matter of confidentiality, or a matter of spatiotemporal access to site-specific data or to company data, some gaps in data are inevitable. Using generic databases is often necessary to complete specific analyses, although the use of such generic databases involves a loss in the specificity of the results of the assessed system (UNEP, 2020).

Data can also be classified according to whether the practitioner has collected it himself, or it has been collected by a third party:

- Primary data is *"data that has been directly collected by the practitioner through, for example, interview, survey, or participant observation".*
- Secondary data is *"data that has been initially collected and manipulated by another person/institution than the practitioner or collected for another purpose than the one being currently considered or, often a mix of the two".*

The method and application of the inventory analysis phase to the S-LCA of the OWF sector is presented in Chapter 4. This section presents some methodological aspects and the terminology for a better understanding of the next chapters.

- **Site-specific data**

Site-specific data are generally preferred to generic data, as they relate specifically to the system being assessed. There are several ways of collecting them, for example, by consulting information in the literature, or by directly consulting different related stakeholders (Macombe et al., 2013; UNEP, 2021). This includes external stakeholders, such as NGOs, but also internal stakeholders as workers' unions or

workers' representatives. Some frameworks are oriented to the consultation of the different departments of the organisation commissioning the S-LCA study (Harmens et al., 2022; WBCSD, 2016). Regarding the value chain stakeholder category, annual reports or audit report can be consulted (Goedkoop et al., 2020). Other frameworks favour external stakeholders' consultations (Bouillass, 2021; Mathe,2014). Among internal stakeholders, purchasers can provide information about upstream and downstream activities, project engineers can provide information about project characteristics, and human resources can provide information about employees (WBCSD, 2016). For this reason, at the beginning of data collection, involving several internal members of an organisation with different knowledge of the system may be relevant.

It should be mentioned that, depending on the geographical location of processes or the type of companies, site-specific data collection may be difficult or time-consuming. For example, this may be the case for small companies. In addition, the access to internal data seems to be partially conditioned by the role of the S-LCA practitioner with respect to the company. If the practitioner is external to the company commissioning the S-LCA study, the access to data can be restrictive. In addition to primary data that the practitioner can collect himself, the "grey literature" relative to the assessed system can be consulted to collect some secondary data. It should be noted that data can be both secondary and site-specific at the same time. For example, site-specific information on an existing OWF can be found in public reports, which constitute a secondary data source. Depending on the sector, the relevant literature available may be extensive.

- **Inputs for addressing social risks through databases**

Generic data does not strictly inform about the impacts that the system generates on stakeholders, but rather on the social context at the level of countries and sectors linked to the system. For example, these generic data can provide a level of risk associated with forced labour in steel manufacturing process in China, but not the impact of a specific facility in a specific place. Thus, the results based on such data sources may be useful to inform which process or processes are most likely to present social risks among involved sectors and countries within the life cycle of a product or service, but not to accurately evaluate the actual social impacts of each process.

The two most widely used generic databases in S-LCA are the Product Social Impact Life Cycle Assessment (PSILCA) database, developed by Ciroth et al. (2015) and the Social Hotspot Database (SHDB) (UNEP, 2020). Their principles are relatively similar and are presented in more detail in the section 2.1.4.3. Based on the activity variable principle, a S-LCA database allows input and output flows to be interlinked to reflect the relevance of each social impact subcategory related to the process output. Currently, the most common activity variable is the number of working hours per monetary unit

produced. The equations to calculate the value of this activity variable for a given activity are present below.

Worker hours are related to the process (or sector) output using monetary values and are calculated in PSILCA through the following equations (1) and (2) (Maister et al., 2020):

$$\text{Worker hours} = \frac{\text{Unit labour costs}}{\text{Mean hourly labour cost (per employee)}} \quad (1)$$

With:

$$\text{Unit labour costs} = \frac{\text{Compensation of employees (in USD per country-specific sector and year)}}{\text{Gross output (in USD per country-sector and year)}} \quad (2)$$

Finally, the working time for a given activity can be calculated using equation (3).

$$\text{Working time} = \text{worker hours per 1 USD product output} * \text{total price of the product} * \text{share of labour costs} \quad (3)$$

Using generic S-LCA databases requires a preliminary work that consists of collecting different inputs in relation to the system and, if needed, the formulation of assumptions to fill the data gaps. Firstly, for the system definition, the practitioner must define what industrial sectors and countries should be integrated in the study to model the different processes within the life cycle. Typically, life cycle inventories for environmental LCA are obtained by gathering data about the system's components and their associated raw materials. If they are available, these data can also be used in S-LCA. Once these elements have been defined, their corresponding generic process according to the database terminology must be identified and monetarily quantified.

A generic process corresponds to an activity of a particular economic sector associated to a particular country. Each component of the system can be linked to several processes. The tricky task consists of defining the respective shares of the different process activities for each component. The most common unit used for allocating these shares is the USD. Thus, the practitioner must identify the different sectors and countries related to each sub-system and assign a monetary cost in USD. After assigning the monetary costs to the different components, the share of the corresponding labour cost needs to be estimated. In the absence of an inventory providing exact costs, including the labour costs, monetary cost of components, or their associated raw materials, can be estimated by using reference prices communicated on wholesale websites for similar components or raw materials (GreenDelta, 2016). By identifying the cost of components, then the share of labour cost corresponding to each component with respect to the total labour, it is possible to estimate the unit labour cost. The total labour cost allows the worker hours to be estimated according to the equation (1). The percentage of labour cost must be defined. Depending on the system, labour costs can be sensitive information (Bouillass et al., 2021). In the absence of specific data of labour costs relative to the assessed system, the use of assumptions or a sector-wide baseline value may be necessary.

Despite their usefulness, it should be noted that databases are subject to uncertainties that may considerably affect the accuracy of the values of the indicators due to lack of transparency and up-to-date data (Bouillass et al., 2021). According to (UNEP 2020), PSILCA database still provides more information on data quality than SHDB. Moreover, PSILCA has been used in previous studies on the sustainability of OWF (Buchmayr et al., 2022). Results from previous work using the same tool can act as data sources for the definition of PRPs. For these reasons, PSILCA is preferred rather than SHDB in this thesis. Additional uncertainties may also come from the level of aggregation of sectors. For example, when aiming to model "cast iron" or "low-alloyed steel" production processes using social LCA databases such as PSILCA, the database can only propose a generic process activity "Manufacture of basic metal", which is supposed to be representative of the whole sector. To avoid this oversimplification, some studies propose to generate new process activities by defining more precisely all their raw materials inputs.

2.1.4.3. Phase 3: impact assessment

The application of the impact assessment phase to the S-LCA of the OWF sector is presented in detail in Chapter 4. This section introduces some methodological aspects and the general terminology. Based on experience from previous S-LCA studies, this PhD thesis considers two main ways of assessing impacts depending on the evaluated scope: i) using sectoral and geographical social risk databases and ii) using the performance reference point approach.

- **Social risk assessment using generic S-LCA databases**

For assessing social impacts among upstream and downstream processes, the PSIA Handbook suggests looking at: i) risks on human rights in the country where process activities take place, ii) social risks related to the sector (e.g., hazardous waste treatment), or iii) social risks related to one of the organisations in the value chain (e.g., small subcontractors) (Goedkoop et al., 2020).

This work can be conducted by using a generic S-LCA database, as already mentioned. Using a generic database, such as PSILCA, generally requires identifying the geographical areas where the life cycle stages, and their associated industrial processes, take place. As mentioned in the inventory analysis section, geographical and sectoral information are, thus, used as inputs to define process activities the subsequent social impact assessment should focus on. Indeed, the country-sector assumption of upstream processes is based on inputs included in PSILCA database, based on the economic trade flows provided by the Eora[6] database. A fictive example of Eora database gathering commercial flows between

[6] multi-region input-output table (MRIO) model that provides a time series tables for 190 countries (worldmrio.com)

sectors is presented in Figure 2.2. The table presents the amount of USD for domestic transactions, imports and exports, for a given country. Thus, for example, the generic process "Manufacture of basic metals" in France involves not only domestic transactions but also upstream supplier countries such as Belgium, Italy, Germany, Spain, and the Netherlands to fulfil the final domestic demand.

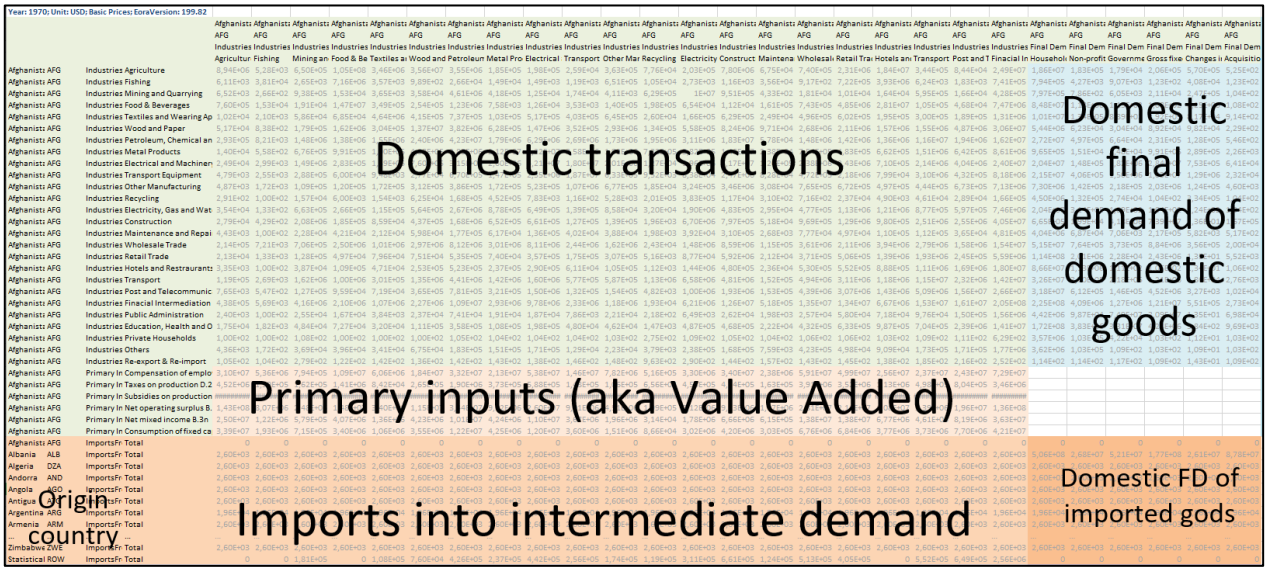


Figure 2.2. Example of individual country table layout from Eora database (https://worldmrio.com/).

PSILCA uses this input-output database (i.e. Eora database) as a source of data for global supply chains, then adds levels of average social risk based on various international sources (e.g, World Bank), and cross-references this generic information with the technical-economic characteristics of the system defined by the practitioner.

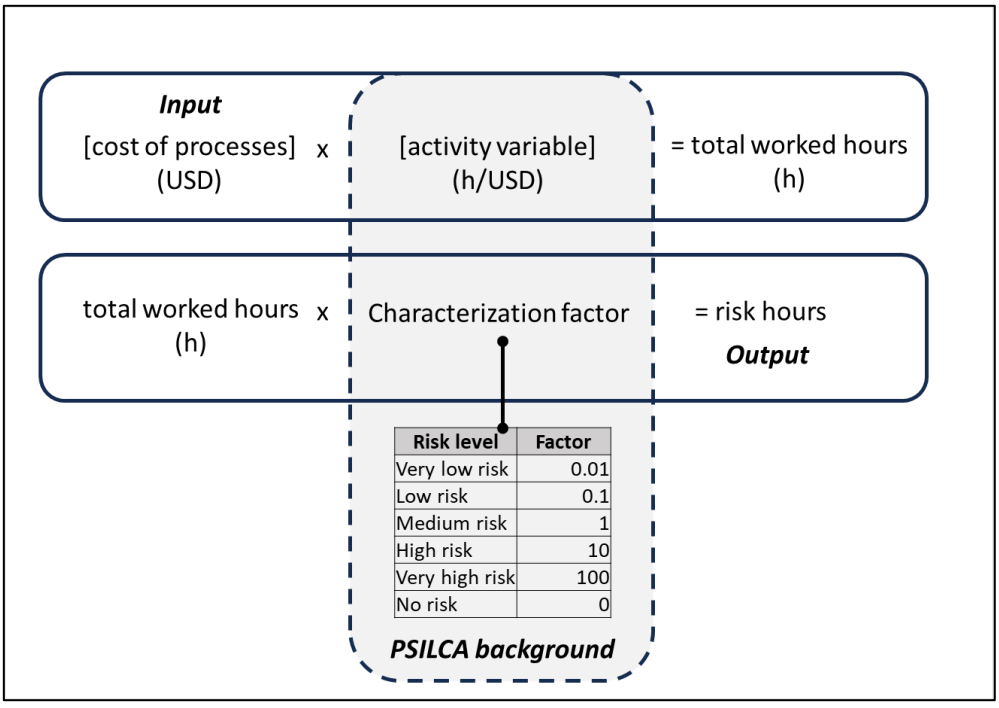


Figure 2.3. Summary of PSILCA operating principles. Characterisation factors are filled into PSILCA for the different impact subcategories of each country-sector combination. (adapted from Maister et al., 2020).

The calculation model involved when using databases such as PSILCA is briefly explained in Figure 2.3. Total worked hours are estimated by multiplying the costs of processes by the activity variable. Then, this amount of worked hours is multiplied by the corresponding characterisation factor for each indicator. Indicators are expressed as “medium risk hours” for the impact assessment phase. The role of the characterisation factors is therefore to weigh the number of working hours according to the level of risk assigned to each of the impact subcategories considered. As previously mentioned, PSILCA characterisation factors are based on exponential distributions of values where 0.01 factor corresponds to a very low risk and 100 factor corresponds to a very high risk.

Based on these principles, the generic assessment presents a limitation that should be noted. In particular, given the fact that activities from the database are modelled based on country-level sectoral data, generic databases do not allow different management practices for companies working in the same country and sector to be accurately evaluated. Thus, two different companies can operate in the same country, in the same sector and have very different management practices, and therefore different social performances, but an S-LCA only considering a generic approach will not be able to characterise these differences.

- **Social performance assessment using reference scales and performance reference points**

While the general definition of “performance” originally refers to the achievement of a target that an organisation aims to reach, its use in S-LCA has been extended to a more global and not strictly organisation-centred purpose (Russo Garrido et al., 2018).

Regarding the reference scale approach presented in the frameworks provided by the *“Handbook for product social impact assessment”* and the Guidelines UNEP, the application involves assigning a score between a minimum and a maximum level (e.g., between -2 and +2). As a reminder, this assignment is made with respect to a set of reference values called Performance Reference Points (PRP). This assignment is made to each social indicator for each assessed scenario. S-LCA studies may adopt scales of different widths. Thus, scales between -2 and +2 are probably the most common ones, but other scales exist, including scales between -4 and +4, or scales between -1 and +1 (Yu and Halog, 2015; UNEP, 2020). In general, a positive score suggests that the social performance in terms of the evaluated indicator is favourable with respect to the social objective, whereas a negative one usually indicates an unfavourable or insufficient performance. Some frameworks, such as the one provided by the "*Social topics for product social impact assessment*", propose reference scales for several indicators (e.g., forced labour, discrimination). However, depending on the sectoral context and the objective of the study, the practitioner may need to define new performance indicators, and therefore new reference scales. In this case, a good practice, which is, however, absent in some studies, is to be transparent about the thresholds assigned to the different reference scales. (Bouillass, 2021; Gompf et al., 2020).

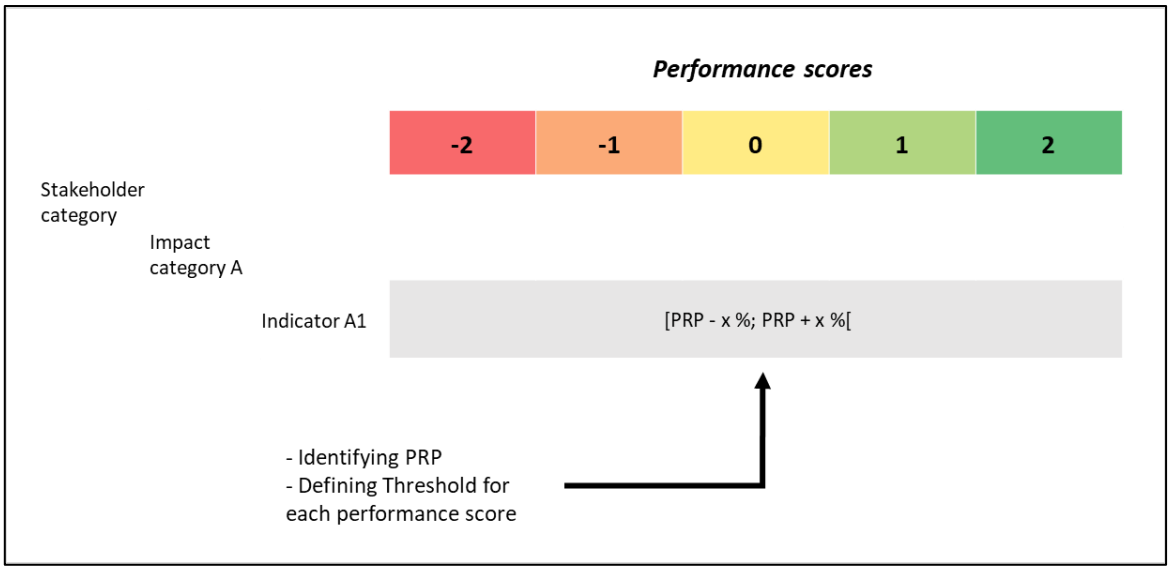


Figure 2.4. Summary of the performance reference point (PRP) framework adapted from Guidelines with definition of thresholds.

Assigning scores to indicators makes it possible to evaluate each indicator individually, but also to aggregate all the scores obtained for the different indicators. This can be done to obtain a single social performance score for a given stakeholder category, for a given impact subcategory, or for the whole set of stakeholder categories and impact subcategories. However, it is essential to point out that aggregating the performance scores attributed to the indicators can lead to hiding social information and losing accuracy. To overcome these issues, some studies recommend presenting results both disaggregated and aggregated (WBCSD, 2016). An example of defining a quantitative threshold for performance scores based on a reference value is illustrated in Figure 2.4.

Reference points were originally designed to allow the comparison of S-LCA indicators with respect to international norms or laws. In practice, the S-LCA studies have revealed some flexibility in the definition of PRPs. Based on a literature review, Russo Garrido et al. (2018) identified 6 different types of sources to identify PRPs: (1) norms and best practice, (2) socio-economic context, (3) internal expert's judgment of companies', (4) external expert's judgment (e.g., by researchers), (5) average sector, country, or worldwide performance, and (6) comparison between alternatives.

It seems that the choice of the PRP depends on the nature of the different indicators and data collected in the inventory analysis phase. Some of the social impacts identified may be externalities that the standards or norms do not yet cover. In the case of a PRP equivalent to a value identified in an international norm or standard, it is quite intuitive to assign it a score of 0, meaning a neutral performance to indicate compliance with the norm. In this case, a negative score means that the indicator measured reveals non-compliance, whereas a positive score means that the indicator measured represents a level above compliance (e.g., companies that promote good practices within the value chain) (Russo Garrido et al., 2018). However, in case of the absence of a norm or standard value regarding the

assessed impact subcategory, the choice of the PRP can involve a certain level of subjectivity. Moreover, in this case, it can be difficult to justify systematically what level of performance can an identified PRP match to. For example, some organisations as "sectoral observatories" offer grey literature describing one or more sectors on different topics. Consulting this grey literature can help identify a PRP for a social impact subcategory at the sector level. Thus, this PRP's sectoral value can be used to establish the performance score 0. However, it is possible that the PRP value reflects a lower performance than other sectors (e.g., a high accident rate compared to other sectors). The choice of the type of reference value can therefore influence performance results and their comparability.

There is an inherent limit to the definition of thresholds for each score. The allocation of scores depends on the definition of thresholds. In case of quantitative thresholds, allocating a difference of 10%, 50% or 100% around the PRP to define the thresholds of each score may considerably change the result of the performance assessment. To the present knowledge, there are no detailed rules on the definition of the thresholds to be used. Therefore, enhancing transparency on the definition of thresholds is an essential need to improve the usefulness and reliability of the further interpretation of the results.

2.1.4.4. Phase 4: interpretation

Any S-LCA result requires interpretation. Interpretation involves making sense of the impact assessment results to provide useful conclusions for decision-making and awareness raising.

Among others, the interpretation phase of an S-LCA aims to identify, among the assessed indicators, which ones play a major role in the potential social impacts of the evaluated system and thus, constitute the main hotspots. Interpretation can be applied to the comparison of results. This comparison may be conducted using the PRP approach. In this case, the aim may be to provide recommendations on how to improve the social performance of the different assessed impact subcategories. Comparisons may also be made for different alternative systems. In this case, for example, the aim may be to identify which components or materials are most closely linked to sectoral and geographical social risks.

In general, the same as all the LCA phases, the interpretation is an iterative phase. It involves regularly questioning the intermediary results obtained when applying the S-LCA phases. This may involve refining the assumptions used, for example, regarding the data quality and uncertainty involved in the inventory analysis phase, depending on the type of source used. As mentioned in UNEP Guidelines (2020), some studies provide complementary information together with the score between -2 and +2. These studies may include a quality score that can range, for example, between 1 and 5 (WBCSD, 2016). Information on data quality can be useful to identify the level of reliability of the results and the potential needs of further development and/or readjustment of the reference scales as more accurate data become available.

The aim of this section has been to present the main S-LCA concepts reused in this thesis to conduct S-LCA on OWFs. Despite providing key aspects of S-LCA, the above-mentioned S-LCA frameworks remain general and do not allow for a direct practical application to a given context or sector. For sectoral applications, and especially OWF energy systems in our case, a suitable specific framework needs to be built. Indeed, it is now essential to examine the social issues potentially generated by the system to be assessed. For this purpose, the next section aims to present a review of social issues at the level of the energy sector that have been dealt with in previous work.

2.2. Review on sectoral social issues related to energy systems

This section presents a literature review of the sectoral social impacts related to the assessed system, that is, offshore wind farms. Because there are few S-LCA studies exclusively related to the offshore wind power sector, this sectoral social impact review is extended in two directions: on the one hand, to include studies related to the energy sector in general and, on the other hand, to include sustainability assessments in addition to purely S-LCA studies.

Firstly, it should be noted that the overview of sustainability studies applied to energy systems reveals a lack of harmony regarding the terms used to describe the covered dimensions (excluding the environmental one). Indeed, some studies distinguish the economic dimension from the social dimension, while others consider combined "socio-economic" aspects, and, in some cases, "political", "socio-political", and "technological" ones. According to recent discussions on sustainability frameworks, "environmental life cycle costing" and "social life cycle costing" may be preferred as specific approaches for the assessment of externalities in monetarised units (*ORIENTING LCSA methodology stakeholders' workshop*, 2022).

Local externalities are often not considered, mainly due to the difficulty to quantify these aspects (Masanet et al., 2013). However, in the context of energy planning and project siting, potential favourable and unfavourable social impacts are numerous, including tourism, culture, local industrial context and labour market, among others (Terrados et al., 2007). The "Not in my back yard" syndrome (NIMBY) is widespread among energy projects' implantation, especially in the wind power context. NIMBY can be described as *"an oppositional attitude from local residents against some risk generating facility that they have been chosen to host either by government or industry"* (Hermansson, 2007).

Therefore, at a local level, social concerns arise, inherent to local externalities linked to an industrial project (e.g., impacts on the landscape), which can affect, for example, acceptability. To overcome such concerns, additional indicators may be needed.

2.2.1. Social impacts addressed in energy sustainability studies

As already mentioned, any S-LCA framework may need to be adapted to the context of the assessed system. To do so, in the case of OWF systems, there is a need for a comprehensive view of the state of the art on social impacts assessment focusing on the energy sector.

Sustainability studies differ from S-LCA type I approach mainly in the sense that there is not always a formal association made to stakeholder categories, or a measurement of the indicators on a performance scale. However, the conducted literature review has allowed information on different social impacts to be gathered. These social impacts can be linked to different subcategories and associated impact indicators. The main social impact subcategories and indicators identified in this literature review and their associated sources are presented in Table 2.1. Literature review on social impacts indicators applied on energy systems. The subsections below present these subcategories in more detail.

Table 2.1. Literature review on social impacts indicators applied on energy systems.

"Social impact subcategories"	Indicators	Unit	Ref.
Acceptability / Amenities	Surface area	km²/TWh	(Evans et al., 2009; Santoyo-Castelazo and Azapagic, 2014)
	Visual and noise impacts		(Santoyo-Castelazo and Azapagic, 2014)
			(Hirschberg et al., 2004)
		Score 1-5	(Troldborg et al., 2014)
	Acceptability / Public preference for a technology		(Maxim, 2014)
		Score 1-5	(Troldborg et al., 2014)
	Territories (areas) with local benefits for residents	m²/MW	(Liu, 2014)
Employment	Social and economic impacts (jobs, purchases, etc.)	Score 1 - 5	(Troldborg et al., 2014)
	Direct employment (by life cycle stage)	Person-year/TWh	(Roinioti and Koroneos, 2019)
			(Maxim, 2014)
			(Atilgan and Azapagic, 2016)
			(Hirschberg et al., 2004)
			(Azapagic et al., 2016)
	Indirect employment (by life cycle stage)		(Atilgan and Azapagic, 2016)
	Total employment (direct and indirect)		(Roinioti and Koroneos, 2019)
			(Azapagic et al., 2016)
	Hours number of new employments over 10 years	Number	(Liu, 2014)
Equity/Intergenerational issues	Depletion of fossil resource reserves		(Santoyo-Castelazo and Azapagic, 2014)
			(Hirschberg et al., 2004)
	Hazardous waste production		(Santoyo-Castelazo and Azapagic, 2014)
	Use of abiotic resources	kg Sb eq./kWh	(Azapagic et al., 2016)
	Use of abiotic resources - fossil fuels	MJ/KWh	(Azapagic et al., 2016)
	Volume of radioactive waste	m^3/TWh	(Azapagic et al., 2016)
	Waste containment time	Thousands years	(Hirschberg et al., 2004)
	Volume of liquid CO2 to be stored	m^3 / TWh	(Azapagic et al., 2016)
Proliferation (nuclear)	Nuclear proliferation potential	Relative scale	(Hirschberg et al., 2004)
	Use of unenriched, enriched uranium, reprocessing	Score 0-3	(Azapagic et al., 2016)
Health and safety	Injuries	Number/TWh	(Azapagic et al., 2016)
			(Roinioti and Koroneos, 2019)
			(Santoyo-Castelazo and Azapagic, 2014)
			(Atilgan and Azapagic, 2016)
	Major accidents		(Roinioti and Koroneos, 2019)
	Fatalities due to serious accidents		(Azapagic et al., 2016)
	Maximum fatalities per accident ("risk aversion")	Number/accident	(Hirschberg et al., 2004)
	Loss of productivity		(Maxim, 2014)
	Potential for non-radiation human toxicity		(Azapagic et al., 2016)
	Impacts of radiation on health (workers, population)	DALY/kWh	(Azapagic et al., 2016)
	Mortality - reduced life expectancy	YOLL/GWh	(Hirschberg et al., 2004)
	Human health costs (hospitalization and medication)	€/kWh	(Maxim, 2014)
	Emissions of SO2, NOx, fine particles, heavy metals	Human toxicity potential	(Santoyo-Castelazo and Azapagic, 2014)
Energy and supply security Energy and supply security	Input supply risks (fuels, uranium, gas, etc.)		(Maxim, 2014)
			(Santoyo-Castelazo and Azapagic, 2014)
	Import of fossil fuels potentially avoided	Toe/kWh	(Atilgan and Azapagic, 2016)
			(Azapagic et al., 2016)
			(Hirschberg et al., 2004)
			(Roinioti and Koroneos, 2019)
	Supply diversity (fuels)	Score 0-1	(Azapagic et al., 2016)
	"Fuel" storage capacity - energy density	GJ/ m^3	(Azapagic et al., 2016)

- **Energy security and diversity of supply**

To address this impact subcategory, indicators can include the share of low-carbon energy, depletion of fossil resource reserves, import dependence, availability of renewable energy or reliability of supply, among others (Santoyo-Castelazo and Azapagic, 2014). Energy security has been measured through a ratio between the share of the domestic energy production and the imported one (Atilgan and Azapagic, 2016). Supply risk is covered in several sustainability studies (Atilgan and Azapagic, 2016; Azapagic et al., 2016; Maxim, 2014; Santoyo-Castelazo and Azapagic, 2014). Supply risk has been mainly assessed in a comparative way. Thus, values are high for natural gas technologies, medium for nuclear or coal, and null for renewable energies including hydro, wind, and photovoltaics (Maxim, 2014).

- **Public acceptability**

It should be noted that acceptability is a complex issue to be addressed. Overall, two ways of addressing this question are identified: by using objective metrics[7] (i.e., physically measurable units), or subjective ones (e.g., perception, preference score based on surveys). Some sustainability studies aim anyway to measure acceptability through different indicators.

- Subjective metrics

Subjective analysis involves taking stakeholders' perceptions into account. It should be noted that perceptions are subjective and may be not always aligned with the degree of impact and depend on the context and the stakeholders considered in the study (Iofrida et al., 2018). For example, some technologies can be perceived by non-informed actors of the society as having a high risk even though no objective indicator demonstrates this risk, while the opposite can also be observed.

Maxim (2014) considered the acceptability of the fuel used rather than the technology itself through previously conducted surveys. On this base, acceptability was evaluated as high for renewable energies, including offshore wind, and low for technologies such as nuclear or coal. However, such a protocol has some limits and aggregated results can erase polarities of opinion between stakeholder profiles. For example, national opinion cannot fully account for or reveal local perspectives. Another aspect that has been observed is that financial participation from local communities in wind farm local projects can influence the level of acceptance. It would be the case, for example, in Denmark or Germany (Moss et al., 2014).

[7] In the sense of "type of impact or performance measure"

- Objective metrics

Some studies recommend addressing acceptability by physical metrics through noise, visual and odour impacts (Moss et al., 2014; Troldborg et al., 2014). Based on these considerations, offshore wind power was ranked 5th out of 11 assessed systems in one study (Troldborg et al., 2014). To address acceptability of wind power systems, Moss et al. (2014) considered in addition electromagnetic fields and even potential biodiversity issues.

Among physics metrics, surface is frequently considered. A sustainability study applied to biomass energy mentions the use of a land-use indicator and the potential competition with other activities (Evans et al., 2010). Also related to the renewable energy sector including wind energy systems, the land-use efficiency (i.e., the square metre) has been assessed with respect to a functional unit (i.e., the TWh) (Evans et al., 2009). Other studies have looked at the land use with respect to the installed capacity (W/m^2), noting, for example, that wind farms, with about 2 W/m^2 could be less efficient than large solar power plants, with about 5-20 W/m^2), under the considered conditions (Moss et al., 2014). Santoyo-Castelazo and Azapagic (2014) also accounted for surface requirements to address amenities[8] for the implementation of energy technologies. Liu (2014) also estimated positive externalities based on surface consideration. In this case, the area of land that includes "local benefits" to residents, in m^2/MW, was considered.

Physical measures are intended to be more objective. However, considering acceptability by this means alone can be seen as limited. Measuring acceptability of a project would need to combine different parameters such as socio-demographic characteristics, the degree of public participation and trust in decision-making processes, and more generally the cultural elements of the territory or place-related identity (Ladenburg et al., 2013). Rather than using only objective or subjective metrics, it seems that both are complementary, and their use depends on the different categories of impacts to be addressed.

- **Health and safety**

Health can be assessed through the human toxicity potential based on emissions from industrial activities (e.g, SO_x, NO_x, fine particles and heavy metals) (Santoyo-Castelazo and Azapagic, 2014). Health issues may also be expressed in DALYs[9] (disability-adjusted life years). These assessments use impact pathway approaches and do not distinguish between stakeholder categories. Maxim (2015) addressed a "socio-political" dimension by including indicators related to human health treatment costs, and induced productivity loss, resulting from externalities on human health such as NO_x and SO_x emissions. Other

[8] Including all the attractive or useful features of a place.
[9] There is no consensus on the use of DALYs for both relevance aspects and the inherent negative interpretation (Dreyer et al., 2010a).

health issues may be considered and related to local communities' stakeholders. For example, specifically related to the onshore wind power sector, sleep disturbance is mentioned due to shadow and stroboscopic effect (Moss et al., 2014). Health impacts can also be translated into monetary costs. For example, a cost of 0.034€ per kWh was estimated by Maxim (Maxim, 2014) for a case study of offshore wind power in Romania.

Safety issues are, in sustainability studies, generally not explicitly related to stakeholder categories. Depending on the scope, the assessment of such issues may consist of addressing only workers' safety, or also including local communities around the plant site, or the sites related to other life cycle stages. The most common indicators are the number of injuries and serious accidents (Roinioti and Koroneos, 2019; Santoyo-Castelazo and Azapagic, 2014). Explosions or oil spills risks are also considered when aiming to address accident risks (Santoyo-Castelazo and Azapagic, 2014). In this sense, a study proposed a risk aversion indicator that measured the maximum number of deaths due to an accident at a site (Hirschberg et al., 2004). In this study, nuclear technology had the highest estimated value (50,000 max fatalities/accident), while wind power had the lowest one (5 max fatalities/accident) (Hirschberg et al., 2004).

- **Employment and job creation**

Job creation is among the most frequent impact subcategories assessed. Atilgan and Azapagic, (2016), estimated the generation of direct and indirect employment for different renewable and non-renewable energy generation technologies during all the life cycle stages (i.e., construction and installation, component manufacturing, operation and maintenance, fuel extraction and processing, and dismantling). This estimation was carried out by using an employment factor (or coefficient). The factor was calculated by considering the ratio between the number of jobs for each life cycle stage and the country's gross domestic product. This full life-cycle assessment required several modelling assumptions. In particular, for the dismantling phase, the authors assumed a value of 20% with respect to the jobs needed for the construction phase. Among the results, hydropower was estimated as the most job-creating technology, with 459 person-years/TWh, followed by onshore wind with 256 person-years/TWh (Atilgan and Azapagic, 2016). While the employment indicator remains one of the most valued, and maybe one of the most communicated ones, few studies explore the quality of the jobs generated. Integrating this parameter can bring nuance to the results.

- **Intergenerational issues**

These issues are related to long-term potential impacts. They are mainly addressed by considering categories such as global warming potential and depletion of fossil resources, already mentioned for the

security and diversity of supply issues. In addition, the notion of hazardous waste is considered in relation to radioactive waste and CO_2 capture technologies (Santoyo-Castelazo and Azapagic, 2014). Defined in this way, the assessment of intergenerational issues is strongly linked to environmental LCA. If S-LCA is conducted in parallel with an environmental LCA, attention should be paid to avoid double counting of impacts. In this case, it may be appropriate to exclude global warming and resource depletion impact categories from the S-LCA if they are already included in the environmental LCA.

2.2.2. S-LCA methodological review and gaps applied to the energy sector

To the current knowledge, few S-LCAs using reference-scale approaches have been applied to energy systems. Yu and Halog (2015) conducted an S-LCA on photovoltaic systems in Australia. This study illustrates a case of UNEP/SETAC (2009) Guidelines adaptation to energy systems. Based on a review, the stakeholder categories considered in the analysis were the core-company, an R&D centre, the state government, the electricity distribution network, and the customers (Yu and Halog, 2015). In the study, the value chain stakeholder category was divided into several sub-groups. Most of the impact subcategories considered were similar to the UNEP/SETAC (2009) proposed subcategories. A limitation of the study was that the impact assessment phase was conducted using a qualitative approach. No explicit description of the criteria to define the reference scales or threshold values were specified for the attribution of scores to the different impact subcategories. This may limit the potential for understanding and interpreting the results.

Some social concerns refer to a particular industrial component or process. The question of "rare earths" is a recurring one in debates on renewable energies. For example, it has been raised during public debates on floating wind turbines project in southern Brittany, in France. In response to this kind of issue, some S-LCAs focus on assessing the social impacts associated with specific industrial processes. Schlör et al., (2017), looked at S-LCA applied to permanent magnet production based on rare earth elements. In this study, the social impact of the process was measured by considering the Human Development Index of the country involved, which involves the notion of marginal social footprint.

Specifically related to the offshore wind sector, the Vattenfall[10] company conducted an S-LCA study on offshore wind farm systems in Sweden. The methodology included both internal and external interviews, surveys with direct suppliers (i.e., rank 1) and generic data for suppliers further among the upstream (i.e., rank 2 and more). The study mainly focused on the workers and value chain stakeholder categories, although some indicators were related to the stakeholder categories of local communities and the society. Following S-LCA principles about addressing potential impacts on a global scale, the study used generic data. For this purpose, some assumptions about countries-sectors implications were mentioned: for

[10] Electricity generation and distribution company owned by the Swedish state (https://group.vattenfall.com)

example, plastics were assumed to be produced in Europe, copper in Chile and steel in China (Vattenfall AB, 2016). Based on specific information and assumptions, countries-sectors contextual risks were, thus, assessed. This step was conducted by using Verisk Maplecroft, a data risk "asset-oriented" mapping tool (Vattenfall AB, 2016; Verisk Maplecroft, 2020).

The main conclusions of this study highlighted the low level of impacts on workers' labour and human rights in the countries where the wind farms were located, mainly Sweden and Denmark, thanks to the good implementation of the International Labour Organisation (ILO) conventions in these countries. The results were similar for value chain workers in other European countries, with less favourable conditions in Eastern Europe. Higher risks were identified for value chain workers in the mining sector, related to indicators such as freedom of association and collective bargaining, breach of women's rights, child labour, forced labour and working hours, among others. Risks on health and safety related to mine processing were also highlighted for both workers and local communities living near the mines (Vattenfall AB, 2016). Based on this work, different types of limitations and perspectives can be noted.

Firstly, there are limits formulated by the company itself. Indeed, the study highlighted the difficulties to obtain quantitative data for some of the indicators related to activities within the supply chain outside the boundaries of the company's own operations (Vattenfall AB, 2016). Besides, one of the main perspectives to be addressed was the need for a methodology that would better describe local stakeholder categories, and the assessment of impact subcategories related to access to material and immaterial resources (Vattenfall AB, 2016).

Secondly, an appendix mentions the critical viewpoint of the S-LCA expert. One key aspect is that, even if Verisk Maplecroft is among the proposed generic databases in UNEP (2020) Guidelines, it may be too "business-risks" oriented and not sufficient for the assessment of well-being aspects. Therefore, SHDB or PSILCA databases would be preferred to conduct the impact assessment phase (Ekener, 2016). Further discussion and justification on "favourable" and "unfavourable"[11] definition of social impacts subcategories considered would have been appreciated, as well as the indicators' identification (Ekener, 2016). Another key perspective mentioned is the use of relevant external stakeholders consultation for the selection of impact subcategories (Ekener, 2016).

Thirdly, some complementary limits can be mentioned. Concerning the scope definition phase, some stakeholders related to upstream activities were excluded, such as companies responsible for consulting, environmental studies, vessel operations, upstream processes as oil and fuel's production for maintenance. This was also the case for other stakeholders related to downstream activities, such as electricity consumers and partially the workers involved in waste treatment. Concerning the impact assessment phase, unfavourable impacts on the local community were only assessed throughout visual,

[11] Original terms are "positive" and "negative"

noise and shadowing impact (i.e., stroboscopic effect). However, as already mentioned, territories may reveal broader concerns and can be more complex to address. Job creation was only considered as a favourable impact without questioning the quality of jobs concerned (e.g., types of contracts or well-being). This point is discussed in a sustainability study applied to offshore wind power sector. The study proposes to consider not only the number of jobs created, but also the rate of temporary and stable employment (Buchmayr et al., 2022).

Another study developed an aggregated index of social sustainability for OWF in Taiwan based on 14 indicators (Shiau and Chuen-Yu, 2016). These indicators were gathered into 3 "subcategories", namely internal human resources, external population mainly around the sitting area, and macro social performance corresponding to the national scale. Fishery issues were highly regarded (i.e., more than 60 occurrences of "fish" word). The indicators were measured using the literature. Metrics mixed subjective indicators (e.g., percentage of support, percentage of acceptance) with objective ones (e.g., number of jobs, number of working hours). Each indicator was then assigned an "utility" and a "weight score" by experts allowing a social impact index to be calculated for each one, by a simple additive weighting method. Then a single value aggregating all the social impact indices was obtained. The "(unfavourable) fishery impact" was among the lowest social impact indices, while "(favourable) job creation" was the first one. According to the results, the social impact index represented a favourable overall social effect, although opposition from fishermen remained (Shiau and Chuen-Yu, 2016). The expert panel included two wind industry members, nine government members, five academia members, and three members representing the fishing industry and the public (Shiau and Chuen-Yu, 2016). A more detailed explanation of the choice of this distribution would have helped justify it. Besides, the scope definition and selection of indicators remain a lack of transparency. Generic impacts related to technological choices were considered. No impact assessment was, therefore, included for the upstream stages of the life cycle at the global level of the other countries and sectors involved. Since the study was not a formal S-LCA application, a reference-scale approach was not used.

A different study addressing social impacts related to OWF systems, also in Taiwan, using S-LCA was published by Tseng et al. (2017). This study also highlighted fishery issues (i.e., more than 40 occurrences of "fish" word). The scope included manufacturing, construction, maintenance and operation and dismantling stages, but not the raw materials' extraction. The S-LCA approach did neither fully correspond to a type I nor to a type II approach. No generic database or quantitative indicator was used. The results were mainly qualitative transcriptions of the different impact subcategories addressed, and suggested action plans for improvement. The main conclusions were that the integrated assessment could decrease the development time of the offshore wind sector, mainly by making investors more confident about the risk management and potential impacts (Tseng et al., 2017).

The study by Buchmayr et al (2022) integrated both global and local social impacts for Danish wind technologies. One offshore and two onshore wind power systems were considered. To articulate the different geographical scales to be assessed, the different frameworks used included i) a type II S-LCA to address human health through DALY, ii) a type I S-LCA to address human rights and working conditions at global scale through generic PSILCA database, iii) a job quality assessment and iv) impact perception surveys to address more specifical local scale aspects. Regarding the generic assessment, high level of detail and transparency were provided for the inventory and assumptions used. Results were not presented based on a PRP approach but according to a relative scale between 0 and 100% allowing for comparisons between scenarios. Among the results, offshore wind system were found to have higher impacts due to the important amount of material required for foundations and other infrastructure (e.g., the high amount of steel). In comparison, the use of permanent magnets (sometimes decried by public opinion) did not generate a particularly high social risk, given their lower mass compared to other components.

The method presented by Buchmayr et al. (2022) illustrates the relevance of articulating different S-LCA frameworks depending on whether the assessment is oriented to global or local impacts. In the case of energy systems, one specific issue to be addressed at the local scale is acceptability. In this work, the local scale is addressed through the "local quality of life and landscape quality" subcategories, by subjective surveys' scores. It would have been interesting to confront the subjective score addressed through surveys with other objective metrics. Despite the interest of this study for the multi-scale multi-framework aspects, it is not fully adapted to be directly transposed to the French offshore wind power context. Indeed, addressing this context requires an in-depth consideration of the question of conciliation between an OWF and existing socio-economic activities.

Considering this literature review, focused on S-LCA frameworks and energy applications, some key points have been identified, which the S-LCA methodology proposed in this PhD thesis should consider to be adapted to the French offshore wind sector.

As mentioned, offshore wind energy applications in S-LCA are scarce. Therefore, to identify the sectoral impacts of offshore wind power in France, other disciplines should be considered. The grey literature on current OWF projects in France is very extensive. Therefore, it is widely used in this thesis as part of a secondary data collection exercise. Figure 2.5 presents an overview of the various sources of information used in this PhD thesis. Most of the sources used relate to literature reviews on social LCA methods, focusing on energy system applications as close as possible to the system under study, namely OWFs.

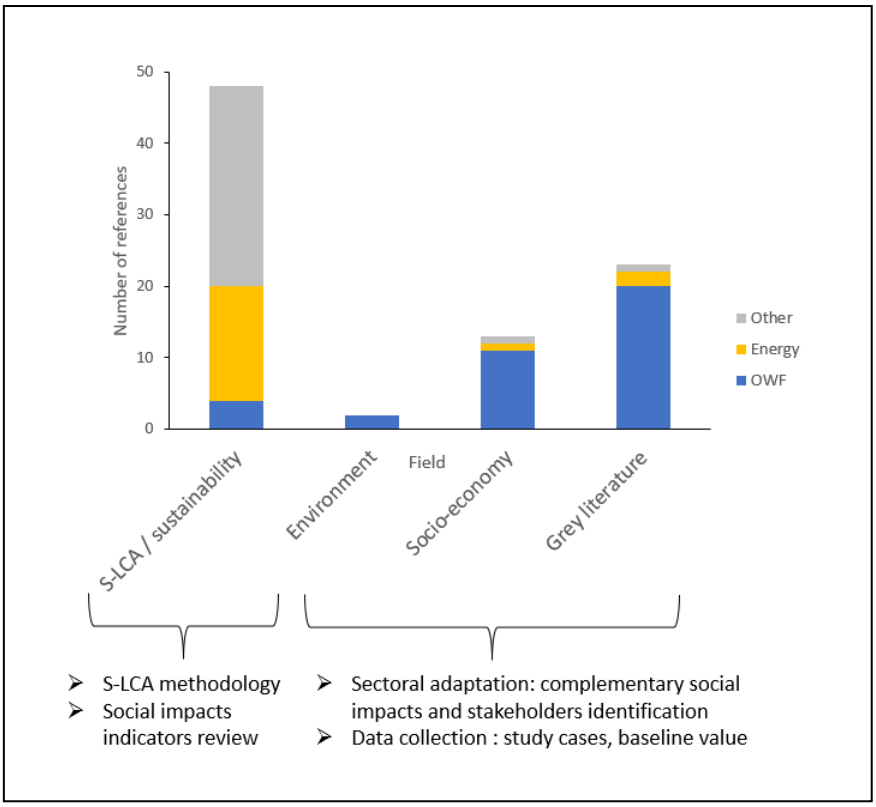


Figure 2.5. Summary of sources used by discipline.

As previously mentioned, given the limited level of development of type II approach, a type I approach was preferred to conduct the phases of the S-LCA application to OWF sector in this PhD thesis. This application included the typical four phases of ISO 14040 and 14044 (2006), also established in the UNEP guidelines for S-LCA, namely i) goal and scope definition, ii) inventory analysis, iii) social life cycle impact assessment and iv) interpretation.

2.3. Conclusions

The aim of this chapter was to provide an overview of the state of the art, firstly in terms of social sustainability and S-LCA methodology, and secondly in terms of applications in the energy sector, with a special focus on offshore wind power systems. The outcome of this review has led to the identification of several aspects that should be taken into account for an appropriate adaptation of type I S-LCA methodology to the specific context of French OWF systems.

Regarding S-LCA methodology, the scope to be covered may be broad. This scope potentially includes a large number of stakeholders linked to the system being evaluated, as well as many social impact categories and subcategories to be assessed. Defining the scope is therefore an important phase in S-LCA that determines what the next S-LCA phases should focus on. For this purpose, the use of participatory approaches can help the practitioner to delimit a scope in a legitimate way. This family of approaches will be explored in Chapter 3, which presents a methodology for the identification and hierarchisation of the social impact subcategories according to their relevance. Consultations to both internal and external stakeholders will be presented.

Another aspect identified as a result of the literature review presented in this chapter is the need for more systematic and transparent approaches to measure social impacts for both global and local scales. These approaches require certain adaptations to be applicable to the French OWF sector. For the global scale, generic databases may be used. In the second case, reference scales and PRPs could be applied. However, among the revised studies, few articles considered such PRP approaches, and none provided an explicit list of numerical thresholds to define PRPs. The main objective of Chapter 4, therefore, is to provide a comprehensive framework to conduct such analysis including global and local impacts and proposing a systematic definition of reference scale approaches.

One additional challenge for this development is the emerging nature of OWFs in France. Indeed, there were no operational projects at the time the data was collected, and the associated information was scarce and often inaccessible. This involves major constraints to access primary data (i.e., data that the practitioner builds). The use of secondary data (i.e., previously collected and publicly communicated) involving data collection based on literature specific to OWF projects in France, and scientific studies on cases abroad, may be used instead for the identification of impact ranges. To help this process, a systematisation of the choice of different sources and levels of resolution in data collection is proposed in Chapter 4.

3. A systematic approach to hierarchise S-LCA impact subcategories

The selection of impact subcategories to be assessed is a key aspect to be established within the goal and scope definition phase of an S-LCA. Indeed, S-LCA includes a large number of stakeholders and impact subcategories that can be evaluated. From an S-LCA practitioner's perspective, a broad range of impact subcategories suggests a substantial deployment of time and resources. Defining the scope and system boundaries of the assessed system is necessary because a complete assessment would take an infinite amount of time and resources (Grießhammer et al., 2006). However, in practice, social impact subcategories are often selected arbitrarily and restricted to a reduced list only including some of them, with lack of justification on whether to include or exclude a given subcategory. To overcome this difficulty in the initial phase of the goal and scope definition of the S-LCA, prioritisation, also known as hierarchisation, strategies have been proposed in previous S-LCA work (Bouillass et al., 2021; Zanchi et al., 2018). By helping to define goal and scope, hierarchisation aims to focus on which social impact subcategories should be considered as a priority for the subsequent inventory and impact assessment phases.

Different articles in the literature claim that the goal and scope definition should reflect stakeholders' values and consider their perceptions. Accounting for stakeholders' perceptions may ensure that the impact categories used in S-LCA make sense for them at the local level and help to enhance the validity of the outcomes (Mathe, 2014; Sureau et al., 2017, Garrabé et al., 2014). For this purpose, bottom-up approaches can be relevant, if not necessary. Participatory approaches seek to address stakeholders directly. They can be seen as bottom-up approaches that increase the legitimacy of results (Feschet, 2014; Mathe, 2014). Several tools can be used, such as focus groups or surveys. One of the first outcomes of a participatory approach is the identification of social concerns from stakeholders' perspectives. However, social concerns arising from participatory approaches can encompass a broad scope. Besides, the results may be insufficient to clearly establish the social concerns on which the next phases of the S-LCA should focus. Social impact subcategories may not be of equal relevance, or of equal priority for the aim of improving the social performance of a system. Indeed, from certain stakeholders' perspectives, some social impact subcategories may be considered urgently, while others

may find them important but not particularly problematic, or associated with a minority of affected individuals, or even of little significance.

In this PhD thesis, two hierarchisation approaches are tested. The first approach is addressed to a panel of companies. The other one focuses on external stakeholders. The first approach involves consulting the companies in the sector, such as project owners, who can be the same as the ordering body of the S-LCA study or those affected by public decision-makers ordering the study. In this case, project owners are assumed to be the ordering body of the study. The expected advantage of consulting project owner companies is that their perspective would reflect sector expertise and could provide accurate information of the context. The second approach targets the external stakeholders, following bottom-up principles, and more generally involves the categories of stakeholders related to the UNEP Guidelines (2020). Conducting these two approaches makes it possible to identify elements for discussion and note divergences and convergences by comparing the perspective of stakeholders directly involved in the project with that of external stakeholders potentially affected by the project. These two different consultations were conducted using different approaches, which are presented in the next section.

3.1. Methodology: hierarchisation of S-LCA impact subcategories based on consultations to internal and external stakeholders

This section presents the methodology developed in this thesis to conduct hierarchisation of impact subcategories based on consultation. The main features of each approach are presented in Figure 3.1.

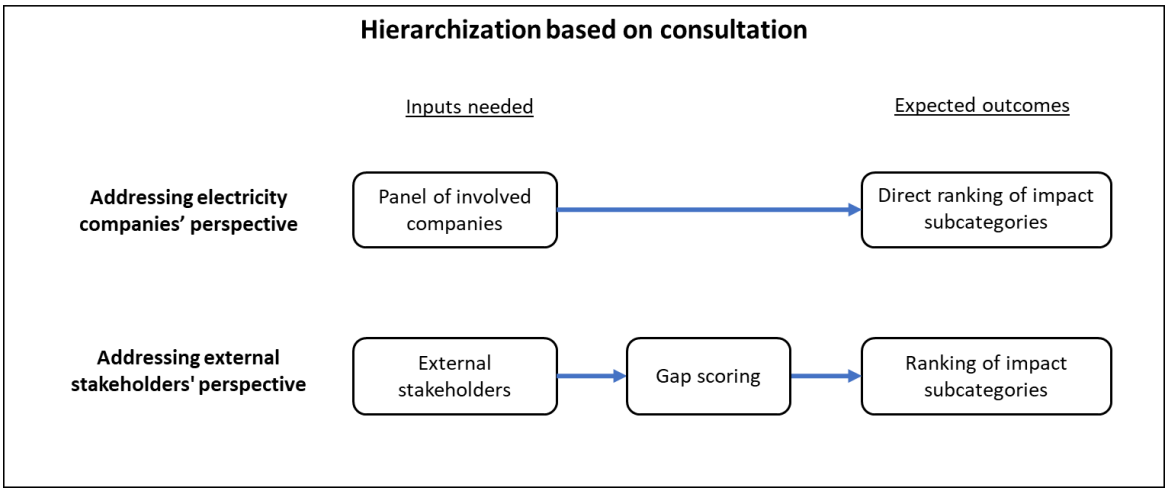


Figure 3.1. Main inputs and expected outcomes for the two approaches of hierarchisation of impact subcategories based on consultation.

The first approach aims to rank the subcategories of impacts according to the directly involved companies' perspective, that is, to an internal stakeholder's perspective. This approach consists of asking the participants from involved companies to directly rank the impact subcategories, that is, to directly order them by level of importance, from the most to the least important one. A panel of large-sized companies is involved. In addition to the main objective of ranking the subcategories, the involvement of companies in discussions with the practitioner also provides expertise on sectoral issues and feeds the reflection for other phases of the study.

In the second approach, external stakeholders are consulted. For this approach, a need for specific methodological development was identified in the thesis. Indeed, some bottlenecks were found for external stakeholders' consultation. Among these bottlenecks were the lack of a systematised access to the stakeholders themselves and limitations to measure the level of representativeness of the respondents by considering the diversity of stakeholder sub-groups (or profiles). These bottlenecks have been considered in the proposed approach, and some steps have been included to deal with them. In addition, the impact subcategories are reformulated to make sense to the respondents, less familiar with S-LCA principles.

3.1.1. Methodology to address directly involved companies' perspective

This section presents the methodology for a hierarchisation of social impact subcategories based on companies' perspectives. Figure 3.2 illustrates a five-step approach proposed in the present work to integrate companies' perspective into the S-LCA of the system. The approach is based on the S-LCA prioritisation method developed by Bouillass et al. (2021), which has been adapted to the context of the application of this PhD thesis to the OWF sector. Based on the terminology from this study, the current section uses "prioritisation" as a synonym of "hierarchisation. The approach combines information from the literature with a participatory approach that includes a survey and a focus group. The five steps are grouped in two larger phases that include, for phase A, all the steps to design the survey and, for phase B, the steps to apply it. The phases and sub-steps are introduced here and the results of their application are presented in more detail in the following subsections.

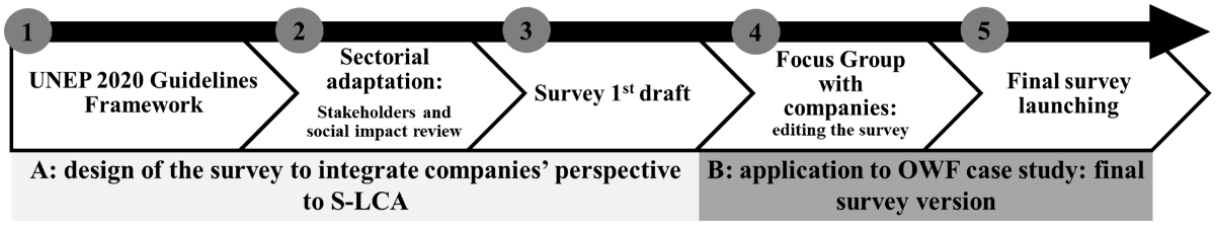


Figure 3.2. Main steps to co-construct the survey to collect companies' perspective.

Phase A aims to prepare the elements required to co-construct the survey together with companies. Firstly, a list of recommended stakeholders and impact subcategories is identified (step 1) and adapted to the sectoral context (step 2). This information allows a first draft of a prioritisation survey to be built (step 3) that is used in phase B. Involving members of the companies in the design of the survey is believed, in this case, to help to ensure the representativeness of their perspective and motivate them to respond. Thus, the organisation of a focus group (step 4) is proposed to introduce S-LCA interests and main definitions, as well as to collect companies' feedback to improve the survey. The discussion with the panel allows the survey to be adjusted and sent to the companies (step 5).

The consign provided when launching the survey is to "rank the impact subcategories for each stakeholder categories in the order of you consider the most important to the less considering the [sector being assessed]". Then, the data processing consists of aggregating the respondents' answers to obtain the rank of the impact subcategories according to the aggregated point of view of the companies. For the interpretation standard deviation is also determined as a measure of dispersion to identify the level of divergence or convergence in responses by different companies' representatives.

3.1.2. Methodology for addressing the external stakeholders' perspective

This section presents the methodology used to consult external stakeholders to hierarchise social impact subcategories. The method, illustrated in Figure 3.3, is based on five main steps. It starts with a literature review that leads to the identification of a list of impacts (1) and a scoring method adapted to the objective of the study (2). Then the pools of stakeholders' contacts (3) and the questionnaire of the survey (4) are designed. The method ends with the processing of the survey answers (5).

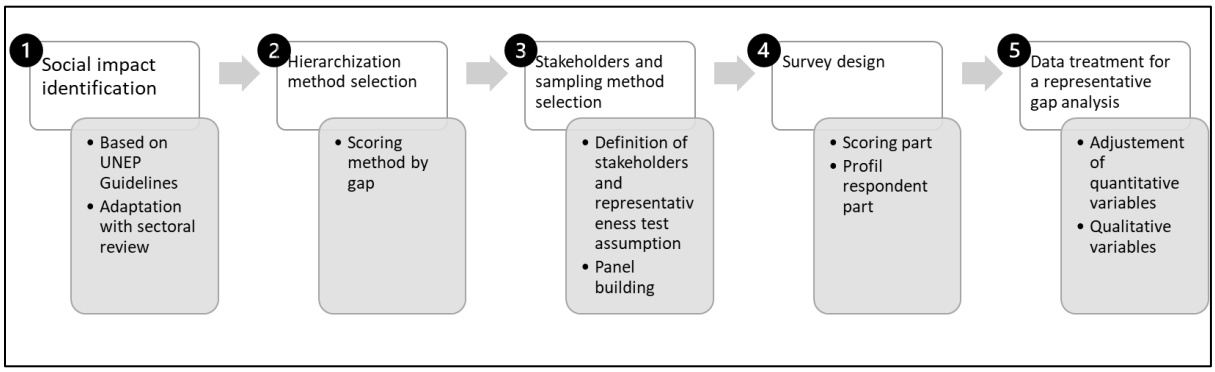


Figure 3.3. Steps for the construction of social impacts survey to be addressed to external stakeholders for hierarchisation.

The main novelty of the method is that, to address the level of representativeness of the responses, a comparison is made between the panel of respondents obtained (i.e., the sample) and the category of stakeholders as a whole (i.e., the population), defined beforehand. Conducting sample-to-population comparisons entails the definition of at least one calibration variable. This operation aims to identify whether an adjustment of the responses is necessary to limit bias or not. Each of these stages is explained in more detail below.

- **Identification and adaptation of social impact subcategories**

This section explains the method used to select social impact subcategories to be considered in the survey to external stakeholders. To ensure the reliability of the hierarchisation, an adaptation of the terminology and the impact subcategories to the context is needed, so that the nature of the different subcategories can be better understood by the respondents. Firstly, a literature review to identify social impact subcategories typically used to assess the target sector should be conducted. In cases of low technology readiness level or of technologies that are not yet implemented in a particular region, its potential social impacts are unlikely to be fully documented in the literature. Therefore, the literature review may be extended to similar systems in the same sector, assuming that these substitutes can provide relevant complementary information. It is important to avoid omitting potential social impact aspects as much as possible.

Following the framework proposed by Bouillass et al., 2021 the literature review begins with UNEP impact subcategories (UNEP, 2020). Then, the contextualisation consists of integrating studies on the sector, both S-LCAs and other types of social assessments, to adapt the impact social impact subcategories related to the sector. This stage is called a sectoral risk analysis in some studies (Bouillass et al., 2021). Scientific literature, but also other sources such as public reports, may be useful. In this PhD thesis, the concept of social aspects is used for this purpose: it corresponds to the different subjects covered by the literature, which are not originally impact subcategories proposed by the S-LCA framework. The social aspects are identified, then aggregated into new impact subcategories adapted to the sector.

- **Hierarchisation method selection**

To improve the legitimacy of S-LCA scope definition, participatory approaches are proposed by some authors (Bouillass, 2021, Manik, 2014). Hierarchisation methods can be based on a ranking directly assigned by respondents for each impact subcategory, as the approach presented in the section 3.1.1 to address companies' perspective. In such cases, each impact subcategory is ordered with respect to other ones. However, this approach has limitations. For example, while it may be intuitive to identify which impact subcategory may be in first or last position, it could be complex for the respondent to differentiate between intermediate positions. Moreover, respondents may not be able to assign a different order of magnitude between ranks when, in fact, it is possible that the first-ranked elements are significantly more relevant to the stakeholder than other categories in lower positions of the ranking.

Conversely, assigning a score rather than directly attributing a rank may result in identifying impact subcategories having almost equal relevance, which may be all very high, or very low. Hierarchisation is then carried out in a second step during data treatment of survey results based on attributed scores. The scores are the quantitative responses to one or several criteria that aim to characterise the different impact subcategories. The choice of the criteria strongly influences the results of the hierarchisation. Depending on whether the goal consists of revealing the most important impact subcategories, or those for which there is a potential hotspot or criterion to be used are different.

Based on the approach proposed by Manik et al (2014), the method consists in measuring the difference between a level of expectation and a level of perception of the stakeholders about impact subcategories. For this, each identified impact subcategory receives scores from 1 to 5 according to two criteria: the "Expectation" criterion and the "Perception" criterion. "Expectation" reflects the level of interest the respondent has with respect to an impact subcategory in general, while "Perception" reflects the level of satisfaction with the current level of performance of the sector the respondent perceives with respect to the same impact subcategory (Manik, et al., 2013)**.** As presented in the equation (1), the difference between these two scores corresponds to a gap for each impact subcategory. Bigger the gap, bigger the

difference is between what the stakeholder ideally expects and what he currently observes, that is, elements in which effort should focus for overall improvement.

$$\text{Gap score} = [\text{Perception score}] - [\text{Expectation score}] \quad \textbf{(1)}$$

A high expectation score combined with a low perception score, means that the respondent attributes a strong level of interest and that the current situation of the sector does not fully meet their expectations. In this case, the subcategory is identified as having a high priority and needing an urgent improvement. Conversely, a high expectation score with a low perception score, means that the respondent attributes a high level of interest to the impact subcategory but there is no dissatisfaction. In other words, the impact subcategory is important but there does not seem to be any urgency to improve the performance. If both scores are equally high or low, the gap between them will be low, meaning that either the subcategory does not generate a high interest to the respondent so the low level of satisfaction with the current performance is not problematic, or that the respondent considers the subcategory of interest but is satisfied with the current performance of the sector.

- **Stakeholder categories and sub-groups definition**

One of the first elements to be defined in the goal and scope definition phase of S-LCA are the stakeholder categories to be included in the assessment. UNEP guidelines (2020) propose six stakeholder categories. Depending on the context and the evaluated system, some of these six stakeholder categories may be more relevant than others. Furthermore, stakeholder categories defined in UNEP guidelines are broad categories of actors. Indeed, a stakeholder category may include several sub-groups with different perspectives and concerns. Subdividing each of the categories into several sub-groups or "examples" is a way to include the diversity of social representations with higher accuracy (Mathe, 2014). For examples, Mathe (2014) proposes to split the stakeholder categories "value chain" into more specific subcategories such as upstream chain, nonfarmers owners, producers, etc.

Mathe's (2014) suggestion of subdividing the stakeholder categories in sub-groups was followed in this PhD thesis. The identified sub-groups for the different stakeholder categories related to the sectoral context is presented in the results section. It should be noted that this PhD thesis keeps an approach with only five stakeholder categories without considering the recent update about the children's stakeholders as a whole category. Social impacts related to children in this thesis is restricted to the issue of child labour related to workers' stakeholder category.

As presented in Figure 3.4, different levels of bias can exist between the commonly-use level of aggregation in S-LCA (i.e., stakeholder category) and the smaller entities of participatory approach (i.e., the individual level). The purpose of presenting disaggregated stakeholder subgroups, and then disaggregated survey results is to verify the influence of the scoring responses of the stakeholder sub-

groups who responded to the survey. If the results indicate remarkable differences in responses according to sub-groups, this may involve that considering the stakeholders at the stakeholder category level may not be enough, and a deeper analysis of the different profiles within a stakeholder category may be needed.

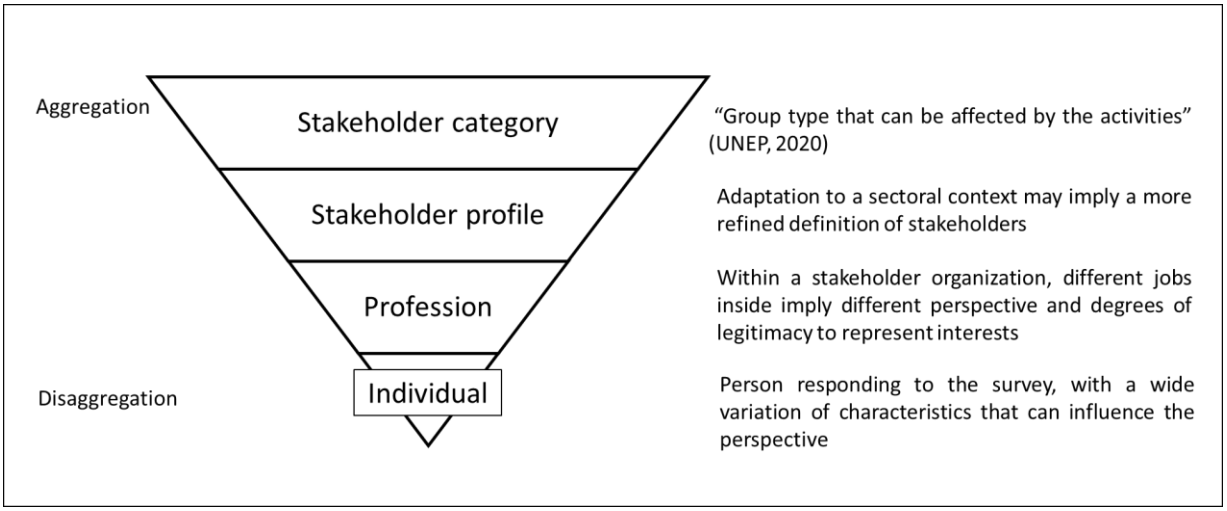


Figure 3.4. Main levels of bias aggregation data between the respondents and the stakeholders' categories.

- **Sampling method definition**

For practical implementation of the consultation, there is a need for identifying the people to be included within the stakeholder categories. For this task, the notion of statistical population is used. The statistical population is the set of individuals sharing one or more common characteristics, in this case, all the individuals included in a given stakeholder category. These characteristics are measured through one or more descriptive variables.

A population of stakeholders includes many individuals. Consulting them all is often not possible. Only a sample is consulted, namely a part of the population of stakeholders who could be consulted. In this case, it is necessary to question the relevance of the profiles of people that respond to the survey, in relation to the definition of the entire stakeholder category. To do so, it is relevant to conduct a sample-to-population comparison which is a common practice in socio-economic sciences (Ladenburg, 2009; Ladenburg et al., 2013; Ladenburg and Dubgaard, 2007; Westerberg et al., 2013).

For the comparison of the sample with the statistical population, at least one relevant descriptive variable has to be identified. This variable is used to compare the sample of respondents with the statistical population previously defined and adapt it if needed. For example, for the value chain actors category, a descriptive variable may correspond to the main types of activities among companies of the value chain, such as the supply of components, civil work, R&D. For local communities, a descriptive variable could correspond to the main professions outside of the value chain that are present in the area, such as farmers, fishermen, public administration. The proportion of these different sub-groups should therefore be determined at the level of the stakeholder category or categories that are addressed in the study. The

use of the descriptive variable for data treatment is presented in more detail in the data processing section but its use has to be anticipated in the survey design step.

Following the definition of the stakeholder's population and the descriptive variable to allow sample-to-population comparison, the sampling is conducted. In the case of this thesis, the consultation of several sectoral cluster websites (i.e., structures that bring organisations together based on a common sectoral dimension), and complementary literature allowed the construction of a significant survey panel mailing list. Email contact information and associated names of the organisations (e.g., company, authority, association, trade unions, etc.) can be collected automatically through a web scraping tool and quickly build a large directory. To avoid attributing excess weight to an organisation, duplicate organisation have been removed from the mailing list in this work. The sorting is performed at the beginning of the survey by a preliminary question which aims to keep only those respondents who consider themselves to be stakeholders related to the system.

- **Survey design**

Considering the large sampling approach, several general principles need to be considered. The survey aims to be a trade-off between the amount of data to be collected and their comprehensiveness. The survey requires the collection of variables that allow for the verification that the survey sample is representative of the population concerned (OECD, 2007). At the same time, the survey should require a short time to be completed and ensure anonymity. Indeed, because of the potential sensitivity of some information provided by the respondents, non-anonymisation could discourage respondents to fill in the survey. The survey includes a respondent description section, a scoring section and an additional section to characterise the organisation the respondent represents.

The first section includes three general questions about the respondent. Because the survey is intended for stakeholders related to the system under study, the first question asks whether the respondent's activities are or can be influenced by the evaluated system. This enables an initial sorting of the respondents. The question is formulated as follows:

- *"Are your activities affected, or could they be affected, by the implementation of [system being evaluated]?"*)

The second section of the survey corresponds to the assignment of scores to the social impact subcategories, for a subsequent application of the gaping approach defined in 2.1. To do so, each impact subcategory gets two scores. It should be noted that "no opinion" responses are proposed among possible responses to avoid forcing the respondent to give a non-relevant answer by default. Based on the wording by Manik et al. (2013), the related questions are formulated as follows:

- *"On a scale of 1 to 5, where 1 means "not important" and 5 means "very important", how would you rate the importance of the following issues in the context of the implementation of an offshore wind farm project?"*

- *"Currently, on a scale of 1 to 5, where 1 means "not at all" and 5 means "fully", to what extent would you say that offshore wind development meets the requirements of [impact subcategory]?"*

An optional question offers the respondent the possibility of suggesting additional impact subcategories that should be considered (*In your opinion, in the context of the [system being evaluated] project, are there other social issues specific to the territories that should be emphasized?*). This allows verbatim data to be collected and ensures that the questionnaire covers stakeholders' real concerns.

The third section of the questionnaire includes questions that aim to characterise the profile of the respondent's organisation.

- *"Which of the following activities best describes your organisation?"*

Because this may be considered as the most sensitive information, this part is recommended to be placed at the end of the questionnaire to avoid respondents to be discouraged. Four questions aim to define the respondent. The question of the main socio-economic activity of the respondent aims to analyse the representativeness of the sample in comparison to the population of stakeholders. To identify possible bias in the generalisation of a respondent's answers to the entire stakeholder group he represents, the respondent is asked to qualify their location, the scope of their activity and the interests represented. Identifying a geographic location for the respondent also verifies their legitimacy to respond as a representative of a local community related to projects of the assessed technology. To identify the role within the life cycle perspective, the respondent also specifies which stage of the project concerns them. In the conducted assessment, respondents were expected to be mostly associated with the construction and operation stages. The respondent can attribute their answers to one or more specific projects of the assessed technology. These projects were, in this study, proposed in the form of a list.

Finally, an optional question at the end of the questionnaire allows respondents to provide contact information for further consultation. This part can be adapted regarding the stakeholder category. For example, for value chain stakeholder categories, additional variables to characterise them more precisely can be requested (e.g., the turnover related to the system assessed, the size of the company, etc.)

The complete survey used in this work is presented in Appendix 1 of this PhD manuscript.

- **Data treatment for a representative gap analysis**

The data obtained from the survey is to be treated so as to adjust the feedback of the sample to better represent the population. The obtained data include two types of information, namely quantitative scores that represent the gap between the perception and the expectation of each respondent about each impact subcategory, and qualitative information about the respondent including the descriptive variable or variables.

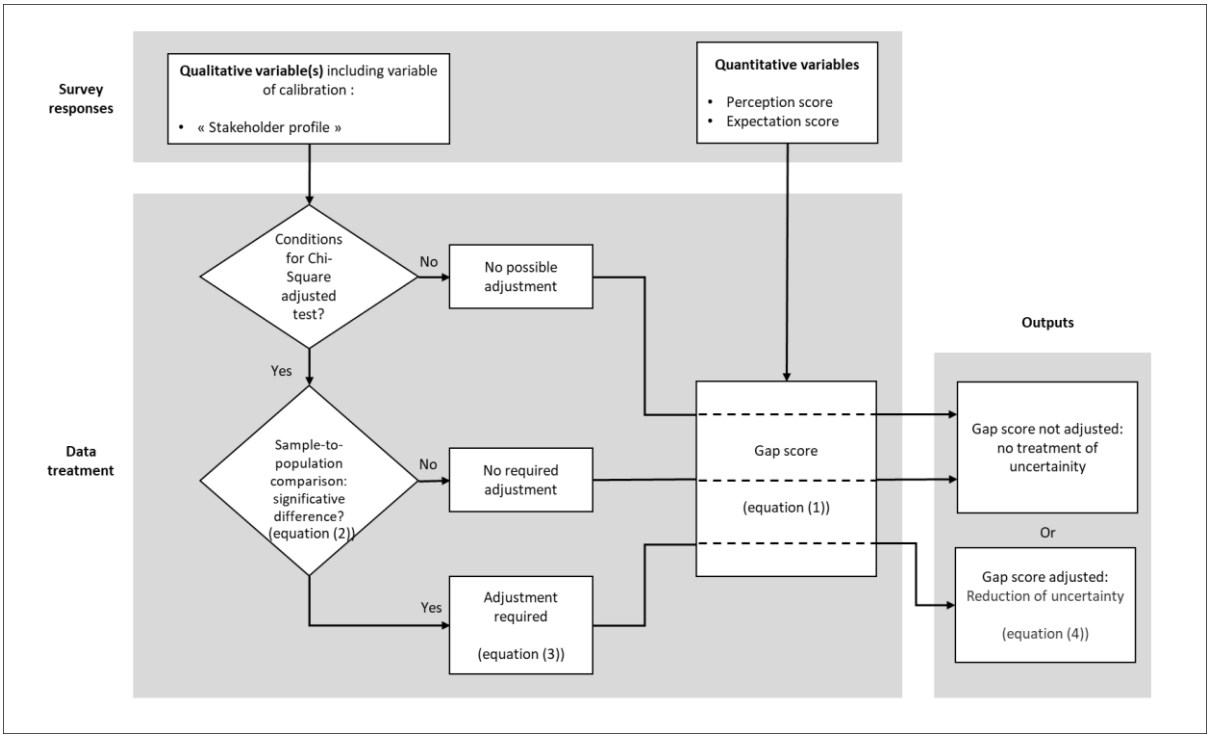


Figure 3.5. Decision-tree for a representative gap analysis.

As previously mentioned, the ability of the sample to represent the statistical population needs to be verified. A significant difference between both the sample and the population distributions of profiles may involve that the sample is not representative of the population, and therefore, a difference between the results obtained and reality is expected. In this case, it is necessary to adjust the answers as explained further in this section. The representativeness of the sample compared to the population can be measured by applying a Pearson Chi-Squared test.

The chi-square test serves to verify whether the frequencies observed in the sample differ significantly from the theoretical frequencies of the statistical population. In practice, the test involves comparing these two frequencies. This comparison is carried out using the formula (2).

$$x^2 = \sum_{ij} \frac{(O_{ij} - T_{ij})^2}{T_{ij}} \qquad \textbf{(2)}$$

With

T: theoretical profile distribution

O: observed profile distribution

The calculated chi-square (x^2) is compared with the chi-square critical value. The chi-square critical value depends on the number of modalities that the variable being tested can take. The chi-square critical value is provided by the chi-squared distribution table (Pearson, 1900) and acts as a threshold that is used to determine the representativeness. Namely, if the x^2 calculated is greater than this threshold, the test concludes that the sample is statistically not representative of the statistical population and

vice versa (Ugoni and Walker, 1995). It is generally admitted that a minimum threshold of 30 responses is required for this statistical test to be applicable, and that for each modality (i.e., the different values that the variable can take) there are at least 5 observations (Cochran, 1954).

The collected responses from a non-representative sample can be adjusted with a coefficient. Adjustment involves giving more weight to the responses on the sub-groups that are underrepresented and vice versa. Adjusting survey results to improve representativeness, has been investigated in the past (Deville and Särndal, 1992). A simple adaptation of the adjustment approach by using one descriptive variable as a calibration variable is presented in (3). This adjustment based on one calibration variable can be decomposed into several calculation steps. Firstly, the raw values for the considered calibration value of the sample and the population are identified (e.g., "stakeholder's profile"). Then the values are normalised, i.e., their frequency is adjusted so that their sum equals 1. The coefficients are obtained by dividing the normalised values in the sample by those in the population. A high coefficient, above 1, for the stakeholder profile concerned means that the normalised value of the sample is low compared to that of the population. In this case, the coefficient serves to attribute more weight to the response than what that stakeholder profile would have without the adjustment. Conversely, if the ratio between the normalised value of the sample and the population is below 1, the stakeholder profile is overrepresented. When both normalised values are close, the coefficient tends to 1. The closer the coefficient is to 1, the more representative a given sample is compared to the population and, thus, the less significant the calibration. Table 3.1 below presents a fictive dataset consisting of the raw values from a certain survey's sample and the corresponding population, the normalised values and the resulting calibration coefficients. In the example, the population is divided in two types of stakeholder sub-groups: 400 individuals belong to the sub-group 1, whereas 600 individuals belong to the sub-group 2. If the sample to represent these profiles consists of 45 individuals of sub-group 1, and 85 individuals of sub-group 2, then the ratios (0.35 and 0.65, respectively) are not the same as those of the original population (0.40 and 0.60). The coefficients adjustment can be calculated by dividing the original population by the sample.

For J profiles: $Coef_j = \frac{T_j}{\sum_{j=1}^{J} Tj} \div \frac{O_j}{\sum_{j=1}^{J} Oj}$ **(3)**

With

T: theoretical sub-groups distribution

O: observed sub-groups distribution

Table 3.1. Calibration coefficient determination (fictive dataset).

	Sample	Population	Sample	Population	Coefficient
	Raw values		Normalised values		
Stakeholder's sub-group 1	45	400	0.35	0.40	1.16
Stakeholder's sub-group 2	85	600	0.65	0.60	0.92
Total	130	1000	1	1	

In the proposed framework for the hierarchisation of impact subcategories of OWF sector, the adjustment coefficient is applied to the gap score (4). Table 3.1 resumes the adjustment of the gaping scoring method to improve the sample's representativeness.

$$\text{Adjusted gap score} = Coef_j \times \text{gap score} \quad \textbf{(4)}$$

- **Pareto approach to address trade-offs in goal and scope definition**

Theoretically, a complete S-LCA should cover all impact subcategories identified in the initial sectoral risk analysis. However, due to time and resource limitations, this is not always possible. Given the wide scope of S-LCA, the practitioner may have to find a balance between the feasibility of including a sufficient number of subcategories while still being able to assess them with a certain level of detail. This issue can be addressed by applying a Pareto approach as illustrated in Figure 3.6. Pareto approach is widely recognised to deal with trade-offs and can be applied to different fields (Janusz and Andrzej, 2014).

The Pareto principle states that, for many events, roughly 80% of the consequences come from 20% of the causes. Based on this principle, the Pareto chart is used in many fields as a tool to highlight the most important factors among a set of them. The approach consists of representing individual values of these factors in descending order and selecting the first n factors for which the cumulative percentage covers at least 80% of the total. The application of this principle to the selection of social impact subcategories in this study would involve selecting the number of subcategories that cover at least 80% of the cumulative score. In S-LCA, a systematic threshold of 80% may not always be achievable or not always meaningful.

As an alternative, an adaptative definition of the threshold is proposed in this PhD thesis, instead of applying the fixed threshold of 80%. Thus, instead of using this fixed threshold regardless of the case study, a percentage of the scope covered by the hierarchised criteria may vary depending on the context and available information for the analysed case studies. This percentage should be clearly specified, and if possible, justified. This information may contribute to transparency on the scope finally retained. For example, Figure 3.6 depicts a hypothetical set of five impact subcategories for which the first three ones

cover 95% of total cumulative score. In this situation, it may be more relevant to use time and resources for assessing these three impact subcategories covering a 95% threshold, rather than including all the five impact subcategories to achieve 100% of the impact assessment.

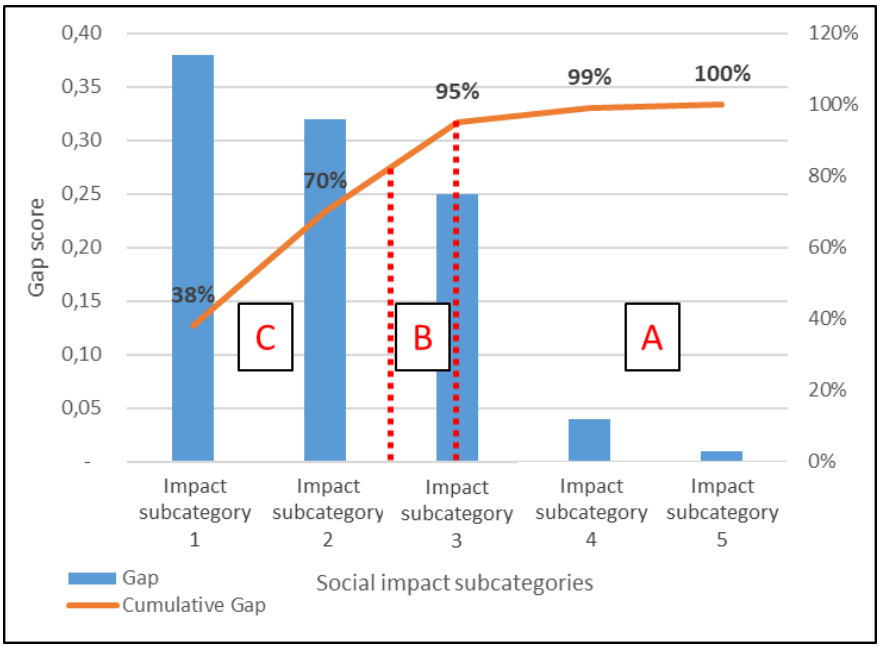


Figure 3.6. Visual representation of the results using Lorenz curve derived from Pareto approach and applied to S-LCA impact subcategories hierarchisation (adapted from (Janusz and Andrzej, 2014).

3.2. Application of the impact subcategories hierarchisation to the French OWF context

The two described approaches to hierarchise social impact subcategories has been applied to the French OWF context. The next sections present the results of the hierarchisation from the perspective of directly-involved stakeholders, followed by the results of the hierarchisation carried out with external stakeholders.

3.2.1. Impact subcategories ranking from electricity companies' perspective

This section presents the results of the ranking of impact subcategories according to the electricity companies' perspective. In this study, these companies are electricity operators involved in the development of OWFs. A set of companies represented by twelve employees responded to the ranking exercise. The responses provided were used to obtain an aggregated ranking of impact subcategories

that represent the electricity companies' perspective regarding their importance. The results revealed the most important impact subcategories S-LCA should focus on, considering the sector and according to these companies directly involved in the installation and operation stages. In the consultation, five stakeholder categories from UNEP guidelines were considered. For the category "Workers", based on companies' feedback, it was estimated relevant to distinguish between two sub-groups, namely direct workers and indirect workers. Direct workers refer to workers directly involved in the activity conducted for the electricity companies responding to the consultation (i.e., workers involved in the installation and operation of OWFs by the electricity companies themselves), whereas indirect workers intervene in other activities within the value chain (e.g., support functions).

Regarding the ranking of social impact subcategories, the perceptions among companies show a great variability, as shown in the results presented in Table 3.2. The dispersion of the result, measured according to the standard deviations, was high. Despite these deviations, it is still possible to identify some social impact subcategories that are, on average, ranked in a high position and that present a relatively low standard deviation. This is the case for "Health and safety", which is ranked in the first position for almost all affected stakeholder categories. Child labour is absent among the top 3 subcategories for direct workers, but present for indirect workers. This can be simply explained by the fact that direct workers are located in France, where specific laws and mechanisms prevent child labour from happening, whereas indirect workers within the value chain are not only located in France, but also abroad where the traceability of working conditions seems more difficult and there are potentially more risks of child labour.

Table 3.2. Results of social subcategories ranking (top 3) based on electricity companies' perspective.

	Rank 1		**Rank 2**		**Rank 3**	
	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation
Direct workers	Health and safety		Social benefits / social security		Equal opportunities discrimination	
	1.3	0.50	3.3	2.06	4.3	3.30
Indirect workers	Health and safety		Child labour		Fair salary	
	2.8	2.87	3.5	1.00	4.8	2.87
Value chain	Promoting social responsibility		Fair competition		Supplier relationships	
	2.3	1.50	2.8	0.96	2.8	2.06
Local community	Safe and healthy living conditions		Local employment		Secure living conditions	
	1.8	0.50	2.5	3.00	3.0	1.15
Consumers	Health and Safety		Transparency		Consumer privacy	
	1.0	0.00	2.3	0.50	3.0	0.82
Society	Contribution to economic development		Poverty alleviation		Public commitments to sustainability	
	3.3	2.22	3.3	1.71	3.3	2.63

For the local community category, the local employment impact subcategory appears in the top 3.OWF companies promote this argument to highlight the potential positive impacts of their projects on the local development. However, even if an emerging sector such as OWF may create jobs, some concerns arise

among other activities already established in the territories (e.g., fishing). As such, we could also consider potential impacts on landscapes or cultural heritage impact when addressing the issue of sharing space between multiple coastal activities.

Despite the information provided to clarify the methodology, it may have been difficult for the respondents to rank the impact subcategories because of their potentially complex definition.

The methodology allowed a ranking of the social impact subcategories to be obtained, based on the importance criterion. However, due to the lack of consensus and the small size of the panel, this ranking may not exhaustively reflect the concerns of all stakeholders, which should be integrated in the study. For a hierarchy based on companies' perspectives ordering an S-LCA, an improvement would be to increase the number of people involved in the survey, as well as to diversify the profiles in terms of roles assigned within the companies. For example, internal experts in social issues of the companies who interact directly with external stakeholders could be involved. Also, rather than a ranking carried out through an individual survey, the exercise could be carried out during a complementary focus group, which could lead to greater consensus on the results. Overall, the results obtained in this work reinforce the need to consult external stakeholders.

3.2.2. Impact subcategories ranking from external stakeholders' perspective

This section presents the results of the proposed hierarchisation framework from the perspective of affected stakeholders in the context of French OWF sectors. Results of data surveys consists of a ranking of social impacts subcategories ordered from those with the largest gap between the perception and the expectation of a given impact subcategories to those with the smallest gap. The section below presents the detailed application of the approach to the local community stakeholder category for the context of OWF in France. The application to the value chain actors category is also briefly presented. Workers, Consumers and Society stakeholder categories have also been addressed. In the case of these three categories of stakeholders, the number of responses was not enough for the representativeness test to be applied and the adjustment was not possible. Therefore, the results of the gap analysis were used without adjustment.
The following sub-section presents the work carried out to adapt the subcategories of local community impacts to take the sectoral specificities identified in the literature into account.

3.2.2.1. Social impact subcategories adapted to OWF

This section presents the list of social impact subcategories included in the survey sent to external stakeholders, namely individuals or groups other than the companies operating OWFs. As suggested by some authors (Mathe, 2014) and mentioned in the methodology section, an adaptation of the terminology to refer to stakeholders sub-groups and impact subcategories may be needed when participatory approaches are used, to enhance the understanding by the respondents. The adaptation includes ensuring that the proposed subcategories for the score assignment reflect stakeholders' concerns.

For this sectoral adaptation based on literature review, the "social aspects" notion is used. In this thesis, social aspects refer to any topic related to social impact studies that are not restricted to "social impact categories" in the corresponding studies. In this sense, the sectoral literature review reveals existing social aspects mainly for the "local community" category around the OWF installation area. The adaptation work focused on this category of stakeholder. In the case of the other stakeholder categories, an adaptation of the impact subcategories proposed by the UNEP guidelines was not considered necessary.

In this work, the local community stakeholder category is defined as a group of individuals who are located near the installation area of an OWF, along the French coastline. Some of these people are involved in well-established activities that are of economic importance for the territories (e.g., tourism sector, professional fishing), or that contribute to the local well-being (e.g., quality of life, landscape).

Social concerns of local communities can therefore be related to the preservation of these economic, social or cultural benefits. Some scientific studies, together with grey literature such as public debate reports (CNDP, 2021a) provide insights about the stakeholders' positions and their strategies to adapt to emerging OWF sector (Bas, 2017; Fofack-Garcia et al., 2023; Oiry, 2017). As shown in Table 3.3, job creation issues are by far the most recurrent social aspect of the literature. The cross-review of grey and white literature feeds into a broad identification of social impact subcategories that are specific of the OWF sector or adapted from UNEP 2020 impact subcategories to it. Except for local employment, which is directly transposed from UNEP Guidelines, the impact subcategories presented in Table 3.3 result from a sectoral adaptation of UNEP categories. The adaptation has been an important step towards hierarchisation.

Table 3.3. Definition of impact subcategories related to offshore wind local communities in France. Apart from local employment, which is directly transposed from the UNEP, all the other social impact subcategories have been adapted to sectoral context.

Social impact subcategories adapted to sectoral context	Aspects considered in the literature	References
Access to energy facilitated	Storage capacity and energy density	(Azapagic et al., 2016)
	Renewable energy availability	(Santoyo-Castelazo and Azapagic, 2014)
Fair sharing of maritime and terrestrial spaces	Land occupation	(Santoyo-Castelazo and Azapagic, 2014)
	Effect on professional fishing	(Buchholzer et al., 2022; Schupp et al., 2021)
	Effect on recreational activities	(Hooper et al., 2017)
Investments in favour of the territory	Amount of fiscal benefits	(CGEDD, 2021b)
Benefits and technology transfers	Share of local content	(Allan et al., 2020; Connolly, 2020)
Attractiveness of the territory	Evolution of tourist frequentation	(Ladenburg, 2009; Smythe et al., 2020; Westerberg et al., 2013)
Consideration of quality of life and absence of related detrimental effects	Level of visual and noise impacts	(Hirschberg et al., 2004; Santoyo-Castelazo and Azapagic, 2014; Troldborg et al., 2014)
	Public preference for a technology	(Maxim, 2014)
Respect for the rights of residents	Local benefits for residents	(Liu, 2014)
	Real estate price evolution	(ADEME, 2022; Jensen et al., 2018)
Quality of the dialogue between local stakeholders and decision-makers	Trust rate in electricity developers	(Hooper et al., 2017)
	Number of meetings with local communities	(UNEP 2020)
Extent of citizen participation	Participatory funding of projects	(Oiry, 2017)
Safety management and industrial risks	Maximum fatalities per major accident	(Hirschberg et al., 2004)
	Probability of accident with a civilian	(SSPA 2008)
Local employment (UNEP 2020)	Number of direct and indirect jobs	(Bengtsson Ryberg et al. 2013; Liu 2014; Troldborg, Heslop, and Hough 2014; Maxim 2014; Atilgan and Azapagic 20(CRE, 2018)16; Santoyo-Castelazo and Azapagic 2014; Azapagic et al. 2016; Kahouli and Martin 2018; Roinioti and Koroneos 2019)
	Qualitative characterization of created jobs	(Podevin, 2017; WavEC, 2012)
	Social clauses	(CRE, 2018)

3.2.2.2. Delineating the perimeter to sample the stakeholders related to the French OWF context

The following sub-sections present the identified sub-groups, based on a review of the scientific literature and public reports, to define more precisely the stakeholder categories involved in French OWF projects. The subdivision has been applied to all stakeholder categories included in the assessment, though workers and value chain actors are the two categories for which the largest diversity has been found. These sub-groups are listed in Table 3.4. List of identified stakeholder categories and sub-groups.

Table 3.4. List of identified stakeholder categories and sub-groups.

Stakeholder category	Stakeholder sub-group
Workers	Components' assembly Technical studies / R&D Components' manufacturing and supply Raw material extraction/supply Civil engineering/sea operations OWF's exploitation & maintenance Transport & logistics Auxiliary services
Value chain actors	Components' assembly Technical studies / R&D Components' manufacturing and supply Raw material extraction/supply Civil engineering/sea operations OWF's exploitation & maintenance Transport & logistics Other services
Society	Public administration Training / Employment Media / Culture Research
Local communities	Local associations Public administration Professional fishing / Aquaculture Maritime & air navigation / Boating / Harbour activities
Consumers	Industrial users Households

- **Workers**

Workers are individuals associated with the different companies of the value chain of a product or service. The types of jobs and training that such a chain generates are numerous. Establishing an exhaustive list of sub-groups of workers involves a thorough work (Podevin, 2017). For this reason, worker sub-groups are identified according to the main activity of the company they are linked to. The evaluation of workers' social issues involves, in general, impact subcategories referring to the individual level and related to fair conditions (e.g., fair salary, reasonable number of worked hours).

- **Value chain actors**

Value chain actors stakeholder category is rather focused on an organisational level, and more related to organisational practices (e.g., fair competition, respect of intellectual properties). Defining sub-groups at the organisational level of the value chain means looking at the economic actors involved all over the life cycle. To deal with the large diversity of the two stakeholder categories, the sub-groups they were divided into were limited, in this thesis, to an adapted definition of the G4 standard, an international standard used for organising sustainability practices. (GRI, 2015).

- **Society**

The notion of society is broad and not linked to a particular territory or sector. The stakeholder sub-groups chosen to define Society are public administration (at a national level), training and employment organisation, media and culture, and NGOs.

- **Local community**

Depending on the territories and related life cycle stages considered, the definition of local communities can be broad. Social studies applied to French OWF projects consider, in general, the local community as people living around the plant installation. This includes private and public actors. Conversely, specific information related to local communities (and associated social issues) in other areas involved in the life cycle are scarce, especially data on local communities located in foreign areas where mining activities, for example, take place.

To consider the local community around an OWF installation area, the definition of sub-groups was based on the profiles of participants in public meetings identified in a previous PhD thesis (Bas, 2017). According to this reference, the terms used are the residents, local authorities, associations, recreational users, professional fishermen and other professionals as tourism professionals. As a reminder, the procedure to install an OWF project may differ from one country to another. In the case of France, this procedure involves public meetings between project developers and stakeholders. During these meetings, the stakeholders express their concerns, so they constitute a relevant source of information.

To gain a better understanding of the issues at stake for the stakeholders, the records of public meetings about a Southern Brittany OWF project were consulted in this PhD Thesis. These meetings allowed the

identification of some of these concerns. With respect to socioeconomic aspects, participatory funding was mentioned as a factor to be accounted for, as well as economic benefits for the territory. Participatory financing refers to the possibility for citizens to buy shares in a project. According to some participants attending public meetings, there are some concerns about the possibility of foreign companies being selected for their high skills in offshore operations (e.g., highly specialised vessels in construction stage coming from north U.E.) instead of French ones. This possibility would reduce the opportunities for the development of the French industry. Other socio-economic concerns include the quality of job creation and the professional training development (CNDP, 2021b). Some stakeholders requested to be involved in the development of potential shared uses around the OWF site, such as shipping or aquaculture activities (CNDP, 2021b). Overall, these elements reveal concerns mainly focused on the OWF construction and operation stages.

- **Consumers**

Consumers can be described as the customers using (i.e., buying) the product or service evaluated in the S-LCA. In this thesis, these consumers are the customers of electricity suppliers. Two types of customers have been identified: the industrial consumers, whose requirements in terms of electricity quality (i.e., continuity of supply, quality of voltage wave and service) can be high especially in certain sectors, and the individual consumer (e.g., households).

- **Statistical population assumptions for French OWF stakeholders**

This work focuses on two categories of stakeholders to apply the method for defining statistical populations and testing representativeness, namely local community and value chain actors. This choice is based on the elements highlighted by the literature review and the available data for the definition of statistical populations.

In this PhD thesis, the local offshore wind energy communities are defined as all private and public actors present in a territory potentially affected by OWF implementation in France. This definition excludes local value chain actors to avoid overlapping of groups that are already included in the value chain stakeholders' category. This work defines the statistical population for OWF local community based on an assumption related to the distribution of the main profiles of participants observed in public debates on offshore wind energy. This assumption is based on the PhD thesis by Bas (2017), in which the average distribution of sub-groups of local community stakeholders has been calculated from the information of public debates for four OWF projects: Courseulles-sur-mer, Fécamp, Saint-Brieuc and Saint-Nazaire. This results in the following distribution of sub-groups: Local NGO (38%), Public administration (33%), professional fishing (12%) and Maritime & air navigation / Boating / Harbour activities (21%). Some participants may have been assigned to more than one sub-group. It should be noted that the distribution of the local NGOs is rather dispersed with a standard deviation of 21% over

the four debates. Professional fishermen are represented by entities such as committees and producers' organisations, which could explain the low percentage of this profile in public debates. On the contrary, the other profiles are linked to atomised organisations and fewer clustered ones (e.g. pleasure boating, local NGOs). Therefore, more people would be invited to represent these types of profiles.

There are a few points to be aware of regarding the assumptions for the sample definition of local community. For instance, for professional fishermen, there is a risk that perceptions are hierarchically dependent on official opinions expressed by their professional organisations, namely fishery committees, since these committees have full mandate to represent fishermen and negotiate on their behalf (Kermagoret, 2014). Such awareness can concern any stakeholder's representatives whose role is to aggregate the points of view of a socio-economic group during public consultations or to negotiate on behalf of this group. Besides, due to the complexity of accessing residents and citizen profiles, which require special survey methods (e.g., field survey), this work assumes that their perspective is indirectly expressed through local associations and public institutions as local municipalities.

Concerning the sample of the value chain actors, the assumption used to define the statistical population is based on the census carried out by the French offshore wind observatory (Observatoire des énergies de la mer, 2020). The following distribution of the descriptive variable used for calibration in the representativeness test is identified as: Assembly of components (12%), Design / R&D (25%), Manufacturing of components (19%), Civil engineering (13%), Operation and maintenance (14%), Transport and logistics (8%), Support services (9%).

- **Sampling methods and tools application**

For the sampling of the different stakeholders' categories, mailing lists have been constituted from different sectoral cluster websites. The estimated relevant clusters cover sectors such as renewable energy, marine energy, and diverse maritime activities. For the local community, the final mailing list includes 342 different local public and private actors, and 640 for the value chain. At this stage, it should be specified that it is not possible to check one by one that each individual recipient of the survey is the most legitimate person to answer in the name of each organisation.

It should be mentioned that large sampling potentially involves the collection of off-scope contacts. These off-scope contacts may include generic emails, non-usable emails, or redirections to various support functions (e.g., communications, IT) that may not feel legitimate to answer to subcategories scoring. Therefore, it is assumed that off-scope contacts do not answer to the survey because they do not feel concerned. Conversely, it is assumed that for people choosing to respond to the survey, their answer is considered as legitimate.

As mentioned in the methodology section, among the mailing list, for organisations having more than one representative within the list, only one of them was kept. This was to avoid over-representation of the views of one organisation over others. However, considering the views of only one person within a stakeholder organisation is arguable. Indeed, an organisation may represent many people with different points of view. To increase the robustness of the data collection, it would be possible to consider as many respondents as possible for each organisation participating in the survey rather than just one. In this case, to avoid over-representation of organisations compared to others, the responses an average score per organisation could be used. Special attention should be paid to the anonymisation of the questionnaire, for reasons of data protection and to increase the completion rate.

- **Sample analysis and representativeness test**

For the local community stakeholder category, the survey collected 50 responses, which corresponded to a 16% feedback rate. As expected, almost all the respondents are in coastal departments involved in the implementation of an offshore wind farm. For the value chain actors, the survey collected 82 responses, that is, a 13% rate. In contrast to the local communities, it appears that not all companies were around an installation area.

Chi-squared adjusted test was applied to identify whether the distribution of stakeholder sub-groups was significantly different between the sample and the population. According to the result of this test, neither the sample of local communities nor the sample of the value chain actors were fully representative of their respective statistical population. For the local community (Table 3.5) the navigation and nautical actors were overrepresented in the sample (45%) compared to their presence within the statistical population (20%). On the contrary, public administration were underrepresented in the sample (14%) compared to the statistical population (32%). For the value chain actors (Table 3.6), the main difference was an over-representation of support services and design / R&D, with 19% and 32% of the sample, respectively, instead of 9% and 25% within the population. For consumers, workers and society stakeholder categories, respondents were fewer than the recommended threshold of 30 individuals. For this reason, no chi-square test of representativeness or adjustment was performed.

Table 3.5. Calibration variable for offshore wind farm local community stakeholder category.

Variables	Modalities	Sample (N=50)	Population (Public debates)
Local community sub-groups (calibration variable)	Local NGO	33%	38%
	Public administration	14%	33%
	Professional fishing	8%	12%
	Maritime & air navigation / Boating / Harbour activities	45%	21%

Table 3.6. Calibration variable for offshore wind farm value chain stakeholder category.

Variables	Modalities	Sample (N=82)	Population (Sectoral observatory)
Value chain sub-groups (calibration variable)	Assembly of components	7%	12%
	Design / R&D	32%	25%
	Manufacturing of components	16%	19%
	Extraction of raw materials	0%	n/a
	Civil engineering	8%	13%
	Operation and maintenance	13%	14%
	Transport and logistics	5%	8%
	Support services	19%	9%
	Other	0%	

At this stage, neglecting the representativeness bias would lead to a risk of generalising scoring results from samples that are not aligned to the real perspective of the whole stakeholder categories' members. An adjustment of the scores assigned by the sample to the impact subcategories is, therefore, proposed. To adjust the results, an adjustment coefficient is applied according to equation (3) presented in the section 3.1.2. Regarding the local community stakeholder category, the adjustment coefficients range from 0.45, for navigation and nautical actors, up to 2.33 for public administrations, who were, respectively, the most overrepresented and underrepresented profiles in the sample. In the case of the value chain actors, the coefficients ranged between 0.48 and 1.74. These coefficients were then applied to the gap values of each social impact subcategory.

3.2.2.3. Results of the gap analysis

This section provides a descriptive overview of the responses both at an aggregated and a disaggregated scale. Aggregated responses correspond to the results classified per large stakeholder category (e.g., local community), whereas disaggregated responses allow for the distinction between sub-groups within a given stakeholder category (e.g., local NGO, public administration, professional fishing and navigation and nautical activities, all of them belonging to the local community stakeholder category).

- **Disaggregated results**

The difference in score responses among the stakeholders' sub-groups within the local community category is analysed here. Based on scores associated with the criterion "Importance", responses do not vary greatly between respondents. Respondents scored the importance of all the impact subcategories as being relatively high. Conversely, scores on the criterion "Perception" showed a higher variability

depending on stakeholder sub-groups. Figure 3.7 presents disaggregated perception scores per stakeholder group within the local community category.

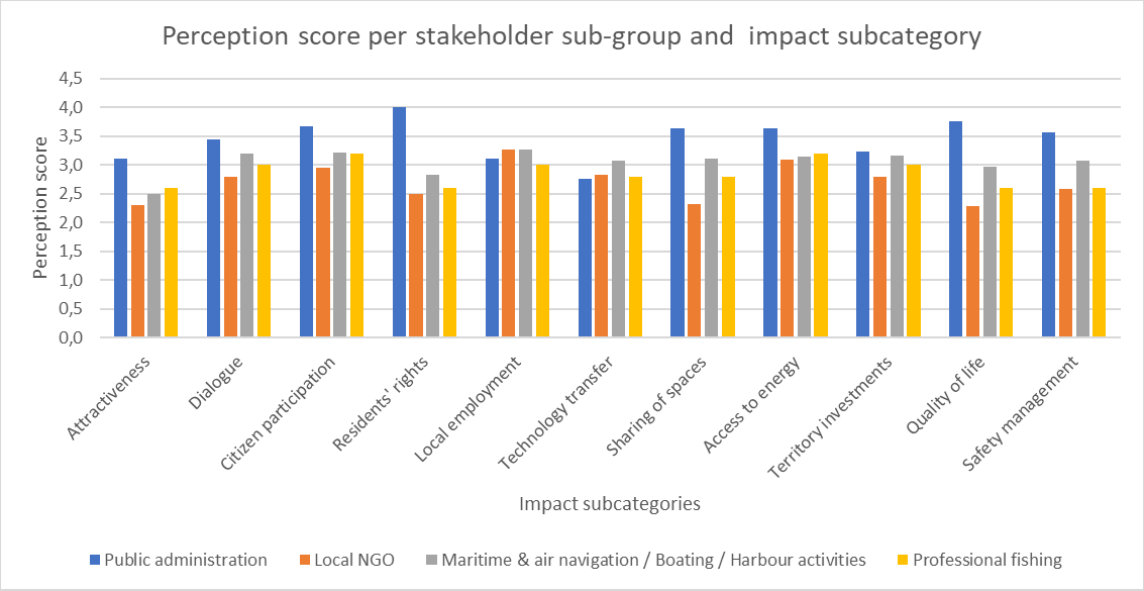


Figure 3.7. Disaggregated perception scores according to stakeholders' sub-group within the local community stakeholder category.

For most of impact subcategories, public administration representatives assigned a higher perception score than other sub-groups. According to the perception criterion defined in 3.1.2, this result means the public administration has, on average, a higher level of satisfaction than the other stakeholder sub-groups for the different impact subcategories addressed. Conversely, local associations assigned a lower average perception score than the other sub-groups, meaning that they may have more critical view of the social aspects related to the sector.

Disaggregated results support the assumption that the stakeholders' sub-groups may have a substantial influence on the perception of the social impacts of offshore wind systems. Considering the local community stakeholder category as a homogeneous group may result in hiding information. Therefore, interpretations at the aggregated level should be considered carefully. Based on these results, this work recommends considering the disaggregated data below the stakeholder category level at least as additional information. This information should make the results of the hierarchisation process more balanced and transparent, and then help anticipate issues about the limits of further S-LCA results. Moreover, these results highlight the necessity to question the representativeness of stakeholders' sub-groups in the survey, prior to the further aggregation of the results. For example, according to our results, a hypothetical over-representation of public administration sub-group in the sample should lead to overestimate the perception score compared to the perception of what would come close to the real local community stakeholder category. Based on these observations, aggregation of scores must be applied with transparency and by addressing representativeness issues.

- **Aggregated results**

Figure 3.8 presents the ranking of impact subcategories related to the local community stakeholder category based on the gap analysis approach. The figure shows the difference between the non-adjusted ranking and the adjusted ranking. Applying the adjustment changes the order of several impact subcategories, indeed. Thus, considering the non-adjusted gap score, results of the survey lead us to prioritise the impact subcategory "sharing spaces" (1.32), followed by the "quality of dialogue with the developer" (1.18) and the "safety management" (1.05). Based on the adjusted gap score, the first two impact subcategories "sharing of spaces" (-1.4) and "quality of dialogue with the developer" (-1.26) are still ranked at the top, but the "safety management" impact subcategory is replaced by the "local employment" (-1.07). Local employment is, indeed, a good example of the influence of the adjustment. Thus, it was ranked 6th according to the results without adjustment but reached the 3rd position in the results with adjustment. Regarding the Pareto approach, a threshold of 80% coverage of the total adjusted and normalised gap, is reached with at least 7 impact subcategories.

Among the results, the adapted impact subcategories related to "sharing of spaces" and "quality of dialogues" seem to have a priority for the consulted stakeholders. Conversely, "access to energy" appears in the last position of the gap analysis results. The electricity supply, which is the function of the assessed system, does not appear as a crucial issue for the sample according to the gap analysis. Employment issues, which are by far the most recurrent in the literature, are not ranked in the first place by stakeholders, who considered sharing space as an issue with higher priority in this study. It should be noted that these results represent a specific socio-economic context, and differences could be found in other territories. For example, areas with problems of access to energy could assign a much higher priority to this impact subcategory.

It should be noted that the standard deviation presents a high value. This high standard deviation can be explained by the variability of the respondents' perspective. Indeed, even if all individuals in the population are interviewed, the standard deviation will persist. This information is crucial and traduces the high heterogeneity of respondents' interests. This can be explained by the polarising nature of large-size installation projects in a territory, such as offshore wind power projects in France. Respondents' perspectives vary widely depending on whether they are in favour, against, or without opinion about the offshore wind development.

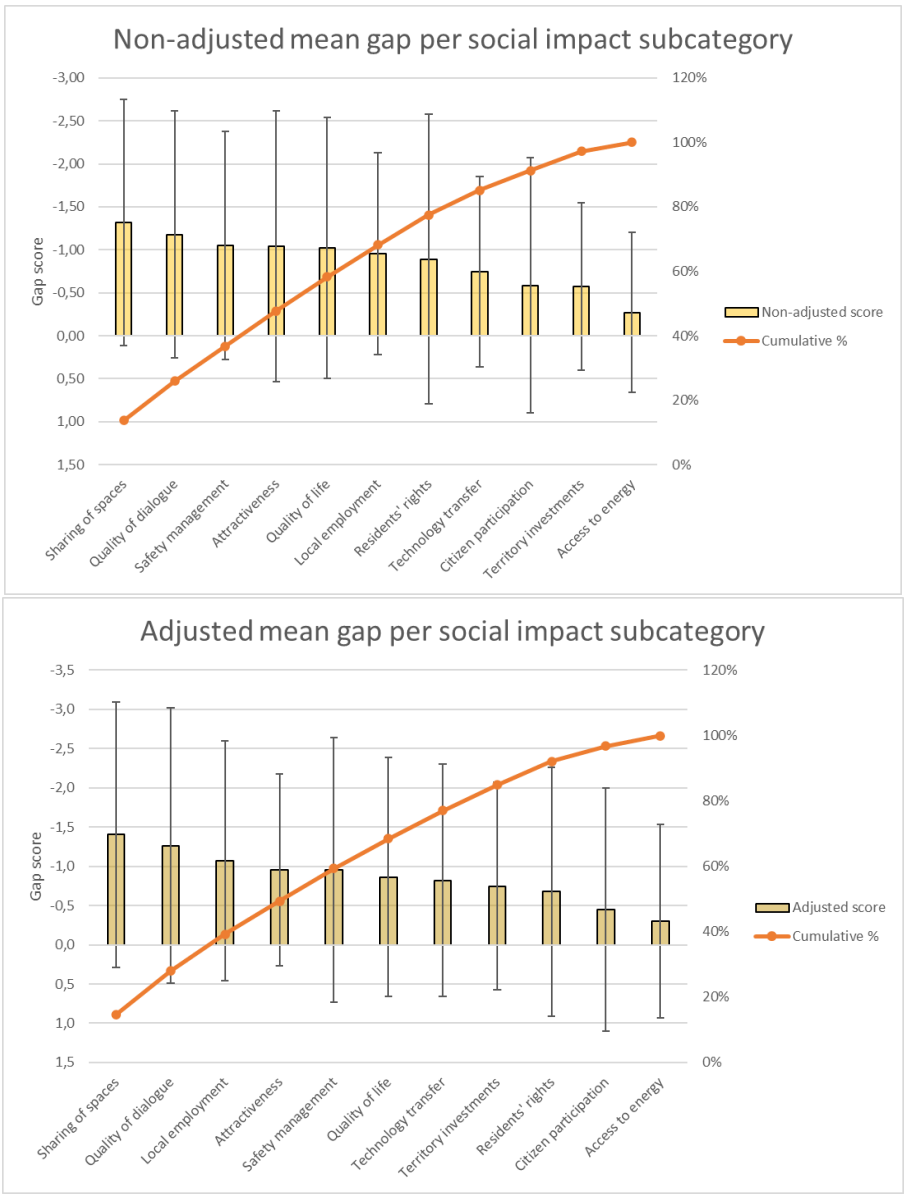


Figure 3.8 Hierarchisation results of local community ICs with Pareto – Lorenz curve (in red). A (above): sample without adjustment. B (below): adjusted sample based on distribution hypothesis.

Figure 3.9 shows the adjusted results of the impact subcategories hierarchisation for value chain actors stakeholder category. It should be noted that the adjustment of the responses does not change the ranking of the impact subcategories compared to the non-adjusted ranking. “Wealth distribution” was found to be the impact subcategory with the largest measured gap, followed by “supplier relationships”, “promoting social responsibility” and “fair competition”. The 80% coverage threshold is reached by considering four impact subcategories out of the five categories provided by the UNEP.

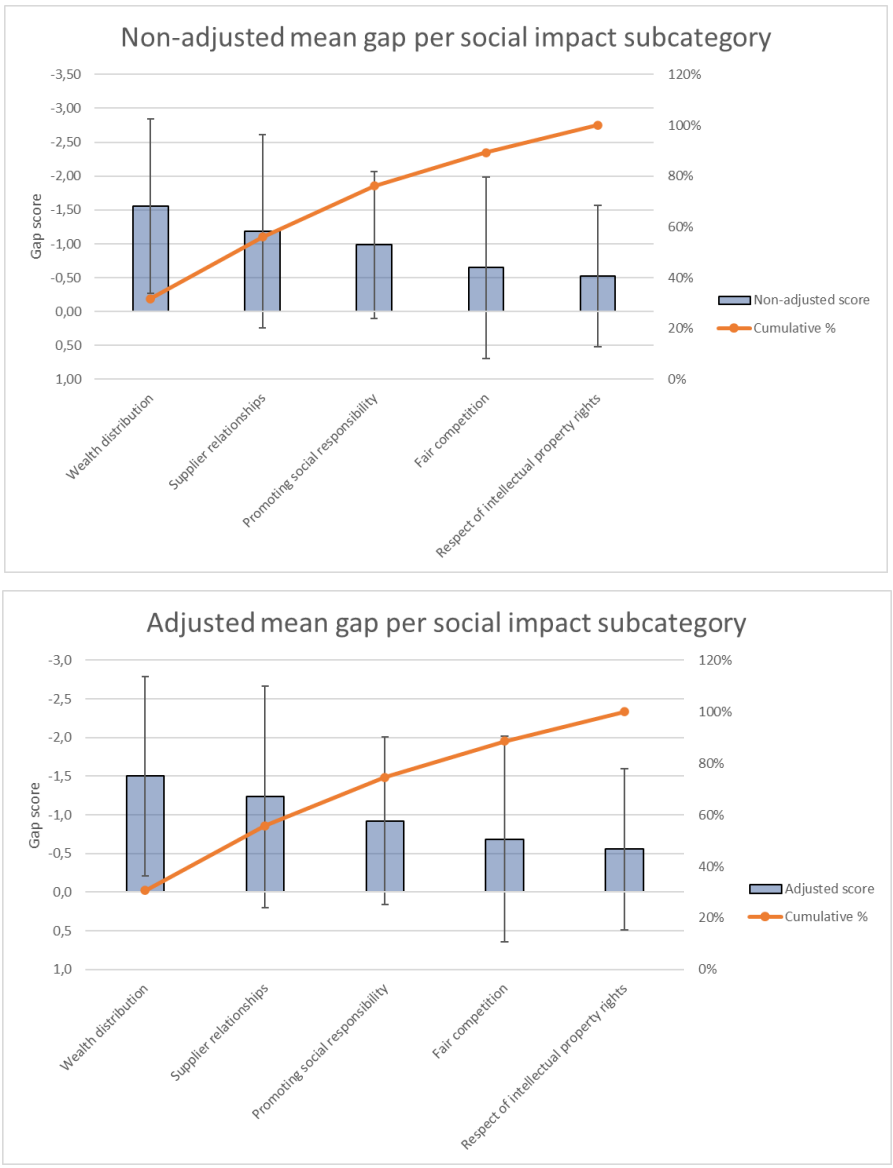


Figure 3.9. Hierarchisation results of impact subcategories related to value chain actors with Pareto – Lorenz curve (in red) - adjusted sample based on distribution assumptions.

Based on the gap analysis applied to the surveys intended to the different stakeholder categories, the normalised gap scores obtained from the hierarchisation surveys are listed in the Table 3.7. As a remainder, these scores have been adjusted only for local community and value chain actors stakeholder categories. For the other stakeholder categories, namely for consumers, society and workers, the score has not been adjusted due to the lack of a large-enough sample to respect the threshold needed for the representativeness test to be valid. For these stakeholder categories, the uncertainty surrounding the hierarchisation results is, therefore, considered higher.

Table 3.7. Summary of normalised gap scores per impact subcategory used to assess potential impacts based on survey results.

Stakeholder category (answers collected)	Social impact subcategory	Normalized gap score
Local community (N=50)	Sharing of spaces	15%
	Quality of dialogue	13%
	Local employment	11%
	Attractiveness of the territory	10%
	Safety management	10%
	Quality of life	9%
	Technology transfer	9%
	Territory investments	8%
	Residents' rights	7%
	Citizen participation	5%
	Access to energy	3%
Consumers (N=9)	Service to consumers	18%
	Respect for privacy	18%
	Possibility to identify the energy source in contracts	17%
	Environmental quality	13%
	Contribution to the development of industry at national scale	13%
	Quality and stability of the network	12%
	Contribution to the development of the territories	9%
Value chain actors (N=82)	Wealth distribution	31%
	Supplier relationship	25%
	Social and environmental commitments	19%
	Fair competition	14%
	Respect of intellectual property rights	11%
Workers (N=29)	Fair salary	17%
	Employer relationship	15%
	Working hours	13%
	Equal opportunity	12%
	Employee benefits	9%
	Health and Safety	9%
	Sexual harassment	9%
	Forced labor	8%
	Child labor	5%
	Freedom of association	2%
Society (N=21)	Absence of corruption risks	31%
	Social and environmental commitments	24%
	Energy independance	18%
	National economic development	16%
	Development of the territories	7%
	Technological development	3%

The results obtained should make it possible to identify which impact subcategories the practitioner should focus on for the next stages of the S-LCA, namely the inventory analysis and the impact assessment phases. The S-LCA practitioner can proceed from the subcategory with the highest score to the subcategory with the lowest score, as far as time resources allows. If exhaustiveness is not achieved, the S-LCA practitioner may inform transparently about the scope that will finally be covered. Limits of the conducted study should be noted, especially for the stakeholder categories consumers, workers, society. For these stakeholders categories, samples sizes were too low and no representativeness test was

carried out. Further work could aim to improve the systematisation of sampling with a specific focus on these stakeholder categories.

3.3. Conclusions

This chapter 3 aimed at addressing the issue of transparency in the hierarchisation of social impacts categories, from the designing of surveys to the processing of results. The results of the two hierarchisation approaches raise several issues for further discussion. First, it is important to remember the differences between the two approaches. In the case of the projects owners consultation (i.e., directly-involved stakeholders), the panel of respondents was restricted to a few people with similar profiles and representing large-size companies in the electricity sector. In the second approach, there were many stakeholders with very different profiles, more or less familiar with the sector, some of whom were more favourable to the technology than others. The ranking criteria also differed. In the case of electricity companies, the criterion used was directly the overall "importance" of the impact categories. For the external stakeholders, it was a question of measuring the gap between an expectation and a perception of the current situation.

The two approaches led to the ranking of impact subcategories. There is an important issue common to the two approaches. In both cases, a high variability of the responses was observed, based on the standard deviation obtained. This means that, overall, the hierarchisation results may not always ensure a consensus among all the respondents.

This Chapter 3 proposes a new methodological approach to rank the impact subcategories related to different stakeholder categories, based on a gap analysis followed by an adjustment of the sample to better represent the statistical population. Moreover, the work explores the influence of disaggregating the results according to the respondents' sub-groups, using an intermediate level of disaggregation, in order to increase the transparency and the robustness of the proposed gap adjustment. The results show that the respondents' position in an organisation could influence their perception of social impact subcategories. For instance, considering the professional fishermen group within local community category, their perspective may be different to a policy officer in a fisheries committee.

In general, participatory approaches appear to be time-consuming for the practitioner. The surveys and sampling method proposed in this work can be redeployed. As a result, this work contributes to the systematisation of the use of participatory approaches for goal and scope definition in S-LCA. Such an approach at the start of an S-LCA study helps to guide the other S-LCA phases, including the inventory analysis, impact assessment and the interpretation phases. Based on the scores from a hierarchisation, explorations should be carried out to define an optimum threshold of impact subcategories to be retained. This would involve defining rules to identify a compromise between the breadth of the scope (i.e., the number of impact subcategories to be retained considering their hierarchisation score) and the depth

(i.e., the further analyses to define and assess impact indicators). In addition, future work could be oriented towards combining the results of the hierarchisation with the weighting of the impact subcategories following the impact assessment phase. Indeed, these two operations could converge. However, weighting needs to be treated carefully. When weighting is coupled to an aggregation operation to combine the impacts into a single score, the aggregation should be carefully considered to ensure that it does not result in effects being masked, or unfavourable impacts being offset by other favourable impacts.

Regarding variables that may influence the perception on different impact subcategories, the disaggregated characterisation of stakeholders should be deeply explored. In this work, only one calibration variable was used. To make the fit more accurate, and thus the results more robust, further work should improve further statistical data processing and explore the use of several calibration variables. Using several calibration variables, however, involves identifying in advance which variables could influence the allocation of scores for each impact subcategory. Designing the survey to identify the type of profession of the respondent should bring, at least, more transparency about the legitimacy of the respondent's perspective. This information could be provided by adding a question about the job category with a baseline list such as: self-employed / engineer / business manager, support (HR and communications), technical and operational. Beyond the professional function, other inherent bias on impact subcategories perspective related to diverse socio-economic characteristic exist, such as age, level of education, income, geographical area, etc. Including these potential additional variables could make the study of representativeness more accurate and the results more robust at the level of a stakeholder category. The disaggregated results could be studied in different cases of OWF projects, whenever data are available. It is also likely that the territorial context differs according to the OWF projects and influences the level of relevance of the different impact subcategories as seen by the stakeholders.

4. Multi-scope inventory and impact assessment applied to offshore windfarm systems in France

Following the identification of stakeholders and the hierarchisation of impact subcategories presented in the previous chapter, chapter 4 focuses on the inventory analysis, impact assessment and interpretation phases applied to offshore wind power in France. The inventory analysis phase involves collecting the data required to model the system over their life cycle and to conduct the impact assessment. The impact assessment consists of identifying sectoral social risks and/or measuring social performance of the system with respect to the selected impact categories. Carrying out these phases requires an understanding of the link between the OWF system and the stakeholders potentially affected by them.

The literature reveals many socio-economic concerns related to the offshore wind power sector, with particularities to be considered in relation to the installation and operation areas. These particularities are, for example, related to the cohabitation of a new OWF with existing local jobs. To achieve a level of detail that integrates these different local particularities into an S-LCA framework, a local scope is needed. In addition, the literature reveals certain impacts at a national level, for example linked to the consequences of the development of a new sector. Thus, a national scope is also required. To integrate all life cycle activities, sectoral social risks are considered in this thesis on a global scope. The global scope is addressed with a conventional S-LCA approach that consists in the use of a database of sectoral and country-level social risks and an LCA software. The application is carried out on different technological scenarios to comparatively identify the activities and components most linked to sectoral social hotpots. National and local scopes are covered by the performance-reference-point approach, notably because its flexibility allows the inclusion of new indicators related to sector-specific issues.

4.1. Distinction between geographical scopes in S-LCA

In general, the S-LCA framework considers a global geographical scope by including all countries involved in the life cycle of a product or service. As mentioned in chapters 1 and 2, several studies recommend dealing with the local dimension of energy plant development in the context of energy transition (Buchmayr et al., 2022; Jollivet, 2013; Mocquet et al., 2021). In particular, for the development of the OWF sector, the scientific literature and stakeholders' consultation, generally highlight social concerns at the geographical level of the installation and operation site.

As a reminder, one of the main objectives of S-LCA is the identification of social hotspots and opportunities for the improvement of the social performance of product systems. Thus, the proposed S-LCA framework aims to achieve this identification. Depending on the specific sectoral issues, the application of S-LCA may require adapting existing impact subcategories and related indicators or even proposing new ones.

These elements lead to the need for distinguishing different geographical scopes related to both inventory analysis and impact assessment phases. The distinction involves defining the impacts related to the identified geographical areas where they occur. The approach proposed in this PhD thesis aims to highlight the distinction of impacts depending on where they occur within the life cycle of the system.

The definition of a local scope results from the need for specific impact subcategories and indicators to measure the externalities related to the implementation of energy generation projects. For example, metrics from environmental economics can be used to estimate impacts on the landscape or land values. Similarly, metrics developed in marine ecology or marine economics can be used to assess the impact of projects on the marine environment and, consequently, related to stakeholders dependent on marine ecosystem services. The local scope may also serve to reinforce the distinction between jobs created across the value chain in the whole country, and those created locally in the installation site. Thus, local scopes correspond to life cycle activities relative to the installation area extended to the regional administrative boundaries, including mainly construction and operation of an OWF. Regarding the decommissioning and end of life stages, though the dismantling stage itself is local, other end of life activities can occur in different countries. Due to the lack of information on the potentially different countries linked to the end-of-life of offshore wind farms, this stage has been excluded from the system boundaries in this PhD thesis.

A national scope is also proposed, to consider the impacts related to the development of a sector in the country, by considering the government's perspective. As a decision-maker, the government is interested in developing an economy for the country, promoting energy transition and sovereignty.

Finally, social hotspots must be considered over the entire life cycle. This means looking at the social context of the different sectors and countries related to the life cycle activities, with a conventional S-

LCA approach using databases and LCA software. In this PhD thesis, a global scope assessment is also conducted, to complement the local and national scopes previously described. Overall, the proposed approach in this PhD thesis is illustrated in Figure 4.1.

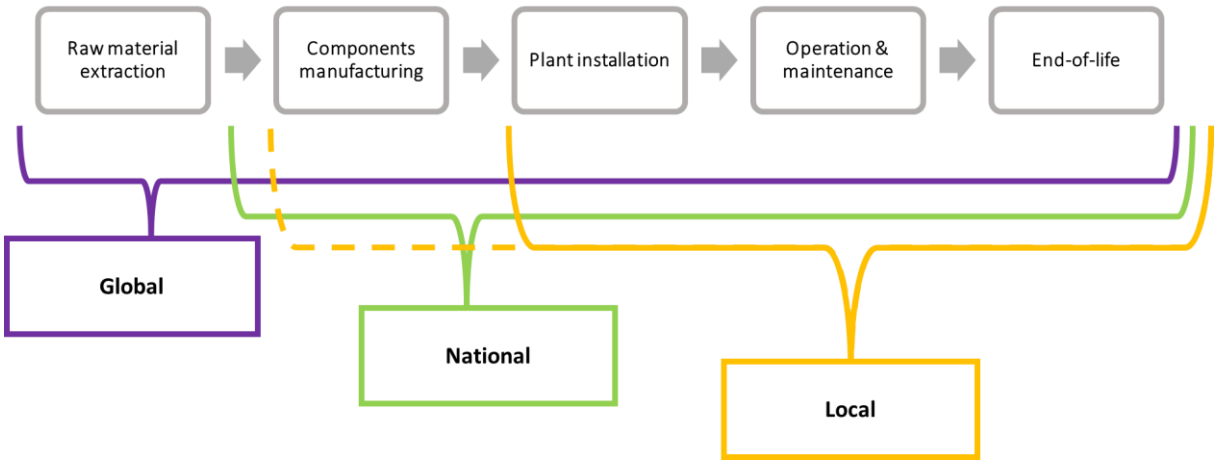


Figure 4.1. Diagram of the main offshore wind life cycle stages and corresponding geographical scope assumptions according to the methodological approach proposed in this PhD thesis. Some components manufacturing life cycle stage may be occuring at local scope.

To analyse the social performance of a system at the global scope, S-LCA databases are suitable for obtaining an estimate of the order of magnitude of potential social impacts occurring in related process-activities and countries involved within the whole life cycle, including all the stages. Collecting site-specific data at this global geographical scope would be not only complicated and time-consuming, but also restricted to very few indicators. As mentioned in chapter 2, this PhD thesis favours using the PSILCA S-LCA database because it provides more information on data quality than other available databases, such as SHDB (UNEP,)**,** and it has been already used in an OWF context (Buchmayr et al., 2022). Generic databases such as PSILCA or SHDB have some limitations in terms of resolution. Thus, they may not cover all the impact subcategories perceived as a priority by the stakeholders. Moreover, they do not cover impacts' specificities on a lower scope than the country level.

It is important to consider the perspective of stakeholders without omitting sectoral specificities, as for example local concerns related to construction and operation life cycle stage of OWFs. Because some of these concerns are not covered by S-LCA databases, some indicators need to be added to those already included in the databases and measured using different types of sources. Some of these indicators may be adopted from previous studies in S-LCA or sustainability analysis applied to energy systems. This is the case for indicators related to, for example, "job creation" or "avoided fuel imports allowed by renewable energy" that are addressed is some sustainability studies (Roinioti and Koroneos, 2019). However, some of the social concerns related to OWF are not yet covered by available studies on S-

LCA or sustainability. In this case, identifying indicators from sectoral literature other than S-LCA and sustainability studies is necessary. For example, to cover issues related to conciliation between OWF and maritime uses, indicators can be adapted from studies in social sciences, such as “the willingness to practise recreational fish near” (Hooper et al., 2017), or ecology sciences through the evaluation of potential impacts of OWF on fisheries (Halouani et al., 2020).

Based on the same examples of indicators, the differences between local and national scopes should be highlighted. Depending on OWF projects and regional profiles, the share of jobs created locally is likely to differ. An example can be illustrated by referring to the distinction between companies located close to an OWF, and those located elsewhere in France, based on survey results mentioned in chapter 3.

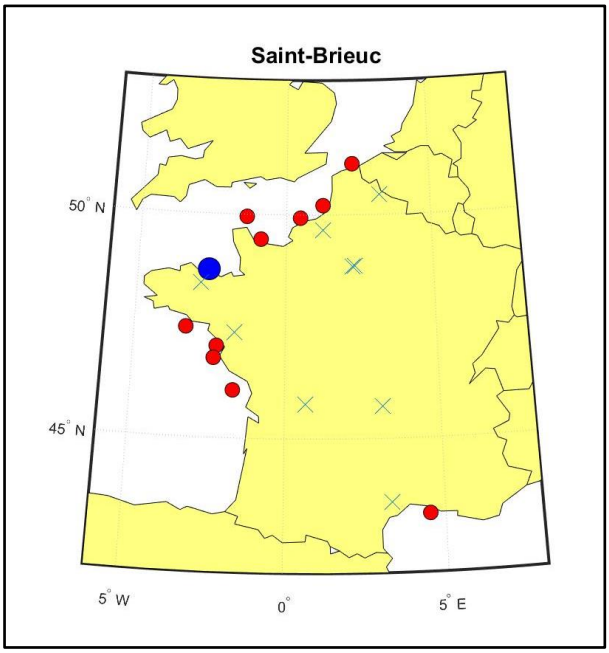


Figure 4.2. Geographical location of companies responding to the impact subcategory hierarchisation survey for the Saint-Brieuc OWF

The map in Figure 4.2 presents the various wind farm projects mentioned in the surveys (red circles), and the location of the companies that responded (crosses) related to the Saint-Brieuc wind farm (blue circle). These results revealed that only a part of the value chain is located near the Saint-Brieuc wind farm. This trend was similar to other OWFs. This observation supports the need for distinguishing between economic benefits associated to different geographical scopes.

Conversely, the national scope considers not only consequences around the OWF installation site, but the consequences of the industry created on the whole country. This allows consequences such as national economic development or energy independence to be accounted for, in the context of energy planing, from a government level.

This distinction of scope involves the identification of different indicators and the use of different tools and data sources. The following section presents the inventory phase conducted in this PhD thesis by considering this scope distinction.

4.2. Review on French OWF social issues in France

This section gathers social specificities related to the emerging French OWF sector. Most of these aspects are local concerns. Some of them are addressed by different studies (Ladenburg, 2009; Ladenburg and Dubgaard, 2007). One key challenge consists of identifying to what extent the S-LCA framework developed in this PhD thesis can integrate these considerations. Energy production systems such as OWFs involve the installation of large-size infrastructures within a territory, which are expected to interact with several stakeholders' activities. It is therefore necessary to consider the characteristics of the installation site, such as the job profiles present there prior to the installation of the OWF. A sectoral literature review was conducted to identify such characteristics. As a complement to this sectoral literature review, a verbatim of almost 20 hours of public meetings' recordings about the South Brittany OWF project and additional documentation on the topic have been collected.

- **Tourism and landscape**

Consequences of OWF projects on the existing tourism sector for a given territory have been explored by available studies that estimate the tourists' preferences. For example, a study has been conducted to define variables that influence the tourist preferences related to sites of offshore wind farms in the Mediterranean Sea (Westerberg et al., 2013). The preferences of tourists were evaluated based on the distance of hypothetical OWFs to the shore (i.e., 5, 8, 12 km). Economic sciences methods were used to find a theoretical willingness to pay according to different scenarios. Among the outcomes, the literature review showed that a number of social and demographic variables can influence the perception of OWF impacts on tourism, including age, gender, income, level of education and the geographical origin of tourists (Ladenburg, 2009; Ladenburg and Dubgaard, 2007). The respondents with higher education level were found to be significatively less concerned by wind farms near the coast (Westerberg et al., 2013). Besides**,** results showed that the impact of discomfort (i.e., visual annoyance) on tourism tends to zero for OWFs located beyond 8 km from the shore. Despite these results from the literature, stakeholder verbatims of public debates in France still revealed some concerns about the potential consequences that the impacted seascape could have on local jobs such as those in tourism (CNDP, 2021b). The notion of acceptance is complex and depends on numerous factors, such as the socio-demographic background of individuals. Other studies assessed the willingness to pay to reduce landscape impacts from OWF. In this case, in addition to the distance from the shore, other attributes

were found to have an influence over the potential impacts. For example, the number of turbines of the OWF to be installed in a given site, and the existence of previous OWF in the country can influence the perception of a new OWF implantation. While most studies are based on the perceptions of tourists, a recent study focus on the perception of impacts from the perspective of tourism services, as well as actors who develop and provide these services (Eudleur, 2023). This study makes it possible to distinguish between the different impacts on tourism according to the typology of the areas where it is developed. Among these areas are the retro-littoral area, which is inland, the touristic coastline on the equipped seashore, the beach up to the distance of 300 m from the shore and the navigation zone beyond the distance of 300 m from the shore.

- **Professional fishing**

Depending on territories, professional fisheries can be an important activity for a local economy. Therefore, stakeholders related to fishery activities are frequently consulted because of their link with maritime space and fish stocks. Main concerns are related to the potential impact of OWF on commercial fish species or the constraint in terms of navigation area (e.g., the lengthening of routes and therefore additional fuel consumption) (MEDDE, 2012). It would be complex to consider all these aspects in this thesis. However, existing work could provide generic data on the potential impact of OWF on fisheries resources (Halouani et al., 2020).

Potential impacts of OWFs related to this concern may be either favourable or unfavourable. Indeed, OWF may involve benefits. For example, in some cases, OWF may be linked to a “reserve effect” or “spillover effect” that can entail changes on fishery resources. These effects consist in a situation in which closing areas to navigation could result in an increase of productivity in terms of fish resources, due to the reduction in fishing pressure. Another concept is the fish aggregating device (FAD) effect, which explains that submerged structures can attract founder species to the ecosystem. For example, a study found that fish catches may increase in the surrounding areas of a OWF closed to fishing (Halouani et al., 2020). In the absence of feedback from existing OWFs in France, this study can be used as a source of generic data to estimate the potential future effect of an OWF on fishery resources, and therefore on the stakeholder group of professional fishermen. It is important to note that using such a generic value involves large uncertainties.

- **Navigation constraints**

The application for the obtention of the environmental authorisation and the concession to use the public maritime domain requires considering air and sea navigation, as well as military servitudes. For example, in the case of a commercial OWF project around South Brittany, the installation area is off the main shipping routes such as the Ouessant rail (Gouvernement and RTE, 2022a). Considering that maritime issues related to military activities and navigation are already managed during the delimitation

of a OWF installation area, such kinds of stakeholders are not considered as a priority in this social impact study. In addition, the distance between an OWF and the shore is generally greater than the maximum distance for coastal leisure boating (6 nautical miles, equivalent to around 11 km). More in-depth studies could assess whether the change of seascape still affects the attractiveness of the navigation site. The issue of navigational safety is still frequently raised during public debates. This issue can be considered through generic data by estimating an average risk of collision between a boat and OWF structure.

4.3. Inventory analysis phase

As a reminder, the S-LCA inventory analysis phase involves gathering data related to stakeholders and activities of the life cycle, as well as site-specific and generic data depending on indicators to be measured. In this section, the collection of information is organised according to the three scopes previously presented in this chapter. The inventory analysis phase differs depending on the scope considered, namely the global, national and local scopes. The details to conduct the inventory analysis phase for each scope are explained in sections and 4.3.1 and 4.3.2.

Before the description of the method applied to each scope, a specific feature of the assessed system in this study should be reminded. In particular, the emerging nature of the OWF in France should be considered. In this context, the strong industrial competition context in the sector implies a high sensitivity for data related to technical and economic data defining the system. This can translate into confidentiality of information and therefore restricted, if not impossible, access to primary data. Primary data is directly collected by practitioners through, for example, surveys, while secondary data corresponds to information initially collected and manipulated by another person/institution before being used by the practitioner (UNEP, 2020). For the above-mentioned reasons, the emerging nature of the OWF sector makes it difficult to base studies on primary data due to the lack of feedback and the data access constraints for the different stages of the life cycle, including the installation and operation stages. The extensive literature on existing OWF projects currently in operation or under development, namely the grey literature, constitutes a valuable alternative source of secondary data that could help address the issue of lack of primary data. Secondary data may be either site-specific or generic. Depending on the indicators to be addressed and the projects for which information is available, the possibility to collect site-specific data may be limited. This may sometimes lead to the use of generic data for certain indicators and case studies.

The number of socio-economic impacts to be covered involves the need for a wide range of sources. Due to all these constraints related to data availability and the different levels of specificity, the process followed by a practitioner to identify the most relevant data sources to be used should be clearly stated

and justified in an S-LCA. In the context of this thesis, and according to the UNEP 2020 definition, data labelled as "site-specific data" corresponds to all information related to a specific OWF project in France, whereas generic data refers to all the information that is not specifically related to a given OWF project in France. Based on the expected level of reliability and representativeness of the reality of different sources, the highest preference should be given to data from on-site measurements for a given case study, and the lowest preference for generic data at the level of a whole sector, for example, the whole energy production sector. There are other intermediate levels of preference, such as, for example, unspecific secondary data referring to systems other than the case study but similar to it, either located in the same country or in a different one. Additional discussion on this topic for the specific case of OWF systems is provided in 4.3.2.2.

In line with the general principles of LCA, and whatever the geographical scope, the whole methodology should be applied iteratively. This reasoning has long been used in the social sciences: during data collection, iterations serve to refine the understanding of social processes under study (Becker, 1970). The inventory analysis phase is particularly liable to this iterative approach. Indeed, different sources can be used for the collection of data for a given impact subcategory and/or associated indicator(s). Successive consultation of these sources can lead to enhance or update an indicator measurement. However, it can also lead to raise some questions about the indicator's definition, or even to replace it.

The following sub-sections present the application of the inventory according to the different scopes defined.

4.3.1. Global scope

The global scope aims to assess the potential social impacts, or risks, that occur over the entire life cycle of a product or service. In this PhD thesis, the global scope is addressed using a conventional S-LCA modelling. The approach consists of assessing social risks regarding sectoral and geographical context of activities involved in the whole life cycle of OWF. For this, an S-LCA database is used. This type of database gathers social risk data for different impact and stakeholder categories, according to the industrial sector and the country where each activity takes place.

To model the activities of the life cycle using the PSILCA S-LCA database (Ciroth et al., 2015; *GreenDelta*, 2016), the different sub-steps carried out in this thesis can be resumed as follows:

- estimating the amounts of components and associated raw materials;
  related to the system (common part with environmental LCA inventory);
- identifying the monetary costs of the components and relative share labour costs for the components' manufacturing;
- identifying the related process-activities and countries.

4.3.1.1. Methodology for global scope inventory

To build the S-LCA model for the global scope using existing databases, the inventory data needed to correspond to data of materials and components of the assessed system, as well as related cost of materials, labour cost, and geographic origin. For a given activity (e.g., "tower manufacturing"), the cost of labour corresponds to the workforce expenditure relative to the activity itself, and the cost of the material represents the price of the different materials used (e.g., steel). In the absence of exhaustive information on these costs specifically related to the system, assumptions could be used. Assumptions may consist of identifying prices of raw materials, and/or the cost of labour in each sector from generic sources. On this basis, it is possible to estimate costs of components by aggregating the costs of all the materials they are composed of.

Figure 4.3 below shows the steps to be taken to identify and to collect the inventory required for an impact assessment using an S-LCA database. More specifically, the methodology outlines the steps to be taken in the absence of an exhaustive inventory, using generic information. This is a common situation when aiming to assess the social performance of projects that are not developed yet, as is currently the case for most OWFs in France.

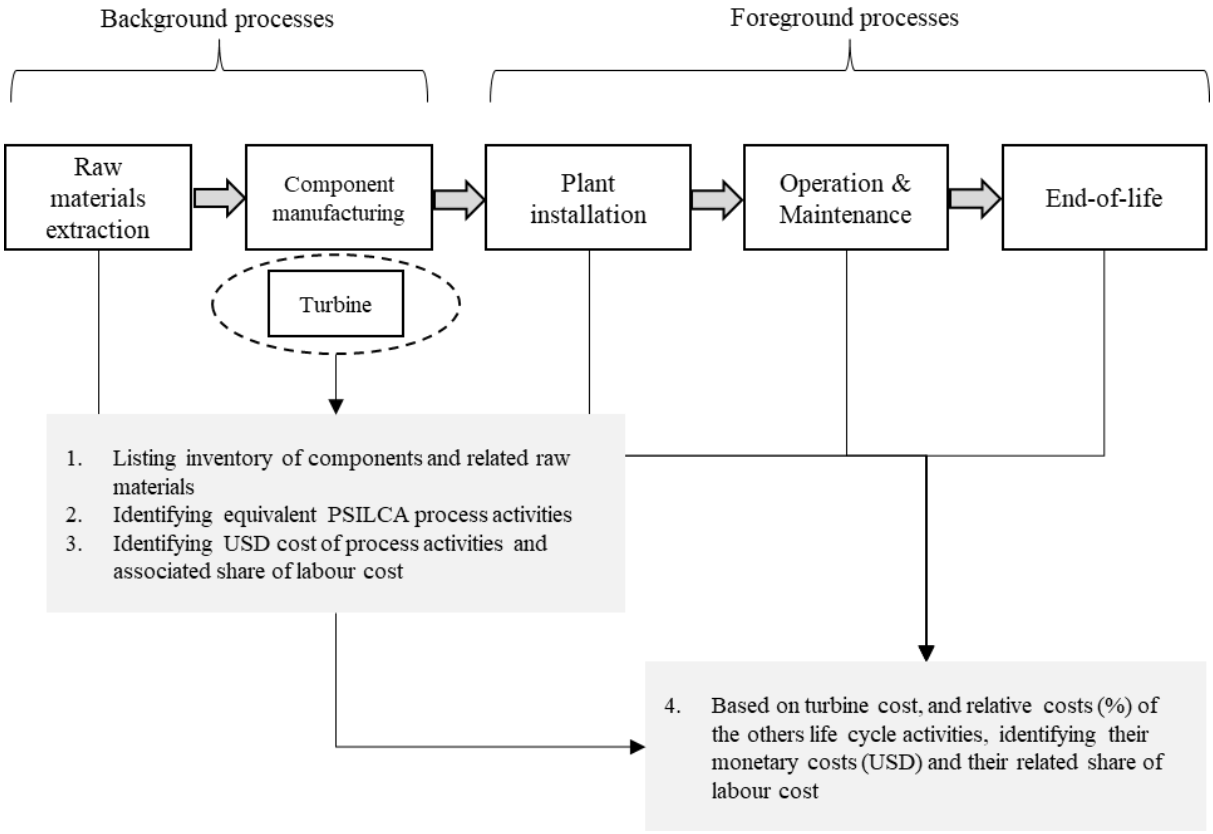


Figure 4.3. Life cycle stages of a baseline OWF and associated methodological steps to conduct the inventory analysis phase related to global scope assessment.

First, in the absence of a specific inventory related to a French OWF case study, the inventory of a generic wind turbine could be used. Depending on the turbine power of the studied OWF, the corresponding inventory can be scaled based on a generic turbine model close to the reality of the assessed French OWF case study. The list of materials used per component and their associated individual costs can be used to estimate the cost of a turbine. Then, grey literature is used to identify average costs ratios between the turbine and the other activities within the life cycle. Then, once the cost of the turbine has been estimated, it is possible to estimate the cost of these other activities, including installation as well as operation and maintenance activities.

In addition to estimating the cost of the activities, the different industrial sectors need to be identified, as well as the country where the activities are carried out. In the absence of information on the geographical origin of the materials used, it is possible to use the default information corresponding to the trade flows provided by Eora to PSILCA database, as explained in the chapter 2. For a given process, different background supplying countries and sectors are considered, according to available data from Eora Input-Output database. Eora provides background data on money flows between country-level sectors. For example, the generic "Manufacture of basic metals" process in France involves upstream suppliers' countries as Belgium, Italy, Germany, Spain, and the Netherlands. Thus, the specification of the country when defining the processes does not mean that all the production is conducted within the designated country, but that the market mix corresponds to the one in the country. Following the steps described in Figure 4.3 the life cycle can be modelled, and the social impacts assessed.

Figure 4.4 resumes the different steps typically conducted to convert a life cycle inventory for environmental LCA into an appropriate inventory to model the system with a S-LCA database.

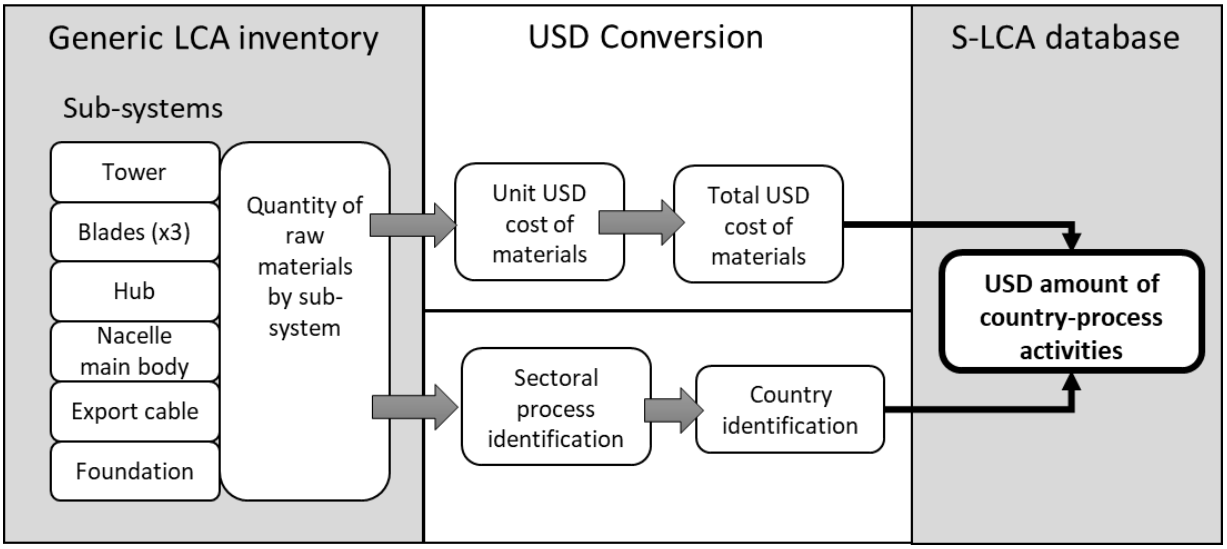


Figure 4.4. Standard steps for converting an environmental LCA inventory for use in a Social LCA database, adapted for the OWF case.

While estimating different activities per country and associated USD costs, the activity variable has to be quantified. The notion of activity variable and related equations have been presented in chapter 2. The activity variable is used by S-LCA background databases such as PSILCA and SHDB to measure the share of a given activity with respect to the whole system. For instance, the “worker hours” is a common activity variable. It corresponds to the time workers spend to produce a certain amount of product in the given process or sector (Maister et al., 2020; UNEP, 2020). In the PSILCA database, it is presented as working hours per 1 USD of product output. This number of working hours is filled in for foreground activities. For foreground activities, such as components’ manufacturing (e.g., "tower production"), working hours must be determined. In the absence of specific data, however, assumptions could be used to assign working hours. This assumption can consist of using working hours identify for a similar generic activity already available in PSILCA. Other assumptions may be necessary to determine the activities’ costs, the share of labour cost, and the geographical location of the activities. These assumptions constitute sources of uncertainty that affect the results of the global scope assessment. Therefore, for the implementation of the approach, it is important to present all these assumptions clearly. The application and related assumptions to the case studies considered in this study are detailed in the following sub-sections.

It is important to consider that OWF systems can considerably differ in many parameters, such as size and number of turbines, foundation types or distances from the shore. These parameters have an influence on the industrial sectors involved, and thus, on the modelling of the life cycle using S-LCA databases and the subsequent results of the impact assessment phase. In this PhD thesis, two OWF scenarios were modelled in PSILCA, characterised according to these parameters. The assumptions to define the values for these parameters were mainly based on average observations of different French OWF cases. A comparative analysis of social hotspots between these baseline average scenarios for the global scope was conducted and is presented in more detail in the next section. The results allowed the identification of potential risks in the life cycle that could be linked to each of the two assessed design choices. The inventory will be mainly based on the use of generic data, i.e., the use of an LCA-inventory from the literature and adapted according to the parameters of the two scenarios modelled. Cost data and assumptions on the geographical location of the manufacture of the main components will be used.

4.3.1.2. Application of the global scope approach to OWF inventory analysis

- **OWF baseline scenarios for the application of the global scope approach**

The global scope impact assessment has been tested on two hypothetical OWFs. Based on the average designs observed among emerging wind farm projects in France, it is possible to distinguish two main types of wind farm configurations: systems equipped with floating foundations and systems relying on fixed foundations. Fixed wind farms correspond to the first offshore wind farms developed in France. Floating technologies are expected to be progressively developed, given a number of advantages compared to fixed ones. Thus, floating foundations make it possible to install offshore wind turbines further away from the coast, with potential benefits in terms of construction advantages, better wind resource in the installation location a reduction of some social concerns, such as visual impacts.

Based on observations, two scenarios are used to estimate the potential risk related to each of the two main families of OWF technologies. The offshore wind farm designs considered in these two scenarios differ on several parameters, including the distance from the shore, the foundation technology, the power and the number of turbines. Both scenarios present a total power capacity around 500 MW. A summary of the parameters considered is provided in Table 4.1 below.

Table 4.1. Summary of technical parameters considered for two OWF scenarios.

Parameters / Scenarios	Fixed scenario	Floating scenario
Number of turbines	50	42
Power of turbines (MW)	10	12
Total power (MW)	500	504
Foundation model	Jacket	Semi-submersible steel floater
Distance to the shore (km)	25	50
Length of export cable (km)	50	80

The expected outcome of the generic S-LCA for the global scope, applied to two different technologies is a range of risk hours obtained from the comparison of the two scenarios. It should be noted that results may be considerably affected by uncertainties. These uncertainties are dependent on the limited level of detail of the sectoral information provided by the S-LCA databases (in this case, PSILCA), which make distinctions between case studies of similar technologies hard to model, as well as on the scarcity or even absence of specific inventory data. These factors suggest that the differences between real cases studies with similar technological designs to the two baseline scenarios assessed here may be rather limited compared to the large level of uncertainty inherent to the modelling limitations. This is one of

the main reasons to justify why only two average scenarios are used. They are considered to represent the main differences between the two main families of technological scenarios. Thus, based on the obtained results, it is possible to identify which of the two technological choices may generate more risks due to the sectors involved. It is important to note that these scenarios rely on various assumptions regarding the inventory that are presented in the following sections.

- **OWF sub-systems identification**

An OWF system is relatively complex and involves several components and activities. To identify and select the most relevant activities and sub-systems to be accounted for, a cut-off criterion could be applied. Cost allocation was selected in this study. As mentioned in chapter 2, cost allocation is preferred as the cut-off criterion rather than mass, because cost may better reflect the intensity of workers' presence (Benoît-Norris et al., 2012). This choice of allocation for sub-system selection involves identifying the costs of the various sub-systems. Only the activities with the highest costs are selected. Activities representing less than 5% of total costs were not considered in this study, but this threshold may be adapted depending on the context of study. This assumption involves that the most expensive activities are considered to be those potentially linked to the highest number of hours worked upstream, thus, potentially generating more social impacts.

Costs can be useful to estimate the activity variable (i.e., the working time). Based on generic sources, approximate costs of the main activities for a baseline fixed and floating OWF have been collected. Relative shares of CAPEX, OPEX, and end-of-life activities cost for baseline OWFs have been identified from MTES (2021). Then, costs of the activities (in €/MW) including components' production, have been identified for average fixed and floating OWF (Cruciani, 2019). They are presented in Table 4.2. Table 4.2 shows approximate average costs, which may vary depending on the design of the offshore wind farm (e.g., turbine model, distance from the shore). Foundation manufacturing costs can vary from 7% to 37% in relation to total costs of a given OWF project (Cruciani, 2019). Given these uncertainties, the standard deviation of the cost share may be relatively high, due to the different existing models and materials used, especially regarding the technology of the foundations and their raw materials (e.g., concrete and/or steel). In particular, foundations manufacturing costs are remarkably higher for floating foundations than for fixed ones, likely due to the higher average quantity and type of materials required. On the contrary, installation costs are lower for floating wind turbines. Indeed, floating wind turbines require less civil engineering work in the sea, as they are towed from harbour.

Table 4.2. Approximate average costs (€/MW) of the main activities for a baseline fixed and floating OWF (adapted from Cruciani, 2019; MTES, 2021)

	Cost (%)	Source	Activities	Fixed (generic values)		Floating (generic values)		Source
				Cost €/MW	Cost (%)	Cost €/MW	Cost (%)	
CAPEX	78%	(MTES, 2021)	Design / R&D	1,0E+05	4%	1,0E+05	3%	(Adapted from Cruciani 2019)
			Turbine manufacturing	8,0E+05	30%	8,0E+05	22%	
			Foundation manufacturing	2,0E+05	7%	1,3E+06	37%	
			Cable connection	5,0E+05	18%	5,0E+05	14%	
			Installation	5,0E+05	18%	2,5E+05	7%	
OPEX	18%		Operation and maintenance	5,0E+05	18%	5,0E+05	14%	
End of life	4%		Dismantling, recycling	1,1E+05	4%	1,1E+05	3%	
			Total	2,7E+06	100%	3,6E+06	100%	

Figure 4.5 illustrates the main components of the modelled system in PSILCA. Based on the choice of the cost-based cut-off approach to select the main activities to be included in the assessment, the following ones were identified: turbine and foundation manufacturing, cable connection, installation, operation, and maintenance. The processing of design / R&D and end-of-life activities were excluded from the scope, as they only represented between 3% and 4% each of the total cost, approximately, and few data are available on these activities. Depending on the technology, the cost of the foundation ranged between 7% and 37% and, thus, representing a relatively high contribution to the total cost of the OWF. Moreover, whether the OWF was floating or fixed, the cost of the turbine remained significant, representing between 22% and 30% of the total project cost. This information led to consider turbine components in greater detail. Concerning the OPEX, due to the lack of reliable information, the difference of OPEX cost/MW between fixed and floating OWF was assumed to be negligible. Assumptions concerning the geographical origins of the different components are discussed later in this section. Figure 4.5. Illustration of main components considered for social risk analysis related to supply chain of an OWF system. A: components of a turbine (Hood et al., 2014; Teunis et al., 2020), B: composition of export cable schema (adapted from RTE and MTE, 2022), C: Models of floating OWF foundations (Kaynia et al., 2022), D: Models of fixed OWF foundations (Miceli, 2012).

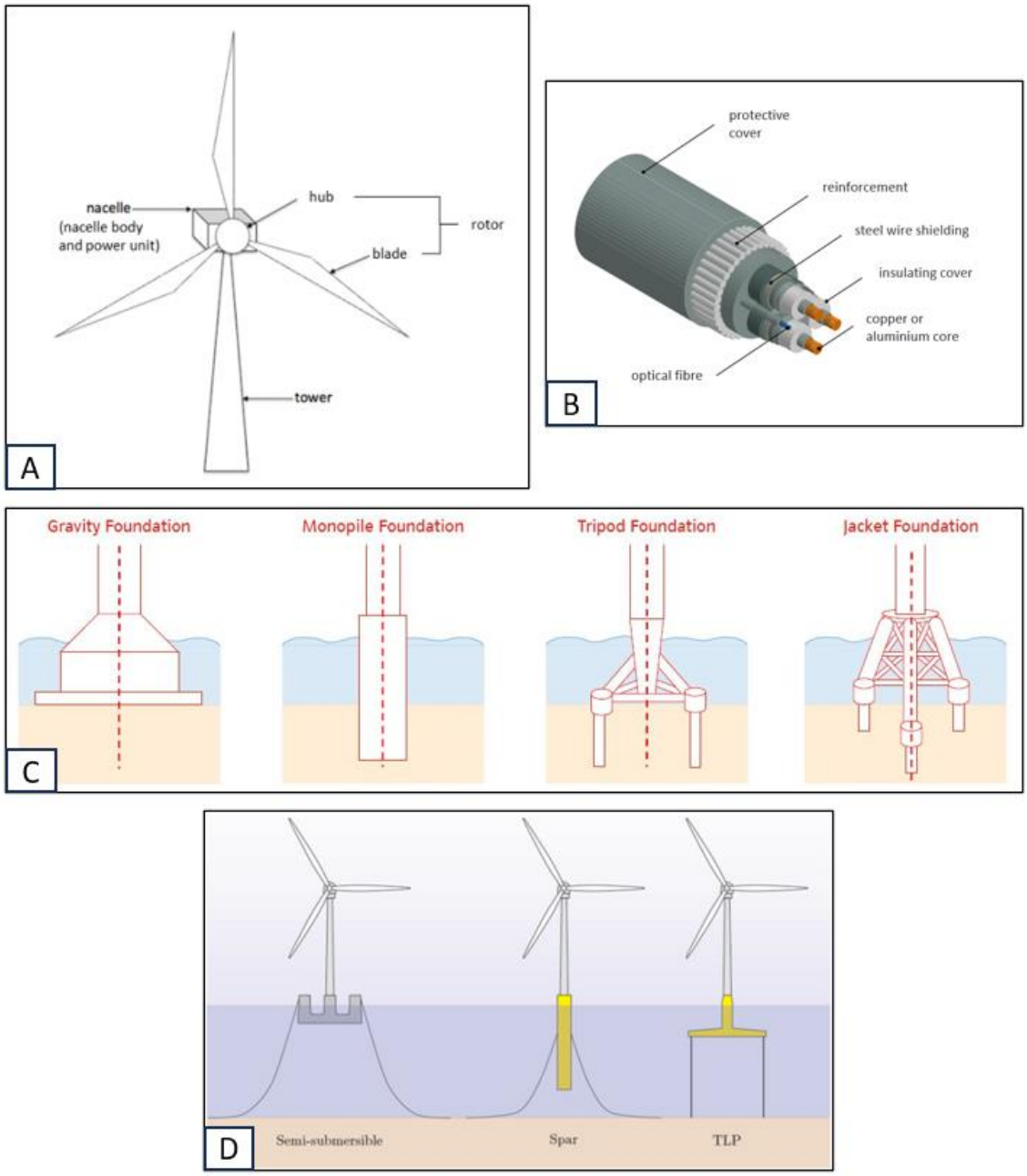


Figure 4.5. Illustration of main components considered for social risk analysis related to supply chain of an OWF system. A: components of a turbine (Hood et al., 2014; Teunis et al., 2020), B: composition of export cable schema (adapted from RTE and MTE, 2022), C: Models of floating OWF foundations (Kaynia et al., 2022), D: Models of fixed OWF foundations (Miceli, 2012).

In the absence of access to an environmental life cycle inventory providing data on materials and energy specific to French OWF projects, generic information has been used and calibrated as described below. Full data are presented in the appendix. It should be noted that offshore substations and fuel consumption during installation and maintenance have not been considered, also due to the lack of information to complete these elements of the model.

- Turbine model: an inventory of a 5 MW turbine is used, based on Kouloumpis and Azapagic (2022) and presented in the appendix. This inventory for a 5 MW turbine can then be extrapolated

to other turbine powers, using the relationships between the power and the rotor diameter, and between the diameter and the rotor weight, as identified in Sacchi et al (2019). The extrapolation is, however, to be considered carefully and should only be conducted within the limits of the applicability domain.

- Cable connection: power connection between the OWF and the platform is assumed to be made with 225 kV cable (RTE and MTE, 2022). To estimate the weight and materials in the absence of specific data or alternative scaling equations, a linear relationship between weight and voltage was assumed, to calculate the inventory of the 225 kV based on the inventory of 132 kV cable with 800 mm2 section from Kouloumpis and Azapagic, 2022). Activities related to digging/excavation, as well as inter-array cables, have not been considered due to lack of information. Only the export cable between the platform and the landing station is considered.
- Foundations: Table 4.3 presents the ratio of materials used for the main types of turbine foundations. To represent floating technologies, the use of the *Windfloat* semi-submersible steel model was assumed. The ratios of raw materials were estimated from Li et al. (2022).
-

Table 4.3. Inventory used for different models of foundations.

Foundation types	Model	Materials	Source
Fixed	Jacket	Low alloyed steel (85.8%) Concrete (14.2%)	(Li et al., 2022)
	GBS	Concrete (100%)	
	Monopile	Low alloyed steel (100%)	
Floating	Semi-submersible	Low alloyed steel (94.2%) Concrete (5.8%)	

- **Cost conversion: converting mass and energy quantities into USD**

Once the inventory assumptions for all the components of the system under evaluation have been defined, their monetary costs (USD) are estimated. Due to the lack of accurate data on the costs of the different components, these costs were estimated by converting the quantity of raw material and energy used into monetary metrics. This conversion was based on publicly available prices, communicated on wholesale websites. This type of source is among the options recommended by the PSILCA S-LCA database framework (*GreenDelta*, 2016). Market price fluctuations are not considered but would constitute a relevant perspective for further research related to sensitivity analysis of S-LCA results. For prices originally identified in EURO (EUR), the conversion rate used, from EUR to USD was 1.0139 USD/EUR, observed in August 2022.

In addition to the cost of raw materials and energy used for the components' manufacturing, the cost of labour used during the activity itself (i.e., the cost of work spent to manufacture a component) was

estimated. The estimation of labour cost is necessary to assess the social risks and/or opportunities linked to the activity itself, for instance the activity of components' manufacturing. The assumption used to calculate the labour cost consisted in using a 20% rate of the total cost of the different components. This assumption is based on the low estimate of the labour cost share identified in the civil engineering sector from the grey literature (Richer, 2020).

To summarise, the total amount of USD cost for an activity as "component manufacturing" corresponds to the sum of the raw materials and energy costs relative to the given component and the cost of the labour during the activity of manufacturing. Following the share of labour cost assumption based on Richer, 2020, this corresponds to a ratio of 20% of labour cost and 80% of cost related to the raw materials and energy market price. It should be noted that this cost may be underestimated compared to reality because some technical and economic aspects are excluded considered (e.g., cost related to support functions, specialised labour, other subsystems, other intermediary processes and activities). It is a complex task to quantify the uncertainty of these assumptions. In-depth studies could make it possible to analyse the effect on the results of the uncertainty.

- **Geographical area identification**

As already mentioned, it is necessary to identify the country or countries where the activities modelled in the S-LCA database are carried out. Social risks depend not only on the industrial sector, but also on the countries where these activities take place. In the case of French OWF systems, various component production sites have been identified. According to the sources listed below, all the components identified were manufactured and assembled in France. These components require input materials that may come from other countries. Here, in the absence of specific data, PSILCA background data based on trade flows from Eora were used (Maister et al., 2020). The list below, presenting the manufacturing activities of OWF components associated with their production site in France, was prepared using information from different literature sources:

- Manufacture of turbines: offshore wind turbine factory at Saint-Nazaire (GE Renewable Energy, 2019a) ;
- Manufacture of blades: Cherbourg (GE Renewable Energy, 2019b) ;
- Manufacture of nacelle and assembly of blades: factory at Le Havre (Siemens Gamesa Renewable Energy, 2023) ;
- Assembly of jacket foundations and tower: Brest (CMF, 2022) ;
- Design, manufacture and offshore installation of the gravity foundations (GBS): Le Havre (Bouygues Travaux Publics, 2020) ;
- Assembly of the floats and integration on the turbines: Port-La-Nouvelle (Government and RTE, 2022b) ;

- Logistical hub for the foundations: La Rochelle (Port Atlantique La Rochelle, 2021).

Based on the findings from these sources, it was assumed that the facilities related to all foreground activities to be modelled were also located in France. This assumption was maintained for other processes, such as the manufacture of the cable, for which no explicit information was found in the literature.

4.3.2. National and local scopes

This section aims to present the methodology for the inventory at both national and local scopes, with a focus on the specificities of the OWF sector, in the life cycle stages of installation and operation. As previously mentioned, considering local and national scopes in the social impact assessment serves to consider, thanks to sectoral impact indicators, social issues specifics of the OWF sector that are not covered by generic country-level S-LCA databases such as PSILCA. These social issues and indicators are relevant, based on the literature and the perspective of stakeholders consulted in the countries or territories where OWFs operate. The OWF sectoral adaptation, in this study, has been applied, in particular, to consider a certain number of social issues related to the installation and operation stages. The interest to consider such aspects linked to the installation site is justified by considering the average number of years of operation of OWFs, ranging between 20 and 25 years, which involves relevant consequences in the mid to long-term for stakeholders in the area that should be better analysed.

The application of a performance-reference-point approach allows indicators to be defined, to cover these particular issues. However, while the measurement of several indicators with S-LCA databases requires no more effort than for a single one once the model is built in the LCA software, this is not the case for indicators measured using the performance-reference-point (PRP) approach proposed here. Thus, the indicators are here identified and measured one-by-one, which may be more time-consuming. As a reminder, the main principle of the PRP approach is to evaluate an indicator value in comparison with one or more reference values that may be taken, for example, based on international standards or best practices observed in the sector (UNEP, 2020). The result of this comparison is a score which aims to determine to which extent the performance measured is relatively favourable (i.e., positive score) or less favourable (i.e., negative score). To apply the PRP approach, the inventory can be resumed in three sub-steps as follows:

- identifying relevant social impact indicators;
- designing the reference scales around one or several reference values;
- measuring the indicators for the different case studies.

Ideally, the measurement of indicators should be based, as much as possible, on primary site-specific data, that is, data specific to the OWF projects being evaluated. However, whenever primary site-specific

data are not available, which is often the case for emerging systems such as OWFs in France, secondary site-specific data or generic data may be used instead, in accordance with UNEP guidelines. Site-specific secondary data correspond to data that are specific of the assessed case study itself, but that come from a literature source or a person other than the S-LCA practitioner who has collected the data. Generic data may correspond to the level of a sector, a company, or feedback from a OWF in other countries.

4.3.2.1. Identification of social indicators

Previous work consisted of the identification of a set of impact subcategories, followed by their hierarchical organisation through participatory approaches (Chapter 3). As a reminder, the list of impact subcategories used in the surveys of the chapter 3 was adapted mainly for local community stakeholder category. For the other stakeholder categories, impact subcategories correspond to UNEP guidelines list. Once this step of impact subcategories hierarchisation conducted, impact subcategories can be evaluated. This requires the identification of appropriate indicators.

As mentioned, OWF sector is currently under development in France. Consequently, social impact studies are still incomplete because they do not cover all the subcategories of social impacts. Therefore, this PhD thesis combines scientific and grey literature on various wind farm projects in France but also from other countries, to cover as broadly as possible the different indicators that could be used to measure their social impacts. This literature includes project reports, scientific literature, and regulatory and legal sources. To ensure transparency on how the indicator(s) for each impact subcategory were identified, chosen and defined, the steps involved in the processing of such diverse sources should be clearly explained and justified. Figure 4.6 illustrates the approach used to identify indicators in this case. This approach is based on an iterative consultation of the literature. Key words related to the OWF sector in particular and the energy production sector in general were used on a search engine, then articles were screened to determine whether an indicator could be extracted from them. For example, to integrate the issue of sharing maritime space with professional fishing, the keywords “co-location”, “offshore wind”, “fishery” were used. Among the identified articles, the next step was to identify which indicator(s) could be used to evaluate the impact subcategory. Depending on the complexity of the different impact subcategories, one or several indicators can be required for the further impact assessment phase. Impact subcategories identified as relevant may not have, yet, adequate indicators to fully represent their effect. In this case, existing indicators providing partial measures of the impact subcategory were proposed here, as a preliminary attempt, though they are to be interpreted carefully and to be completed or replaced in the future by more relevant ones.

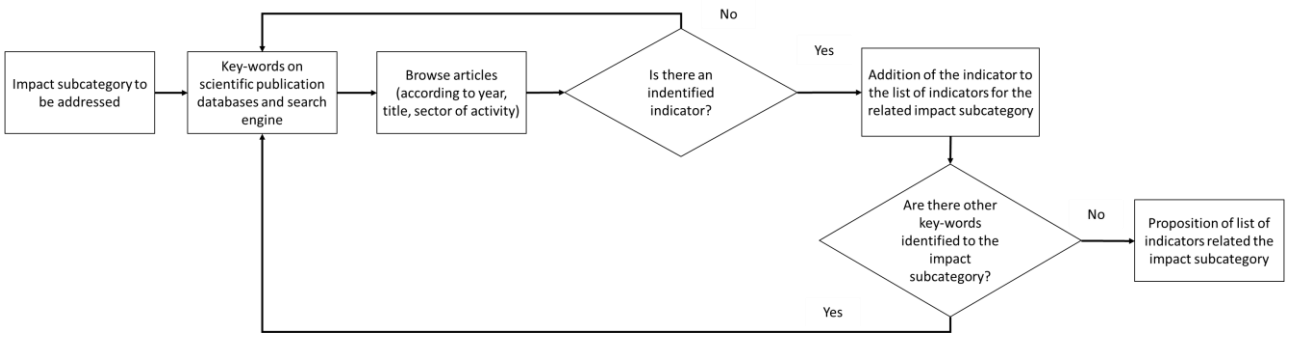


Figure 4.6. Iterative process proposed in the PhD thesis for the identification of social indicators based on scientific and grey literature review.

Table 4.4 presents the core set of social indicators identified at the national and local scopes for all stakeholder categories except for children. Most of the sources used are specifically related to offshore wind energy systems, although some of them were identified in studies including several energy systems and can, therefore, be easily transposed to other energy sectors. Additional information on OWF-specific subcategories vs subcategories applicable to other energy technologies is later provided in Table 4.6. The identified indicators are defined and classified according to the impact subcategory they aim to represent and the related stakeholder category. In addition, the table specifies the relative gap score corresponding to each impact subcategory for the hierarchisation following the stakeholder consultation presented in the chapter 3. In practice, the core set of indicators is a compromise between the extent of the total scope covered, that is, the number of impact subcategories, and its depth, namely the capacity of identified indicators to provide relevant measurement of the impacts. Wherever possible, impact subcategories were considered in order of priority based on the gap score from the external stakeholders' participatory approach conducted in the chapter 3. Lack of sources to identify indicators and/or available secondary data to measure indicators can explain why some categories were not retained.

This PhD thesis proposes to indicate this cumulated gap scores to enhance the transparency of the total share of the gap finally covered by the impact assessment. Thus, a hypothetical score of 100% would mean that all impact subcategories submitted to hierarchisation for a given stakeholder category are addressed in the impact assessment phase. In the application conducted in this PhD thesis, and using the hierarchisation gap scores calculated in the chapter 3, the following gap share covered by the assessed impact subcategories were 67% for local communities, 18% for Consumers, 75% for Value Chain actors, 27% for Workers, and 58% for Society. Considering the ratio between all prioritised impact subcategories versus impact subcategories addressed in the impact assessment, the cumulated score gap is covered by more than 50% for three out of the five stakeholder categories, whereas for the other two, namely consumers and workers, only 15 to 30% is covered. It is also important to remember that these gap scores are related to the local and national scopes. As previously explained, these indicators are assessed using the performance-reference-point approach. For other impact subcategories not covered

by the local and national scopes, it should be noted that some impact subcategories proposed by the UNEP 2020 Guidelines and in sustainability studies in the energy sector, are still addressed on the global scope using the S-LCA database (e.g., corruption risks, safety measures for workers, etc.). It is mainly the case for the Workers stakeholder category, for which impact subcategories related to Fair salary, Working hours, Health and safety, Forced labour, Child labour and Freedom of association have been addressed at global scope using PSILCA S-LCA database. It appears that PSILCA includes extensive information to address certain impact subcategories, mainly related to workers. However, to ensure comprehensiveness and sectoral adaptation, especially for stakeholder categories for which PSILCA provides less exhaustive results, additional indicators should be evaluated.

Table 4.4. Core set of social impact subcategories and associated identified indicators for the social impact assessment applied to offshore wind farms in France at local and national scopes.

Spatial scope	Stakeholder category	Impact subcategory	Normalized gap score	Indicator	Definition	Unit	Sources / adapted from
Locale scope	**Local community**	Attractiveness of the territory	10%	Potential touristic development	Evolution of tourism services: number of visits or projects to visit to wind farms during the year	*Number*	(Vues sur Mer, 2018)
				Effect on landscape: "spatial integration"	It considers the density of the farm (number of turbines by surface of farm) and the distance from the shore	*Index*	Based on technical parameters from the project owner's documents and interview
		Sharing of spaces	15%	Potential devaluation on property prices	Possibility of affecting the price of surrounding properties	*%*	(ADEME, 2022; Jensen et al., 2018)
				Surface efficiency	Electricity generation / Land occupation	*km²/MW*	(DGEC, 2023; Santoyo-Castelazo and Azapagic, 2014)
				Potential increase in catches close to a wind farm	Spillover effect from a spatial closure of the wind farm to fishing activities	*%*	(Halouani et al., 2020)
				Percentage of willingness to practice recreational fish near OWF	Willingness to practice recreational fishing near OWF	*%*	(Hooper et al., 2017)
		Safety management	10%	Probability of accident with a civil	Probability of ship collision with a farm	*Number/year*	(La compagnie du vent, 2010; SSPA Sweden AB, 2008)
		Territory investments	8%	Annual taxes	50% to coastal communities, 35% to the committees of maritime fisheries, 5% allocated to sea rescue organisations, 10% OFB	*Millions €/year*	(CGEDD, 2021b)
		Local employment[1]	11%	Indirect local job	Indirect local job communicated / or at region scale	*Number/MW*	(CRE, 2018)
		Quality of dialogue	13%	Amount of people met with local communities / littoral population	Number of people met during the debate in relation to the population of the maritime façade	*‰*	(UNEP, 2021)
				Trust rate in electricity developers	Percentage of trust in electricity developers	*%*	(Hooper et al., 2017)
	Consumers	Service to consumers[1]	18%	Percentage of local power for the administrative region	Percentage of local power delivered for the administrative region	*%*	(MTE, 2022a)

				Price per MWh: cost of public support	Guaranteed price to secure the investment at long term (assumption: a low guaranteed price suggests an affordable energy)	*€/MWh*	(European Commission, 2019)
	Value chain	Wealth distribution[1]	31%	Local content: share of project cost captured by regional companies	Share of project cost captured by regional companies	*%*	(CRE, 2018; UNEP, 2021)
	Workers	Employer relationship[1]	15%	Temporary employment	Based on human resources requirements	*%*	(Buchmayr et al., 2022 based on Rutovitz et al., 2015; UNEP, 2021)
		Equal opportunities[1]	12%	Social clauses	Device for people far from employment	*h/MW*	(CRE, 2018; UNEP, 2021)
National scope	**Value chain**	Supplier relationship[1]	25%	Payment rate without delay	Payment deadline is the 30th (up to 60) day after receipt of the goods or performance of the service	*%*	(Banque de France, 2018; Harmens et al., 2022)
		Social and environmental commitments[1]	19%	EcoVadis score of developer	Environment, Ethics, Social and Human Rights, Responsible Purchasing	*Index*	(Ecovadis.com, 2023; Goedkoop et al., 2020)
	Society	**Society**					
		Energy independance	18%	Avoiding fossil fuel costs	Avoided fuel imports allowed by renewable energy	*Millions €*	(EWEA, 2014)
				Import dependency rate for critical raw materials	Critical material mass per MW	*Kg/MW*	(ADEME, 2019; Baranzelli et al., 2017)
		Social and environmental commitments	24%	CSR score of OWF electricity company	Environmental, social and governance issues	*Index 0-100*	(Ecovadis.com, 2023; UNEP, 2020)
		National economic development	16%	Indirect jobs in the value chain	Jobs created in the sector on a national scale	*Number/MW*	(Bengtsson Ryberg et al., 2013)
				Indirect spin-off jobs	Induced jobs result'from employees' income	*Number/MW*	(Bengtsson Ryberg et al., 2013)

[1]Impact subcategories tagged with this index were directly taken from UNEP (2020) guidelines. All other categories correspond to an adaptation of a UNEP category or a new category identified in the reviewed literature

The list provided in Table 4.4 reveals a quite heterogeneous core set of indicators with different units of measurement, depending on the nature of indicator. This core set of indicators should not be considered as an exhaustive definitive list that fully covers all the possible social aspects of the OWF sector in particular and, by extension, to energy systems in general. Indeed, due to the above-mentioned limitations, related to the lack or scarcity of measurable indicators for certain impact subcategories for the time being, the list should be rather interpreted as a first attempt to provide a transparent preliminary proposal based on a systematic framework for indicators' identification and definition. The list is expected to evolve in the future and become more complete as more indicators are developed in the field.

This literature-based identification of indicators provides a perspective on complementary ways of identifying indicators. For example, it would be interesting to explore the possibilities of selecting, or even co-constructing, indicators with experts or the companies involved. This approach should be carefully applied, to limit potential biases by stakeholders with specific interests related to the development of the sector.

4.3.2.2. Systematisation of data collection for the evaluation of the indicators

Once the indicators have been identified, the next step is to collect the data and measure them for the assessed case studies. As previously mentioned, the identified indicators are heterogeneous, involving different disciplines and requiring different types of sources for their measurement. Also, the emerging nature of the sector implies that some impacts have not occurred yet, particularly for the operation stage. This means that, for some of them, the impacts have not yet been generated. In this case, these impacts are potential, and their values involve a degree of uncertainty. This is particularly relevant in the case of using generic data, for example related to impacts observed on wind farms abroad, which correspond to a different context than the case studies evaluated in this thesis. As a reminder, specific data are related to a particular assessed project or process, conversely to generic data.

In many available S-LCA studies, the approach to identify and select appropriate sources of data lack of transparency and/or systematisation, which considerably hinders the reproducibility, and therefore, the possibility to verify the studies. Therefore, this PhD thesis proposes a systematic framework to overcome these challenges and help to conduct this task.

For accuracy purposes, the evaluation of social indicators should be based, as much as possible, on primary site-specific data, which may, if necessary, be completed by secondary site-specific data. However, primary data involves, by definition, that the practitioner directly collects this data. Following this definition, conducting S-LCA exclusively based on primary data involves either a very long data collection process, conditioned to the existence of such data, or a partial assessment focusing on a limited

number of indicators. To complete the information so as to ensure a larger number of indicators to be evaluated, data on existing projects in the literature may be used as a proxy to cover more indicators and impact subcategories. A decision tree, presented in Figure 4.7, is proposed in this PhD thesis to organise the different sources of secondary data depending on the expected level of relevance when aiming to represent a case study for which no primary data are available.

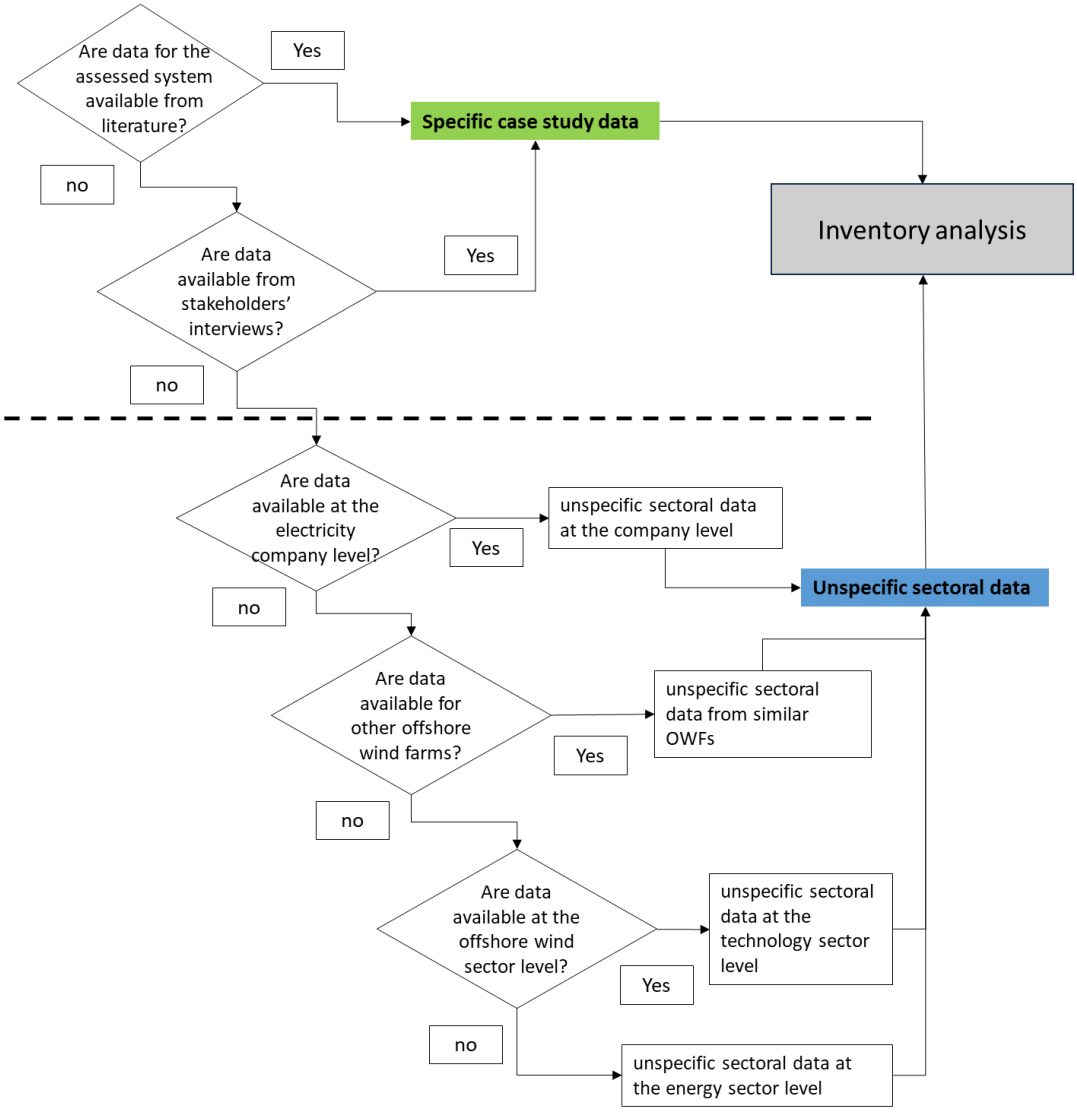


Figure 4.7. Decision-tree proposed in this PhD thesis to prioritise data sources for evaluating the indicators.

Literature can, indeed, provide a significant amount of secondary site-specific data for different impact subcategories and case studies. For large infrastructure projects requiring public discussion between project owner and local communities, grey literature resulting from public reports is generally available to collect some of these site-specific secondary data. However, this available literature may not be sufficient to measure the indicator, given that most of the technical studies produced by project owners

are not publicly accessible. In this case, consulting stakeholders through interviews can help to complete the literature review. For site-specific data collection, a literature review is recommended in a first level of priority, to ensure a large data collection in a relatively short time, and then completed by stakeholders' consultation in a second level. Some stakeholders may have expertise on certain impact subcategories. These stakeholders may include representatives of organisations and can be, for example, consulted via interviews. Open question such as *"What are the social issues that concern your activity in relation to the project?"* can add relevant information on the impact subcategories identified. Other questions to be addressed in interviews could include if *"indicators, or tools for measuring or monitoring considered impact, are used in the context of the project implementation"* or if *"particular attention is paid to different protect parameters"*. Moreover, in the case of complex impact subcategories to be addressed, interviews can be used to improve understanding of the links between the system and the affected stakeholders. Related questionnaires used for these interviews are available in the appendix and results of conducted interviews are presented in the next section.

Despite the extensive literature review and the interviews with stakeholders, it may not be possible to identify site-specific values related to the assessed case studies for some of the identified indicators. In this situation, generic data may be required to complete the missing information. A generic value refers to any data that does not specifically correspond to the system being evaluated. However, it may provide useful information for a preliminary estimate of the potential impact. This estimate can serve as a reference value until a more accurate assessment becomes possible, notably when site-specific values become available. Depending on the indicators, the choice of generic values can be wide. Not all generic values have the same level of resolution or closeness to the evaluated system. This results in different levels of uncertainty. Hence, it is useful to label the different types of generic values and give the possibility to assign a higher priority to those that are, in principle, affected by less uncertainty. The methodological path schematised in Figure 4.7 consists of identifying, where applicable, available public generic data on the following aspects:

- Company (e.g., project developer) including management practices, employee information or corporate social performance;
- Feedback from projects in other countries;
- Aggregated technology sector, alternatively the upwards level (e.g., energy sector).

The level of generic data attribution depends on the proximity with the study cases. It is considered that company data and information of OWF systems installed out of France are more relevant than sectoral data referring to the energy production sector in general. Nevertheless, the reason to keep the energy production sector in the list, despite the low representativeness with respect to the OWF sector, is that such generic information could potentially serve to position the social performance of OWFs compared

to alternative energy production systems, which could be useful depending on the goal and scope of the study. The following sub-section introduces the application of data collection to different French OWF case studies.

4.3.2.3. Application of the sector-specific approach for the national and local scopes to OWF inventory analysis

The application of the sector-specific approach for the national and local scopes to different case studies is presented in this section. For this application, different OWF projects, have been considered. None of these projects has been identified as being sufficiently described in the literature or through interviews with experts to ensure the evaluation of all the identified indicators with either primary or secondary site-specific data. Some OWF projects present site-specific data for certain indicators, while others OWF present data for other indicators. To ensure a large site-specific data collection, it is therefore relevant to consider several OWF. Using several OWF case studies for site-specific data collection should provide a broader view of social impact assessment for the sector.

Secondly, for a given indicator, obtaining several values from different OWF can allow a range of an impact to be obtained. If the values differ depending on the case study, it is interesting to identify which parameters have an influence on this differentiation. Considering several case studies, therefore, allows the notion of variability in social performance within the OWF sector to be introduced. Moreover, the different values collected aim to provide information on reference values and related thresholds to be used later in the impact assessment phase. As later explained in the section 4.4.2.1, some of these reference values can be generic (i.e., unrelated to a specific case study), but others may be based on a comparative performance between case studies.

For these reasons, a total of five French OWF case studies have been selected to test the applicability of the data collection approach, and further evaluate the subcategories during the impact assessment phase. The selection was based on the ability of these case studies to represent a certain level of diversity of OWF projects. The selected OWFs are designed according to different technological choices (number and size of turbines, steel or concrete foundations), either floating or fixed. They involve different maritime territories (Atlantic, North Sea Channel, Mediterranean). Their tender years range from the No. 1 (2011) to the No. 6 (2022), and commissioning dates ranging from 2022 to 2030.

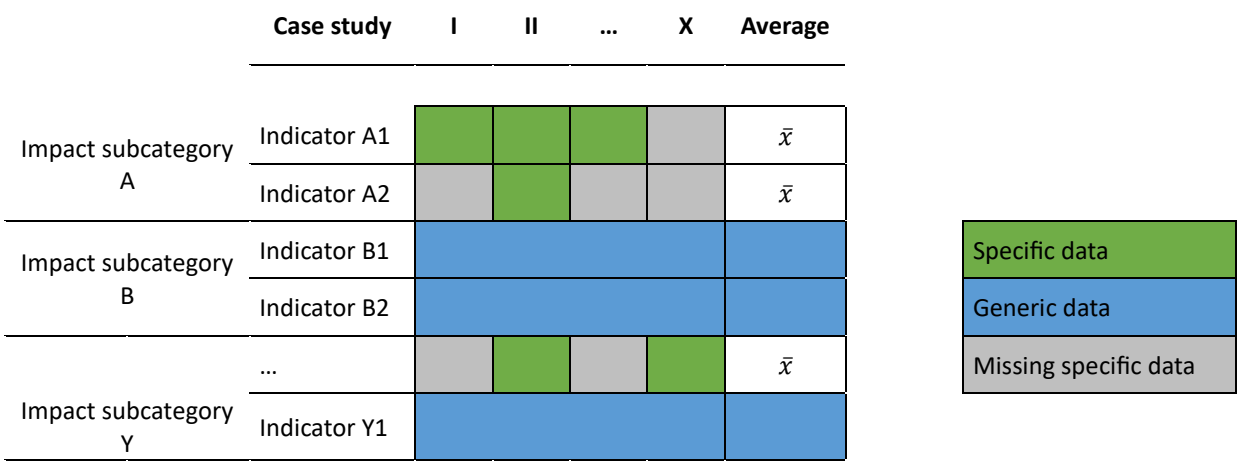


Figure 4.8. Levels of data collection conducted in the S-LCA inventory analysis phase.

Lack of data availability is inherent to the current stage of development of the OWF sector in France. As previously discussed, primary data may not exist, may be incomplete, or may not be publicly accessible. The extent of data availability varies depending on the cases study. The diverse status of OWF projects (planned, under development, commissioned) leads to a diversity of related potential sources of information to be explored. As a result, some of the information available for a specific OWF is missing for others, and vice versa. Figure 4.8 presents the different levels of data obtained during the data collection and their application to the selected OWF case studies. This is a schematic representation of the result of applying the decision tree presented in the previous section. Using such an approach could, for example, serve to identify the level of reliability of the results easily and visually for a given case study based on the level of representativeness of the data source linked to its nature.

To complement the literature review, as mentioned in the previous section, interviews with stakeholders can help to target and enrich data collection.

- **Summary of external stakeholders' consultations**

Following the interview consultation process, 55 people were contacted by email to request a telephone interview (i.e., contacted stakeholders). The list of emails came both from public information, such as social networks, and from emails voluntarily provided through the surveys used for the hierarchisation of impact subcategories (chapter 3). Among them, 14 people answered favourably for a consultation through an interview (i.e., consulted stakeholders). The average time of the interview was around 50 minutes. Table 4.5 presents the number of contacted and consulted stakeholders for an interview per stakeholder category. These profiles were heterogeneous and included, for example, representatives of committees of fishermen and networks of local NGO, one worker on wind turbine foundations'

manufacturing, an energy project manager, and public administration representatives related to various French OWF. As mentioned, the main purpose of the interviews was to collect data for the inventory analysis phase as a complement to the literature review. In addition to their use in the inventory analysis phase, some outputs from the interviews also fed the impact assessment and interpretation phases.

Table 4.5. Overview on stakeholders' interviews.

Stakeholder category	Contacted	Consulted	Feedback rate
Value chain	10	6	38%
Local community	14	5	26%
Workers	8	2	20%
Consumers	17	1	6%
Total	**49**	**14**	**22%**

The next sub-section presents the raw data collected regarding the various indicators identified for the selected OWF case studies.

- **Overview of secondary data collection**

The values identified per indicator are presented below in Table 4.6 for the local and national scopes. In this study, 24 quantitative indicators were identified and are here presented, including 15 indicators for the local scope and 6 for the national scope. Some values were missing for certain case studies and target indicators. For some indicators, specific values were available for some case studies but not for others. In other cases, no specific values were available for any of the case studies, requiring the use of generic values that did not allow for differentiation between case studies.

Some ranges of values per indicator can be noted. For example, indirect local job creation varies from approximately 1 job/MW to 4 jobs/MW for the considered case studies (CMF, 2022; CNDP, 2021c; Emploi-Environnement, 2020; Energie recrute, 2021; Parc éolien en mer de Saint-Nazaire, 2021). At national scope, the induced jobs (or "spin-off jobs") would range from 5.3 jobs/MW to 11.4 jobs/MW, while indirect jobs in the value chain would vary from 4.5 to 9.3/MW (INNOSEA, 2022). Another example of values' variation is related to the local content indicator. The local content is an indicator that serves to assess the integration of local companies and local employment into OWF development processes. It corresponds to the share of project cost associated with contracts with local organisations. Partnerships with local suppliers and subcontractors contribute to the increase of the local content indicator. Depending on the case study, the value of local content may vary significantly, from around 10% to 50% (Energies de la mer, 2021; Gouvernement and RTE, 2022b; Ailes Marines, 2022b,

Interviews from Le Télégramme, 2022; Interview from Ouest france, 2020). Parameters likely to influence the variation of these values will be discussed in the impact assessment section 4.4.

Concerning other indicators, as the values for taxes and the amount of avoided fuel imports, they are determined based on the power capacity of the considered OWF following by assuming a linear relationship in the absence of more accurate information. Social clauses indicator also shows some variation. In the tender specifications, social clauses are generally considered in terms of the inclusion of “people who are far from employment”. Although it reflects a favourable effect, which encourages it to be communicated, this indicator has been identified only for two study cases.

It should be noted that the values of indicators presented in Table 4.6 correspond to the outcome of the inventory analysis phase and are not part of the results of the impact assessment phase. In accordance with the PRP approach, it is necessary to assess the performance of these values by representing them with respect to a reference scale. The following section presents the impact assessment phase, which includes a detailed explanation of the definition of thresholds used for the application of the PRP approach for the evaluation of all the indicators of the national and local scopes.

Table 4.6 Values of indicators collected based on literature. Ranges of values are presented for indicators for which data for several case studies were collected, otherwise the single generic value found in the literature is indicated.

Scope	Indicator	Range of values from study cases	Type of value	Indicator applicability		Sources of values
				Specific to OWF	Transposable to other energy systems	
Local	Potential touristic development	[No parallel projects planned; Parallel projects underway]	Site-specific		x	(Eudleur, 2023)
	Effect on landscape: spatial integration	[0,009;0,091]	Site-specific		x	(Ailes Marines, 2022b; Eoliennes offshores des hautes falaises, 2013; MTE, 2022b, 2022b, 2022a; Parc de Banc de Guérande, 2022a)
	Potential devaluation on property prices (%)	0%	Generic		x	(ADEME, 2022)
	Surface efficiency (Km²/MW)	[0,12;0,20]	Site-specific		x	(Ailes Marines, 2022b; Eoliennes offshores des hautes falaises, 2013; MTE, 2022b, 2022b, 2022a; Parc de Banc de Guérande, 2022a)
	Potential increase in catches close to a wind farm (index)	7%	Generic	x		(Halouani et al., 2020)
	Willingness to practice recreational fish near OWF (%)	25%	Generic	x		(Hooper et al., 2017)
	Probability of accident with a civil (number/year)	[1,55E-04;2,40E-03]	Generic		x	(La compagnie du vent, 2010; SSPA Sweden AB, 2008)
	Annual taxes (€)	[4,31E+06;8,61E+06]	Site-specific		x	(CGEDD, 2021b)
	Indirect local job at region scale (number/MW)	[0,92;4,01]	Site-specific		x	(CMF, 2022; CNDP, 2021c; Emploi-Environnement, 2020; Energie recrute, 2021; Parc éolien en mer de Saint-Nazaire, 2021)
	Share of littoral population met in public meeting (‰)	[0,72‰;2,9‰]	Site-specific	x		(CNDP, 2021b, 2013a, 2013b; INSEE and SOeS, 2009)
	Trust rate in electricty developers (%)	12%	Generic		x	(Hooper et al., 2017)
	Percentage of local power (administrative department)	[23%;76%]	Site-specific		x	(Gouvernement and RTE, 2022a; INSEE, 2019; INSEE, 2022a; Parc de Banc de Guérande, 2022a; Eoliennes Offshore des Hautes Falaises, 2022; INSEE, 2022b; MTC and MTE, 2022; Ailes Marines, 2022a)

	Price per MWh: Cost of public support (€/MWh)	[135;155]	Site-specific		x	(European Commission, 2019)
	Local content (%)	[9%;50%]	Site-specific		x	(Energies de la mer, 2021; Gouvernement and RTE, 2022b; Ailes Marines, 2022b) Interviews (Le Télégramme, 2022; Ouest france, 2020)
	Temporary employment (%)	67%	Generic		x	(Buchmayr et al., 2022 based on Rutovitz et al., 2015)
	Social clauses (h/MW)	[167;440]	Site-specific		x	(Parc de Banc de Guérande, 2022b; Saint-Nazaire Agglo, 2020; CNDP, 2013d)
National	Payment rate without delay (%)	61%	Generic		x	(Banque de France, 2018)
	Ecovadis score of developper (score)	[67;80]	Company level		x	(EDF, 2022; Iberdrola, 2023)
	Avoiding fossil fuel costs (m€)	[36;72]	Generic		x	(EWEA, 2009)
	Import dependency rate for critical raw materials (kg/MW)	200	Generic		x	(ADEME, 2019; CCI Bretagne, 2017; Eoliennes offshores des hautes falaises, 2013; GE Renewable Energy, 2022; Wind-turbine-models, 2016)
	CSR score of OWF developer	74	Company level		x	(Le Point and Statista, 2022)
	Indirect jobs in the value chain (number/MW)	[4,5;9,3]	Site-specific		x	(INNOSEA, 2022)
	Indirect spin-off jobs (number/MW)	[5,35;11,4]	Site-specific		x	

4.4. Impact assessment and interpretation phases from a multi-scope approach

This section presents the methodology and results related to the impact assessment phase and according to the different geographical scopes defined in this PhD thesis. The following sub-sections focus respectively on the global scope, then the local and national scope.

4.4.1. Global scope

As a reminder, the impact assessment for the global scope of OWFs is addressed through a generic S-LCA database, namely, PSILCA, and a conventional LCA software, namely openLCA. The S-LCA database impact assessment phase involves the use of an activity variable. In the absence of specific data regarding the activity variable for the foreground activities (Figure 4.4), an assumption was used. This assumption consists of estimating the working hours based on values for similar activities already available in the S-LCA database. For the OWF systems modelled with PSILCA in openLCA, the foreground system and the working hours are used from the following generic activities:

- "*Machinery and equipment*" for the components' manufacturing activities;
- "*Construction*" for the OWF installation activity;
- "*Electrical energy*" for the OWF operation activity.

Table 4.7 summarises the different data used to estimate the amount of the activity variable "working time in hours" for the foreground OWF activities. To consider maintenance and operation stage of an OWF system, the activity "Electrical energy – FR" of the PSILCA database was used. It is assumed that this activity mainly corresponds to employees working in the electricity generation sector.

Table 4.7. Summary of working hours by activities used for a generic OWF system modelled in PSILCA

Activities		**Working hours (h/USD)**	**Source of working hours estimation (PSILCA activity)**
Foreground	Tower production	6,33E-03	Machinery and equipment n.e.c. - FR
	Blades production	6,33E-03	
	Hub production	6,33E-03	
	Nacelle production	6,33E-03	
	Power production	6,33E-03	
	Cable production	6,33E-03	
	Foundation production	6,33E-03	
	Installation	3,53E-02	Construction – FR
	Operation	4,60E-03	Electrical energy - FR

For the installation stage, the estimation of working hours per 1 USD is based on the use of the French construction sector variable activity as reported by PSILCA. In particular, the construction sector has a working hour value of 0.0353 hours/USD, which is almost 10 times higher than the other activities, corresponding to components' manufacturing or operation stage, with respectively 0.0046 to 0.0063 hours/USD. This means that the construction sector would take approximately 10 times more working time to generate the equivalent of a dollar's worth of "finished product" (or value) than the other activities. Thus, a significant weighting of the medium risk hours will be attributed to the installation activity compared to the other activities. The uncertainty of the working hours could be further studied by applying sensitivity analysis, for example, by varying working hours values.

Then, as mentioned earlier in the section 4.3.1.1 of this chapter, the activity variable is applied to the different activities of the system, considering their USD cost. The USD cost of the activities multiplied by the activity variable provides a total number of hours worked for the different activities modelled. This involves calculating the cost of the activities.

As a reminder, the global scope is addressed by considering two main technological scenarios described in the inventory section, namely the fixed OWF scenario and the floating OWF scenario. The cost of turbine models in both scenarios is calculated based on the estimation of costs of raw materials and labour. Then, as mentioned in the methodology section related to the inventory analysis phase, once the cost of the turbine manufacturing has been estimated, the cost of the other activities can be roughly estimated based on the cost/MW identified in grey literature (Cruciani, 2019) . Because these scenarios present different designs, they involve different industrial sectors and the costs associated with the activities are also different. Table 4.8 below presents the relative costs breakdown for both the fixed and the floating OWF scenarios.

Table 4.8. Relative costs breakdown used for a hypothetical 500MW fixed offshore wind farm (10MW turbines, fixed, jacket foundation, 25km to the shore) and a hypothetical 504MW floating offshore wind farm (12MW turbines, floating, semi-submersible floats, 40km to the shore).

	Activity		Relative costs	
			Fixed scenario	**Floating scenario**
CAPEX	Export cable production		18%	21%
	Foundation production		15%	27%
	Turbine production	Tower production	10%	8%
		Blades production	12%	10%
		Hub production	8%	6%
		Nacelle production	14%	11%
		Power production	9%	7%
	Installation		7%	5%
OPEX	Operation		7%	5%
Total			100%	100%

The costs of activities, including labour cost estimation, associated with the activity variable can now be used to obtain the medium risk hours for different indicators using the LCA software (in this case, openLCA) together with PSILCA database.

Figure 4.9 below presents the results of the social risk assessment for the fixed and floating scenarios. To ensure a reasonable level of detail and processing time when running the S-LCA model built upon PSILCA database, a compromise was found using a 0.0001 cut-off. The selection of this cut-off may vary depending on required level of exhaustivity (in terms of life cycle processes included) and the capacity computer, as explained in PSILCA support documents (Maister et al., 2020). Selecting a 0.001 cut-off means that all background activities contributing to at least 0.0001 USD of the total value of the system were included. The set of indicators was selected based on the frequency of their use in S-LCA or sustainability studies, such as the one by Buchmayr (2022).

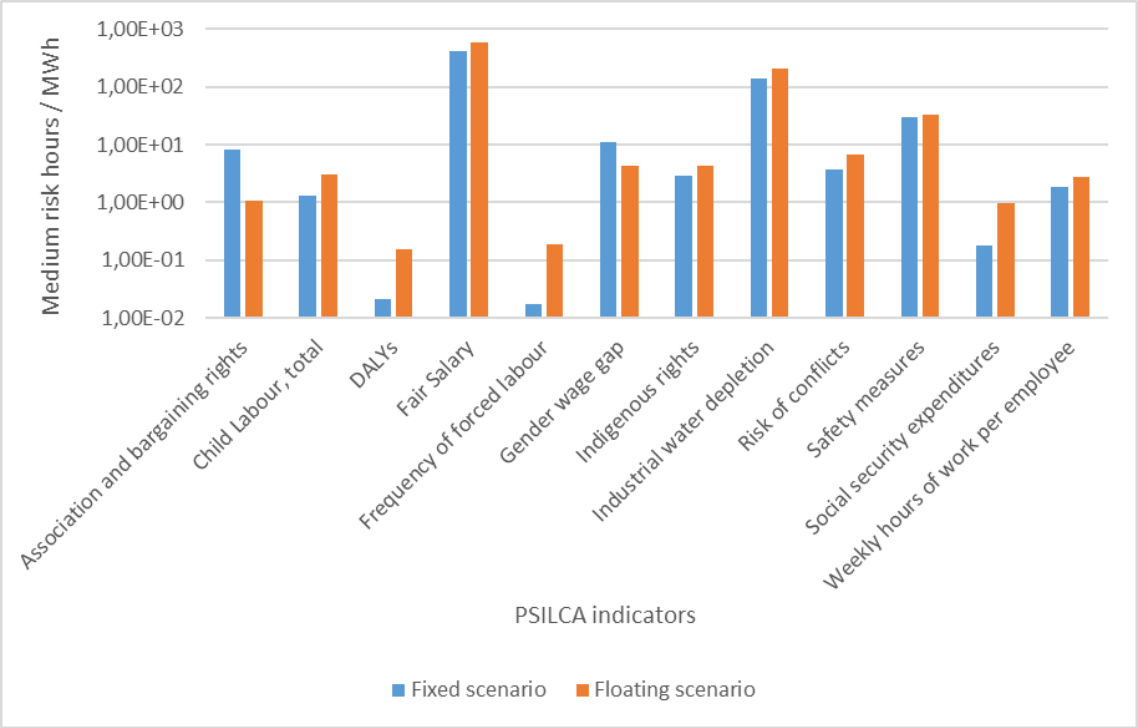


Figure 4.9. Comparison of medium risks hours between fixed and floating hypothetical scenarios.

Figure 4.9 compares the values of medium risk hours for 12 indicators extracted from PSILCA for the baseline fixed and floating scenarios. Overall, the values of the indicators measured in medium risk hours vary greatly from one indicator to another. The highest values identified concern the "fair salary" and "industrial water depletion" indicators, followed by "safety measures". Conversely, the "DALYs" and "frequency of labour" indicators have the lowest medium risk hours values among the core set of indicators used. For 10 out of 12 indicators, the floating scenario would generate higher risk hours than the fixed scenario. The largest relative differences are identified for the disability-adjusted life years (DALYs), which measure the frequency of forced labour and social security expenditures. The fixed scenario would be more closely related to risk hours concerning the right for union and negotiation, as

well as gender wage gap indicators. Relative contributions of the different activities to the medium risks hours toned to be analysed, to identify what activities contribute the most to these results. The relative contributions of the medium risks hours for the different subsystems are presented below for fixed scenario (Figure 4.10) and floating scenario (Figure 4.11).

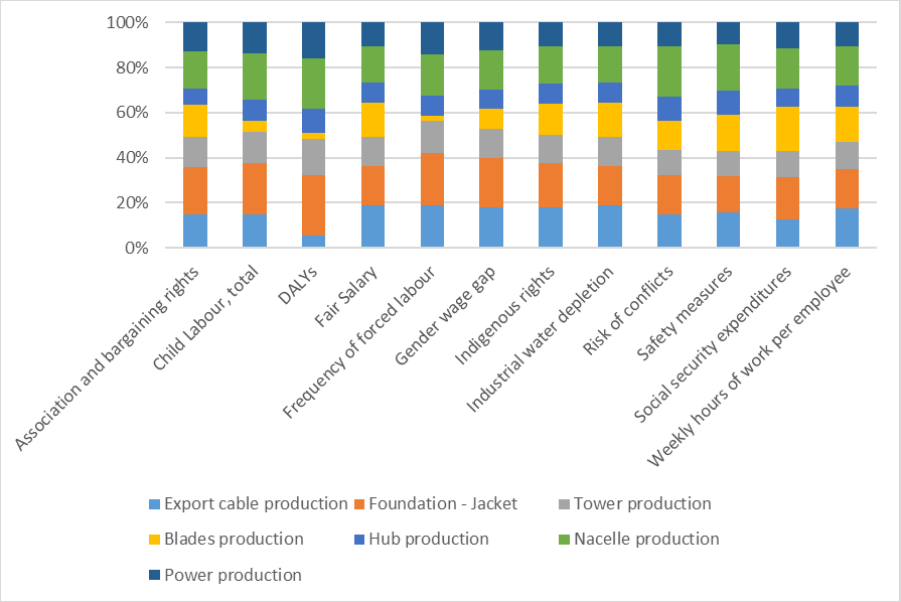


Figure 4.10. Relative contribution of activities for the fixed scenario

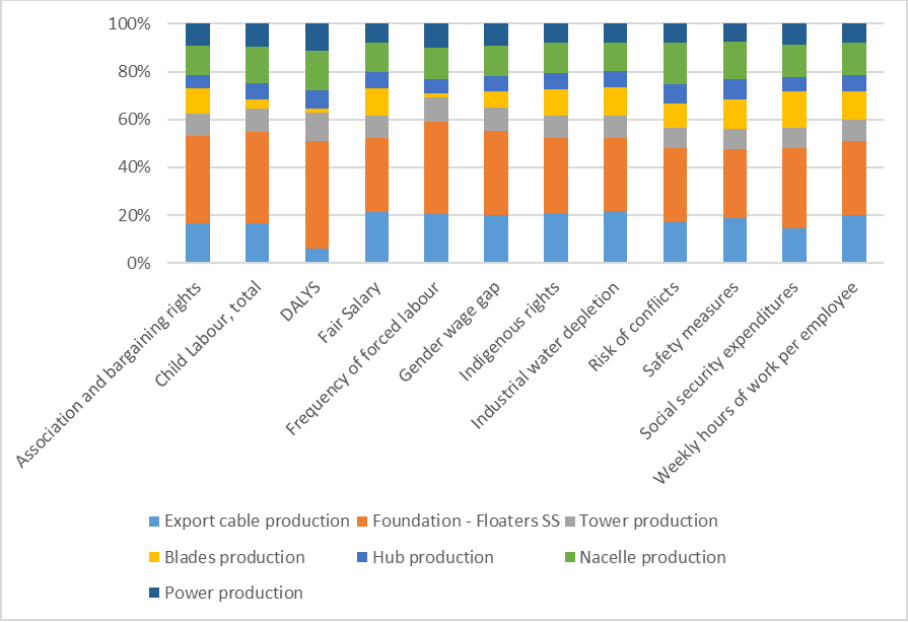


Figure 4.11. Relative contribution of the activities for the floating scenario

In the case of the floating scenario, the main contribution to medium risk hours is due to the manufacture of the floaters. This is to a large extent due to the assumption, in the inventory phase, that the used floaters correspond to a steel semi-submersible technology, which significantly involves the steel sector.

For both scenarios and all the analysed impact subcategories, turbines account for less than half of the relative contributions. Within the turbine, the nacelle is the component that is most exposed to risk. Based on background data from PSILCA, the manufacture of basic metal in France sector would be linked to upstream processes such as mining in South Africa, which would explain the related contextual social risks.

4.4.2. National and local scopes

The impact assessment of local and national scopes is addressed in this section through the PRP approach. This approach involves the use of values for indicators from primary data when possible, or secondary data such as data from literature to define the performance reference scale for each indicator considered For optimal interpretation, the score performance results should be considered using the thresholds defined.

4.4.2.1. Defining the reference scales

As already explained, the PRP approach consists of establishing levels of performance for a given indicator based on a reference value or set of reference values. In practice, the reference scale in five levels of performance scores, ranging from -2 to +2 is the most used one when implementing PRP approaches (UNEP, 2020). The values used for defining the reference scales can be based on standards, legislation or industry best practices (UNEP, 2020). As specified in some S-LCA studies (Bouillass, 2021; Gompf et al., 2020), to enhance transparency and interpretation, it is important to clarify the thresholds used to attribute the different reference scores. As presented in chapter 2, these thresholds aim to delimit the levels of performance score. They may be based on one or several reference values taken from literature.

During the inventory analysis phase conducted in this PhD thesis, the indicators were specifically identified with respect to the context of emerging OWF sector in France, and the related stakeholders and prioritised impact subcategories. To current knowledge, these specific indicators have not yet been used in other S-LCA studies using a PRP approach applied to this context. None of the revised articles reported explicitly a systematic approach to establish thresholds to define PRP on OWF sector or at least threshold values used for the evaluated indicators. This results in a lack of reproducibility. Depending on the indicators and data available, different ways of defining the reference scale are possible. One of the methodological proposals in this PhD thesis is an approach to an explicit definition of the preferences to define thresholds for reference scales applied to the French OWF sector.

In practice, in the conducted work, the definition of thresholds depends on the values available. Given the available information on the identified sources, four approaches were used to define thresholds. Each

approach corresponded to a different level of resolution. Considering the expected representativeness of each option, a protocol was proposed in this PhD, providing recommendations about the preferred approach to establish reference scales, as a result of the experience of the application to the different OWF case studies. Thus, the alternatives should be used in the following order of preference:

1) use the values as presented in the literature when they are explicitly defined (e.g., probability of accident with a civil, rate for critical raw materials);

2) deduce thresholds by establishing regular intervals based on values observed for different case studies in the literature,

3) deduce thresholds by establishing regular intervals based on values observed for a set of case studies selected and evaluated in a given S-LCA;

4) in the case where only one generic value is identified, proposing regular thresholds on this basis according to the range this value could take.

These preferences have been considered to define the different reference scales for all the indicators in the local and national scope presented in Table 4.9. The approach used to establish the performance reference points for each indicator is provided in the corresponding column, using the indices 1, 2, 3 and 4 as previously presented in the list and whether the reference values used to come from case studies in France (a) or other countries (b). For nuance between 2) and 3), there is no absolute priority applicable to all contexts, the suitability of one or the other depends mainly on the goal and scope of the study and the level of comprehensiveness. For example, if 10 case studies are available in the literature to apply approach 2) and the set of case studies to be specifically evaluated in the S-LCA using 3) only includes 2 case studies, using approach 2 may be more appropriate. On the contrary, if only 2 case studies are available in the literature to apply approach 2), whereas the selection of case studies in approach 3) includes 10 case studies, the approach 3 may be more appropriate.

Table 4.9. Reference scales definition for indicators for the Social LCA of offshore wind farms.

Spatial scope	Stakeholders' category	Impact subcategory	Indicator	Unit	Reference scale and performance reference					Reference scale proposed	Source of reference value
					-2	-1	0	1	2		
Local scope											
	Local community		Potential touristic development	*Number of visits*	X	No parallel projects planned	Parallel projects planned	Parallel projects underway	Parallel projects underway >100 visits	3a	(Vues sur Mer, 2018) (Eudleur, 2023, master internship)
		Attractiveness of the territory	Effect on landscape: "spatial integration"	*Index*	> 0,20	[0,20-0,15)	[0,15-0,10)	[0,10-0,05)	≤ 0,05	3a	Based on technical parameters from the project owner's documents
			Potential devaluation on property prices	*%*	> -5%	[0%; -5%]	0%	x	x	4a	(ADEME, 2022; Jensen et al., 2018)
		Sharing of spaces	Surface efficiency	*km²/MW*	> 0,4	[0,4-0,3)	[0,3-0,2)	[0,2-0,1)	≤ 0,1	3a	(Santoyo-Castelazo and Azapagic, 2014)
			Potential increase in catches close to a wind farm	*%*	<-10	[-10;-5[	[-5;5[	[5;10[	<10	4b	(Halouani, et al., 2020)
			Willingness to practice recreational fish near OWF	*%*	X	x	[0-25)	[25-50)	≥ 50	4a	(Hooper et al., 2017)
		Safety management	Probability of accident with a civil	*Number / year*	X	≥ $1{,}4.10^{-1}$	[$8{,}6.10^{-3}$; $1{,}4.10^{-1}$)	[$5{,}8.10^{-4}$; $8{,}6.10^{-3}$)	< $5{,}8.10^{-4}$	1b	(La compagnie du vent, 2010; SSPA Sweden AB, 2008)
		Territory investments	Annual taxes	*Millions € / year*	X	x	< 4	[4-6[	≥ 6	3b	(CGEDD, 2021b)

	Local employment	Indirect local job	*Number / MW*	X	< 1	[1 – 2]	> 2 *regional	> 2 *departmental	3a	(CRE, 2018)
	Community engagement	Share of littoral population in public meeting	*‰*	< 0.01	[0.01-0.1)	[0.1-1)	[1-2)	≥ 2	3b	(UNEP, 2021)
		Trust rate in electricity developers	*%*	< 25	[25-50)	[50-75)	[75-90)	≥ 90	4a	(Hooper et al., 2017)
Consumers	Service to consumers	Percentage of local consumption (administrative department)	*%*	< 15	[15-35)	[35-55)	[55-75)	≥ 75	3b	(MTE, 2022a)
		Price per MWh: cost of public support	*€ / MWh*	X	>200	[100-200] Or Na	<100	x	3b	(European Commission, 2019)
Value chain	Wealth distribution	Local content: share of project cost captured by local companies	*%*	< 20	[20-30)	[30-40)	[40-50)	≥ 50	3b	(CRE, 2018; UNEP, 2021)
Workers	Employer relationship	Temporary employment	*%*	> 60	[60-45)	[45-30)	[30-15)	≥ 15	2a	(Buchmayr et al., 2022 based on Rutovitz et al., 2015; OECD, 2023)
	Equal opportunities	Social clauses	*hours / MW*	No identified clauses	< 200	[200-300)	[300-400)	≥400	3b	(CRE, 2018; UNEP, 2021)

Spatial scope	Stakeholders' category	Category	Indicator	Unit	Reference scale and performance reference points					Reference scale proposed	Source of reference value
					-2	-1	0	1	2		
National scope	Value chain										
		Supplier relationship	Payment rate without delay	*%*	< 60	[60-70)	[70-80)	[80-90)	≥ 90	4b	(Banque de France, 2018)
		Social and environmental commitments	Ecovadis score of the OWF developer	*Score*	< 40	[40-50)	[50-60) Or Na	[60-80)	≥ 80	3b	(Ecovadis.com, 2023)
	Society										
		Energy independence	Avoiding fossil fuel costs	*Millions €*	< 35	[35-50)	[50-65)	[65-80)	≥ 80	3b	(EWEA, 2014)
			Import dependency rate for critical raw materials (related to type of turbine)	*kg / MW*	≥ 200 (PMG-DD)	~ 50 (PMG-MS)	~30 (PMG-HS) or Na	< 30 Other technology	x	1b	(ADEME, 2019; Baranzelli et al., 2017)
		Social and environmental commitments	CSR score of OWF developer	*Score*	< 65	[65-70)	[70-75) Or Na	[75 – 80)	≥ 80	3b	(Ecovadis.com, 2023; UNEP, 2020)
		National economic development	Indirect jobs in the value chain	*Number / MW*	< 0,6	[0,6-1,2)	[1,2-2,5)	[2,5-5)	≥ 5	3a & 3b,	(Bengtsson Ryberg et al., 2013), INNOSEA, 2023
			Induced (or spin-off) jobs	*Number / MW*	< 0,2	[0,2-2,5)	[2,5-5)	[5-10)	≥ 10	3a & 3b,	(Bengtsson Ryberg et al., 2013), INNOSEA 2023

Several aspects from can be highlighted, concerning the reference values and related thresholds defined for the indicators.

- Potential increase in catches close to a wind farm: a reference value of 7% has been identified in the context of a park closed to fishing which would generate additional catches around the OWF (Halouani et al., 2020). This is not a fixed and systematically transferable value but a potential effect. Although this is a generic value, it identifies the value that this impact could have in similar contexts.
- Probability of accident with a civil: thresholds are based on values from a study related to hypothetical OWF projects of various sizes (SSPA Sweden AB, 2008).
- Annual taxes: they are based on the ratio in euros per MW capacity defined by the related French law on marine energy (CGEDD, 2021b).
- For local jobs, thresholds have been defined based on an average of 1.7 jobs/MW for the projects identified, with a proposal to disaggregate the local jobs presented on a regional scale and those on a departmental scale to consider different levels of proximity to an OWF project.
- Rate of trust in developers: in the absence of several case study measurements, thresholds of performance score are based on a generic value from a survey of offshore wind in the UK and considered as representing a low performance (Hooper et al., 2017).
- For the indicators Temporary employment and Payment rate without delay, reference values have been identified in the literature related respectively to the sector of Northern Europe offshore wind sector and French civil engineering sector. The associated values have been estimated to reflect a low performance compared with those available, which are identified in other sectors.
- Avoiding fuel cost: based on a generic value from a study on the reduction in fossil fuel imports that development of wind energy would generate. An average cost per MW is mentioned, then applied to the different study cases depending on their total power capacity (EWEA, 2014).
- Import dependency rate for critical raw materials (related to the type of turbine): based on the amount of critical raw materials related to three main types of permanent magnet technologies (ADEME, 2019; Baranzelli et al., 2017). These related thresholds may evolve depending on the development of other technologies.
- For employment on a national scope, the thresholds were defined based on values identified in the literature for on wind farms project from various countries and on the basis of simulations using a tool that assesses the number of jobs based on gross value added (INNOSEA, 2022).

The list of indicators and reference scales presented in this section is a first proposal based on the identification of impact subcategories and indicators in this PhD. This list of subcategories and indicators may be completed in future S-LCA studies. The described approach for the identification of

reference values and thresholds can be extrapolated to other indicators. Furthermore, the reference values and related thresholds should be refined as more data become available. Given the sources available to date, the use of these thresholds and related performance scores is limited to the context of this thesis. The application of these reference scales to OWF that have not been covered in this work without adapting the thresholds should be done carefully. These thresholds are based on site-specific values for certain OWF projects for some indicators, or on generic values for all indicators for which site-specific values were not available. As OWF sector develops and more studies become available, data availability is expected to increase. Consequently, the proposed thresholds, as well as the indicators, should be seen as a preliminary reference that will evolve and be adapted to the context in the future.

4.4.2.2. Performance assessment results

This section presents the results of the social performance assessment of five OWF systems, firstly for the local scope and then for the national scope. The indicators identified during the inventory phase are here evaluated according to the performance scale defined in the previous section, and for the related impact subcategories and stakeholder categories. These results were presented in terms of social performance, based on the defined performance scale. The results obtained on several case studies led to the identification, for certain indicators, of variations in social performance and certain parameters explaining these variations. The results of interviews complete the interpretation of literature-based results by providing stakeholder viewpoints on different impact subcategories. The performance scores are presented for the five case studies, together with the lowest, highest and average values of social performance observed or, if needed, related to a generic value.

Table 4.10 below presents the results of the performance assessment for the indicators of the local community stakeholder category related to installation and operation stage of OWF. Values are presented for the different OWF case studies, together with the extreme and average reference values for each category. The following section discusses trends of social performance scores for the local scope and national scope, respectively.

Table 4.10. Performance score of analysed case studies and reference levels One cell merged means that only one generic value has been used to attribute the performance score for all the case studies and no distinction between case studies for this indicator is possible at the moment.

Spatial scope	Stakeholder category	Impact subcategory	Normalised gap score	Indicator	Performance scores							
					Case study 1	Case study 2	Case study 3	Case study 4	Case study 5	Min	Average	Max
Local scope	**Local community**	Attractiveness of the territory	10%	Potential touristic development	2	2	1	2	1	1	2	2
				Effect on landscape: "spatial integration"	2	1	1	2	1	1	1	2
		Sharing of spaces	15%	Potential devaluation on property prices	0					0	0	0
				Surface efficiency	1	1	1	1	1	1	1	1
				Potential increase in catches close to a wind farm	1 (based on one generic value)					1	1	1
				Percentage of willingness to practice recreational fish near OWF	1 (based on one generic value)					1	1	1
		Safety management	10%	Probability of accident with a civil	2	1	1	1	1	1	1	2
		Territory investments	8%	Annual taxes	1	2	2	2	2	1	2	2
		Local employement	11%	Indirect local job	1	2	2	-1	0	-1	1	2
		Quality of dialogue	13%	Amount of meetings with local communities / littoral population	0	0	2	1	0	0	1	2
				Trust rate in electricity developers	-2 (based on one generic value)					-2	-2	-2
	Consumers	Service to consumers	18%	Percentage of local consumption for the administrative department	0	0	1	-1	2	-1	0	2
				Price per MWh: cost of public support	0	0	0	0	0	0	0	0

Value chain	Wealth distribution	31%	Local content: share of project cost captured by regional companies	2	-1	0	-1	-2	-2	-1	2
Workers	Employer relationship	15%	Temporary employment	-2 (based on one generic value)					-2	-2	-2
	Equal opportunity	12%	Social clauses	-2	-1	2	0	-1	-2	0	2

Spatial scope	**Stakeholder category**	**Impact subcategory**	**Normalized gap score**	**Indicator**	**Performance scores**							
					Case study 1	**Case study 2**	**Case study 3**	**Case study 4**	**Case study 5**	**Min**	**Average**	**Max**
National scope	**Value chain**	Supplier relationship	25%	Payment rate without delay	-1 (based on one generic value)					-1	-1	-1
		Social and environmental commitments	19%	Ecovadis score of the OWF developer	0	2	2	0	1	0	1	2
	Society	Energy independance	18%	Avoiding fossil fuel costs	-1	1	1	1	1	-1	0	1
				Import dependency rate for critical raw materials	0	-2	-2	0	-2	-2	-2	0
		Social and environmental commitments	24%	CSR score of OWF developer	0	0	0	0	0	0	0	0
		National economic development	16%	Indirect jobs in the value chain	2	1	1	2	1	1	2	2
				Induced (or spin-off) jobs	2	1	1	2	1	1	1	2

Considering the data collection and the related definition of thresholds, different trends on social impacts can be noted. This section discusses firstly the performance score results based on specific values, then those based on generic values.

Regarding local content, namely the share of project cost obtained by regional companies, the performance scores range is relatively high. This range may be explained by the dependency on the territorial context: thus, projects that benefit from a well-developed local industrial context could find it easier to sign contracts with local companies. For example, the needs of territories to develop their port areas may also favour the creation of local contracts. Depending on the OWF and associated installation site, the need to invest locally may vary. In the case of projects requiring specialised skills that are not available locally, it may be difficult to achieve a high level of local content. Some territories can attract upstream activities related to different OWF projects. Conversely, other territories may constitute installation sites for OWF projects without benefiting from the same number of upstream activities (e.g., if components are manufactured in another territory). Some variations of the performance have been observed for local job creation. This variation in job creation is likely dependent on the choice of the technology used. Among the case studies, those with floating foundation technology seem to generate more jobs than those with fixed technology.

Social clauses promote social inclusion by encouraging the hiring of people who have difficulties accessing employment. By promoting the hiring of local labour, social clauses stimulate the economy of the territories in which the OWF projects are implemented. While for some OWFs communication activities have been carried out on actions related to the number of social clauses, for other OWF, the data is either not communicated or not yet available. The use of social clauses can be limited by various factors. Considering that social clauses could affect costs and recruitment processes or involve additional administrative management for monitoring and evaluating their implementation, some companies may not be encouraged to deploy social clauses. Despite these potential obstacles, social clauses play a crucial role in promoting a more inclusive, ethical, and sustainable economy and contribute to improved social performance.

Some indicators may serve to identify potential issues (i.e., social hotspots) or benefits for the national scope, too. Current offshore turbine models generally include neodymium and dysprosium materials through permanent magnets' components (ADEME, 2019). Direct-drive permanent magnet generators are the identified technologies, with around 200 kg/MW of these materials used. Due to a concentration based almost exclusively on certain mining sites in China, these materials generate a geographical dependence and are considered as critical materials by the European Commission (Baranzelli et al., 2017). In this context a material is considered critical if it presents a risk of supply failure while having a major economic importance. In the absence of alternatives, the use of these critical materials raises several issues. Dependence on a few suppliers can lead to a concentration of control, which can influence

prices and supply conditions. The development of alternative materials is therefore a key issue in reducing dependence on critical materials and strengthening the resilience of the industry.

For performance score results based on one generic value, as discussed below, there is no distinction between case studies. For the indicator rate of trust in OWF developers, the result reveals a relatively low performance (-2). In absence of site-specific values, this indicator is based on a generic value for a study in the UK (Hooper et al., 2017). Based on this result, the lack of trust between communities and OWF developers is underlined by Hooper, 2017. Therefore, this generic value the rate trust is estimated to correspond as a low performance. It should be noted that the legislation around offshore wind projects implementation is different between the UK and French legislations. Indeed, the French regulatory system encourages public consultation and participation. To the current knowledge, there is no evaluation of trust rate for case studies in France. The low value should not be seen as a directly transferable result to OWF case studies but as a point of attention revealed by feedback in other countries. A recommendation would consist of the evaluation and monitoring of this value over time for the development of wind farms in France. For the local community stakeholders, it should be reminded that other indicators are not based on site-specific data but on generic data. This is the case for indicators such as the potential devaluation on property prices, the potential effect on marine ecosystems and the recreational willingness to fishing.

Regarding the temporary employment indicator, data concerning the share of temporary vs stable employment were not identified at the level of each OWF project. For this reason, the value used for the evaluation is a generic value at the offshore wind sector scale which is around 67% and estimated as low performance compared to the all-sector average value in France of 16% (OECD, 2023) . Different parameters could influence the percentage of temporary employment. Firstly, while the installation stage is likely to generate the highest number of jobs compared to other stages, it is also a relatively short stage. Conversely, the operation and maintenance stages generate fewer jobs, but are more stable over time. While a large proportion of the jobs created may be temporary, OWF sector can also offer long-term opportunities for workers, as the sector grows and becomes more stable.

Concerning the payment rate, the value was not obtained specifically at the level of each OWF case study. The value used is therefore a generic value at the French civil engineering sector level. This generic value used at this stage involves, obviously, a large level of uncertainty and the limitation that the different case studies cannot be compared. However, it is important to include this indicator in the list, given the relevance of the supplier relationship impact subcategory. This identification serves to highlight that, despite current limitations for its evaluation, the indicator should be considered in the future and enhancing available information is key for a more relevant evaluation. Companies in the construction and civil engineering sectors are tending to improve their supplier payments, but continue to be subject to late payments from their customers (Banque de France, 2018). Given that some

companies in this sector are involved in certain stages of the OWF life cycle, this may be a point to monitor. For example, half of the companies in the construction and civil engineering sectors suffer delays, compared with only one quarter for activities such as the retail sector. A high rate of payment without delay can mean efficient cash-flow management and, thus, low risk of financial default. Conversely, a low rate of payment without delay could lead to a delay in the designing and construction stages of a project.

The interviews conducted during the inventory analysis phase have brought some additional information related to different stakeholders and impact subcategories. For the consumers' category, managers from various consumer associations were contacted. However, the low level of feedback from their side, combined with the lack of identification of sectoral social issues related to the sector during the hierarchisation steps, led the local impacts on the consumers stakeholder category to be considered only through one impact subcategory. For electro-intensive consumers, the electricity generation from OWF did not seem to represent a social concern.

Concerning value chain actors, relationships with suppliers was a key issue, in particular, regarding the respect of the delivery date agreements. For example, the high costs associated with the use of highly specialised vessels for offshore civil engineering work involve heavy penalties in case of delay. To avoid these delays, tasks must be carried out respecting strict deadlines. This could generate pressure, which would then be transferred between subcontractors within the industry. In the absence of an indicator more closely related to this concern, it is estimated that the indicator "rate payments without delays" could approach the consideration of this category of impact. This indicator can be identified at a sectoral level. In this case, it constitutes a generic value that does not allow distinguishing between OWF projects based on currently available information. This is an example of an indicator for which a preliminary source is provided but that could be improved in case additional information or alternative indicators become available.

Interviews with local administration actors confirmed the relevance to consider local economic benefits in terms of job creation and taxes. Job creation includes direct jobs related to an OWF project (i.e., mainly linked to the manufacturing and construction stages, as well as the operation stage), but also indirect and induced jobs resulting from the arrival of new employees in a region, who may spend part of their salary locally (e.g., accommodation, food). Local administrations are also concerned about the interactions with the pre-existing socio-economic sectors on the territory, namely the sharing of maritime space between previous uses and an OWF implementation. To identify the interactions between maritime uses, the consultations with local community also involved several fisheries committees' representatives. This consultation revealed that the quality of the dialogue plays an important role during the installation stage of an OWF project. Other parameters could have been considered to address the interaction between OWF implantation and fishery, such as the soil type. For example, on a sandy soil,

the artificial reefs provided by OWF infrastructure may be more favourable than in an area that was already composed of natural reef. Regarding navigation practices, floating foundations may be perceived as more restrictive for fishing activity, especially if these OWF are far from the shore, as they may interfere with larger vessels. Fixed foundations, particularly jackets, may be perceived as having less effect on fishing activities. Fishery concerns would be more focused on the impact on biodiversity, mainly linked to halieutic species, during the installation and operation stages. This suggests the reinforce the need to identify a generic indicator estimating the potential impact of a OWF on fishery resources.

The work presented in this section allowed the reference scales previously defined to be tested, by applying them to the assessment of five specific French OWF case studies. From the application, the usefulness and limitations of these reference scales in their current form were verified. Some indicators allowed performances to be specifically evaluated for each case study and compared, thanks to the data availability. In other cases, the lack of specific data allowed to consider generic alternatives with different levels of resolution (e.g., generic data for companies, generic data for the whole OWF sector). In these cases, the comparison is partial or not possible, and should be interpreted carefully. However, the inclusion of such indicators in the list was still considered relevant, to allow at least potential hotspots to be identified, and to support the need for orienting future research to increase the number of indicators or enhance the existing ones and the associated available information.

4.5. Conclusions

This chapter 4 aimed at developing a methodology to assess the potential social impacts of offshore wind farms in France including three complementary geographical scopes. Overall, this work provides a systematic framework to apply S-LCA to OWF projects, as well as additional elements of discussion and a preliminary identification of potential hotspots related to social impacts of OWF.

Existing S-LCA tools were used and adapted to cover social aspects at different levels of the OWFs life cycle. On the one hand, S-LCA models using a generic database and a conventional LCA software were used to evaluate the social risks of the sector's activities on a global scope. Within this framework, two hypothetical main technological scenarios were defined to estimate the variability of medium risks hours as associated with different OWF technologies. On the other hand, sector-specific indicators were proposed to cover relevant impact subcategories for the local and national scopes. In this case, the assessment was based on more heterogeneous data sources. To explain this heterogeneity, the context of the sector should be highlighted. The sector is, indeed, characterised by a strong industrial competition, which is reflected in the limitations observed in this PhD thesis to access data (i.e., missing, incomplete or confidential data). Due to these limitations, the PhD thesis has developed an approach for a systematic

and transparent data collection method. Despite these limitations, this chapter proposes a set of social impact indicators adapted to the OWF sector, of which certain indicators are specific to the sectors while others are also transferable to other energy systems.

It should be highlighted that conducting the inventory analysis and impact assessment phases require a number of assumptions and are subject to uncertainty. In particular, assumptions and data sources for the definition of the reference values and thresholds, essential to evaluate social performance, should be revised and should evolve as more data becomes available. Moreover, it may be complex to define precisely how many indicators an impact subcategory should contain. For example, an impact subcategory may be considered as important, but associated with a low number of available indicators or even not associated with any indicator at all. In the case of OWF application, for example, "maritime space sharing" should be better investigated. Further work could be carried out to study protocols for experts' consultation in the definition and/or identification of indicators. The challenge is to systematise the way to find a compromise between accurate assessment and feasibility, by taking into account the broad scope of S-LCA, related to the inventory analysis and the impact assessment phases. Expert consultation could be further combined with the definition of the reference scales and associated thresholds so as to reinforce the reliability.

Regarding the application for the global scope, certain limitations of the S-LCA databases were also identified, in terms of geographical and temporal data coverage, but also in terms of the transparency of the sources.

Future research may deal with several aspects. Among challenges that can be further explored is the need for improving the accuracy of the impact assessment phase and reducing the number of assumptions contributing to uncertainty, mainly technical-economic information about the different activities and components identified, such as the related involved sectors or share of labour costs estimated.

Other perspectives can also be noted for further consideration of sectoral issues related to OWF systems and the territorial specificities of installation sites. Methodologies for a better integration of pre-existing activities and stakeholders in an area in parallel to the implementation of a project should be investigated. Regarding marine renewable energy, it may include environmental economics, coastal management, and ecosystem services. These different disciplines propose specific metrics for certain impacts related to interaction between OWF and external stakeholders living in the territory.

5. General conclusion and perspectives

5.1. Main outcomes of this PhD thesis

The fight against global warming is leading to the need for an energy transition. This transition is ongoing and entails the development of new energy production technologies. In this context, offshore wind power is an emerging sector in France that is rapidly growing, with several projects currently under development. Because of their size and complexity, offshore wind farms (OWF) involve many different stakeholders at different stages of the life cycle, which results in a considerable number of potential social concerns that should be accounted for. To achieve offshore wind sustainability, considering social concerns is key, and the corresponding assessments must be extended to the entire life cycle. S-LCA is a methodological framework that can be used to this end. However, the current level of development of S-LCA calls for more transparent approaches and more systematic data collection processes to increase its applicability and usefulness. Furthermore, some sectoral particularities of the offshore wind energy sector in France have led to the need to adapt existing frameworks. This need of adaptation led to the formulation of two research questions within this thesis.

5.1.1. First scientific question

Firstly, this thesis focused on an existing challenge related to the definition of the goal and scope. The formulated question was:

- **How to develop a systematic approach for the identification of the relevant impact subcategories based on stakeholders consultation?**

To answer this question, a methodological framework was proposed for the hierarchisation of impact subcategories, using participatory and representative approaches. Two methodologies based on surveys were explored, one addressed to power electricity companies directly involved in the operation of OWFs and the other one, at external stakeholders related to local and national scopes. The approach targeting electricity companies produced a direct ranking of subcategories, but also a large dispersion of the results (i.e., relatively high standard deviation) for the hierarchisation of UNEP impact subcategories. The results revealed that the "Health and safety" impact subcategory ranked first in order of importance for different stakeholder categories such as direct and indirect workers, and consumers, as well as “Safe and

healthy living conditions" for local community. However, the size of the sample for this survey and the lack of consensus among the respondents for the majority of impact subcategories led to the need for complementary views. Thus, a consultation of external stakeholders was launched to increase legitimacy on the impact subcategories hierarchisation step.

For the second hierarchisation survey addressed to external stakeholders, a literature review of participatory approaches revealed some bottlenecks, mainly related to the definition of statistical samples and representativeness. For overcoming these bottlenecks, this PhD thesis proposed a methodological approach to: (i) access these stakeholders by considering their diverse profiles, (ii) adapt the identification of relevant impact subcategories from the UNEP list to the offshore wind power sector, (iii) then measure the level of representativeness of the respondents. The methodology proposed in this section of the PhD thesis is seen as transferable to other contexts also related to the offshore wind sector, but also to other energy generation sectors. The proposed method makes it possible to systematise the construction of a panel representative of the concerned population, by considering different profiles of respondents within a given stakeholder category. Besides, the method uses a statistical representativeness test to analyse the relevance of respondents based on a descriptive variable, namely the distribution of stakeholder sub-groups. This method allows the legitimacy of survey respondents' profiles representing the evaluated stakeholder category to be checked. This representativeness test has been coupled with the gap scoring method identified in the literature to address both expectation and perception aspect of the stakeholder's perspective. The protocol includes an attribution of a gap score followed by an adjustment of the gap scores attributed by the respondents to avoid under- or over-estimating certain sub-groups of stakeholders compared to whole stakeholders' category as defined. Among impact subcategories identified with the highest scores, "sharing of spaces" and the "quality of dialogue" was identified for local community, whereas "Wealth distribution" and "Supplier relationship" were highlighted for value chain actors.

The disaggregated results of the surveys revealed that the answers given to classify the impact subcategories may differ according to these sub-groups. These disaggregated results therefore reinforced the need to account for the distribution of these sub-groups in a sample. The response proposed was intended to help make the hierarchisation of impact subcategories more inclusive of the stakeholders' diversity. A certain variability of responses was identified among external stakeholders as well. This suggests a wide range of opinions about the system being evaluated and the impact subcategories proposed for hierarchisation. Future work should be carried out to better account for the disaggregated aspects of respondents (i.e., the variables which may influence opinions). Some persistent limits have been noted to integrate representativeness testing approaches for the other stakeholder categories, namely consumers, workers, and society.

5.1.2. Second scientific question:

The sector of application in this PhD thesis was the emerging offshore wind power sector in France, which entails the installation and operation of large-size infrastructures potentially affecting other activities and stakeholders located on these territories. To identify a methodological pathway to assess such potential effects, the second question was proposed:

- **How to adapt the current S-LCA framework to couple LCA-holistic view and local aspects of for a given stage of the life cycle when data are scarce?**

Analysis of the sector's social concerns revealed their diversity and complexity, and the need to consider a detailed description of the installation area, including the interactions of the OWF with activities already established in the territory. To conduct the inventory analysis and impact assessment phases, this thesis proposed to proceed by distinguishing among different geographical scopes and applying an approach for the assessment adapted to each of the scopes.

The global scope corresponded to the assessment of general social impacts over the whole life cycle of the evaluated systems. To assess this scope, a classic S-LCA analysis using a LCA software and a generic database containing inventories for activities at the country and sector level was conducted. Two hypothetical scenarios were used to identify sectoral risks. These scenarios were based on the two main families of configurations depending on the foundation type, namely fixed and floating OWF technologies. The results reveal a slight tendency for the floating scenario to be more related to upstream sectoral risks. This can be explained by the assumptions used on raw material and related involved generic sectors, in particular regarding the manufacture of basic metal. The assumptions used were based on generic data and the geographical and sectoral information provided by default in PSILCA. For this reason, a social risk assessment based on more case studies with similar designs would not be expected to provide a significant level of additional information. Several elements could lead to improve the evaluation based on S-LCA, mainly in terms of uncertainty reduction.

The national and local scopes were explored by the identification of sector-specific impact subcategories and indicators and the definition and use of reference scales, including performance-reference-points. The set of sector-specific indicators was complementary to those assessed for the global scope. In this case, the stakeholder categories and impact subcategories corresponded, in particular, to stakeholders involved or affected by the installation and operation stages. The assessment led to the identification of new and adapted indicators, including specific indicators for OWFs and transferable indicators to other energy systems. Some of the reference values identified can be reused in further comparative analyses, or refined as further information is made available.

To address these scopes based on a PRP approach, a protocol was proposed to systematise secondary data collection and establish levels of priority of sources. A decision tree was depicted, including an

extensive literature review, as well as stakeholder consultations as sources of site-specific data, but also other sources of generic data to be used as a proxy when no other information is available. This protocol takes the limited access to site-specific data into account and proposes to order the collection of site-specific and generic data depending on the expected level of capacity to represent the real system. Different types of generic data have been labelled, depending on their level of resolution. Stakeholder consultation, conducted during the inventory phase, also served to complete the data collection for the impact assessment and provided complementary elements for the interpretation of some impact subcategories. However, obtaining data from different sources, and covering different levels, also involves non-negligible levels of uncertainty. Further work should be conducted for better covering current challenges related to data access and accuracy and its relation to inventory data in the context of PRP approaches.

5.2. Perspectives

This PhD thesis provided a general framework for the S-LCA of the OWF sector in France, with a special focus on representativeness of impact subcategories' hierarchisation, and on the importance of considering the role of territories at the different levels of the life cycle. While many topics have been addressed in this thesis, many challenges or S-LCA persist, and additional questions have arisen after the development and application of the proposed approaches. These perspectives could contribute to enhancing the methodology and the applicability of the proposed approaches to other sectors. The aspects to be further developed include the following topics:

- **Participatory approaches for the hierarchisation step**

Participatory approaches are recognised as a technique contributing to the legitimacy of the goal and scope definition phase. However, certain points still need to be improved. In this work, two distinct approaches were tested: one addressed to electricity companies and the other one to external stakeholders. The possibility of using these two approaches in a more complementary manner needs to be explored. It is a matter of finding the right balance between the sectoral expertise that can be provided by the companies' perspectives, and the diversity of perspectives of different external stakeholders. Protocols should be defined to deepen the comparison of the two perspectives, namely, to identify the parameters which can explain the divergences and the convergences of points of view in the hierarchisation of the impact subcategories.

In addition, these participatory approaches were carried out at the hierarchisation step (i.e., at the start of the S-LCA application). There are similarities with the weighting step, which consists in attributing more importance to certain indicators and/or impact subcategories. These subcategories are, thus,

weighted once the impacts have been assessed (i.e., at the end of the S-LCA application). In this thesis, no weighting step was carried out once the impact subcategories had been assessed. However, the absence of weighting implicitly suggests that the same weight should be assigned to all the impact subcategories. Given the similarities between the hierarchisation and weighting steps, the interest in coupling these two steps could be explored.

- **Enhancing the integration of uncertainty for S-LCA inventory analysis and impact assessments stages**

A PRP approach was used for national and local scopes. In the context of the PRP approach, the definition of thresholds is necessary for the assessment of the social performance of systems based on indicators defined by the practitioner. However, it may be difficult to find appropriate data for this task. According to the levels of threshold definition defined in this PhD thesis, three configurations have been used. To the current knowledge, there is no rule to define which interval level should be used to define each performance score when a single reference value has been identified. To address this aspect, expert consultation could replace the decision of the practitioner on the intervals in the definition of thresholds.

Regarding the indicators defined in the PRP approach, adding information on the quality of the data collected could have been useful for the interpretation phase. Information on the quality of the data should help to identify the indicators whose values are the most uncertain. Also, it seems appropriate to allow for the possibility of updating the performance definition thresholds as more S-LCA evaluations are carried out in a sector. The PRP values identified today may not be relevant in the future. What is a considered a favourable performance today may no longer be so in the future. This is why, depending on the meaning of the indicators, and especially when they are constructed from values observed among assessed case studies, performance scales need to be designed flexibly.

Regarding the global scope, using generic databases involve many types of inventory data to be quantified by the practitioner (e.g., raw material, monetary prices, working time by activity). Unless the inventory is exhaustive, many assumptions are needed. Also, generic information contained in the database itself can be not accurate or not updated. These two levels of generic impact calculation may conduct to large uncertainties affecting the assessment results.

Different elements could contribute to improving the accuracy of risk measurement based on S-LCA background databases. To make the PSILCA database assessment reliable, and in the case of real case studies, access to specific inventories is highly recommended. These specific inventories may include the technical and economic information specific to the components and raw materials, as well as the labour costs, but also the social impact levels themselves. For example, visits to manufacturing sites may allow accurate information on social risks to be collected at the site level to replace generic data

provided at the country level in S-LCA databases. A site visit can include the use of surveys to be completed by employees or managers. Their feedback may provide information to measure the risk levels for some indicators. The risk levels estimated by this method could then be allocated to the indicators used in PSILCA for a more accurate impact assessment. It is important to note, however, that such methodologies for accessing primary data are time-consuming and are unlikely to be applicable to all life cycle stages.

- **Improvement of indicators and consideration of local scope related to S-LCA inventory analysis and impact assessment stages**

S-LCA, as the general LCA framework, is an iterative framework. This involves that a set of indicators identified in a given study for a given sector, such as the current study of OWF sector, can be reviewed and discussed. A practical example of this iterative nature would be possible adjustment of an indicator initially proposed in this study but that can evolve in the future. The indicator included in this work on the percentage of electricity that a OWF will supply in relation to all the means of production on the territory could be considered as an example. In a context of energy autonomy, regions have an interest in having their own means of energy production. To deal with this aspect, we have only considered the number of inhabitants of the department supplied by an OWF, as this is what is often communicated. However, it might be more relevant to consider the share of electricity that an OWF will supply in relation to other production technologies already established in the department. For departments within the peninsular region of Brittany, which is highly dependent on the electricity grid, electricity from OWF wind farms could significantly contribute to energy independence.

It would be interesting to explore methods for defining indicators to help measure the degree of conciliation between a project, depending on how it is conceived, and existing stakeholders in the area. For example, based on fishery consultation, considering potential conciliation between OWF implementation and fishery activities could include surface footprint during the installation stage, quality of dialogue (i.e., work sequencing), technical parameters of the farm such as the type of foundation, hours of presence in the area and the type of fishing vessels. Considering these parameters would allow an indicator to be adapted by considering the technical and territory-related specificities of the OWF.

Finally, it is important to highlight that the national and local scopes defined in this thesis only concern certain phases of the OWF life cycle. These scopes have been defined to help focus the inventory analysis and impact assessment phases on the OWF sector specificities. As a reminder, the literature has revealed numerous specificities related to the installation and operation stages of OWF systems. However, to be coherent with the principles of life cycle, site-specific data collection should also be encouraged for the upstream and downstream stages. An in-depth study could lead to the identification

of other specificities in relation to other upstream or downstream sectors linked to the system. In this case, a PRP approach stays relevant to define specific indicators to complement those available in the S-LCA databases. Given the inherent difficulty of site-specific data collection related to such a scope, it could be useful to promote the consultation of experts related to some social issues.

The work carried out in this PhD thesis has made a methodological contribution to the integration of stakeholder representativeness and territorial specificities into the S-LCA framework, including goal and scope, inventory analysis, impact assessment and interpretation phases. These developments are mainly seen as transferable to other systems within the energy sector, after a careful adaptation of the approach, and, by extension, to infrastructure projects. S-LCA is expected to develop further in the coming years. In a context where sustainability issues, including social ones, are recurrent and will be increasingly present in the future, it is certain that this method will be deployed both by public and by industrial decision-makers.

Scientific communications and publications

- Lehmann, J., Bouillass, G., Fofack-Garcia, R. and Pérez-López, P., 2021, Towards social life cycle assessment of energy systems: a case study on offshore wind farms from companies' perspective, Poster at the 10th International Conference on Life Cycle Management, 1-8 September, Stuttgart.

- Lehmann, J., Bouillass, G., Fofack-Garcia, R. and Pérez-López, P., 2022, Towards social life cycle assessment of energy systems: a case study on offshore wind farms from companies' perspective, E3S Web of Conferences 349, 12002. https://doi.org/10.1051/e3sconf/202234912002

- Lehmann, J., Fofack-Garcia, R. and Pérez-López, P., 2022, Hierarchy of social impacts: towards a consolidated method for a representative social impact prioritization, Oral communication at the 8th International Conference on Social Life Cycle Assessment, 5-8 September, Aachen.

- Lehmann, J., Fofack-Garcia, R., Pérez-López, P. and Bouillass, G., 2023, Multi-scope social life cycle impact assessment, Application to offshore wind energy sector in France, Oral communication at the 11th International Conference on Life Cycle Management, 6-8 September, Lille.

- Lehmann, J., Fofack-Garcia, R., Ranchin, T., and Pérez-López, P., 2024, Hierarchization of social impacts: towards a systematic approach for accessing to representative stakeholders' perspective, International Journal of Life Cycle Assessment. https://doi.org/10.1007/s11367-023-02275-6

References

ADEME, 2022. Agency for the Environment and Energy Management. Wind turbines and real estate, Analysis of the evolution of real estate prices near wind farms, Final report. https://librairie.ademe.fr/cadic/7130/rapport_final_eolien_immobilier.pdf.

ADEME, 2019. Terres rares, énergies renouvelables et stockage d'énergie 12. https://www.ademe.fr/sites/default/files/assets/documents/avis_technique_terres-rares-energies-renouvelables-et-stockage-denergie-2020.pdf.

AER law, 2023. LOI n° 2023-175 du 10 mars 2023 relative à l'accélération de la production d'énergies renouvelables - Dossiers législatifs - Légifrance [WWW Document]. URL https://www.legifrance.gouv.fr/dossierlegislatif/JORFDOLE000046329719/ (accessed 10.26.23).

Ailes Marines, 2022a. Les entreprises du projet, Ailes Marines, parc éolien en mer de Saint-Brieuc [WWW Document]. URL https://ailes-marines.bzh/les-entreprises-du-projet/

Ailes Marines, 2022b. Le projet en bref | Ailes Marines - le parc éolien en baie de Saint-Brieuc. URL https://ailes-marines.bzh/le-projet-en-bref/ (accessed 5.10.23).

Allan, G., Comerford, D., Connolly, K., McGregor, P., Ross, A.G., 2020. The economic and environmental impacts of UK offshore wind development: The importance of local content. Energy 199, 117436. https://doi.org/10.1016/j.energy.2020.117436

Arcese, G., Lucchetti, M.C., Massa, I., Valente, C., 2016. State of the art in S-LCA: integrating literature review and automatic text analysis. Int. J. Life Cycle Assess. 23, 394–405. https://doi.org/10.1007/s11367-016-1082-0

Atilgan, B., Azapagic, A., 2016. An integrated life cycle sustainability assessment of electricity generation in Turkey. Energy Policy 93, 168–186. https://doi.org/10.1016/j.enpol.2016.02.055

Azapagic, A., Stamford, L., Youds, L., Barteczko-Hibbert, C., 2016. Towards sustainable production and consumption: A novel DEcision-Support Framework IntegRating Economic, Environmental and Social Sustainability (DESIRES). Comput. Chem. Eng. 91, 93–103. https://doi.org/10.1016/j.compchemeng.2016.03.017

Banque de France, 2018. Rapport annuel de l'Observatoire des délais de paiement 2017, Banque de France. https://publications.banque-france.fr/sites/default/files/medias/documents/odp2018_book_web2603.pdf.

Baranzelli, C., Blagoeva, D., Blengini, G.A., Ciupagea, C., Dewulf, J., Dias, P., Kayam, Y., Latunussa, C.E.L., Mancini, L., Manfredi, S., Marmier, A., Mathieux, F., Nita, V., Nuss, P., Pavel, C., Pennington, D., Talens Peirò, L., Torres De Matos, C., Tzimas, E., Vidal-Legaz, B., European Commission, Directorate-General for Internal Market, I., Entrepreneurship and SMEs, 2017. Methodology for establishing the EU list of critical raw materials: guidelines. http://dx.publications.europa.eu/10.2873/769526.

Bas, A., 2017. Analyse de la compensation écologique comme instrument d'internalisation et de lutte contre l'érosion de la biodiversité marine : illustration par l'éolien en mer. These de doctorat. Préparée au Centre de Droit et d'Economie de la Mer, UMR 6308 AMURE Brest. https://www.theses.fr/2017BRES0022.

Becker, H.S., 1970. Sociological work. Method & substance. Routledge publishing. ISBN 9780878556304.

Bengtsson Ryberg, J., Bluhm, G., Bolin, K., Bodén, B., Ek, K., Hammarlund, K., Henningsson, M., Hannukka, I.-L., Johansson, C., Jönsson, S., Mels, S., Mels, T., Nilsson, M., Skärbäck, E.,

Söderholm, P., Waldo, Å., Widerström, I., Åkerman, N., Sverige, Naturvårdsverket, Sverige, Energimyndigheten, 2013. The effects of wind power on human interests: a synthesis. Naturvårdsverket, Stockholm. https://www.naturvardsverket.se/Documents/publikationer6400/978-91-620-6545-4.pdf

Benoît-Norris, C., Cavan, D.A., Norris, G., 2012. Identifying Social Impacts in Product Supply Chains:Overview and Application of the Social Hotspot Database. Sustainability 4, 1946–1965. https://doi.org/10.3390/su4091946

Benoît-Norris, C., Vickery-Niederman, G., Valdivia, S., Franze, J., Traverso, M., Ciroth, A., Mazijn, B., 2011. Introducing the UNEP/SETAC methodological sheets for subcategories of social LCA. Int. J. Life Cycle Assess. 16, 682–690. https://doi.org/10.1007/s11367-011-0301-y

Berlie, A.B., 2018. Global Warming: A Review of the Debates on the Causes, Consequences and Politics of Global Response 10. https://www.researchgate.net/publication/343690598_Global_Warming_A_Review_of_the_Debates_on_the_Causes_Consequences_and_Politics_of_Global_Response.

Bilgili, M., Alphan, H., 2022. Global growth in offshore wind turbine technology. Clean Technol. Environ. Policy 24, 2215–2227. https://doi.org/10.1007/s10098-022-02314-0

Bilgili, M., Yasar, A., Simsek, E., 2011. Offshore wind power development in Europe and its comparison with onshore counterpart. Renew. Sustain. Energy Rev. 15, 905–915. https://doi.org/10.1016/j.rser.2010.11.006

Bouillass, G., 2021. Sustainability assessment of electric mobility scenarios with the integration of a life cycle perspective. Engineering Sciences [physics]. Doctoral Thesis. MINES ParisTech - Université PSL, 2021. English. https://www.theses.fr/2021UPSLM071.

Bouillass, G., Blanc, I., Perez-Lopez, P., 2021. Step-by-step social life cycle assessment framework: a participatory approach for the identification and prioritization of impact subcategories applied to mobility scenarios. Int. J. Life Cycle Assess. https://doi.org/10.1007/s11367-021-01988-w.

Boursorama, 2022a. Acier, Cours Acier HR - Prix, Cotation, Bourse NYMEX - Boursorama [WWW Document]. URL https://www.boursorama.com/bourse/matieres-premieres/cours/_HR/ (accessed 5.13.23).

Boursorama, 2022b. Copper, Cours - Prix, Cotation, Bourse LME - Boursorama [WWW Document]. URL https://www.boursorama.com/bourse/matieres-premieres/cours/7xCAUSD/ (accessed 5.13.23).

Bouygues Travaux Publics, 2020. Bouygues Travaux Publics - Projet - Parc éolien en mer de Fécamp [WWW Document]. URL https://www.bouygues-tp.com/fr/projets/parc-eolien-en-mer-de-fecamp (accessed 5.15.23).

Buchholzer, H., Frésard, M., Le Grand, C., Le Floc'h, P., 2022. Vulnerability and spatial competition: The case of fisheries and offshore wind projects. Ecol. Econ. 197, 107454. https://doi.org/10.1016/j.ecolecon.2022.107454

Buchmayr, A., Verhofstadt, E., Van Ootegem, L., Thomassen, G., Taelman, S.E., Dewulf, J., 2022. Exploring the global and local social sustainability of wind energy technologies: An application of a social impact assessment framework. Appl. Energy 312, 118808. https://doi.org/10.1016/j.apenergy.2022.118808

Caisse d'Epargne Normandie, 2021. La parc éolien en mer de Fécamp - Interview d'Alban Verbecke [WWW Document]. URL https://www.youtube.com/watch?v=mi7OFbIg2PY (accessed 5.11.23).

Carbonnier, G., Grinevald, J., 2011. Energie et développement. Rev. Int. Polit. Dév. 2, 9–28. https://doi.org/10.4000/poldev.687

Carroll, A.B., 2008. A History of Corporate Social Responsibility: Concepts and Practices, in: Crane, A., Matten, D., McWilliams, A., Moon, J., Siegel, D.S. (Eds.), The Oxford Handbook of

Corporate Social Responsibility. Oxford University Press, p. 0. https://doi.org/10.1093/oxfordhb/9780199211593.003.0002

CCI Bretagne, 2017. Parc éolien offshore à Saint-Brieuc: Ailes Marines adopte une nouvelle technique d'éolienne [WWW Document]. URL https://www.bretagne-economique.com/actualites/parc-eolien-offshore-saint-brieuc-ailes-marines-adopte-une-nouvelle-technique-deolienne (accessed 5.10.23).

Cerema, 2023. Eoliennes en mer [WWW Document]. Eoliennes En Mer. URL https://www.eoliennesenmer.fr/eoliennes-en-mer (accessed 9.30.23).

CGEDD, 2021a. Rapport CGEDD n° 013619-01, n° 2021/02/CGE/SG, n° IGAM 2021 - 060, La simplification des procédures d'autorisation applicables aux éoliennes en mer. https://www.economie.gouv.fr/files/files/directions_services/cge/autorisation-eolienne.pdf?v=1667228450.

CGEDD, 2021b. General Council for the Environment and Sustainable Development. Offshore wind turbines in the exclusive economic zone (legal and fiscal status), Rapport CGEDD n° 013631-01, IGAM n° 2021-039, IGF n° 2021 - M - 003. https://igedd.documentation.developpement-durable.gouv.fr/documents/Affaires-0012206/013631-01_rapport-publie.pdf.

ChemAnalyst, 2022. https://www.chemanalyst.com/Pricing-data/epoxy-resin-79 [WWW Document]. ChemAnalyst. URL https://secure.livechatinc.com/ (accessed 5.13.23).

Ciroth, A., Eisfeldt, F., GmbH, G., 2015. A new, comprehensive database for social LCA: PSILCA, GreenDelta GmbH, New Delhi, ILCM 2015, September 2015. https://www.greendelta.com/wp-content/uploads/2017/03/PSILCA_ILCM2015-finalfinal.pdf.

Citepa, 2022. Inventaire des émissions de polluants atmosphériques et de gaz à effet de serre en France. https://www.citepa.org/wp-content/uploads/Citepa_Rapport-Secten-2022_Rapport-complet_v1.8.pdf.

CMF, 2022. Énergies marines renouvelables : les investissements et les emplois au rendez-vous au rendez-vous, Observatoire des énergies de la mer, merenergies, Cluster Maritime Français [WWW Document]. URL http://merenergies.fr/media/Rapport-OEM-2022.pdf (accessed 5.10.23).

CNDP, 2021a. Eclairage - éolien en mer, enseignements de 11 ans de débats publics et concertations. https://www.debatpublic.fr/sites/default/files/2021-10/CNDP-Eclairage-Eolien-A4.pdf.

CNDP, 2021b. Compte rendu du débat public 20 juillet > 21 décembre 2020 éoliennes flottantes au sud de la bretagne, établi par le président de la commission particulière du débat public [WWW Document]. URL https://eolbretsud.debatpublic.fr/wp-content/uploads/EolBretSud-Compte-rendu.pdf (accessed 5.10.23).

CNDP, 2021c. Projet de parcs commerciaux d'éoliennes flottantes en méditerranée compte rendu du débat public 12 juillet au 31 octobre 2021. https://eos.debatpublic.fr/wp-content/uploads/EOS-CR-2021_bd.pdf.

CNDP, 2013a. Commission particulière du débat public Parc éolien en mer de Saint-NAzaire, Compte rendu établi par la présidente de la Commission particulière du débat public [WWW Document]. URL https://parc-eolien-en-mer-de-saint-nazaire.fr/wp-content/uploads/2014/09/SNA_DP_CR.pdf (accessed 5.10.23).

CNDP, 2013b. Commission particulière du débat public Eolien en Mer Fécamp, Compte rendu établi par la commission particulière du débat public [WWW Document]. URL https://cpdp.debatpublic.fr/cpdp-fecamp/docs/documents-cpdp/fecamp-dp-compte-rendu.pdf (accessed 5.10.23).

CNDP, 2013c. Commission particulière du débat public, Projet d'un parc éolien en mer au large de la baie de Saint-Brieuc, Cahier d'acteur, Contribution des acteurs économiques du territoire de

Saint-Brieuc [WWW Document]. URL https://cpdp.debatpublic.fr/cpdp-eoliennes22/DOCS/CAHIERS_ACTEUR/CA_SBE.PDF (accessed 5.11.23).

CNDP, 2013d. Commission particulière du débat public Projet d'un parc éolien en mer au large de la baie de Saint-Brieuc, Compte rendu établi par la commission particulière du débat public. https://cpdp.debatpublic.fr/cpdp-eoliennes22/DOCS/CR.pdf.

Cochran, W.G., 1954. Some Methods for Strengthening the Common χ 2 Tests. Biometrics 10, 417. https://doi.org/10.2307/3001616

Connolly, K., 2020. The regional economic impacts of offshore wind energy developments in Scotland. Renew. Energy 160, 148–159. https://doi.org/10.1016/j.renene.2020.06.065

coursdesmétaux.fr, 2022. Suivez le cours de la fonte au kilo et à la tonne [WWW Document]. URL https://www.coursdesmetaux.fr/fonte/ (accessed 5.13.23).

CRE, 2018. Energy Regulatory Commission. Competitive dialogue n° 1/2016 concerning offshore wind power installations in an area off Dunkirk, Technical specifications. https://www.cre.fr/documents/Appels-d-offres/Dialogue-concurrentiel-n-1-2016-portant-sur-des-installations-eoliennes-de-production-d-electricite-en-mer-dans-une-zone-au-large-de-Dunkerque.

Cruciani, M., 2019. L'éolien offshore flottant dans sa dimension industrielle et technologique », Études de l'Ifri. https://www.ifri.org/sites/default/files/atoms/files/cruciani_eolien_flottant_2019.pdf.

Daudigeos, T., Ottaviani, F., 2021. La loi PACTE : une opportunité pour interroger la « raison d'être territoriale » des entreprises. Dév. Durable Territ. https://doi.org/10.4000/developpementdurable.19491

Deville, J.-C., Särndal, C.-E., 1992. Calibration Estimators in Survey Sampling. J. Am. Stat. Assoc. 87, 376–382. https://doi.org/10.1080/01621459.1992.10475217

DGEC, 2023. Competitive tender procedure n° 1/2021 for floating wind turbines for offshore power generation in an area off southern Brittany specifications june 7, 2023. https://www.cre.fr/documents/Appels-d-offres/dialogue-concurrentiel-n-1-2021-portant-sur-des-installations-eoliennes-flottantes-de-production-d-electricite-en-mer-dans-une-zone-au-large-du-sud.

Dreyer, L., Hauschild, M., Schierbeck, J., 2010a. Characterisation of social impacts in LCA. Part 1: Development of indicators for labour rights. Int. J. Life Cycle Assess. 15, 247–259. https://doi.org/10.1007/s11367-009-0148-7

Dreyer, L., Hauschild, M., Schierbeck, J., 2010b. Characterisation of social impacts in LCA. Part 2: Implementation in six company case studies. Int. J. Life Cycle Assess. 15, 385–402. https://doi.org/10.1007/s11367-010-0159-4

Dreyer, L., Hauschild, M., Schierbeck, J., 2006. A Framework for Social Life Cycle Impact Assessment (10 pp). Int. J. Life Cycle Assess. 11, 88–97. https://doi.org/10.1065/lca2005.08.223

EC, 2020. Communication from the commission to the European parliament, the council, the European economic and social committee and the committee of the regions. An EU Strategy to harness the potential of offshore renewable energy for a climat neutral future. [WWW Document]. URL https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52020DC0741 (accessed 9.30.23).

EC, 2019. Communication from the commission to the European parliament, the European council, the council, the European economic and coscial committee and the committee of the regions. The European Green Deal. [WWW Document]. URL https://eur-lex.europa.eu/resource.html?uri=cellar:b828d165-1c22-11ea-8c1f-01aa75ed71a1.0002.02/DOC_1&format=PDF (accessed 9.30.23).

Ecovadis.com, 2023. Homepage [WWW Document]. EcoVadis. URL https://ecovadis.com/fr/ (accessed 5.9.23).

EDF, 2022. Notations et performance ESG (Environnement, Social et Gouvernance) | EDF FR [WWW Document]. URL https://www.edf.fr/groupe-edf/espaces-dedies/investisseurs-actionnaires/performances-financieres-et-extra-financieres/notation-extra-financiere-environnement-social-et-gouvernance-esg (accessed 5.10.23).

Ekener, E., 2016. Review of Social Life Cycle Assessment conducted by Vattenfall AB reported in "Social impacts from Wind power, Appendix to Vattenfall AB Certified Environmental Product Declaration EPD® of Electricity from Vattenfall's Nordic wind power".

Emploi-Environnement, 2020. Éolien en mer : 2.000 emplois locaux grâce au chantier du parc de Fécamp et à une usine au Havre [WWW Document]. Empl.-Environ. URL https://www.emploi-environnement.com/news/eolien-mer-emplois-locaux-2000-chantier-edf-renouvelables-fecamp-havre-usine-503.html (accessed 5.10.23).

Energie recrute, 2021. Projet éolien en mer de la Baie de Saint-Brieuc : une filière qui mobilise des emplois [WWW Document]. URL https://www.energierecrute.com//actualites-energie-environnement/6309-projet-eolien-en-mer-de-la-baie-de-saint-brieuc-une-filiere-qui-mobilise-des-emplois (accessed 5.10.23).

Energies de la mer, 2021. Le contenu local, clé du déploiement de l'éolien flottant français ? | Énergies de la Mer. URL https://www.energiesdelamer.eu/2021/11/19/le-contenu-local-cle-du-deploiement-de-leolien-flottant-francais/ (accessed 5.10.23).

Eoliennes Offshore des Hautes Falaises, 2022. Présentation du projet | Parc éolien en mer de Fécamp. URL https://parc-eolien-en-mer-de-fecamp.fr/le-parc-eolien-en-mer/presentation-du-projet/ (accessed 5.10.23).

Eoliennes offshores des hautes falaises, 2013. Projet de parc éolien au large de fécamp, débat public, dossier du maître d'ouvrage [WWW Document]. URL https://parc-eolien-en-mer-de-fecamp.fr/wp-content/uploads/2013/09/Fecamp_DMO.pdf (accessed 5.10.23).

Eudleur, J., 2023. De quelles façons les parcs éoliens en mer affectent les activités touristiques et les prestataires touristiques ? Mémoire de fin d'étude Master 2, Université Paul Sabatier III et France Energies Marines, mars-septembre 2023.

European Commission, 2019. Aide d'État - France Parc éolien en mer, commission européenne [WWW Document]. URL https://ec.europa.eu/competition/state_aid/cases1/201933/269222_2088484_174_2.pdf (accessed 5.9.23).

Evans, A., Strezov, V., Evans, T.J., 2010. Sustainability considerations for electricity generation from biomass. Renew. Sustain. Energy Rev. 14, 1419–1427. https://doi.org/10.1016/j.rser.2010.01.010

Evans, A., Strezov, V., Evans, T.J., 2009. Assessment of sustainability indicators for renewable energy technologies. Renew. Sustain. Energy Rev. 13, 1082–1088. https://doi.org/10.1016/j.rser.2008.03.008

EWEA, 2014. Avoiding fossil fuel costs with wind energy, A report by the European Wind Energy Association - March 2014. https://www.qualenergia.it/sites/default/files/articolo-doc/Avoiding_fossil_fuel_costs_01.pdf.

EWEA, 2009. Chapter 4: Costs and benefits of wind development in the EU27 [WWW Document]. URL https://www.wind-energy-the-facts.org/index-75.html (accessed 5.10.23).

Falkner, R., 2016. The Paris Agreement and the new logic of international climate politics. Int. Aff. 92, 1107–1125. https://doi.org/10.1111/1468-2346.12708

Feschet, P., 2014. Social life cycle assessment : Towards a new conceptual and theoretical framework. https://www.theses.fr/178165573.

Feschet, P., Macombe, C., Garrabé, M., Loeillet, D., Saez, A.R., Benhmad, F., 2013. Social impact assessment in LCA using the Preston pathway: The case of banana industry in Cameroon. Int. J. Life Cycle Assess. 18, 490–503. https://doi.org/10.1007/s11367-012-0490-z

Finkbeiner, M., Schau, E.M., Lehmann, A., Traverso, M., 2010. Towards Life Cycle Sustainability Assessment. Sustainability 2, 3309–3322. https://doi.org/10.3390/su2103309

Fofack-Garcia, R., Mazé, C., Safi, G., Lejart, M., Chauvac, N., Thermes, M., Ragueneau, O., Le Loc'h, F., Niquil, N., 2023. Socio-political acceptability of floating offshore wind farms in France: challenges and perspectives for marine governance towards sustainability. Ocean Coast. Manag. 236, 106513. https://doi.org/10.1016/j.ocecoaman.2023.106513

Fontes, J., Gaasbeek, A., Goedkoop, M.J., Contreras, S., Evitts, S., 2016. Handbook for Product Social Impact Assessment 3.0. https://doi.org/10.13140/RG.2.2.23821.74720

GE Renewable Energy, 2022. Haliade 150-6MW Offshore Wind Turbine | GE Renewable Energy [WWW Document]. URL https://www.ge.com/renewableenergy/wind-energy/offshore-wind/offshore-turbine-haliade-150-6mw (accessed 5.10.23).

GE Renewable Energy, 2019a. GE Renewable Energy annonce le début de la production des éoliennes qui fourniront le premier parc éolien en mer français au large de Saint-Nazaire | GE News [WWW Document]. URL https://www.ge.com/news/press-releases/ge-renewable-energy-annonce-debut-production-eoliennes-haliade-saint-nazaire-emf-offshore (accessed 5.15.23).

GE Renewable Energy, 2019b. General Electric inaugure sa nouvelle usine de pales d'éoliennes à Cherbourg | GE News [WWW Document]. URL https://www.ge.com/news/press-releases/general-electric-inaugure-sa-nouvelle-usine-de-pales-eoliennes-a-cherbourg (accessed 5.15.23).

GéoLittoral, 2022. Découverte de la France maritime et littorale [WWW Document]. GéoLittoral. URL https://www.geolittoral.developpement-durable.gouv.fr/decouverte-de-la-france-maritime-et-littorale-a1298.html (accessed 9.30.23).

Goedkoop, M.J., de Beer, I.M., Harmens, R., Saling, P., Morris, D., Florea, A., Laure Hettinger, A., Indrane, D., Visser, D., Morao, A., Musoke-Flores, E., Alvarado, C., Rawat, I., Schenker, U., Head, M., Collotta, M., Andro, T., Viot, J.-F., Whatelet, A., 2020. Product Social Impact Assessment Handbook - 2020, Amersfoort, November 1st, 2020. Int. J. Life Cycle Assess. 27, 603–622. https://doi.org/10.1007/s11367-022-02051-y

Gompf, K., Traverso, M., Hetterich, J., 2020. Towards social life cycle assessment of mobility services: systematic literature review and the way forward. Int. J. Life Cycle Assess. 25, 1883–1909. https://doi.org/10.1007/s11367-020-01788-8

Gouvernement, RTE, 2022a. Débat public, Septembre 2021 - Janvier 2022, Dossier des maîtres d'ouvrage, Projet éolien en mer en Sud-Atlantique [WWW Document]. URL https://www.debatpublic.fr/sites/default/files/2021-09/2021-09-Eolien_mer_Oleron_DMO.pdf (accessed 5.10.23).

Gouvernement, RTE, 2022b. Projet d'éoliennes flottantes en méditerranée et leur raccordement, Rapport du Ministère de la transition écologique, établi conjointement avec RTE, consécutif au débat public portant sur un projet d'éoliennes flottantes en méditerranée et leur raccordement [WWW Document]. URL https://www.debatpublic.fr/sites/default/files/2022-03/Eoliennemed_rapportMOA.pdf (accessed 5.11.23).

GRI, 2015. G4 Sustainability Reporting Guidelines - G4 Sustainability Reporting Guidelines - Implementation Manual. https://respect.international/wp-content/uploads/2017/10/G4-Sustainability-Reporting-Guidelines-Implementation-Manual-GRI-2013.pdf.

GRI, 2002. Global Reporting Initiative: Sustainability Reporting Guidelines; GRI: Boston, MA, USA, 2002. https://www.r3-0.org/wp-content/uploads/2020/03/GRIguidelines.pdf.

Grießhammer, R., Norris, C., Dreyer, L., Flysjö, A., Manhart, A., Mazijn, B., Méthot, A.-L., Weidema, B., 2006. Feasibility Study: Integration of Social Aspects into LCA. https://www.researchgate.net/publication/265142341_Feasibility_Study_Integration_of_Social_Aspects_into_LCA.

Halouani, G., Villanueva, C.-M., Raoux, A., Dauvin, J.C., Ben Rais Lasram, F., Foucher, E., Le Loc'h, F., Safi, G., Araignous, E., Robin, J.P., Niquil, N., 2020. A spatial food web model to investigate potential spillover effects of a fishery closure in an offshore wind farm. J. Mar. Syst. 212, 103434. https://doi.org/10.1016/j.jmarsys.2020.103434

Hannouf, Marwa B., Assefa, G., Hannouf, Malek B., Gates, I., 2021. Cause-effect chains in S-LCA based on DPSIR framework using Markov healthcare model: an application to "working hours" in Canada. Int. J. Life Cycle Assess. 26, 936–949. https://doi.org/10.1007/s11367-021-01900-6

Harmens, R., Pillay, S., David, D., Goedkoop, M.J., de Beer, I.M., Saling, P., Florea, A., Hettinger, A.L., Visser, D., Morao, A., Musoke-Flores, E., Alvarado, C., 2022. Product Social Impact Assessment- Social Topics Report,. Amersfoort. https://storage.ning.com/topology/rest/1.0/file/get/10437874286?profile=original.

Hauschild, M., Dreyer, L., Jørgensen, A., 2008. Assessing social impacts in a life cycle perspective—Lessons learned. CIRP Ann. - Manuf. Technol. 57, 21–24. https://doi.org/10.1016/j.cirp.2008.03.002

Hello Watt, 2022. Prix du gaz en France : Tarifs du kWh TTC en Mai 2023 [WWW Document]. Hello Watt. URL https://www.hellowatt.fr/contrat-gaz-naturel/prix-gaz (accessed 5.13.23).

Hermansson, H., 2007. The Ethics of NIMBY Conflicts. Ethical Theory Moral Pract. 10, 23–34. https://doi.org/10.1007/s10677-006-9038-2

Hirschberg, S., Dones, R., Heck, T., Burgherr, P., Schenler, W., Bauer, C., 2004. Sustainability of electricity supply technologies under German conditions: a comparative evaluation. Paul Scherrer Institut 79. https://inis.iaea.org/collection/NCLCollectionStore/_Public/36/111/36111076.pdf.

Hoen, B., Wiser, R., Cappers, P., Thayer, M., Sethi, G., 2011. Wind Energy Facilities and Residential Properties: The Effect of Proximity and View on Sales Prices. J. Real Estate Res. 33, 279–316. https://doi.org/10.1080/10835547.2011.12091307

Hood, K., M. Torres, S., D. Palmer, R., 2014. Automatic Detection of Wind Turbine Clutter Using Doppler Spectral Features. https://www.researchgate.net/publication/252444494_P101_AUTOMATIC_DETECTION_OF_WIND_TURBINE_CLUTTER_USING_DOPPLER_SPECTRAL_FEATURES?

Hooper, T., Hattam, C., Austen, M., 2017. Recreational use of offshore wind farms: Experiences and opinions of sea anglers in the UK. Mar. Policy 78, 55–60. https://doi.org/10.1016/j.marpol.2017.01.013

Iberdrola, 2023. Integrated report February 2023. https://www.iberdrola.com/documents/20125/42388/IB_Integrated_Report.pdf/140d1cf3-b535-8751-469a-31f1df3abdab?t=1650538974859.

IEA, 2019. IEA – International Energy Agency [WWW Document]. IEA. URL https://www.iea.org/statistics/co2emissions (accessed 9.30.23).

INNOSEA, 2022. Development of tool assessing the number of jobs and Gross Value Added for Social LCA.

INSEE, 2022a. Comparateur de territoires − Département de la Loire-Atlantique (44) | Insee [WWW Document]. URL https://www.insee.fr/fr/statistiques/1405599?geo=DEP-44 (accessed 5.10.23).

INSEE, 2022b. Populations légales des départements en 2020 − Populations légales 2020 | Insee [WWW Document]. URL https://www.insee.fr/fr/statistiques/6683015?sommaire=6683037 (accessed 5.10.23).

INSEE, 2019. Dossier complet − Département du Morbihan (56) | Insee [WWW Document]. URL https://www.insee.fr/fr/statistiques/2011101?geo=DEP-56 (accessed 5.10.23).

INSEE, SOeS, 2009. L'Observatoire du littoral, Démographie et économie du littoral [WWW Document]. URL https://www.insee.fr/fr/statistiques/1379044 (accessed 5.10.23).

Iofrida, N., De Luca, A.I., Strano, A., Gulisano, G., 2018. Can social research paradigms justify the diversity of approaches to social life cycle assessment? Int. J. Life Cycle Assess. 23, 464–480. https://doi.org/10.1007/s11367-016-1206-6

IPCC, 2023. IPCC, 2023: Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, H. Lee and J. Romero (eds.)]. IPCC, Geneva, Switzerland. Intergovernmental Panel on Climate Change (IPCC). https://doi.org/10.59327/IPCC/AR6-9789291691647

IRENA, 2021. Offshore renewables: An action agenda for deployment, International Renewable Energy Agency, Abu Dhabi. https://www.irena.org/publications/2021/Jul/Offshore-Renewables-An-Action-Agenda-for-Deployment.

ISO 14040, 2006. Environmental management - Life cycle assessment - Principles and framework (ISO 14040:2006). https://www.iso.org/fr/standard/37456.html.

ISO 26000, 2010. ISO 26000:2010 (en), Guidance on social responsibility [WWW Document]. URL https://www.iso.org/obp/ui/#iso:std:iso:26000:ed-1:v1:en (accessed 4.13.23).

Janusz, T., Andrzej, J., 2014. Pareto - ABC Analysis of High Voltage Single Core Cable Temperature. Przeglad Elektrotechniczny 172–178. https://doi.org/10.12915/pe.2014.10.44

Jensen, C.U., Panduro, T.E., Lundhede, T.H., Nielsen, A.S.E., Dalsgaard, M., Thorsen, B.J., 2018. The impact of on-shore and off-shore wind turbine farms on property prices. Energy Policy 116, 50–59. https://doi.org/10.1016/j.enpol.2018.01.046

Jollivet, M., 2013. Bertrand Zuindeau (ed.), Développement durable et Territoire, Presses universitaires du Septentrion, 2010, 517 pages, nouvelle édition originale (Collection « Environnemen. Dév. Durable Territ. https://doi.org/10.4000/developpementdurable.9756

Jørgensen, A., Finkbeiner, M., Jørgensen, M.S., Hauschild, M.Z., 2010. Defining the baseline in social life cycle assessment. Int. J. Life Cycle Assess. 15, 376–384. https://doi.org/10.1007/s11367-010-0176-3

Jørgensen, A., Hauschild, M., Jørgensen, M., Wangel, A., 2009. Relevance and feasibility of social life cycle assessment from a company perspective. Int. J. Life Cycle Assess. 14, 204–214. https://doi.org/10.1007/s11367-009-0073-9

Jouini, M., Burte, J., Biard, Y., Benaissa, N., Amara, H., Sinfort, C., 2019. A framework for coupling a participatory approach and life cycle assessment for public decision-making in rural territory management. Sci. Total Environ. 655, 1017–1027. https://doi.org/10.1016/j.scitotenv.2018.11.269

Kaynia, A.M., Blekastad, H., Schell, P., Walter, E.L., 2022. Seismic response of floating wind turbines due to seaquakes. Wind Energy 26, 145–162. https://doi.org/10.1002/we.2791

Kermagoret, C., 2014. Compensation of social and ecological impacts for development projects: acceptance, perceptions and preferences of territorial stakeholders. Application to the offshore wind farm project in the Bay of Saint-Brieuc (Brittany, France). Environment and Society. University of Brest. https://theses.hal.science/tel-02117433/.

Kloepffer, W., 2008. Life cycle sustainability assessment of products: (with Comments by Helias A. Udo de Haes, p. 95). Int. J. Life Cycle Assess. 13, 89–95. https://doi.org/10.1065/lca2008.02.376

Kolsch, D., Saling, P., Kicherer, A., Sommer, A.G., Schmidt, I., 2008. How to measure social impacts? A socio-eco-efficiency analysis by the SEEBALANCE® method. Int. J. Sustain. Dev. 11, 1. https://doi.org/10.1504/IJSD.2008.020380

Kouloumpis, V., Azapagic, A., 2022. A model for estimating life cycle environmental impacts of offshore wind electricity considering specific characteristics of wind farms. Sustain. Prod. Consum. 29, 495–506. https://doi.org/10.1016/j.spc.2021.10.024

La compagnie du vent, 2010. Analyse du risque d'accident maritime dans le parc éolien du projet "les deux côtes", synthèse, La compagnie du vent GDF Suez, Sonovision Itep, Réf. 435S-211FS-2.0 [WWW Document]. URL https://cpdp.debatpublic.fr/cpdp-eolien-en-mer/DOCS/DOSSIER_MO/SYNTHESE_ANALYSE_DE_RISQUE_MARI.PDF (accessed 9.21.22).

Ladenburg, J., 2009. Visual impact assessment of offshore wind farms and prior experience. Appl. Energy 8. https://linkinghub.elsevier.com/retrieve/pii/S0306261908001323

Ladenburg, J., Dubgaard, A., 2007. Willingness to pay for reduced visual disamenities from offshore wind farms in Denmark. Energy Policy 13. https://www.sciencedirect.com/science/article/abs/pii/S0301421507000304

Ladenburg, J., Termansen, M., Hasler, B., 2013. Assessing acceptability of two onshore wind power development schemes: A test of viewshed effects and the cumulative effects of wind turbines. Energy 54, 45–54. https://doi.org/10.1016/j.energy.2013.02.021

Laganier, R., Villalba, B., Zuindeau, B., 2002. Le développement durable face au territoire : éléments pour une recherche pluridisciplinaire. Dév. Durable Territ. https://doi.org/10.4000/developpementdurable.774

Latapí Agudelo, M.A., Jóhannsdóttir, L., Davídsdóttir, B., 2019. A literature review of the history and evolution of corporate social responsibility. Int. J. Corp. Soc. Responsib. 4, 1. https://doi.org/10.1186/s40991-018-0039-y

Law No. 2015-992 of August 17, 2015, n.d. LOI n° 2015-992 du 17 août 2015 relative à la transition énergétique pour la croissance verte (1), 2015-992. https://www.legifrance.gouv.fr/dossierlegislatif/JORFDOLE000046329719/

Le Point, Statista, 2022. Palmarès RSE - Les entreprises les plus responsables en 2023 [WWW Document]. Le Point.fr. URL https://www.lepoint.fr/palmares-entreprises-responsables/ (accessed 5.10.23).

Le Télégramme, 2023. Le parc éolien en baie de Saint-Brieuc, nouvel eldorado du tourisme industriel [Vidéo] [WWW Document]. Le Télégramme. URL https://www.letelegramme.fr/cotes-d-armor/saint-brieuc-22000/le-parc-eolien-en-baie-de-saint-brieuc-nouvel-eldorado-du-tourisme-industriel-6415163.php (accessed 10.26.23).

Le Télégramme, 2022. De La Turballe à Saint-Nazaire, les relais terrestres du premier parc éolien en mer français [WWW Document]. Le Telegramme. URL https://www.letelegramme.fr/economie/de-la-turballe-a-saint-nazaire-les-relais-terrestres-du-premier-parc-eolien-en-mer-francais-07-07-2022-13101874.php (accessed 5.10.23).

Lee, A.H.I., Chen, H.H., Kang, H.-Y., 2009. Multi-criteria decision making on strategic selection of wind farms. Renew. Energy 34, 120–126. https://doi.org/10.1016/j.renene.2008.04.013

Lemeilleur, S., Vagneron, I., 2010. Looking for the (missing) indicators of social sustainability - Evidence from sustainability standards in the coffee sector. https://www.researchgate.net/publication/238598252_Looking_for_the_missing_indicators_of_social_sustainability_-_Evidence_from_sustainability_standards_in_the_coffee_sector.

Li, C., Mogollón, J.M., Tukker, A., Dong, J., Von Terzi, D., Zhang, C., Steubing, B., 2022. Future material requirements for global sustainable offshore wind energy development. Renew. Sustain. Energy Rev. 164, 112603. https://doi.org/10.1016/j.rser.2022.112603

Liu, G., 2014. Development of a general sustainability indicator for renewable energy systems: A review. Renew. Sustain. Energy Rev. 31, 611–621. https://doi.org/10.1016/j.rser.2013.12.038

Lorino, P., 1997. Méthode et pratiques de la performance, Le pilotage par les processus et les compétences. Éditions D'Organisation. http://bibliotheque.pssfp.net/livres/METHODES_ET_PRATIQUES_DE_LA_PERFORMANCE_LE_PILOTAGE_PAR_LES_PROCESSUS_ET_LES_COMPETENCES.pdf.

Macombe, C., Lagarde, V., Falque, A., Feschet, P., Garrabé, M., Gillet, C., Loeillet, D., 2013. Social LCAs. Socio-economic effects in value chains.

Maister, K., Di Noi, C., Ciroth, A., Srocka, M., 2020. A Product Social Impact Life Cycle Assessment database, Database version 3, Documentation, GreenDelta.

Manik, Y., Leahy, J., Halog, A., 2013. Social life cycle assessment of palm oil biodiesel: a case study in Jambi Province of Indonesia. Int. J. Life Cycle Assess. 18, 1386–1392. https://doi.org/10.1007/s11367-013-0581-5

Masanet, E., Chang, Y., Gopal, A.R., Larsen, P., Morrow, W.R., Sathre, R., Shehabi, A., Zhai, P., 2013. Life-Cycle Assessment of Electric Power Systems. Annu. Rev. Environ. Resour. 38, 107–136. https://doi.org/10.1146/annurev-environ-010710-100408

Mathe, S., 2014. Integrating participatory approaches into social life cycle assessment: the SLCA participatory approach. Int. J. Life Cycle Assess. 19, 1506–1514. https://doi.org/10.1007/s11367-014-0758-6

Maxim, A., 2015. Relevant Attributes of Renewable Energy Development in the Case of Romanian Households. Procedia Econ. Finance 20, 372–382. https://doi.org/10.1016/S2212-5671(15)00086-6

Maxim, A., 2014. Sustainability assessment of electricity generation technologies using weighted multi-criteria decision analysis. Energy Policy 65, 284–297. https://doi.org/10.1016/j.enpol.2013.09.059

Mazuyer, E., 2013. CSR et RSE, in: Postel, N., Sobel, R. (Eds.), Dictionnaire critique de la RSE. Presses universitaires du Septentrion, pp. 93–96. https://doi.org/10.4000/books.septentrion.6547

MEDDE, 2012. Energies marines renouvelables. Etude méthodologique des impacts environnementaux et socio-économiques. https://uicn.fr/wp-content/uploads/2019/02/ministere_etude_methodologique_impacts_emr.pdf.

Miceli, F., 2012. monopile Archives. Wind Farms Constr. URL https://www.windfarmbop.com/tag/monopile/ (accessed 5.15.23).

Mocquet, B., Pélissier, C., Cotreaux, S., 2021. Impacts sociétaux et développements du management des technologies organisationnelles. https://www.pressesdesmines.com/produit/impacts-societaux-et-developpements-du-management-des-technologies-organisationnelles/.

Mocquet, B., Vieira, L., Clercq, S., 2018. Gouvernance numérique des territoires isolés: précautions stratégiques à l'ère de la mise en place du très haut débit (THD). https://hal.science/hal-02059330/document.

Moss, J., Coram, A., Blashki, G., 2014. Wind energy, climate and health: evidence for the impacts of wind generated energy in Australia [WWW Document]. Aust. Inst. URL https://australiainstitute.org.au/report/wind-energy-climate-and-health-evidence-for-the-impacts-of-wind-generated-energy-in-australia/ (accessed 4.21.23).

MTC, MTE, 2022. Parcs éoliens en mer Méditerranée : le Gouvernement annonce la sélection de 13 candidats pour participer à la deuxième phase de la procédure [WWW Document]. Ministères

Écologie Énerg. Territ. URL https://www.ecologie.gouv.fr/parcs-eoliens-en-mer-mediterranee-gouvernement-annonce-selection-13-candidats-participer-deuxieme (accessed 5.10.23).

MTE, 2023. L'état des lieux de la filière en France [WWW Document]. Eoliennes En Mer. URL https://www.eoliennesenmer.fr/presentation (accessed 10.27.23).

MTE, 2022a. Le Premier ministre lance l'éolien en mer en Méditerranée et annonce des mesures de France 2030 pour renforcer notre souveraineté énergétique [WWW Document]. Ministères Écologie Énerg. Territ. URL https://www.ecologie.gouv.fr/premier-ministre-lance-leolien-en-mer-en-mediterranee-et-annonce-des-mesures-france-2030-renforcer (accessed 5.9.23).

MTE, 2022b. Éoliennes flottantes au sud de la Bretagne, plaquette, Ministère de la Transition Ecologique [WWW Document]. URL https://www.eoliennesenmer.fr/sites/eoliennesenmer/files/inline-files/20220509_Plaquette_AO5pdf_0.pdf (accessed 5.10.23).

MTES, 2021. Combien coûte un parc éolien en mer en France ? Pourquoi et comment l'état a-t-il choisi de soutenir le développement de l'éolien en mer en France ? Éoliennes en mer au large de la normandie, Ministère Transition Ecologique et Solidaire. https://eolmernormandie.debatpublic.fr/images/documents/dmo/fiches/dmo-fiche-12-combien-coute-un-parc-eolien-en-france.pdf

MTES, 2019. Programmation pluriannuelle de l'énergie. https://www.ecologie.gouv.fr/programmations-pluriannuelles-lenergie-ppe

Navix, 2023. Visites du parc éolien en mer de Saint-Nazaire avec NAVIX [WWW Document]. Navix - Réservation Travers. Belle Ile Golfe Morbihan. URL https://www.navix.fr/visite-du-parc-eolien-en-mer/ (accessed 10.26.23).

Neugebauer, S., 2016. Enhancing Life Cycle Sustainability Assessment - Tiered Approach and new Characterization Models for Social Life Cycle Assessment and Life Cycle Costing. https://depositonce.tu-berlin.de/items/976fb29a-e31a-45e0-a979-5b85e604070d

Observatoire des énergies de la mer, 2020. URL http://merenergies.fr/ (accessed 4.4.23).

OCDE, 2007. Analyse coûts-bénéfices et environnement: Développements récents. OECD. https://doi.org/10.1787/9789264010079-fr

OECD, 2023. Employment - Temporary employment - OECD Data [WWW Document]. theOECD. URL http://data.oecd.org/emp/temporary-employment.htm (accessed 10.26.23).

OECD, 2011. OECD Guidelines for Multinational Enterprises, 2011 Edition. OECD. https://doi.org/10.1787/9789264115415-en

Oiry, A., 2017. Une transition énergétique sous tension ? Contestations des énergies marines renouvelables et stratégies d'acceptabilité sur la façade atlantique française. Thèse de doctorat. Université Paris 1 Panthéon-Sorbonne, École doctorale de Géographie de Paris UMR 8591, Laboratoire de Géographie Physique. https://www.theses.fr/234411368

ORIENTING LCSA methodology stakeholders' workshop, 2022.

Ouest France, 2020. Éolien en mer. Une filière portée par des investissements et des recrutements en Normandie [WWW Document]. Ouest-Francefr. URL https://www.ouest-france.fr/normandie/le-havre-76600/eolien-en-mer-une-filiere-portee-par-des-investissements-et-des-recrutements-en-normandie-7022828 (accessed 5.11.23).

Papadis, E., Tsatsaronis, G., 2020. Challenges in the decarbonization of the energy sector. Energy 205, 118025. https://doi.org/10.1016/j.energy.2020.118025

Parc de Banc de Guérande, 2022a. Présentation du projet | Parc éolien en mer de Saint-Nazaire. URL https://parc-eolien-en-mer-de-saint-nazaire.fr/le-parc-eolien-en-mer/presentation-projet/ (accessed 5.10.23).

Parc de Banc de Guérande, 2022b. Accompagnement du territoire | Parc éolien en mer de Saint-Nazaire. URL https://parc-eolien-en-mer-de-saint-nazaire.fr/projet-industriel-emploi/activitedanslesportsregionaux/ (accessed 5.10.23).

Parc éolien en mer de Saint-Nazaire, 2021. Projet de parc éolien au large de Saint-Nazaire, GT socio-économique [WWW Document]. URL https://www.loire-atlantique.gouv.fr/contenu/telechargement/49258/320833/file/6+-+GT+socio-%c3%a9co+2021+-+PBG.pdf (accessed 5.10.23).

Parent, J., Cucuzzella, C., Revéret, J.-P., 2010. Impact assessment in SLCA: sorting the sLCIA methods according to their outcomes. Int. J. Life Cycle Assess. 15, 164–171. https://doi.org/10.1007/s11367-009-0146-9

Pearson, K., 1900. On the criterion that a given system of deviations from the probable in the case of a correlated system of variables is such that it can be reasonably supposed to have arisen from random sampling. Lond. Edinb. Dublin Philos. Mag. J. Sci. 50, 157–175. https://doi.org/10.1080/14786440009463897

Peruzzini, M., Gregori, F., Luzi, A., Mengarelli, M., Germani, M., 2017. A social life cycle assessment methodology for smart manufacturing: The case of study of a kitchen sink. J. Ind. Inf. Integr. 7, 24–32. https://doi.org/10.1016/j.jii.2017.04.001

Podevin, G., 2017b. CHAPITRE 9 - La filière de l'éolien offshore posé en France : Nouveaux métiers ou nouveau regard sur les métiers ?, in: Chaumette, P. (Ed.), Economic Challenge and New Maritime Risks Management: What Blue Growth?Challenge Économique et Maîtrise Des Nouveaux Risques Maritimes : Quelle Croissance Bleue ? GOMILEX. https://hal.archives-ouvertes.fr/hal-01792232.

Point P., 2022. - - Sable 0/4 le M3 | POINT.P [WWW Document]. URL https://www.pointp.fr/p/gros-oeuvre-bpe-voirie-tp/sable-0-4-le-m3-A6428357 (accessed 5.13.23).

Port Atlantique La Rochelle, 2021. Eolien offshore [WWW Document]. URL https://www.larochelle.port.fr/nous-connaitre/actualites/826-eolien-offshore.html (accessed 5.15.23).

Preston, S.H., 1975. The Changing Relation between Mortality and Level of Economic Development. Popul. Stud. 29, 231. https://doi.org/10.2307/2173509

Purvis, B., Mao, Y., Robinson, D., 2019. Three pillars of sustainability: in search of conceptual origins. Sustain. Sci. 14, 681–695. https://doi.org/10.1007/s11625-018-0627-5

Richer, M., 2020. How to calculate construction labor cost [WWW Document]. Bridgit. URL https://gobridgit.com/blog/how-to-calculate-construction-labor-cost/ (accessed 5.27.23).

Roinioti, A., Koroneos, C., 2019. Integrated life cycle sustainability assessment of the Greek interconnected electricity system. Sustain. Energy Technol. Assess. 32, 29–46. https://doi.org/10.1016/j.seta.2019.01.003

RTE, MTE, 2022. Débat public, projet d'éoliennes flottantes en Méditerranée et leur raccordement, Comment raccorder les parcs éoliens flottants au réseau électrique ? [WWW Document]. URL https://www.eoliennesenmer.fr/sites/eoliennesenmer/files/fichiers/2021/07/EES_AO6_Fiche16_WEB_0.pdf (accessed 5.16.23).

Russo Garrido, S., Parent, J., Beaulieu, L., Revéret, J.-P., 2018. A literature review of type I SLCA—making the logic underlying methodological choices explicit. Int. J. Life Cycle Assess. 23, 432–444. https://doi.org/10.1007/s11367-016-1067-z

Rutovitz, J., Dominish, E., Downes, J., 2015. Calculating global energy sector jobs: 2015 methodology. Prepared for Greenpeace International by the Institute for Sustainable Futures, University of Technology Sydney; 2015. [WWW Document]. URL https://opus.lib.uts.edu.au/bitstream/10453/43718/1/Rutovitzetal2015Calculatingglobalenergysectorjobsmethodology.pdf (accessed 5.9.23).

Sacchi, R., Besseau, R., Pérez-López, P., Blanc, I., 2019. Exploring technologically, temporally and geographically-sensitive life cycle inventories for wind turbines: A parameterized model for Denmark. Renew. Energy 132, 1238–1250. https://doi.org/10.1016/j.renene.2018.09.020

Saint-Nazaire Agglo, 2020. L'éolien, tout un champ à investir. Les clauses sociales donnent de l'élan à l'insertion - Saint-Nazaire Agglo [WWW Document]. Site Internet Dude St.-Nazaire Agglo. URL https://www.agglo-carene.fr/actus/l-eolien-tout-un-champ-a-investir-les-clauses-sociales-donnent-de-l-elan-a-l-insertion-19924 (accessed 5.10.23).

Sala, S., Vasta, A., Mancini, L., Dewulf, J., Rosenbaum, E., European Commission, Joint Research Centre, 2015. Social life cycle assessment: state of the art and challenges for product policy support. Publications Office, Luxembourg. https://doi.org/10.2788/53485

San Cristóbal, J.R., 2011. Multi-criteria decision-making in the selection of a renewable energy project in spain: The Vikor method. Renew. Energy 36, 498–502. https://doi.org/10.1016/j.renene.2010.07.031

Santoyo-Castelazo, E., Azapagic, A., 2014. Sustainability assessment of energy systems: integrating environmental, economic and social aspects. J. Clean. Prod. 80, 119–138. https://doi.org/10.1016/j.jclepro.2014.05.061

Schlör, H., Petra, Z., Josephine, M., Andrea, S., Sandra, V., Jürgen-Friedrich, H., 2017. The social footprint of permanent magnet production based on rare earth elements – a social life cycle assessment scenario. Energy Procedia 142, 984–990. https://doi.org/10.1016/j.egypro.2017.12.157

Schupp, M.F., Kafas, A., Buck, B.H., Krause, G., Onyango, V., Stelzenmüller, V., Davies, I., Scott, B.E., 2021. Fishing within offshore wind farms in the North Sea: Stakeholder perspectives for multi-use from Scotland and Germany. J. Environ. Manage. 279, 111762. https://doi.org/10.1016/j.jenvman.2020.111762

Selectra, 2022. Prix du kWh d'électricité : tarifs en 2023 et évolutions [WWW Document]. Fourniss.-Electr. Sel. URL https://www.fournisseurs-electricite.com/guides/prix/kwh-electricite (accessed 5.13.23).

Selectra, 2021. Quel est le prix de l'eau en France en 2023 ? [WWW Document]. Prix-Eleccom Sel. URL https://prix-elec.com/eau/prix (accessed 5.13.23).

Shiau, T.-A., Chuen-Yu, J.-K., 2016. Developing an Indicator System for Measuring the Social Sustainability of Offshore Wind Power Farms. Sustainability 8, 470. https://doi.org/10.3390/su8050470

Siemens Gamesa Renewable Energy, 2023. L'Usine d'éolienne en mer au Havre [WWW Document]. URL https://www.siemensgamesa.com/en-int/career/career-le-havre (accessed 5.15.23).

Smythe, T., Bidwell, D., Moore, A., Smith, H., McCann, J., 2020. Beyond the beach: Tradeoffs in tourism and recreation at the first offshore wind farm in the United States. Energy Res. Soc. Sci. 70, 101726. https://doi.org/10.1016/j.erss.2020.101726

SSPA Sweden AB, 2008. Methodology for Assessing Risks to Ship Traffic from Offshore Wind Farms, VINDPILOT-Report to Vattenfall AB and Swedish Energy Agency. https://doczz.net/doc/3836980/methodology-for-assessing-risks-to-ship-traffic-from

Statista, 2022. Diesel : prix moyen en France 2013-2022 [WWW Document]. Statista. URL https://fr.statista.com/statistiques/480617/prix-moyen-gazole-france/ (accessed 5.13.23).

Summit Packaging, 2021. Plastic Resin Prices 2021 | Resin Shortage & Cost of Plastic Explained [WWW Document]. URL https://summitpackaging.com/plastic-resin-prices-2021-resin-shortage (accessed 5.13.23).

Sureau, S., Mazijn, B., Garrido, S., Achten, W., 2018. Social life-cycle assessment frameworks: a review of criteria and indicators proposed to assess social and socioeconomic impacts. Int. J. Life Cycle Assess. 23. https://doi.org/10.1007/s11367-017-1336-5

Sureau, S., Neugebauer, S., Wouter, M.J.A., 2020. Different paths in social life cycle impact assessment (S-LCIA)—a classification of type II impact pathway approaches. Int. J. Life Cycle Assess. 25382–393. https://doi.org/10.1007/s11367-019-01693-9)

Terrados, J., Almonacid, G., Hontoria, L., 2007. Regional energy planning through SWOT analysis and strategic planning tools. Renew. Sustain. Energy Rev. 11, 1275–1287. https://doi.org/10.1016/j.rser.2005.08.003

Teunis, M., Collier, M.P., Bakker, E.G.R., Didderen, K., Gyimesi, A., Lengkeek, W., 2020. Ecological impact of decommissioning offshore wind farms 70. https://www.noordzeeloket.nl/publish/pages/188961/ecological-impact-of-decommissioning-offshore-wind-farms.pdf

Trading Economics, 2022. Lumber - 2023 Data - 1978-2022 Historical - 2024 Forecast - Price - Quote - Chart [WWW Document]. URL https://tradingeconomics.com/commodity/lumber (accessed 5.13.23).

Troldborg, M., Heslop, S., Hough, R.L., 2014. Assessing the sustainability of renewable energy technologies using multi-criteria analysis: Suitability of approach for national-scale assessments and associated uncertainties. Renew. Sustain. Energy Rev. 39, 1173–1184. https://doi.org/10.1016/j.rser.2014.07.160

Tseng, Y.-C., Lee, Y.-M., Liao, S.-J., 2017. An Integrated Assessment Framework of Offshore Wind Power Projects Applying Equator Principles and Social Life Cycle Assessment. Sustainability 9, 1822. https://doi.org/10.3390/su9101822

Ugoni, A., Walker, B.F., 1995. The Chi-square test, an introduction. COMSIG Rev. 4, 61–64. https://pubmed.ncbi.nlm.nih.gov/17989754/

UNDP, 2011. Guiding Principles on Business and Human Rights | United Nations Development Programme [WWW Document]. UNDP. URL https://www.undp.org/asia-pacific/bizhumanrights/publications/guiding-principles-business-and-human-rights (accessed 4.13.23).

UNEP, 2021. Methodological Sheets for Subcategories in Social Life Cycle Assessment (S-LCA) 2021. Traverso, M., Valdivia, S., Luthin, A., Roche, L., Arcese, G., Neugebauer, S., Petti, L., D'Eusanio, M., Tragnone, B.M., Mankaa, R., Hanafi, J., Benoît Norris, C., Zamagni, A. (eds.). United Nations Environment Programme (UNEP).

UNEP, 2020. Guidelines for Social Life Cycle Assessment of Products and Organizations 2020. Benoît Norris, C., Traverso, M., Neugebauer, S., Ekener, E., Schaubroeck, T., Russo Garrido, S., Berger, M., Valdivia, S., Lehmann, A., Finkbeiner, M., Arcese, G. (eds.). United Nations Environment Programme.

UNEP/SETAC, 2009. Guidelines for social life cycle assessment of products. Benoît, C., Mazijn, B. CIRAIG, P. and S. Interuniversity Research, Centre for the Life Cycle of Producs, Eds. United Nations Environment Programme.

UNFCCC, 2016. parisagreement_publication.pdf [WWW Document]. URL https://unfccc.int/sites/default/files/resource/parisagreement_publication.pdf (accessed 9.30.23).

Vattenfall AB, 2016. Social impacts from Wind power, Appendix to Vattenfall AB Certified Environmental Product Declaration EPD® of Electricity from Vattenfall's Nordic wind power - Appendix 2.pdf.

Verisk Maplecroft, 2020. Verisk Maplecroft releases world's first subnational human rights risk indices [WWW Document]. Verisk. URL https://www.verisk.com/newsroom/verisk-maplecroft-releases-worlds-first-subnational-human-rights-risk-indices/ (accessed 4.21.23).

Ville du Havre, Fécamp Caux littoral Agglo, Caux Seine Agglo, 2021. Communiqué de presse, Emploi - insertion, Trois collectivités accompagnent la mise en œuvre de la clause d'insertion du grand

projet de parc éolien en mer de Fécamp. https://www.lehavre.fr/espace-presse/trois-collectivites-accompagnent-la-mise-en-oeuvre-de-la-clause-dinsertion-du-grand.

Vues sur Mer, 2018. Retour d'expérience tourisme & éolien en mer 2017-2018, pour le compte de : Eoliennes en Mer Dieppe Le Tréport et Eoliennes en Mer Des Iles d'Yeu et de Noirmoutie cabinet Vues sur Mer, Michèle Cabanis 206. https://dieppe-le-treport.eoliennes-mer.fr/wp-content/uploads/sites/2/2018/09/retourdexperiencetourismeeolienenmer-20172018-vuessurmer.pdf.

WavEC, 2012. Wavec - Offshore Renewables - AQUARET [WWW Document]. URL http://www.wavec.org/en/research-development/projects/aqua-ret-1-e-2 (accessed 4.4.23).

WBCSD, 2016. Social Life Cycle Metrics for Chemical Products A guideline by the chemical sector to assess and report on the social impact of chemical products, based on a life cycle approach. https://docs.wbcsd.org/2016/11/Social_Metrics_Report.pdf.

WCED, 1987. Our Common Future. Report of the World Commission on Environment and Development. https://sustainabledevelopment.un.org/content/documents/5987our-common-future.pdf.

Webinar: Introducing PSILCA 1.0 - Social LCA Database, 2016.

Westerberg, V., Jacobsen, J.B., Lifran, R., 2013b. The case for offshore wind farms, artificial reefs and sustainable tourism in the French mediterranean. Tour. Manag. 34, 172–183. https://doi.org/10.1016/j.tourman.2012.04.008

Wind-turbine-models, 2016. General Electric Company / Haliade 150-6MW / 6MW offshore wind turbine generator nacelle / St. Nazaire, France [WWW Document]. URL https://fr.wind-turbine-models.com/fotos/PQ8tx4EC5kV-general-electric-company-haliade-150-6mw-6mw-offshore-wind-turbine-generator-nacelle-st.-nazaire-france (accessed 5.10.23).

World Energy Council, 2004. Comparison of energy systems using life cycle assessment: a special report of the World Energy Council. World Energy Council, London. https://www.worldenergy.org/assets/downloads/PUB_Comparison_of_Energy_Systens_using_lifecycle_2004_WEC.pdf.

Worldmrio.com, n.d. Eora Global MRIO [WWW Document]. URL https://worldmrio.com/ (accessed 4.18.23).

Xu, Y., Yang, K., Yuan, J., 2021. Levelized cost of offshore wind power in China. Environ. Sci. Pollut. Res. 28, 25614–25627. https://doi.org/10.1007/s11356-021-12382-2

Yu, M., Halog, A., 2015. Solar Photovoltaic Development in Australia—A Life Cycle Sustainability Assessment Study. Sustainability 7, 1213–1247. https://doi.org/10.3390/su7021213

Zanchi, L., Delogu, M., Zamagni, A., Pierini, M., 2018. Analysis of the main elements affecting social LCA applications: challenges for the automotive sector. Int. J. Life Cycle Assess. 23, 519–535. https://doi.org/10.1007/s11367-016-1176-8

Zheng, X., Easa, S.M., Ji, T., Jiang, Z., 2020. Modeling life-cycle social assessment in sustainable pavement management at project level. Int. J. Life Cycle Assess. 25, 1106–1118. https://doi.org/10.1007/s11367-020-01743-7

Appendix

Appendix 1: Survey intended for French local communities of the for offshore wind farm sector

Introduction section

1. Are your activities affected, or could they be affected, by the implementation of an offshore wind farm?
2. On a scale of 1 to 5, how would you rate the level of opportunity that the development of offshore wind farms may have on your organisation?
3. On a scale of 1 to 5, how would you rate the level of risk that offshore wind development may have on your organisation?

Section 1: Social Issues

1. On a scale of 1 to 5, where 1 means "not important" and 5 means "very important", how would you rate the importance of the following issues in the context of the implementation of an offshore wind farm project?
    - Attractiveness of the territory
    - Quality of the dialogue between local actors and decision-makers
    - Extent of citizen participation
    - Respect for the rights of residents
    - Local employment (creation, quality, preservation)
    - Benefits and technology transfers
    - Fair sharing of maritime and terrestrial spaces
    - Access to energy facilitated
    - Investments in favour of the territory
    - Consideration of quality of life and absence of nuisance
    - Safety management and industrial risks

2. Currently, on a scale of 1 to 5, where 1 means "not at all" and 5 means "fully", to what extent would you say that offshore wind development meets the requirements of:
    - Attractiveness of the territory
    - Quality of the dialogue between local actors and decision-makers
    - Extent of citizen participation
    - Respect for the rights of local residents
    - Local employment (creation, quality, preservation)
    - Benefits and technology transfers Fair sharing of maritime and terrestrial spaces
    - Access to energy facilitated
    - Investments in favor of the territory
    - Consideration of quality of life and absence of nuisance
    - Safety management and industrial risks

(Optional) In your opinion, in the context of the implementation of an offshore wind project, are there other social issues specific to the territories that should be emphasized?

Section 2: Profile of your organisation

1. Which of the following activities best describes your organisation?
    - Associative
    - Public administration
    - Professional fishing/Aquaculture
    - Navigation/Nautical/Port

    You can specify:

2. What is the scale of the activity perimeter, or interests represented, for your organisation?
   - Local (commune or group of communes)
   - Departmental
   - Regional
   - National
   - International

   Department(s) of your organisation:
3. In relation to the life of a wind farm, which stage(s) can have an influence on your activities?
   - Manufacturing of components (e.g. foundations)
   - Transportation of components
   - Construction of the wind farm
   - Operation and maintenance of the wind farm
   - Dismantling and end of life of the wind farm

4. If known, wind farm project(s) related to your activities or your territory:
   - Dunkirk
   - Dieppe - Le Tréport
   - Centre of the Channel
   - Fécamp
   - Courseulles-sur-Mer
   - St. Brieuc
   - Southern Brittany
   - St. Nazaire
   - Yeu – Noirmoutier
   - Southern Atlantic
   - Mediterranean
   - Other / Don't know

   Would you be willing to be contacted to discuss this topic in more detail (invitation to a focus group or interview)?

Appendix 2: Descriptive variables for local communities

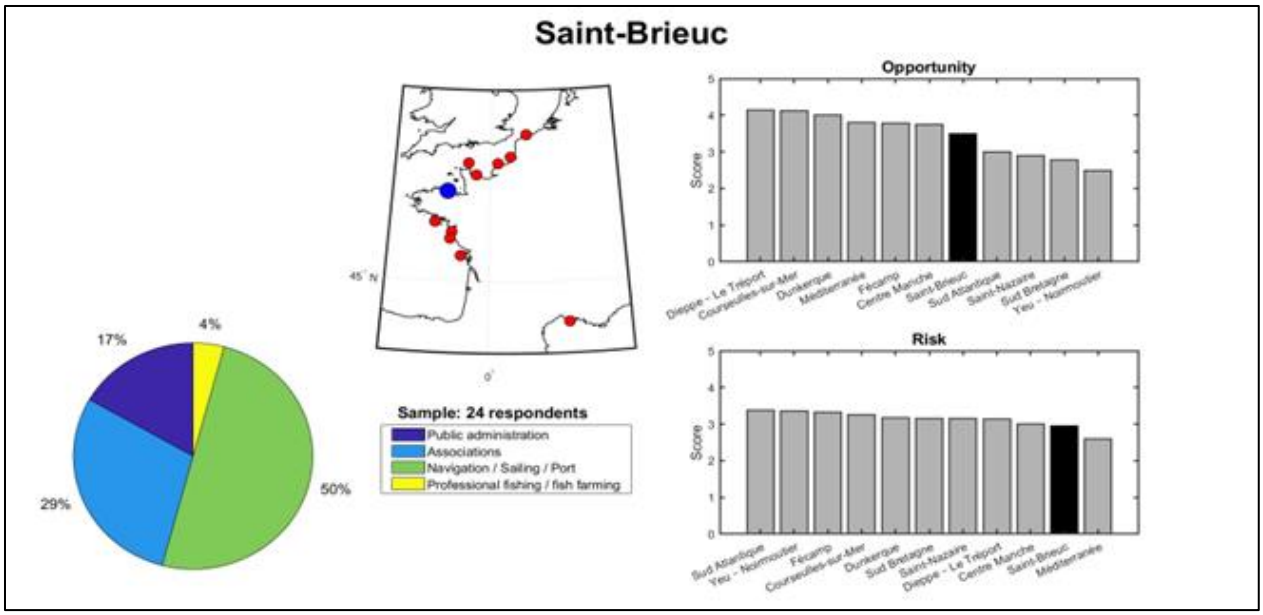
Variables	Modalities	Sample (N=50)	Population (Public debates)
Stakeholders' organisation profile (calibration variable)	Local NGO	33%	38%
	Public administration	14%	33%
	Professional fishing	8%	12%
	Navigation / nautical	45%	21%
Related life cycle stage	Component manufacturing	13%	
	Component transport	15%	
	Farm construction	26%	
	Operation and maintenance	25%	
	Dismantling	20%	
Related offshore wind farm	Dunkerque	4%	
	Dieppe – Le Tréport	5%	
	Centre Manche	6%	
	Fécamp	6%	
	Courseulles-sur-Mer	6%	
	Saint-Brieuc	14%	
	Sud Bretagne	22%	
	Saint-Nazaire	14%	
	Yeu – Noirmoutier	10%	
	Sud Atlantique	6%	
	Méditerranée	4%	
	Other / unknown	4%	

Appendix 3: Descriptive variables for value chain actors

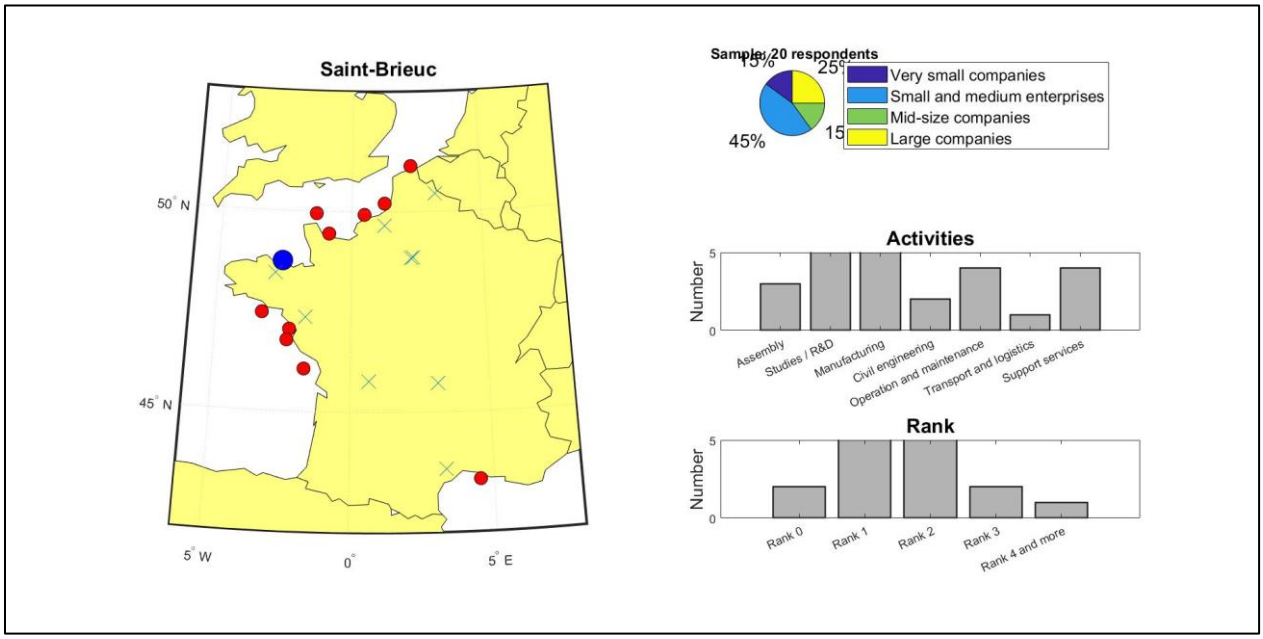
Variables	Modalities	Sample (N=82)	Population (sectoral statistics observatory)
Stakeholders' organisation profile (calibration variable)	Assembly of components	7%	12%
	Design / R&D	32%	25%
	Manufacturing of components	16%	19%
	Extraction of raw materials	0%	n/a
	Civil engineering	8%	13%
	Operation and maintenance	13%	14%
	Transport and logistics	5%	8%
	Support services	19%	9%
	Other	0%	
Organisation's size	Very small enterprises	23%	
	Small and medium enterprises	46%	
	Intermediate-sized enterprises	17%	
	Large enterprises	13%	
	Unknown	27%	
Position with regard to the electricity developer	0 (consortium operating a wind farm)	7%	
	1 (subcontractors for the consortium)	26%	
	2 (second-tier subcontractors)	29%	
	3 (third-tier subcontractors)	5%	
	4 or more	6%	
Relative position in relation to the operational phase	Upstream	51%	
	Operational phase	31%	
	Downstream	18%	
Turnover related to offshore wind sector	Minor (less than 33% of turnover)	76%	
	Medium (33-66%)	13%	
	Major (>66%)	11%	
Geography	France	84%	
	European Union	12%	
	Outside the European Union	4%	
Related offshore wind farm	Dunkerque	6%	
	Dieppe – Le Tréport	6%	
	Centre Manche	4%	
	Fécamp	12%	
	Courseulles-sur-Mer	9%	
	Saint-Brieuc	9%	
	Sud Bretagne	10%	
	Saint-Nazaire	14%	
	Yeu – Noirmoutier	6%	
	Sud Atlantique	4%	
	Méditerranée	11%	
	Other / unknown	9%	

Appendix 4: Disaggregated descriptive survey results by French OWF (example of Saint-Brieuc OWF)

- **Local community of installation site**



- **National value chain**



Appendix 5: List of OWF study cases of the impact assessment S-LCA phase

Technical parameters	Case study 1	Case study 2	Case study 3	Case study 4	Case study 5
Total power (MW)	250	480	498	240	496
Cable length (Km) / or assumption	75	61	50	75	48
Type of turbine (MW)	12	6	6	13	8
Number of turbines	21	80	71	20	62
Foundation types / or assumption	Floating	Fixed - monopile	Fixed - GBS	Floating	Fixed - Jacket
Commissioning date	2030	2022	2023	2030	2023
Coastline	Mediterranean	Atlantic	North Sea	Mediterranean	Channel Sea

Appendix 6: Questions for semi-structured interviews

- General questions:

1) Can you describe your position?

2) What do you associate with the "social issues" of the stakeholder category you represent?

3) Which of these issues would you like to see progress in the future?

- For electricity company professions:

4) In relation to these issues, do you use measurement or reporting tools, such as indicators or others that are reported higher up in the company?

5) Are you in contact with other internal professions? with other external stakeholders?

- Additional question for electricity company CSR profession:

6) In the context of offshore wind energy, do some social issues or stakeholders seem to stand out more than others, to be put forward? In relation to an offshore wind project, at what stage of its life would you say that social issues are addressed: is it very early on, from the design of the farm, or rather just before implementation in terms of acceptability? (Are issues very early on, such as ethical sourcing of raw materials, covered?)

- For local community external stakeholders:

4) On the question of the sharing of maritime spaces: how do you measure a priori the level of conciliation of infrastructures in relation to fishing activities? Are there any parameters that you are sensitive to: such as the spacing between wind turbines, their position in relation to the coast or fishing zones?

5) What is your relationship with the marine professionals themselves: do they have different positions? What other relationships do you have with offshore wind developers or public authorities?

Appendix 7: set of data collection per indicator and study cases used in this PhD thesis

Indicator	Unit	CS 1		CS 2	
		Value	Source	Value	Source
Potential touristic development	Number	No parallel projects planned	Na	Parallel projects underway	(Navix, 2023)
Effect on landscape: "spatial integration"	Calcul	0,011	(MTE, 2022b)	0,085	(Parc de Banc de Guérande, 2022a)
Potential devaluation on proprety prices	%	***0% - Default value*** (ADEME, 2022)			
Surface efficiency	Km²/MW	0,2	(MTE, 2022b)	0,1625	(Parc de Banc de Guérande, 2022a)
Potential increase in catches close to a wind farm	%	***≃ 7% - Default value*** (Halouani et al., 2020)			
Willingness to practice recreational fish near OWF	%	***25% - Default value*** (Hooper et al., 2017)			
Probability of accident with a civil	Number/year	1,55E-04	(La compagnie du vent, 2010; SSPA Sweden AB, 2008)	0,002042915	(La compagnie du vent, 2010; SSPA Sweden AB, 2008)
Annual taxes	Millions €/year	4,31	(CGEDD, 2021b)	8,26	(CGEDD, 2021b)
Indirect local job	Number/MW	2,6	(CMF, 2022)	2,5	(Parc éolien en mer de Saint-Nazaire, 2021)
Amount of meetings with local communities / littoral population	‰	0,72	(CNDP, 2021b; INSEE and SOeS, 2009)	0,83	(CNDP, 2013a; INSEE and SOeS, 2009)
Trust rate in electricty developers	%	***12% - Default value*** (Hooper et al., 2017)			
Percentage of local power for the administrative department	%	53%	(Gouvernement and RTE, 2022a; INSEE, 2019)	49%	(INSEE, 2022a; Parc de Banc de Guérande, 2022a)
Price per MWh: cost of public support	€/MWh	Na	(European Commission, 2019)	143,6	(European Commission, 2019)
Local content: share of project cost captured by regional companies	%	50%	(Energies de la mer, 2021)	21,5%	Interview (Le Télégramme, 2022)
Temporary employment	%	***67% - Default value*** (Buchmayr et al., 2022 based on Rutovitz et al., 2015)			
Social clauses	h/MW	Na	Na	167	(Parc de Banc de Guérande, 2022b; Saint-Nazaire Agglo, 2020)
Payment rate without delay	%	***61% - default value*** (Banque de France, 2018)			
Ecovadis score of developper	Score	Na		80	(EDF, 2022)
Avoiding fossil fuel costs	Millions €	36,13	(EWEA, 2009)	69,38	(EWEA, 2009)
Import dependency rate for critical raw materials	kg/MW	Na	Na	200	(ADEME, 2019; GE Renewable Energy, 2022; Wind-turbine-models, 2016)
CSR score of OWF developper	Score	Na	Na	74,2	(Le Point and Statista, 2022)

Indirect jobs in the value chain	Number/ MW	9,3	(INNOSEA, 2022)	4,9	(INNOSEA, 2022)
Indirect spin-off jobs	Number/ MW	11,4	(INNOSEA, 2022)	5,8	(INNOSEA, 2022)

Indicator	CS 3		CS 4		CS 5	
	Value	Source	Value	Source	Value	Source
Potential touristic development	Parallel projects underway	(Le Télégramme, 2023)	No parallel projects planned	Na	Parallel projects planned	Interview with electricity company
Effect on landscape: "spatial integration"	0,091	(Eoliennes Offshore des Hautes Falaises, 2022)	0,009	(MTE, 2022a)	0,051	(Ailes Marines, 2022b)
Potential devaluation on proprety prices	***0% - Default value*** (ADEME, 2022)					
Surface efficiency	0,12	(Eoliennes Offshore des Hautes Falaises, 2022)	0,2	(MTE, 2022a)	0,15	(Ailes Marines, 2022b)
Potential increase in catches close to a wind farm	***≃ 7% - Default value*** (Halouani et al., 2020)					
Percentage of willigness to practice recreational fish near OWF	***25% - Default value from*** (Hooper et al., 2017)					
Probability of accident with a civil	2,40E-03	(La compagnie du vent, 2010; SSPA Sweden AB, 2008)	2,40E-03	(La compagnie du vent, 2010; SSPA Sweden AB, 2008)	2,33E-03	(La compagnie du vent, 2010; SSPA Sweden AB, 2008)
Annual taxes	8,57	(CGEDD, 2021b)	8,61	(CGEDD, 2021b)	8,54	(CGEDD, 2021b)
Indirect local job	4,01	(Emploi-Environnement, 2020)	0,92	(CNDP, 2021c)	1,01	(Energie recrute, 2021)
Amount of meetings with local communities / littoral population	2,90	(CNDP, 2013b; INSEE and SOeS, 2009)	1,22	(CNDP, 2021c; INSEE and SOeS, 2009)	0,80	(CNDP, 2013d; INSEE and SOeS, 2009)
Trust rate in electricty developers	***12% - Default value*** (Hooper et al., 2017)					
Percentage of local power for the administrative region	60%	(Eoliennes Offshore des Hautes Falaises, 2022)	23%	(INSEE, 2022b; MTC and MTE, 2022)	76%	(Ailes Marines, 2022b; INSEE, 2022b)
Price per MWh: cost of public support	135,2	(European Commission, 2019)	Na	Not identified yet (MTC and MTE, 2022)	155	(European Commission, 2019)
Local content: share of project cost captured by regional companies	30% to 40%	Interviews (Caisse d'Epargne Normandie, 2021; Ouest france, 2020)	18%	(Gouvernement and RTE, 2022b).	9%	(Ailes Marines, 2022a)
Temporary employment	***67% - Default value*** (Buchmayr et al., 2022 based on Rutovitz et al., 2015)					
Social clauses	440	(Ville du Havre et al., 2021)	Na	Na	172	(CNDP, 2013c)
Payment rate without delay	***61% - default value*** (Banque de France, 2018)					
Ecovadis score of developper	80	(EDF, 2022)	Na	Not identified yet (MTC and MTE, 2022)	67-74	(Iberdrola, 2023)
Avoiding fossil fuel costs	71,98	(EWEA, 2009)	72,27	(EWEA, 2009)	71,69	(EWEA, 2009)

Import dependency rate for critical raw materials	200	(ADEME, 2019; Eoliennes offshores des hautes falaises, 2013; GE Renewable Energy, 2022)	Na	Na	200	(ADEME, 2019; CCI Bretagne, 2017)
CSR score of OWF developper	74,2	(Le Point and Statista, 2022)	Na	Not identified yet (MTC and MTE, 2022)	Na	Na
Indirect jobs in the value chain	4,9	(INNOSEA, 2022)	9,3	Input-output database (INNOSEA)	4,5	(INNOSEA, 2022)
Indirect spin-off jobs	5,8		11,4		5,35	

Appendix 8: Inventory for database (PSILCA) assessment

Inventory from Kouloumpis and Azapagic, 2022 (5MW)				USD conversion			Inputs to database	
Sub-system	**Material**	**Unity**	**Quantity**	**Unit cost**	**Source**	**Total cost (USD) / material**	**PSILCA equivalent process activities asummption**	**Total cost (USD) / process activities**
Tower		**kg**	**221 000**					
	Steel low alloyed	kg	217 022	0,58	(Boursorama, 2022a)	125 873	Manufacture of basic metals - FR	142 899
	Aluminium	kg	3 978	4,28	(Buchmayr et al., 2022)	17 026		
	Electricity	kWh	22 564	0,19	(Selectra, 2022)	4 391	Electrical energy, gas, steam and hot water - FR	5 397
	Diesel	litres	111	1,50	(Statista, 2022)	166		
	District heat	kWh	4 265	0,19	(Selectra, 2022)	830		
	Welding gas	kg	22	Na		-		
	Water	kg	3 448	0,003	(Selectra, 2021)	10		
	Fuel oil	litres	1 790	5,50	(Buchmayr et al., 2022)	9 846	Manufacture of chemicals and chemical products - FR	9 846
	Waste unspecified	kg	3 050	Na		-	Na	
	Waste hazardous	kg	22	Na		-	Na	
	Oil waste	kg	4	Na		-	Na	
Blades (x3)		**kg**	65 625					
	Glass fibre	kg	43 838	1,90	(Summit Packaging, 2021)	27 764	Manufacture of chemicals and chemical products - FR	59 161
	Epoxy	kg	17 325	5,30	(ChemAnalyst, 2022)	30 608		
	Polypropylene	kg	1 247	1,90	(Summit Packaging, 2021)	790	Manufacture of wood and of products of wood and cork - FR	268
	Wood (mix)	kg	3 216	0,25	(Trading Economics, 2022)	268		
	Water	kg	67 463	0,003	(Selectra, 2021)	67	Electrical energy, gas, steam and hot water - FR	3 951
	Natural gas/Town gas	kWh	22 509	0,13	(Hello Watt, 2022)	963		
	Electricity	kWh	45 019	0,19	(Selectra, 2022)	2 920		
	District heating	kWh	12 863	Na				
Hub		**kg**	**59 375**					
	Cast iron	kg	27 372	0,97	(coursdesmétaux.fr, 2022)	26 551	Manufacture of basic metals - FR	84 112
	Chromium steel	kg	15 972	3,08	(Buchmayr et al., 2022)	49 193		
	Steel low alloyed	kg	14 428	0,58	(Boursorama, 2022a)	8 368		
	Glass fibre	kg	1 663	1,90	(Summit Packaging, 2021)	3 159	Manufacture of chemicals and chemical products - FR	3 159
	Electricity	kWh	72 081	0,19	(Selectra, 2022)	14 027	Electrical energy, gas, steam and hot water - FR	17 917
	Natural gas/Town gas	kWh	29 688	0,13	(Hello Watt, 2022)	3 812		
	Water	kg	25 947	0,003	(Selectra, 2021)	78	Other mining and quarrying products - FR	11 875
	Sand	kg	237 500	0,05	(Point P., 2022)	11 875		

Nacelle main body	**kg**	**277 830**					
Cast iron	kg	130 024	0,97	(coursdesmétaux.fr, 2022)	126 124	Manufacture of basic metals - FR	179 589
Copper	kg	5 001	7,60	(Boursorama, 2022b)	38 007		
Aluminium	kg	3 612	4,28	(Buchmayr et al., 2022)	15 458	Electrical energy, gas, steam and hot water - FR	37 516
Electricity	kWh	41 675	0,19	(Selectra, 2022)	8 110		
Natural gas/Town gas	kWh	229 021	0,13	(Hello Watt, 2022)	29 406		
Power/transformer unit	**kg**	**37 170**					
Steel low alloyed	kg	19 366	0,58	(Boursorama, 2022a)	4 204	Manufacture of basic metals - FR	70 868
Steel electric	kg	7 248	0,58	(Buchmayr et al., 2022)	4 118		
Copper	kg	7 099	7,60	(Boursorama, 2022b)	53 956	Manufacture of basic metals - FR	69 392
Aluminium	kg	2 007	4,28	(Buchmayr et al., 2022)	8 591		
Processing copper	kg	7 099	7,60	(Boursorama, 2022b)	53 956		
Processing steel	kg	26 614	0,58	(Buchmayr et al., 2022)	15 436		
High density polyethylene	kg	1 450	0,81	(Summit Packaging, 2021)	1 174	Manufacture of chemicals and chemical products - FR	1 174

RÉSUMÉ

L'objectif de cette thèse de doctorat est de développer un cadre méthodologique pour l'évaluation des impact sociaux du cycle de vie de l'énergie éolienne offshore en France. Le premier développement méthodologique est lié à l'étape de définition de l'objectif et le périmètre de l'Analyse de Cycle de Vie Sociale. Une approche systématique de l'identification des sous-catégories d'impact pertinentes, basée sur la consultation des parties prenantes, a été proposée. Cette approche a été formulée sous la forme d'un protocole d'échantillonnage et d'un examen de la représentativité des profils des répondants des parties prenantes. L'objectif était de présenter la manière dont un traitement statistique des données peut améliorer la transparence et renforcer les approches participatives pour hiérarchiser les sous-catégories d'impact social. Le deuxième développement méthodologique est lié aux étapes d'analyse d'inventaire et d'évaluation des impacts. L'objectif est d'intégrer différentes échelles géographiques, y compris les échelles mondiale, nationale et locale des impacts sociaux de l'énergie éolienne en mer. Une approche combinée a été utilisée, avec une évaluation générique des impacts sociaux à l'échelle mondiale et une définition spécifique des différentes catégories d'impacts sectoriels et des indicateurs pour les échelles nationale et locale avec un protocole systématique pour l'identification de sources de données avec des granularités différentes.

Les développements réalisés dans cette thèse visent à contribuer à une meilleure intégration des enjeux sociaux et des parties prenantes, du global au local, dans les processus de décision dans un contexte de déploiement accéléré des parcs éoliens offshore en France et en Europe.

MOTS CLÉS

Analyse sociale du cycle de vie (ACV-S), impacts sociaux, hiérarchisation, approche multi-scope, énergie éolienne offshore

ABSTRACT

The aim of this PhD thesis is to develop a methodological framework for the assessment of social impact of the life cycle of offshore wind power in France. The first methodological development is related to the S-LCA goal and scope step. A systematic approach for identifying the relevant impact subcategories based on stakeholders' consultation has been proposed. This approach was formulated in the form of a protocol for sampling and addressing the representativeness of respondent profiles of stakeholders. The aim was to present how a statistical data treatment may improve the transparency and strengthen participatory approaches to prioritise social impact subcategories. The second methodological development is related to the S-LCA inventory and impact assessment steps. The aim is to integrate different geographical scopes, including the global, national, and local scopes of the social impacts of offshore wind power. For this purpose, a combined approach was used, using a generic assessment for the social impacts on a global scope, and a specific definition of different sectorial impact categories and indicators for the national and local scopes, including a systematic protocol for the identification of data sources with different levels of representativeness of the assessed systems.

The developments carried out in this thesis aim to contribute to a better integration of social issues and stakeholders, from global to local, into decision-making processes in a context of accelerated deployment of offshore wind farms in France and Europe.

KEYWORDS

Social Life Cycle Assessment (S-LCA), social impacts, hierarchisation, multi-scope approach, offshore wind power