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Collective action for bridging digital and sustainability transitions : Modelling and experimenting a new form of co-design between Earth-observation data providers and unknown users

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Raphaëlle Barbier. Collective action for bridging digital and sustainability transitions : Modelling and experimenting a new form of co-design between Earth-observation data providers and unknown users. Business administration. Université Paris sciences et lettres, 2023. English. NNT : 2023UPSLM013 . tel-04234684

HAL Id: tel-04234684

<https://pastel.hal.science/tel-04234684>

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THÈSE DE DOCTORAT
DE L'UNIVERSITÉ PSL

Préparée à Mines Paris-PSL

**Collective action for bridging
digital and sustainability transitions:**
*Modelling and experimenting a new form of co-design between
Earth-observation data providers and unknown users*

Soutenue par

Raphaëlle BARBIER

Le 24 mars 2023

Ecole doctorale n° 543

SDOSE

Spécialité

Sciences de gestion

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Mines ParisTech n'entend donner aucune approbation ni improbation aux opinions émises dans cette thèse. Ces opinions doivent être considérées comme propres à l'auteur.

Acknowledgements

Coming to the moment of writing this acknowledgement section seems to me so special. Although it marks the start of the thesis manuscript, it actually means that I have pretty much come to the end of writing the several hundreds of pages that follow. What a journey to reach this point! It took me longer than expected but it has been an incredibly formative adventure, that has brought me to navigate uncharted and turbulent waters. I have now the feeling of coming out of it with renewed energy for at least several years! Time will tell... Before temporarily drawing this journey to a close, there are so many people I would like to thank wholeheartedly. In your own way, you have all strongly contributed to making it happen.

I start by warmly thanking the members of the jury for having accepted to evaluate and discuss my PhD work. First, I thank Christophe Abrassart and Nicolette Lakemond for having provided me with thoughtful comments and suggestions during the pre-defense. They have been truly helpful to write the present final version of the manuscript, which, I hope, you will find significantly improved. I am also particularly grateful to Sylvain Lenfle, who has shown me the way of bridging Earth Observation and management research, and with whom I had the pleasure to share some discoveries and puzzlements along the way (“do you speak the language of NetCDF??”). I also thank Kathrin Möslin and Irene Pluchinotta for having accepted to be part of this jury. I have found your respective work very inspiring, rooted in both engineering and management cultures, and giving complementary views on sophisticated forms of co-design. I am looking forward to further discussing these questions with you. Many thanks as well to Thierry Ranchin, who has endorsed the tricky role of coordinating the project “e-shape” within which my research work has been conducted, and who has played an important role in introducing me to the world of Earth Observation.

It is important to note that this manuscript is the result of a lot of behind-the-scene but essential contributions of all of those who have kindly accepted to proofread it. The manuscript owes a lot to you Lucien, Agathe, Chipten, Marianne, Harriet, Rebecca (and her family), Claire, Colette, and André.

I also thank all e-shape partners for having made this research work possible. I have learnt so much from you and e-shape has been a wonderful collective adventure! For that,

special thanks to the project management team – Thierry Ranchin, Nicolas Fichaux, Lionel Ménard, Mathieu Reboul. Beyond the scope of co-design, I hope the whole momentum created during the project will keep bearing its fruits.

Thanks as well to Isabelle Bénézech and Yana Gevorgyan for having trusted me and given me the opportunity to participate in the GEO ‘Post-2025 strategy’ working group. Thanks to all the working group members for the stimulating and collective work.

I continue with special thanks to my two PhD supervisors, Pascal and Benoit, for having supported me all along. You have been incredible guides. Your constant trust and encouragement have definitely helped me reach some points I would have never imagined by myself. Thanks for having let me find my own way to the top of the mountain I have been striving to climb. It is probably an unreachable summit and a never-ending climb, but for sure I feel now much better equipped to continue the exploration further. I will also keep in mind a few memorable moments when travelling around to participate in some big events organised by the Earth Observation community, such as our attempt at tracking kangaroos!

Besides my PhD supervisors’ support, I have also benefitted from the unique and stimulating atmosphere of the CGS team. I start by thanking Skander, who has played an absolutely critical role in the success of our involvement in e-shape and of my thesis! It has been a pleasure diving into the world of space, Earth Observation and a whole load of different topics by your side. I also warmly thank all the PhD and former PhD students for creating such a nice atmosphere of support and mutual aid. Thanks to my two mates Musketeers, or Totally Spies depending on our mood, Caroline and Honorine, for having shared such great moments together, having good chinwags and dreaming about the future. Thanks Johanna, Alix, Louise, Justine, Chloé, Charlotte, Corentin, Pierre for having faced together the ups and downs of the final writing process. Thanks Chipten and Maxime for having shown me the way from the major in Engineering design to the PhD. Thanks as well Quentin, Agathe, Nafissa, Jérémy, Antoine (x2) for our discussions about research and life. Special mention as well to the J108 team with Samantha, Chloé, Mariam, Iris, Alix. I keep strong memories of my early PhD days spent with you. I am also very grateful for the support provided by the permanent researchers of the team. In particular, thanks Armand for making me discover the wonderful place of Cerisy-la-Salle, and Sophie for taking your time sharing your experience and advising me. I am also grateful to the “extended” CGS family, in particular Colette and Fred from Stim – I always

come out of our discussions with good vibes and my head full of ideas. Last but not least thanks to you Stéphanie, Céline, and Marie-Michelle, your support through the jungle of all kinds of administrative procedures has been very precious!

I have also been very lucky to benefit from a second research family, the “O.I.E.” dream team in Sophia-Antipolis. Thanks for having embarked our lab on the adventure of e-shape and having made us discover the fascinating world of Earth Observation. It has been a true pleasure to share these moments with you, and it is hopefully just the beginning! Thanks to all the present and former PhD students and all the permanent researchers for always welcoming me as one of theirs. Special mentions to the ones involved in e-shape (or its origins). Thanks Lucien for having introduced me to the history of your research team as well as to the world of Formula 1, what a nice way to start! Thanks Thierry for having welcomed me the very first day of my PhD at the EuroGEO event in Geneva. At that time, I did not have a clue about what was going on. And you have been a very precious guide to help me get my bearings. You also warned me on this very first day that I was already late for my PhD – you proved to be so right! Thanks Philippe for your strong and constant support, all our stimulating conversations and your great humanity - you have shown me such an inspirational way of doing research! Thanks Lionel for having helped me to learn the ropes of data sharing principles and standards with so much pedagogy, and for kindly but firmly reminding me not to overrun my allotted speaking time when giving talks... I can certainly still improve but I promise that I am working on it! But above all thanks for your great sense of humour, countless stories and entertainment ideas such a nice discovery of the Greek rock culture. Although not involved in e-shape, thanks as well Benoit for always taking the time for nice conversations about our respective passions and offering some help whenever you are in Paris and every time I was in Sophia.

Besides my two research families, I would also like to express my immense gratitude to my oldest friends as well as all the people I have met along the way. Every moment spent with you, even the tiniest one, has helped me thrive and keep going. Of course, Sarah, Laura, Claire for our regular “petites vieilles” meetings. Justine for our great adventures in Canada and in the Alps, hopefully many more to come! Raphaël for our very unique filiation link. Mathilde, Claire, Alex, Gaël, the 13rd district flatmates, 518, Soulac and Team Laragne groups

for organising regular opportunities to meet up again, your support has been really vital. Lucie, Pauline, Gwendoline, Guillaume, J-B, Mathilde, Gaëtan and Baudoin for our monthly dinners, deep and essential sharing times. Radix, Allair, Gigi for the adventurous moments we spent together - not frequent, yet memorable! Laurence, Lionel, Carole, Florent and our joyful team of philosophers in the becoming. Ingrid and Heidi for inspiring me and sharing your adventurous vibes. Elise for our dinners every now and then in Geneva. Chantal for your stories and warm welcome every time I came to work in Sophia-Antipolis. Enrico and Cécilia for our great discussions about art and life in London. Thanks to the “B5” as well, Estelle, Lorenzo, Guillaume for learning the “lieutenant” ropes together, to Sébastien and Philippe for their support and understanding, and to all B5 personnel for sharing their incredibly rich mix of experiences. And final mention to Cerisy. The “Foyer de création et d’échange” was a true turning point and regenerative moment. Special thanks to Edith of course, as well as Michaël, Jean-Christophe, Arnaud, all the staff and the incredible people I had the chance to meet there - Colette, Pierrette, Elisabeth, Alain, Alice, Anne, Gisèle, Guillaume, Prisca, and finally Sylvain with whom I had a lot of fun experimenting a new way of doing interviews.

Last and not least, I would like to thank my dear family for their continued support through all the ups and downs I went through. I owe so much to my parents - thanks for your constant and unconditional loving support. Special thanks as well to my little brother and sisters. Mathieu for having spent the first Covid lockdown with me, treating me with delicious chamois barbecues. Charlotte and Colette for coaching me in the most difficult moments and accompanying me in various (sometimes surprising) outings. Special mention to Charlotte who told me once “hmm super interesting your thesis in astrology!”. Thanks as well Denis and Hélène for your support, and your efforts in keeping me entertained with books and theatre plays. Thanks to my cousins for the regular meetings at our “Au petit Suisse” headquarter. And my final thought goes to you André. It has been a sheer joy spending these years by your side, and I cannot wait for the next ones! Thanks for your stories told with so much enthusiasm, your endless desire of learning new things, as well as your understanding and patience. Thanks for always encouraging me to follow my dreams and get my craziest ideas off the ground. Thanks to you, I have managed (at least tried) to focus on the next little step rather than on the intimidating summit, and here I am!

A Malire et ses grands-parents,

*Grand-Milou,
qui lui montrait les étoiles,*

*Grand-Pilou,
qui l'encourageait au travail,*

*Mamé,
qui lui lisait des histoires,*

*Papé,
qui la faisait rire.*

« Le peintre est comme un chef d'orchestre qui gère dans l'instant mille voix et tente de jouer avec. C'est dans ce jeu que l'image surgit. Ce que je trouve tellement difficile, ce qui est une véritable souffrance, c'est qu'à la fin, la peinture, en séchant, redevient quelque chose d'immobile. Or, dans le temps de sa réalisation, tout est vivant, impermanent, mouvant, en incessant devenir. [...] Plus on plonge sans peur de l'inconnu dans ce grand fleuve de matière noire, plus on s'adapte. Plus on s'adapte, plus on apprivoise les accidents, et des transformations fécondes apparaissent, tout naturellement. Ces traces, par la suite, sèchent et gardent tout de même en mémoire cette bataille du peintre. »

"The painter is like a conductor who, at every moment, deals with thousands of voices and attempts at playing with them. The image arises within this game. What I find so difficult, what is a real pain, is that, when the paint gets dry in the end, it becomes static again. Whereas, during the realisation process, everything is living, changing, moving, in the constant process of becoming. [...] The more one plunges into this flow of dark matter without fearing the unknown, the more one adapts to it. The more one adapts to it, the more tamed the accidents become, naturally giving birth to fruitful transformations. Thereafter, these traces get dry, and yet keep the painter's struggle etched in them."

Fabienne Verdier
In *Une séance de peinture, entre cerveau, art et science*,
Alain Berthoz et Fabienne Verdier, 2022. Odile Jacob (p. 60)
(my own translation)

Abstract

In the face of contemporary socio-environmental challenges, our current models of society are increasingly faced with their own limits. Consequently, organisations and individuals are led to explore new forms of collective action spanning current organisational and sectorial boundaries. In this context, the use of “co-design” has been flourishing in the last years to respond to the need of organising intricate innovative and collective processes requiring the involvement of multiple actors. However, these efforts prove to be eminently challenging. Indeed, it involves bridging people who usually evolve in highly different spheres, who have very little in common, and who might not be even aware of the existence of one another. In other words, the actors seem separated by a form of “grand distance”, making them appear as largely unknown to each other. In such conditions, collective action seems nowhere near guaranteed, if even possible.

The thesis contributes to eliciting under which conditions and which forms co-design can help organise collective action in these situations of grand distance. In particular, the thesis proposes a model of co-design named “resilient-fit”, that has been built and experimented in the field of Earth Observation (EO), where the issue of grand distance unfolds in a particularly extreme way, specifically between EO data providers and potential users that remain mostly unknown to each other.

The results of this research are analysed at three different levels (micro, meso, macro), each being the focus on one academic paper. Drawing on these results, the resilient-fit co-design model is characterised according to four dimensions: the methods and tools supporting the co-design process (‘technical substratum’); the overall purpose which co-design is aimed at (‘management philosophy’); the characteristics and roles of the actors involved (‘organisational relations’); and the underlying design mechanisms (‘reasoning logic’).

By eliciting the resilient-fit co-design model, the thesis shows that co-design can indeed help organise collective action even in extreme situations of grand distance where collective action seems highly improbable, provided that co-design adequately takes into account the issue of grand distance. Although further efforts are still needed, the resilient-fit co-design model has already been largely praised by practitioners of the EO field. More broadly, it also offers multi-fold perspectives for management researchers and practitioners, suggesting new forms of collective action in times of digital and sustainability transitions.

Résumé

Nos modèles de société sont aujourd'hui remis en question par de grands défis sociaux et environnementaux. Ces difficultés poussent notamment à explorer de nouvelles formes d'action collective, qui dépassent les frontières habituelles entre organisations et secteurs. C'est dans ce contexte que le « co-design » (ou co-conception) connaît aujourd'hui un fort engouement, répondant notamment au besoin d'organiser des processus collectifs de conception impliquant de multiples acteurs. L'organisation de tels processus s'avère néanmoins particulièrement complexe. Il s'agit en effet de relier des acteurs qui évoluent dans des sphères différentes, qui n'ont que peu d'intérêts communs, et qui peuvent même ignorer leur existence respective. Autrement dit, ces acteurs semblent être séparés par une forme de « grande distance », apparaissant ainsi comme largement inconnus les uns des autres. Dans de telles conditions, une quelconque action collective semble loin d'être assurée, voire même envisageable.

Cette thèse contribue à éclairer dans quelles conditions et sous quelles formes le co-design peut aider à organiser de l'action collective dans des situations de grande distance. En particulier, la thèse propose un modèle de co-design à « haute résilience ». Ce modèle a été construit et expérimenté dans le domaine de l'observation de la Terre, où la problématique de grande distance se pose de manière particulièrement aiguë, notamment entre des fournisseurs de données et de potentiels utilisateurs qui restent très largement étrangers les uns des autres.

Les résultats de cette recherche ont été formalisés dans trois articles académiques, chacun correspondant à un niveau d'analyse spécifique (micro, méso, macro). Ces résultats ont permis de caractériser le modèle de co-design à « haute résilience » selon quatre dimensions : ses méthodes et outils (« substrat technique »), son objectif cible (« philosophie gestionnaire »), les rôles et caractéristiques des acteurs impliqués (« relations organisationnelles »), et les mécanismes de conception à l'œuvre (« raisonnement de conception »).

La thèse confirme ainsi que le co-design peut organiser de l'action collective même dans des situations de grande distance extrême où cela paraît a priori hautement improbable, à condition que le modèle de co-design prenne bien en compte cette problématique de grande distance. Le modèle de co-design à haute résilience a déjà de fortes retombées pratiques dans le domaine de l'observation de la Terre. Ce modèle ouvre également de nombreuses perspectives quant à l'organisation de nouvelles formes d'action collective, notamment dans l'optique de relier transitions digitales et écologiques.

Structure of the document

The present PhD research work has been structured around three academic publications. The document is divided in two main parts. **Part A**, coined the “kappa”, develops the defended thesis. It especially aims at building up the consistency and connection between the three papers. Its structure follows the expected components of a thesis: framing of the research problem (Chapter 1), literature review (Chapter 2), methodology (Chapter 3), main results of papers (Chapter 4), discussion (Chapter 5), and outline of main contributions and perspectives (Chapter 6). **Part B** is a compilation of the three academic papers. They are all already published or submitted to different journals, as synthesised in the following table.

Paper 1 – <i>‘Resilient-fit’ co-design methods: designing the integration of Earth observation data into ecosystems facing grand challenges</i> Authors: Raphaëlle Barbier, Skander Ben Yahia, Pascal Le Masson, Benoit Weil	Submitted to <i>Creativity and Innovation Management</i>
Paper 2 - <i>Data-push innovation beyond serendipity: the case of a digital platform strategically building up the genericity of Earth observation data</i> Authors: Raphaëlle Barbier, Skander Ben Yahia, Sylvain Lenfle, Benoit Weil	Submitted to <i>Technovation</i>
Paper 3 - <i>Co-design for novelty anchoring into multiple socio-technical systems in transitions: The case of Earth Observation data.</i> Authors: Raphaëlle Barbier, Skander Ben Yahia, Pascal Le Masson, Benoit Weil (accessible here: https://doi.org/10.1109/TEM.2022.3184248)	Published in IEEE <i>Transactions on Engineering Management</i>

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PART A – ‘KAPPA’
*BUILDING UP THE CORE
ARGUMENT OF THE THESIS*

CHAPTER 1: A question of grand distance

Summary of Chapter 1

This chapter elucidates the enigma that has driven the present PhD research work. It especially elaborates on the notion of “grand distance”, which is grounded into practical considerations in the field of Earth Observation (EO), and also points to a core theoretical issue for management research. This issue of grand distance can be well illustrated by the case of The Finnish Meteorological Institute (FMI), currently exploring the following question: what could be the value of EO data (especially meteorological and climate data) for tyre companies? This question cannot be simply answered by FMI or tyre companies taken separately. Indeed, on the one hand, EO experts from FMI are interested in designing new instruments or models but are not well aware of the business of tyres. On the other hand, tyre companies are interested in managing tyre logistics as efficiently as possible when winter is coming each year, but can hardly make the connection with EO data. The notion of “grand distance” is introduced to precisely designate this kind of situations, where the actors (here EO data providers and tyre companies) belong to completely separate worlds, with hardly anything in common: these actors don’t have the same expertise, they don’t share the same interests, they might even completely ignore the existence of each other. Yet, to answer the question of the value of data, these actors need to come together and explore it jointly. This example might seem anecdotal, but it actually raises a core question for management research: how to create collective action in “grand-distance” situations, i.e. when collective action seems highly unlikely, if not impossible? This issue especially prevails in the EO field, but also in all sectors involved in contemporary digital and sustainability transitions. More specifically, both EO practitioners and previous literature suggest that “co-design” could be a possible way to create collective action in grand-distance situations. Based on these considerations, the chapter exposes the research purpose addressed by the thesis: *how to unveil and characterise the models of co-design fostering collective action in grand-distance situations?*

Résumé du Chapitre 1

Ce chapitre explicite l’énigme qui a été à l’origine de ce travail de recherche. Le chapitre introduit notamment la notion de « grande distance », qui apparaît notamment de façon empirique dans le milieu de l’observation de la Terre, mais qui pose également un problème théorique majeur pour les sciences de gestion. Le cas de l’institut météo finlandais (FMI) donne une bonne illustration de cette notion de grande distance. Le FMI se pose notamment la question suivante : quelle pourrait être la valeur des données d’observation de la Terre (notamment données météorologiques et climatiques) pour des entreprises de pneus ? Cette question n’a *a priori* pas de réponse évidente, ni pour le FMI ni pour les entreprises de pneus. En effet, d’un côté, les experts en observation de la Terre se préoccupent essentiellement de la conception de nouveaux instruments ou de modèles,

mais ne connaissent pas bien – voire pas du tout - le secteur du pneu. Inversement, les entreprises de pneus sont surtout intéressées par l'optimisation de la logistique de pneus chaque année, mais ne sont pas capables de faire un lien direct avec les données d'observation de la Terre. La notion de « grande distance » désigne précisément ce genre de situations où les acteurs (ici le FMI et les entreprises de pneus) appartiennent à des mondes complètement séparés qui n'ont quasiment rien en commun : ces acteurs n'ont pas la même expertise, ni les mêmes intérêts, et peuvent même totalement ignorer leurs existences respectives. Pourtant, pour répondre à la question de la valeur de la donnée, ces acteurs doivent pouvoir interagir et explorer cette valeur potentielle de façon conjointe. Cet exemple pourrait paraître anecdotique, mais il soulève en fait une question critique pour les sciences de gestion : comment créer de l'action collective dans des situations de grande distance, où l'action collective paraît justement hautement improbable voire impossible ? Cette question se pose dans le secteur de l'observation de la Terre, mais également dans d'autres contextes confrontés aux transitions numériques et écologiques. En particulier, les travaux de recherche existants ainsi que les praticiens suggèrent que le "co-design" (ou co-conception) pourrait être un moyen de créer de l'action collective dans de telles situations. Ceci nous amène à formuler l'objectif de recherche de la thèse de la façon suivante : « *comment mettre au jour et caractériser les modèles de co-design permettant d'encourager l'action collective dans des situations de grande distance ?* »

The research conducted in this thesis was triggered by an enigma coming from the field of Earth observation. This introduction aims at showing that not only is this enigma a burning issue for practice, but that it also raises intriguing and stimulating questions for management research. A first part exposes how this enigma initially unfolded at the starting point of the research, as rooted in the field of Earth observation and resonating with current academic debates on digital innovation (1.1.). A second part further elaborates on this enigma, especially showing how it relates to a core theoretical issue, called "grand distance", offering larger implications for management research (1.2.). Subsequent parts further explain our research purpose derived from this core theoretical issue (1.3.), and our research strategy to address this purpose (1.4.).

1.1. Starting point: fostering the use of data beyond open data policies

Earth observation (EO) basically consists in analysing, monitoring and predicting evolutions of the Earth's physical, chemical, biological, and man-made systems, based on data coming from a wide range of sources. These sources especially include in-situ sensors (e.g. floating buoys to monitor ocean currents, temperature and salinity, or land stations recording

air quality and rainwater trends), airborne and spaceborne sensors (e.g. embedded on drones or satellites), and data computed from large models such as the ones used in meteorology. EO data were initially produced and used mainly for scientific purposes, e.g. for weather forecasting and climatology (Edwards, 2010; Lenfle, 2018; Lenfle and Söderlund, 2022). However, beyond the scientific community, these data also have the potential to provide significant benefits to a large variety of socio-economic stakeholders such as public authorities, private companies, academia, citizens.

In particular, EO data provide promising ways of helping these different actors better face the social and environmental “grand challenges” currently affecting society, such as climate change, access to water, food and energy, health, biodiversity preservation (e.g. George et al., 2016; Eisenhardt et al., 2016; Ferraro et al., 2015). Although, EO data alone will certainly not be sufficient, they can provide means of monitoring a number of phenomena related to these grand challenges, possibly opening up new ways of taking them into account and acting. For example, EO data can be useful to better prepare for natural disasters (e.g. fires and floods) by building early warning systems or mapping the most vulnerable areas. In a different topic, EO data can also contribute to supporting the development of renewable energy industries by providing means of assessing the available resources of solar or wind energy in given areas. As another example, EO data can also prove helpful to support the mitigation of pollution-related health risks by providing means of assessing air quality.

Public bodies have largely invested to make these scientific data freely accessible to all potential users, through so-called “open data” policies. These policies have been fostered and implemented through different forms of instruments and organisations since the years 2000s (Harris and Baumann, 2015). For example, in the USA, since 2008, all data from “Landsat” satellites have been made available and free of charge over the internet by the US Geological Survey. In a similar perspective, the European Union has significantly invested in the Copernicus programme, created in 2014 following the antecedent programme GMES (Global Monitoring for Environment and Security). Copernicus provides open and free access to data coming from a family of “Sentinel” satellites observing a rich set of land, atmospheric and oceanographic parameters (Harris and Baumann, 2015; Borzacchiello and Craglia, 2012).

Such efforts have also been encouraged globally through dedicated intergovernmental bodies, such as the Group on Earth Observations (GEO), launched in response to calls for

action by the 2002 World Summit on Sustainable Development and by the Group of Eight leading industrialised countries. In this respect, GEO aims “to unlock the power of Earth observations by facilitating their accessibility and application to global decision-making within and across many different domains” (GEO, 2016). In the first few years of its creation, GEO has especially highly contributed to the development and implementation of standards related to the production and use of data, with the objective of facilitating the circulation of data across organisations and sectors.

In this respect, EO data can be considered as an exemplary case of a more general trend that is currently debated by management researchers especially in the field of digital innovation. Indeed, the question of fostering the use of data (beyond EO data) by a wide range of actors is prevailing, especially in the perspective of better tackling grand challenges (Chandy et al., 2017; George et al., 2020). In this regard, data appear as a promising way of driving dramatic transformative effects on existing organisational models, as underlined by innovation management researchers (e.g. Appio et al., 2021; Del Vecchio et al., 2018; George et al., 2014; Yoo et al., 2012) and information systems (IS) researchers (e.g. Günther et al., 2017; Agarwal and Dhar, 2014; Yoo et al., 2010). Data are indeed characterised by a certain pervasiveness and “liquidity” as they have the potential of circulating across organisational and sectorial boundaries (e.g. Günther et al., 2017; Lycett, 2013a). In this respect, data are produced for a given purpose, but might be later re-used for other purposes that were initially unexpected (e.g. Aaltonen et al., 2021; Chandy et al., 2017). To unlock this potential, open data policies have been widely encouraged beyond the EO field, especially urging public actors to open up their data to stimulate innovation by third-party actors (e.g. Jetzek et al., 2019; Charalabidis et al., 2018; Zuiderwijk and Janssen, 2014; Janssen, 2011).

However, scholars underline the limits of such open data policies, hindered by a number of technical and social barriers (e.g. Zuiderwijk and Reuver, 2021; Charalabidis et al., 2018; Berrone et al., 2016; Zuiderwijk et al., 2016; Janssen et al., 2012; Goeta, 2016). In particular, it appears that potential users might be unaware or highly unfamiliar with these data, thus dismissing the actual use of data despite their openness (e.g. Janssen et al., 2012).

Moreover, other scholars warn us about the risk of data “solutionism” (Green, 2019; Morozov, 2013), where data providers would value data for their own sake or as a panacea to tackle all sorts of grand challenges. Such a perspective holds the risk of making false

assumptions on the potential benefits of data, by neglecting deeper investigations on critical questions, such as: *for whom and for which purposes might these data be really useful? If usefulness is acknowledged by some actors, how to make data fit into their practices?* However, in the context of grand challenges, actors might need to deeply transform their existing practices and design new ones. In this regard, scholars have underlined the risk of path dependences eventually leading to “lock-in” situations where the possibilities of transforming the practices of actors become extremely limited (Sydow et al., 2020, 2009). The integration of data into actors’ practices also holds this risk. Indeed, data might encourage actors to stick to their existing practices by making them more efficient although they inadequately address grand challenges. As an example, data could offer new monitoring means for crop harvesting without questioning the underlying agriculture model, thus possibly reinforcing intensive agriculture without exploring alternative paths. Therefore, *how to ensure that the use of data does not lead actors to such lock-ins? Beyond improving existing practices, could data stimulate the exploration and design of new paths of actions towards grand challenges?*

These difficulties are also widely recognised in the EO community, highlighting a tension between the transformative promise of data and practice (Findlater et al., 2021; Lemos et al., 2012), depicted by some as “a large gap between scientific products and the type of condensed information needed by authorities and organisations” (Buontempo et al., 2022), as for example illustrated in Figure 1.

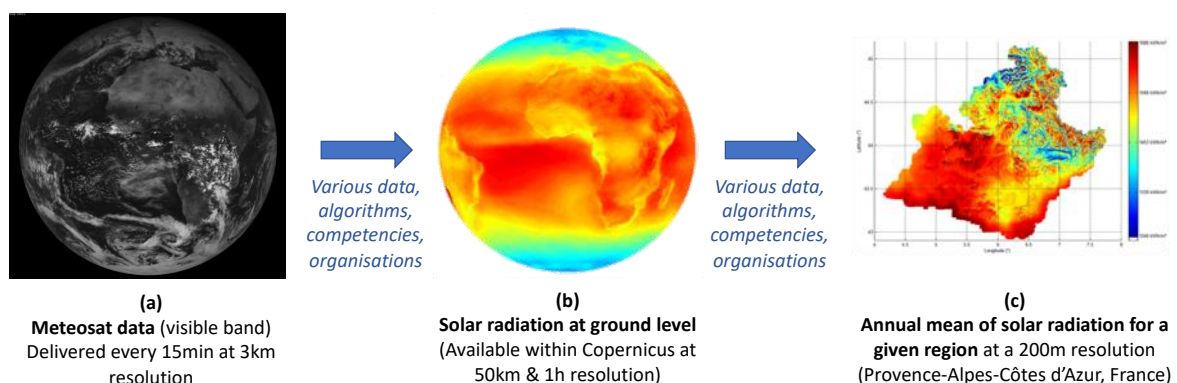


Figure 1: Example of the gap between data as produced by satellites (a), data as typically made available under the Copernicus programme - here under the Copernicus Atmosphere Monitoring Service – CAMS (b), and the types of “condensed information” that might be needed for data to be used in practice, here by local authorities of a French region interested in assessing the solar energy potential for their region (c). Source of the latter image: <http://www.webservice-energy.org/atlas-solaire>

To address these limits, the EO community has called for undertaking significant efforts to make data more easily integrated into users' practices (Buontempo et al., 2022; Goor et al., 2021), especially by fostering effective and long-lasting relationships between data providers and users (Hewitt et al., 2017). Such calls directly resonate with recent studies showing the need for creating dedicated interactions between data providers, users and other relevant actors to stimulate the growth of a vibrant open data ecosystem (e.g. Bonina and Eaton, 2020; Gupta et al., 2020; Ruijter et al., 2017).

In particular, the EO community shows a growing interest in so-called "co-design" approaches (also referred as "co-production" or "co-development"), that mainly seek to involve data users in the design process in order to adjust user demands and the supply of useful information (McNie, 2012). More generally, based on the term itself, "co-design" basically refers to the organisation of a collective design process, including both a *design* aspect, entailing the exploration of innovative objects (e.g. socio-economic applications of EO data), and a *collective* ('co') aspect, entailing the involvement of heterogeneous actors in the design process (e.g. data providers, data users, other relevant actors). Such approaches have also been recognised by researchers in design and innovation management as an interesting way of creating relations between heterogeneous actors (e.g. Dubois, 2015), especially in the perspective of fostering specific forms of collective action to tackle grand challenges (Abrassart et al., 2017; Hyysalo et al., 2019b, 2019c; Lavoie et al., 2021).

However, although co-design tends to be increasingly used, the EO community also underlines that it would deserve further formalisation beyond the buzzword (Goodess et al., 2019). Chris Rapley, professor of climate science at University College London (UCL), interviewed in the TerraWatch Space Podcast produced by Aravind Ravichandran ¹, gives an interesting view on the status of the field. Since the 1970s, Chris Rapley has had a long career as a scientist working on the design of new instruments for space and EO missions, and has also been particularly involved in further bridging EO science and society, especially within the so-called "Climate Action Unit" at UCL. Acknowledging the difficulties of the EO community in doing so, he depicts the future efforts to be made as follows:

¹ <https://podcast.terrawatchspace.com/episodes/42-communicating-earth-observation-and-climate-with-prof-chris-rapley-university-college-london>

*“You need to sit down and have an intelligent and educated conversation with an institution, a community of practice, a community of place to [...] understand what is important to them and see where EO data may be able to help them in the task. And you have to help them **get inside each other’s heads and form a collaboration, a co-production**. At that point, as often as not, you find that what has been provided by the satellite system [...] is not actually quite or even at all what that group or individual really needs, but it could be. [And] it’s not at all obvious that it’s just going to be a one-way thing like “here this is what we offer, and this is how you use it”. **It’s a collaborative process and it takes a lot more efforts and a different set of skills from the ones that the most of us have been trained in and used to.**”*

My PhD research work was precisely triggered by this need of further formalising and developing such co-design approaches, as explicitly stated in the “e-shape” project (Thierry Ranchin et al., 2021) funded by the European Commission under the H2020 programme for 4 years (2019-2023). Within this project, researchers from the Center for Management Science (CGS) of Mines Paris, PSL University - my PhD supervisors, a research engineer and I - have been specifically in charge of leading a work package dedicated to the design and implementation of a co-design approach adapted to the issues faced by the EO community.

Triggering enigma at the starting point of the research

To what extent can *co-design* contribute to overcoming the *limits of open data policies* and further *stimulating the use of data*, especially in the perspective of *better tackling grand challenges*?

Appearing as a critical issue in the EO field, this enigma also resonates with current academic debates in management research, especially related to digital innovation, grand challenges, and co-design. The next section aims at taking a closer look at this enigma. Indeed, it is worth noting that this enigma more broadly relates to a core underlying issue for management research.

1.2. Core issue for management research: creating collective action despite “grand distance”

The core issue underlying the enigma exposed above refers to a so-called issue of “grand distance”, that is hereafter depicted in the EO context (1.2.1.) and grounded

theoretically based on existing research (1.2.2.). These considerations lead us to consider the EO context as an extreme case of grand distance (1.2.3.).

1.2.1. Grand distance seen from the EO context

As underlined above, EO data have the potential to provide significant benefits to society. However, despite strong efforts in making these data open and free for all, EO data still appear largely underutilised beyond the historical EO community. As a matter of fact, there is thus a remaining gap between EO data and society. Society is here taken in a large sense, embracing all kinds of socio-economic actors that could benefit from these data - research communities, but also public authorities, private companies, academia, citizens.

As such, EO experts – also referred as EO data providers - and these various potential users will be hereafter characterised as separated by a “grand distance”, where “distance” is here understood in a metaphoric way beyond physical or geographical distance. It basically aims to designate the fact that EO experts and potential users evolve in separated spheres that have very little in common and might even not be aware of the existence of one another, making them appear as largely unknown to each other. This “grand distance” issue can be perceived in the discourse of EO practitioners, e.g. appearing particularly vividly in the analysis given by Chris Rapley (UCL) in his interview by Aravind Ravichandran previously mentioned. He depicts the difficulties faced by the EO community as follows:

*“There is a tendency [in the EO community] both in academia and in the world of satellite engineering to think rather linearly. So, **[as an EO expert], you come up with an objective, for example we want to measure sea level rise because we know that this is an important issue globally:** a large percentage of populations is living on coastal regions, there are lots of infrastructures there that are hugely important, we know that sea level is rising increasingly rapidly, and that’s having an impact. So you go through the engineering, technology and science process of designing an instrument (be it laser, radar or other) to do that for you. **And there is a kind of assumption that you know what the user community will need.** You certainly know what you as a scientist will need in order to give the best possible estimates of what is happening now and projecting that on into the future. So [...] there is a tendency to get to the point where you’ve done all the work - you’ve designed the mission, you’ve found money for the mission, you’ve contracted the mission out, you’ve built it, tested it, launched it, you are operating it, you’ve built the ground system, you’re pumping out data, you’ve made the user interface which allows people to connect on their computer and have data available to them. But **it’s a bit like tossing the information over the wall and assuming that users will figure out how to deal with it.** And of course **there are many***

sophisticated users out there, particularly in the science community and also in various parts of the industry, who are capable of doing that, because they have been trained and understand what's going on. But then you come against a bit of a limit. If you go to the average fishermen or somebody who is designing the coastal fences for a major port or something like that, they probably don't know anything about satellites or these instruments. They may not even be completely sure what the question is that they are trying to answer in the long-term. How is the sea level rise really going to affect us? What will be the consequences of it? Or indeed any of the other products from EO. At that point, you need to sit down and have an intelligent and educated conversation with an institution, a community of practice, a community of place to [...] understand what is important to them and see where EO data may be able to help them in the task. And that requires [...] bringing together experts who will almost certainly speak quite different arcane languages, who will actually genuinely think differently."

Chris Rapley here highlights several critical elements that underpin this grand distance and make potential users appear as largely unknown to EO experts. Taking the example given by Chris Rapley where EO experts consider the potential of EO data for better managing sea level rise, EO experts might not know which actors could be potential users (would it be fishermen, designers of coastal fences, port managers?). But even in cases where some potential users could have been identified, these users are bound to be known only from a limited perspective, thus remaining largely unknown to the EO experts. It basically stems from the lack of common language but also from the fact that potential users might not very well know themselves what kinds of data uses they could imagine in the future.

To further depict this grand distance, let us elaborate on an example taken from the e-shape project we have been working on. Further details will be given on e-shape in Chapter 3. For now, let us simply indicate that the project involves 37 pilot applications aimed at developing a range of EO-based products or services for a wide range of potential users, in seven thematic areas (agriculture, health, energy, biodiversity, water, natural disasters and climate).

One of these pilots led by the Finnish Meteorological Institute (FMI) has been exploring the development of EO-based products or services for tyre companies. Tyre companies are especially in charge of changing tyres of citizens' cars when the winter season is coming. In this context, FMI has been exploring the development of sub-seasonal and seasonal predictions related to winter tyre season (respectively 3 months and 6 weeks ahead), e.g. the probability of onset and offset of winter tyre season, freezing temperature and snow

conditions. FMI indeed assumes that knowing the weather and driving conditions in advance could help tyre companies prepare operations better for the high season (e.g. by better planning the distribution logistics of tyres and the recruiting of seasonal workers, or enhancing companies' communication with their customers by providing them with indications about the adequate time of changing their tyres).

In this example, it appears clearly that the day-to-day operations of tyre companies are very far from the world of EO. Tyre companies are experts in logistics of tyre changes but are definitely not bound to be experts in weather and climate phenomena. As already underlined by Chris Rapley, they might be even not able to tell directly whether and how EO data might be helpful. Beyond the heterogeneity of their respective expertise, FMI and tyre companies are likely not to share the same performance logics and time horizons. Indeed, the performance logics of tyre companies relies on relatively short timelines, basically driven by their ability to manage each year the high winter season as efficiently as possible with a good satisfaction rate of their clients. Whereas, in order to develop accurate EO-based products or services, FMI might be involved in fairly long cycles of development, e.g. for setting up the instruments that would produce new data or designing new computing models to make best use of available data. This latter point is particularly well highlighted in the history of meteorology (Lenfle, 2018; Lenfle and Söderlund, 2022): in the 1980s-90s, ten years were needed for the meteorological community to devise new data assimilation methods that would be able to make a better use of satellite data and increase the accuracy of weather forecasts.

The example of FMI and tyre companies is nowhere near an isolated case. Indeed, the issue of grand distance appears in a large variety of situations. Box 1 gives a few other examples derived from e-shape pilots in the seven thematic areas mentioned above. It thus depicts how grand distance can unfold in a large variety of sectors, and that it also concerns various profiles of actors from the EO community – be they public or private organisations – undertaking the development of socio-economic applications of EO data.



Thematic area: Agriculture

Profiles of EO experts: research and technology organisation in Belgium (VITO) in the areas of cleantech and sustainable development

Profile of potential users: agricultural cooperatives, agro-consultants, seed multipliers (making accessible different types of seeds to farmers, involving a technical staff to manage intricate logistics for field inspection, testing and harvesting).

Expected socio-economic application of EO data:

Agriculture activities increasingly need to resist and adapt to climate change and at the same time ensure the increase of productivity in a sustainable manner. The application consists in building improved indicators for agriculture monitoring (e.g. ripeness stage of crops and prediction of harvest dates).

Thematic area: Health

Profiles of EO experts: public research institutions (e.g. National Observatory of Athens - the oldest Greek public research institution)

Profiles of potential users: ministry of environment, local authorities (regional and municipal levels), national health authority

Expected socio-economic application of EO data:

The application consists in creating a modular platform for surveillance of air quality and related health issues both globally and in certain urban areas, e.g. in Athens through the combination of several data layers (city-scale air quality modelling data, along with local health, land use and socioeconomic data layers).



Thematic area: Energy

Profiles of EO experts: Public research institute in Denmark

Profiles of potential users: offshore wind farm developers or operators, consultants for offshore wind farm siting and resource assessment, researchers, educators

Expected socio-economic application of EO data:

It consists in providing actors from the offshore wind energy sector with new means of assessing wind resource conditions. Indeed, such assessment is crucial for planning new wind farm projects, but the amount of wind measurements at sea is still very limited. The pilot thus proposes to combine EO data from different types of sensors to overcome the limitations of existing assessment means.

Thematic area: Biodiversity

Profiles of EO experts: public research institutes

Profiles of users: technical staff and managers of European Protected Areas (e.g. Kerkini lake in Greece, Grand Paradiso National Park in Italy)

Expected socio-economic application of EO data:

It consists in building products and services to help managers and staff of Protected Areas in their actions for biodiversity monitoring and conversation (e.g. animal population dynamics, status of vegetation, water extent and in wetland areas).





Thematic area: Water

Profiles of EO experts: well-established private company, subsidiary of the French Space Agency, provider of space-based monitoring and surveillance solutions for Earth since 1986

Profiles of potential users: local actors (public authorities, tourism actors) and emergent entrepreneurs (e.g. involved in algae collection and/or valorisation)

Expected socio-economic application of EO data: Unprecedented massive landings of Sargassum seaweed have been observed since 2011 along the shorelines of a huge area encompassing the Gulf of Mexico and the Caribbean Sea. This issue has tremendous negative impacts, especially for the local population and the tourism and fishing sectors. The application consists in building tools to monitor and predict Sargassum trajectory, allowing concerned actors to anticipate the Sargassum season several weeks/months in advance.

Thematic area: Natural disasters

Profiles of EO experts: private company (start-up) partnering with other partners for engineering and commercialisation

Profiles of users: mountain enthusiasts and groups (e.g. Alpine Clubs), environmental institutions (e.g. safety/accident prevention institutions), tourism industry (e.g. sport equipment retailers, tourism offices)

Expected socio-economic application of EO data:

It consists in building up an advanced live-map of mountain hazards for Europe and the world, to improve mountain safety and better adapt to climate change. It is expected to combine complementary EO data sources, especially satellites and in-situ crowdsourcing allowing people to share mountain observations in real-time (e.g. rock falls, snow/ice avalanches, high river discharge).



Thematic area: Climate

Profiles of EO experts: meteorological offices (Germany, Austria, Finland)

Profiles of users: cities and municipalities

Expected socio-economic application of EO data:

It consists in developing sub-seasonal and seasonal forecast products to help cities and municipalities improve their preparedness and response to hazardous weather conditions (e.g. snow accumulation, heavy precipitation, heat waves and dry spells).

1.2.2. Grand distance seen from academia

Beyond the EO field, the issue of grand distance can also be grounded in management research. Indeed, literature has already shown that the ability of actors to build relationships and undertake innovation processes is impacted by different forms of distance (or its counterpart “proximity”). The following paragraphs aim to review the main prevailing aspects of distance as already described in literature, and derive a definition of “grand distance” that is consistent with these works.

Firstly, considerations on distance can be traced back to seminal works in strategic management, that especially studied knowledge exchange and joint knowledge production between firms. In this perspective, (Grant, 1996) proposed a “knowledge-based view” of the firm, where the firm is conceptualised as an institution for knowledge integration. In this view, distance can be interpreted as the heterogeneity between specialised knowledge bases coming from a number of individuals, that can belong to different firms aiming to build strategic alliances (Grant and Baden-Fuller, 2004).

Still in strategic management, another stream has specifically elaborated on the concept of “cognitive distance” to account for the heterogeneity of resources hold by different actors partnering in strategic alliances (Grabher, 2004; Nootboom, 2000; Nootboom et al., 2007). Therefore, distance here refers to the heterogeneity between partners in terms of cognition, denoting *“a broad range of mental activity, including proprioception, perception, sense making, categorization, inference, value judgments, emotions, and feelings, which all build on each other”* (Nootboom et al., 2007, p. 1017). The authors show that this cognitive distance can especially impact the ability of partners to identify, exchange, integrate or create relevant knowledge (Nootboom, 2000; Nootboom et al., 2007). Drawing on their respective definition of distance, both streams argue that creating sound inter-firm relations is favoured by a balanced degree of distance. Indeed, on the one hand, no distance can be detrimental for collaborations driven by innovative purposes (Nootboom et al., 2007), as novelty creation is supported by the integration of heterogeneous knowledge bases (Grant, 1996). But on the one hand, excessive distance leads to a risk of misunderstanding and would thus prevent partners from effectively interacting. Consequently, scholars especially underline the need for a certain overlap between the separate knowledge bases of respective partners (Brusoni et

al., 2001; Brusoni and Prencipe, 2001; Grant and Baden-Fuller, 2004), or at least *“certain basic perceptions and values to sufficiently align their competencies and motives”* (Nooteboom et al., 2007, p. 1017). This point is summarised by Nooteboom (2000, p.72) as follows: *“A trade-off needs to be made between cognitive distance, for the sake of novelty, and cognitive proximity, for the sake of efficient absorption. Information is useless if it is not new, but it is also useless if it is so new that it cannot be understood.”*

Cognitive distance is here explicitly associated with another widely-developed notion in innovation management: the one of *“absorptive capacity”*, defined by (Cohen and Levinthal, 1990) as *“the ability of a firm to recognise the value of new, external information, assimilate it, and apply it”*. These considerations still remain at stake in more recent innovation management research. For example, in the context of radical innovation, (Le Masson et al., 2012) have shed light on a specific form of absorptive capacity developed by some highly-innovative organisations to make use of distant external knowledge via the well-thought elaboration of creative concepts.

Cognitive distance also appears critical in the so-called *“open innovation”* field, investigating *“distributed innovation [processes] based on purposively managed knowledge flows across organisational boundaries”* (Chesbrough and Bogers, 2014). In this regard, (Bogers et al., 2017) highlight that *“[an] important aspect that is in need of future research is how heterogeneity and cognitive distance between internal and external contributors influence the knowledge creation dynamics as well as innovation output.”* (p. 18). In this vein, scholars have shown that these dynamics might require specific forms of knowledge governance procedures (Lakemond et al., 2016), as well as original organisational forms, e.g. organisations that specialise in helping actors with insufficient absorptive capacities to leverage distant knowledge (Kokshagina et al., 2017).

Similar distance-related considerations can also be traced back to another stream of research that has specifically investigated the *“boundary spanning”* mechanisms involved in fostering collective action across multiple disciplines, e.g. in interdisciplinary projects within or across organisations (e.g. Lenfle and Söderlund, 2019; Kaplan et al., 2017; Kellogg et al., 2006). Scholars in science and technology studies have also shed light on such mechanisms in various historical cases, e.g. within the development of atomic physics requiring to build *“trading zones”* between theorists, experimenters and instrument builders (Galison, 1997), or

the development of specific kinds of instrumentation in “interstitial worlds” between science, state and industry (Joerges and Shinn, 2001).

Beyond these occurrences of distance spanning various research streams, distance has also been further characterised as a **multi-faceted notion entailing multiple dimensions**. In economic geography – in particular within the so-called “school of proximity” - (Bathelt and Cohendet, 2014; Boschma, 2005; Broekel and Boschma, 2012; Torre and Gilly, 2000; Torre and Rallet, 2005), scholars show that several dimensions of distance beyond geography can affect innovation processes between heterogeneous partners. This multi-dimension description of distance has also proved relevant for management research investigating inter-organisational collaborations (Knoben and Oerlemans, 2006), networks (Ibert and Müller, 2015) or industrial fields (Nicklich et al., 2022). As highlighted by (Knoben and Oerlemans, 2006), scholars have developed several typologies of distance, that do not completely coincide.

As our aim primarily lies in unravelling the grand-distance phenomenon without necessarily seeking for exhaustivity, the following paragraphs will focus on the most commonly used dimensions beyond geographical distance: cognitive, institutional, organisational, and social² (Boschma, 2005; Knoben and Oerlemans, 2006; Mattes, 2012). Based on an extensive review of these works, (Ibert and Müller, 2015) summarise them as follows. **Cognitive distance** occurs when actors have *“different disciplinary enculturation and/or use cognitive patterns that are dissimilar with respect to content and structure”* (p. 184).³ **Organisational distance** occurs when actors do not belong to the same organisations or sub-organisational units and thus *“have to interact across organisational boundaries”* (p. 184). **Social distance** occurs when actors *“know each other only ephemerally and do only share few commonalities beyond the professional sphere”* (p. 184). **Institutional distance** occurs when actors adhere to *“dissimilar or different regimes of rules, norms and/or conventions”* (p. 184).

² (Ibert and Müller, 2015) propose three additional dimensions (functional, interest and hierarchical), that will not be used here for a matter of clarity. Indeed, the four most common dimensions (cognitive, institutional, organisational and social) are already sufficient to unravel the grand distance occurring in certain situations.

³ To be noted here that the definition of cognitive distance is not strictly equivalent to the concept developed in (Nooteboom, 2000; Nooteboom et al., 2007). Indeed, the concept proposed by the latter authors would also include other dimensions, as defined by the “school of proximity” authors, especially institutional distance.

Despite some ambiguities in the terms used in the different typologies of distance (Knoben and Oerlemans, 2006), two important conclusions can be drawn from existing literature: the multi-faceted character of distance and the acknowledged effect of excessive distance as hindering the possibility of establishing relations between heterogeneous actors. In this view, (Ibert, 2010) especially suggests that the difficulties in managing distance do not only stem from *“the intensity of tension that seems to be important, but also the multidimensional situation within which [...] distance becomes effective”*.

Following these considerations, **a situation of “grand distance” can be defined as a situation that combines a large degree of distance on a large number of dimensions**. As such, a grand-distance situation significantly impedes collective action by undermining the conditions that are needed to create and sustain relationships between actors. As the core of management precisely lies in organising collective action, grand distance appears as a critical issue for management research.

Grand distance seems all the more critical as **a tendency towards situations of increasing distance is especially noticeable in recent literature**. Organisations are indeed increasingly facing challenges that do not only involve uncertainty but rather high levels of the unknown (Elmquist et al., 2019). According to the latter authors, *“while uncertainty refers to events that are known, and whose probability of occurrence can be estimated (as inherited from statistical decision theory), the unknown denotes events that can be expressed conceptually, but can hardly be imagined, and therefore cannot be described.”* (p. 379). Such situations thus require the creation of new knowledge spanning existing expertise domains, new forms of collective action, and underlying values and rules.

Some vivid examples can be traced back to historical cases of large exploratory and industrial projects such as military projects undertaken during World War II (Gillier and Lenfle, 2019; Lenfle and Söderlund, 2019). The current trends towards digital innovation also lead to situations of increased distance. It indeed dramatically impacts the way organisations and industrial sectors are organised (e.g. Appio et al., 2021; Del Vecchio et al., 2018; George et al., 2014; Yoo et al., 2012; Lakemond et al., 2022; Schymanietz et al., 2022), all the more as data have the potential of circulating across organisational and sectorial boundaries (e.g. Günther et al., 2017; Lycett, 2013a).

In particular, grand distance situations also seem to prevail in the **context of contemporary grand challenges**, described as “*complex problems with significant implications, unknown solutions, and intertwined and evolving technical and social interactions*” (Eisenhardt et al., 2016, p. 1115). A number of recent studies particularly underline that addressing such challenges requires deep transformations of organisations towards new forms of collective action (Doh et al., 2018; Mair et al., 2016; Olsen et al., 2016; Williams and Shepherd, 2016). Collective action can take many different forms and is often acknowledged as a particularly thorny endeavour.

To take only a few examples, scholars report on new forms of relations - associated with “*trials and tribulations*” - between the actors of the energy industry involved in the Australian transition from coal to renewable energy (Dodd and Nelson, 2019); or collective action between actors involved in the development of wind power that appears to be more or less successful depending on the paths followed by the different countries (e.g. Nicklich et al., 2022; Etzion et al., 2017); but also digital collective creativity platforms aimed at harnessing the collective intelligence of thousands of people to define potential solutions to climate change, which raises a few governance issues with regard to regulating the affiliation, participation, and interaction of very diverse people within the platform (Elia et al., 2020).

These studies suggest a significant degree of distance on several dimensions. On the *organisational* dimension, as tackling grand challenges will require an unprecedented “*coordinated and sustained effort from multiple and diverse stakeholders*” (George et al., 2016), thus crossing usual organisational boundaries. On a *cognitive* dimension, scholars underline the heterogeneity of actors’ perceptions with regard to problem framing and exploration of solutions (Pluchinotta et al., 2022; Etzion et al., 2017; Ferraro et al., 2015). As especially underlined by Kuhlmann and Rip (2018), “*the perspectives on what is the problem and what constitutes its resolution differ across various societal groups*” (p. 450). Belonging to different societal groups, actors are unlikely to have already established strong interactions and are thus bound to face a form of *social* distance. In the same vein, actors are also likely to face *institutional* distance as belonging to different societal groups or industrial sectors also implies complying with different forms of rules, norms and regulations.

1.2.3. The EO context as an extreme case of grand distance

In this perspective, compared to these occurrences of grand distance in management research, **the EO context can be considered as an extreme case of grand distance**. Indeed, compared to the grand-distance situations described above, the EO context entails a combination of particularly large degrees of distance on several dimensions.

Considering the *cognitive* dimension, in the cases of grand distance described above, despite divergent perspectives on the formulation of the problem and the identification of solutions, actors at least share a common acknowledgement of a certain issue concerning the different actors. In this respect, the efforts required to address grand challenges can be triggered and directed towards “a clearly articulated problem or goal” (George et al., 2016, p. 1881), thus offering a certain horizon for collective action. By contrast, in the EO context, the nature of the challenge to be addressed is not even shared by the actors. Indeed, the EO scientific community is not directly concerned by the issues faced by the potential data users (e.g. development of new agricultural practices, efficient installation and operation of photovoltaics systems), nor are the potential users directly concerned by the evolutions of the EO field. Moreover, the EO scientific community and the potential users of EO data hardly share any common ground knowledge - even language (technical language related to data vs. language related to the users’ domains of expertise).

Considering the *social and organisational* dimensions, an additional issue arises in the EO context, as the absence of a shared challenge to be addressed also results in a decreased clarity regarding the actors to be involved in collective action. Whereas when based on a given challenge, the identification of the actors to be involved can at least start with the ones that are directly concerned by this challenge, such as local communities addressing suffering of victims following an aftermath (Williams and Shepherd, 2016), or representatives of concerned stakeholders gathered in “advocacy groups” taking part in consortia directed towards the search for solutions to a given challenge (Olsen et al., 2016).

Regarding the *institutional* dimension, the EO scientific community and the potential users fall under different regimes of rules and norms. Indeed, these rules appear as divergent, considering both informal rules (different forms of practices and routines) and formal rules (e.g. regulations related to satellite developments, processing and sharing of data, differing

from other regulations related to the potential user communities such as the Common Agriculture Policy in agriculture).

To conclude, from the enigma that initially triggered our research work, this section has unveiled an underlying core issue, coined “**grand distance**”, that significantly impedes collective action. As such, grand distance appears as a **critical theoretical issue for management research**, that unfolds in a particularly vivid way in the EO context. In this perspective, **the EO context can be considered as an extreme case** of a broader class of grand-distance situations that have already caught the attention of management researchers and deserve further investigations.

1.2.4. Co-design as a legitimate candidate for managing grand distance

Having unveiled this issue of grand distance, it is now important to reconsider the aspects of our initial enigma related to co-design. Indeed, it is highly likely that grand distance could be tackled through a number of different means beyond co-design, e.g. through specific forms of innovation policies (Kuhlmann and Rip, 2018; Robinson and Mazzucato, 2019). Our research does not claim for exhaustively covering all means of managing grand distance, but will focus on co-design as one of these possible means. The question remains as to justify why co-design appears as a legitimate candidate for such purposes and thus as a relevant research focus.

Beyond the empirical growing interest for such approaches in the EO context, several aspects noticeably legitimate co-design as a serious candidate for managing grand distance.

First, co-design has already been acknowledged as promising in certain situations of grand distance (although not necessarily as extreme as in the EO context), especially in the perspective of creating new forms of collective action to tackle grand challenges (Abrassart et al., 2017; Giordano et al., 2020; Lavoie et al., 2021). Co-design also appears as a crucial aspect in the field of transition research (Grin et al., 2010; Hyysalo et al., 2019b, 2019c), where scholars specifically investigate the long-term socio-technical transformations involved in addressing grand challenges through so-called “sustainability transitions” (Geels, 2011; Köhler et al., 2019; Markard et al., 2012).

Beyond the noticeable interest of researchers for co-design in grand-distance situations, the potential of co-design in managing grand distance can also be assumed by further considering the specific nature of the design process. In this regard, grand-distance situations involve a twofold design objective: not only does it require designing a certain *object* (e.g. data-based products or services, solutions for grand challenges), but it also requires designing the nature of *the collective of actors* to be involved (i.e. defining the relationships between the involved actors, especially by agreeing on their respective roles and assignments).

The latter aspect is all the more important as grand distance dismisses the usual enabling conditions for creating collective action. In other words, collective action is strongly unlikely without a dedicated effort to design the relationships between the relevant actors. In this respect, co-design has already proved to address such situations involving a “crisis” of collective action: *“groups resort to co-design only when crises undermine their ability to collectively create using conventional approaches”* (Dubois et al., 2014). In particular, scholars have highlighted the ability of co-design to support the design efforts related to the collective of actors by fostering social and organisational changes, even in intricate situations initially characterised by a lack of appropriate knowledge or poor relations between actors (Abrassart et al., 2015; Dubois, 2015). However, at this point, the ability of co-design to address the extreme case of grand distance as observed in the EO context still remains an open question.

1.3. Research purpose

To summarise previous sections, our research started with the initial enigma as to whether co-design could contribute to stimulating the use of data, especially in the face of grand challenges. Drawing upon this enigma, a core issue with far reaching practical and theoretical implications has been derived and coined the issue of “grand distance”. Existing literature also suggests the legitimacy of co-design as a potential means of managing grand distance. Such forms of co-design involved in managing the issue of grand distance are hereafter coined “grand-distance co-design”. These considerations lead us to formulate our research purpose as follows:

Research purpose

Our research aims at contributing to unveiling and characterising *models of “grand-distance co-design”*, based on empirical investigations in the EO context seen as an extreme case of grand distance.

A few clarifications need to be added here with regard to the term “model”. Indeed, co-design could be more easily associated with some forms of “methods” or “tools” such as probes, toolkits, prototypes (Sanders and Stappers, 2014), or intermediate designs that help participants reach meaningful outcomes (Hyysalo et al., 2019c). However, when reviewing exiting research on co-design, it appears that other aspects of co-design also ought to be characterised. Indeed, co-design outcomes have proved to highly depend on the organisational context in which these methods arise, especially the types of actors involved, their relations, purposes and reasoning logic (Lavoie et al., 2021; Dubois, 2015; Kleinsmann and Valkenburg, 2008; Stewart and Hyysalo, 2008). Therefore, to characterise the forms of co-design at stake, our investigation also aims to embrace this broader organisational context.

Consequently, the term “model” is here introduced to move away from viewing co-design as a mere set of methods and tools, and thus account for these other organisational dimensions that contribute to the overall characterisation of co-design. Drawing upon the model proposed by (Hatchuel and Weil, 1995), four dimensions will be especially considered and further defined in Chapter 2: *management philosophy* (referring to the purpose at which co-design is aimed), *technical substratum* (referring to the tools and methods), *reasoning logic* (eliciting the underlying design process involving the exploration of new knowledge and concepts), and *organisational relations* (eliciting the organisational characteristics, roles and assignments of involved actors).

Moreover, the term “model” better reflects the epistemological stances of our research. Indeed, in line with what (Hatchuel, 2001a) describes as the essence of management research, it does not primarily aim at developing hands-on solutions for the investigated issue, but rather at reaching theoretical advances by more deeply “*understanding, criticizing and inventing models of collective action*”. In this respect, what is referred as “a model of co-design” designates the model of collective action underlying the use of co-design by a certain collective of actors.

1.4. Research strategy and synopsis of the document

To address our research purpose, we have adopted an intervention-research approach that is particularly suited to assessing and designing models of collective action, based on a rigorous collaborative protocol involving both researchers and practitioners (Hatchuel, 2001a). The specificities of this approach will be later detailed in the methodology section. For now, let us merely outline that it has especially involved: characterising the co-design models already considered by the actors at stake (here the members of e-shape project), assessing their relevance with regard to the extreme case of grand-distance as faced in the EO context, formulating an alternative co-design model designed and experimented collaboratively with practitioners, evaluating the relevance of the experimented model with regard to its expected results (here related to the issue of grand distance). These steps will be covered throughout the different parts of the document, structured as follows.

Chapter 2 goes through a review of existing literature with a two-fold objective: identifying existing models of grand-distance co-design and building the analytical framework to characterise such models. Regarding the latter aspect, the chapter especially emphasises that recent research suggests that the effects of grand distance on co-design can be especially observed at three different levels (referred to as “micro”, “meso”, “macro”)⁴. For each analytical level, a research question targeting a specific literature stream is formulated, and addressed in a dedicated academic paper (compiled in Part B of the thesis). Besides observing how co-design unfolds at these three levels, the research purpose proposed in the kappa requires further elaboration efforts to unveil the underpinning model of co-design. Chapter 2 thus draws on previous frameworks proposed by management scholars to analyse models of collective action. These developments especially lead us to characterise a model of co-design by distinguishing between four main dimensions. The analytical framework of the thesis is built upon these two complementary lines of inquiry (analytical levels and model dimensions). The framework thus takes a 4x3 matrixial form: analysing a grand-distance co-design consists in experimenting and analysing co-design at three different levels (columns of the matrix), and

⁴ These different levels will be more precisely described in Chapter 2 (section 2.2.1.) and Chapter 3 (section 3.5.). Their distinction can be briefly summarised as follows: the *micro* level focuses on co-design as occurring within a given co-design action at one moment in time, the *meso* level focuses on the organisational conditions allowing an actor to continue co-design efforts in the long run, the *macro* level focuses on the dynamics of the broader socio-economic ecosystems in which the actors evolve.

characterising how each level contributes to unveiling specific aspects of the four dimensions of the underpinning co-design model (lines of the matrix).

Chapter 3 exposes our methodology and empirical materials. It especially explains how we were led to experiment a specific form of grand-distance co-design model to address the extreme level of grand distance faced in the EO context. The model is coined “resilient-fit co-design model”.

Chapter 4 synthesises the contributions made by each paper (taking respectively a micro, meso and macro perspective on the resilient-fit co-design), with regard to the specific literature streams considered in the paper.

Chapter 5 shows how these insights coming from different analytical levels contribute to unveiling the four dimensions of the resilient-fit co-design model. These results are synthesised in 4x3 matrix where each line corresponds to one of the four dimensions of the model, and each column corresponds to one of the three analytical levels, which a given paper focuses on.

Chapter 6 concludes by summarising the main lines of inquiry, contributions and perspectives for research and practice. A synopsis of these different chapters is proposed next page (see Figure 2).

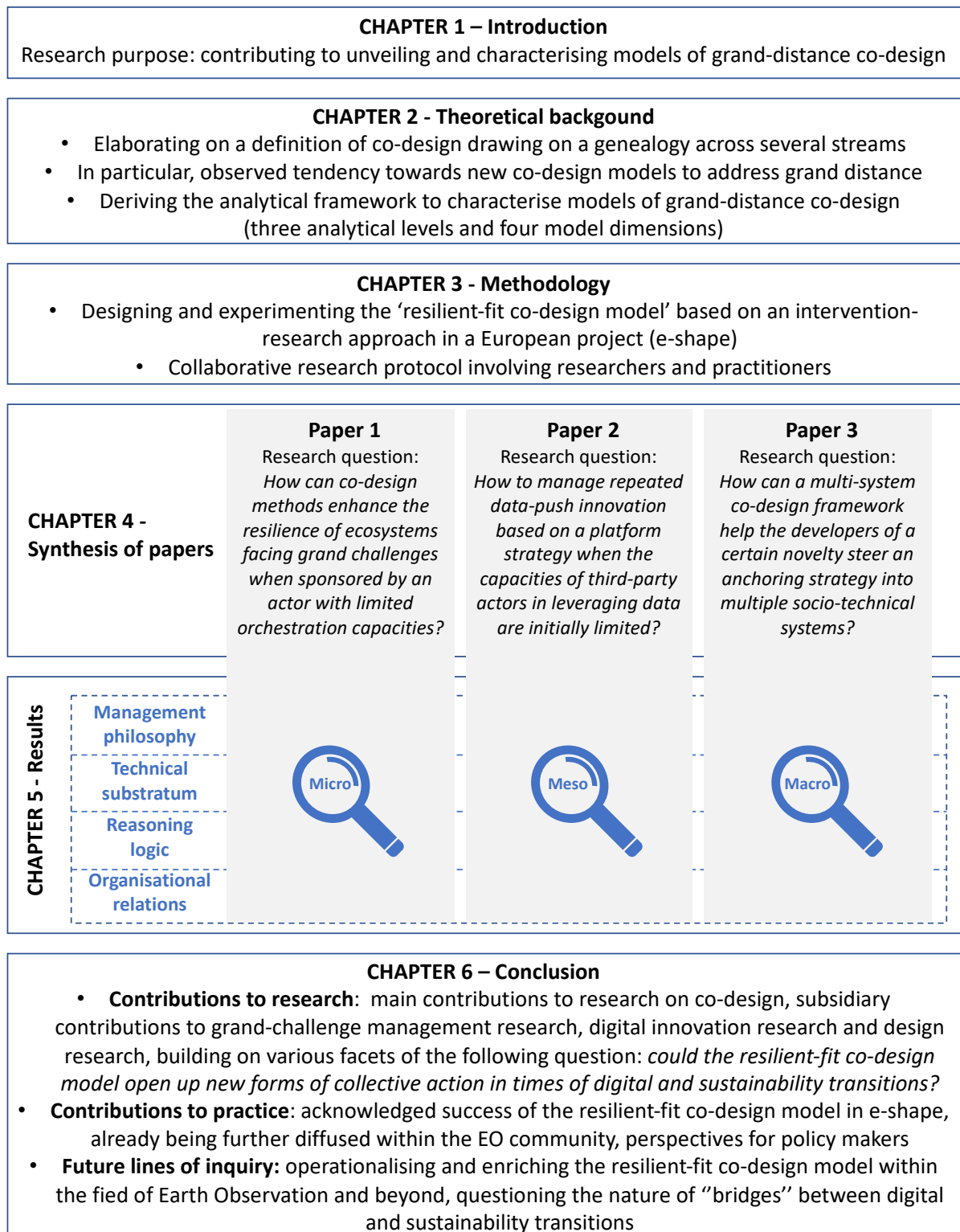


Figure 2: Synopsis of the ‘kappa’

CHAPTER 2: Analysing grand-distance co-design drawing on existing literature

Summary of Chapter 2

The present chapter aims to shed light on a few characteristics of the investigated models of grand-distance co-design based on existing literature, as well as building the analytical framework that will be used to characterise these models. In particular, literature on co-design shows a tendency towards situations of increased distance, where the nature of the collective of actors to be involved and the nature of the action to be conducted become more and more complex to grasp and establish. The EO context follows this last tendency, but goes one step further in terms of grand distance: the action cannot even be triggered by a shared challenge, and it is extremely difficult to tell which actors are relevant to involve. These difficulties suggest that the nature of co-design will certainly need to be further adapted to the level of grand distance at stake. To do so, the literature suggests that co-design needs to consider at least three different levels: the *micro* level focusing on co-design as supporting the development of a given use case, the *meso* level focusing on the long-term strategy of the organisation undertaking co-design, the *macro* level focusing on the dynamics of the broader socio-economic ecosystems in which the actors evolve. These issues led us to raise a specific research question at each level, formalised and investigated in a dedicated academic paper. Beyond the analysis of co-design at these three levels, the thesis also aims to analyse the *overall consistency* of the co-design model which appears through different angles within each level. To this end, a framework is derived from management research on collective action, describing collective action as entailing four intertwined dimensions: a management philosophy, a technical substratum, a simplified view of organisational relations, a reasoning logic. In order to effectively foster collective action, a consistent “model of co-design” must ensure that these four dimensions unfold in a consistent way within each level – micro, meso, macro.

Résumé du Chapitre 2

Ce chapitre a pour objectif de mettre au jour certaines caractéristiques des modèles de co-design à grande distance déjà étudiés dans la littérature, ainsi que de construire le cadre analytique qui sera utilisé pour analyser ces modèles dans la suite de la thèse. En particulier, la littérature sur le co-design montre une tendance vers des situations de distance de plus en plus importante, où la nature du collectif d'acteurs à impliquer et la nature de l'action à mener deviennent de plus en plus complexes à appréhender et à établir. Le co-design dans le contexte de l'observation de la Terre suit cette dernière tendance, mais va encore plus loin en termes de grande distance : l'action ne peut même pas être déclenchée par un défi partagé, et il est extrêmement difficile de dire quels acteurs sont pertinents à impliquer. Ces difficultés suggèrent donc que la nature du co-design devra certainement être adaptée

au niveau de grande distance en jeu. Pour ce faire, la littérature suggère que le co-design doit prendre en compte trois niveaux différents : le niveau *micro*, qui se concentre sur le co-design appliqué au développement d'un cas d'usage donné, le niveau *méso* qui se concentre sur la stratégie long-terme d'un acteur mettant en œuvre du co-design, le niveau *macro* qui se concentre sur la dynamique plus large des écosystèmes socio-économiques dans lesquels évoluent les acteurs. Les problématiques rencontrées à chacun des niveaux ont conduit à poser une question de recherche spécifique à chaque niveau, formalisée et investiguée dans un article académique dédié. Au-delà de cette analyse du co-design à trois niveaux, la thèse vise également à analyser la *cohérence globale* du modèle de co-design qui apparaît sous des angles différents au sein de chaque niveau. Des travaux existants en gestion sur l'action collective proposent de décrire l'action collective comme comportant quatre dimensions imbriquées : une philosophie de gestion, un substrat technique, une vision simplifiée des relations organisationnelles, un raisonnement de conception. Afin de favoriser efficacement l'action collective, un « modèle de co-design » doit donc pouvoir garantir que ces quatre dimensions se déploient de manière cohérente à chaque niveau micro, meso, macro.

2.1. A quick overview of co-design in history

Co-design has received significant attention from scholars in different academic fields. Three main traditions can be more specifically identified, leading to different developments and debates on co-design: industrial design, innovation management and engineering design.

2.1.1. Co-design in industrial design: involving users in the design process

First tracing co-design in the tradition line of industrial design, it mainly refers to a large range of methods and tools, such as probes, toolkits, or prototypes (Sanders and Stappers, 2014), that facilitate the engagement of participants with heterogeneous domains of expertise. In this regard, (Sanders and Stappers, 2008) define co-design as “collective creativity as it is applied across the whole span of a design process, [where] designers and people not trained in design are working together in the design development process”. (Steen, 2013; Steen et al., 2011) show the benefits of such tools in the perspective of developing solutions for and with users that are more adapted to their needs, through a joint exploration of user needs and related solution requirements.

Such approaches have especially gained momentum since the years 2000s, benefitting from important contributions of Scandinavian researchers such as the Aalto University of Art and Design (Mattelmäki and Visser, 2011). The latter authors underline that the term “co-design” is quite ambiguous but encompasses the following dimensions:

- Co-design is *“utilised in design context in which designers are involved and the topic of the activity is related to design exploration, envisioning and solution development”*.
- Co-design has *“an empowering mindset and it gives voice and tools to those who were not traditionally part of design process”*.
- Co-design is *“about engagement of potential users but also about stakeholder collaboration”*.
- Co-design includes *“process and tools of collaborative engagement, events for learning and exploration”*.

These developments are noticeably rooted in a longer history, and have been especially inspired by so-called “Participatory Design” approaches dating back to the 70s (Simonsen and Robertson, 2012). Interestingly, these approaches emerged in the context of introducing new forms of information technologies in organisations to improve working conditions and work practices of employees by leveraging computer systems. In this context, (Simonsen and Robertson, 2012) broadly describes Participatory Design as dealing with *“the direct involvement of people in the co-design of the information technologies they use. Its central concern is how collaborative design processes can be driven by the participation of the people who will be affected by the technology that is being designed”*. Participatory Design especially fosters “mutual learning processes” within which all participants increase their knowledge and understanding: *“Users need knowledge of potential technological options as well as of how these options can be provided. Designers are the source of this knowledge, as well as of relevant design expertise. The designers need knowledge about the users, their practices and the use situation (often the work domain) in question. The users are the source of this knowledge and relevant domain expertise.”* (Robertson and Simonsen, 2012, p. 6)

2.1.2. Co-design in innovation management: co-creating value between a wide range of actors

In parallel, innovation management researchers have also contributed to the development of co-design approaches, in the context of organising collective action among heterogeneous actors. A large stream of research has specifically put forward “open innovation” models considering innovation as a distributed process crossing organisational boundaries (e.g. Bogers et al., 2017; West et al., 2014; Chesbrough et al., 2006). In this perspective, users or customers have been considered as playing a critical role in the innovation process (e.g. Bogers et al., 2010; Gemser and Perks, 2015). Innovation might indeed largely benefit from the involvement of lead users (Urban and von Hippel, 1988; von Hippel, 1986), ordinary users (Magnusson, 2009), or broader user communities (Hienerth et al., 2014), e.g. through the development of specific toolkits (Franke et al., 2008; Franke and Hippel, 2003; Parmentier and Gandia, 2013; Piller and Walcher, 2006; von Hippel, 2001).

Similarly, marketing research has also highlighted the crucial role of customers or users, calling for a shift from considering customers as passive to active actors in the process of value creation (Prahalad and Ramaswamy, 2004; Vargo et al., 2008). Beyond users and customers, management scholars have also shed light on the critical involvement of a wider range of actors taking a network or ecosystem viewpoint (e.g. Frow et al., 2015; Gemser and Perks, 2015; Hienerth et al., 2014; Perks et al., 2012). This has especially led scholars to investigate different forms of “co-creation”, defined in (Perks et al., 2012) as “the joint creation of value by the firm and its network of various entities (such as customers, suppliers and distributors)”. It has especially been largely investigated in the marketing field under the so-called “service-dominant logic” stream of research (Vargo et al., 2008; Vargo and Lusch, 2010).

Beyond the latter developments on co-creation, the term “co-design” is also explicitly mentioned, e.g. in recent studies concerning the engagement of ordinary users or other communities that are difficult to reach, based on specific devices such as pop-up stores (Overdiek and Warnaby, 2020). Previous studies have also depicted co-design as a promising strategy for firms willing to set up new modes of cooperation among various entities of the ecosystem. Such strategies have especially concerned sport goods manufacturers such as Adidas or Nike seeking to develop “mass customisation”, i.e. providing each customer with extended possibilities of customising their products (Berger et al., 2005). In the automotive

industry, especially since the 90s, co-design has also appeared as a way of reshaping collaborations between buyers (Original Equipment Manufacturers) and suppliers beyond usual price negotiation, e.g. to better respond to emerging innovation needs such as designing new modules to increase comfort and reduce pollutant emission of cars (Spina et al., 2002; Zirpoli and Caputo, 2002).

2.1.3. Co-design in engineering design: managing interdisciplinarity to enhance the design process

Finally, as underlined by (Dubois, 2015) in his in-depth analysis of co-design history, co-design approaches have also been used in an engineering design tradition since the 70s, especially in the context of developing innovative embedded systems. According to (De Micheli and Gupta, 1997), *“hardware/software co-design means meeting system-level objectives by exploiting the synergism of hardware and software through their concurrent design”* (p. 349). The underlying ambition is that *“co-design can lead to products of superior quality (i.e., performance/cost, flexibility) with a shorter design and development time as compared to traditional integrated circuit design methodologies”* (De Micheli and Gupta, 1997, p. 362). This type of co-design aims at addressing design issues corresponding to different interpretations of the “co” syllable, as especially highlighted by (Teich, 2012):

- Complexity of embedded system to be designed, involving the integration of hardware (based on physical components) and software;
- Coordination, resulting from the complexity of objects to be designed, to “coordinate the design steps of interdisciplinary design groups [...] to work together on all parts of a system” throughout the development process (including firmware, operating system, and application developers on the software side, as well as hardware developers and chip designers on the hardware side);
- Concurrency, i.e. hardware and software developers need to work concurrently instead of starting the software development only after the hardware platform is available. In this respect, the authors underline the necessity of organising learning at the crossroad of the different fields of expertise involved, especially based on “co-simulation” tools (Wolf, 1994): *“Co-simulation usually refers to some sort of mixed hardware-software simulation-for example, one part of the system may be modelled as instructions executing on a CPU while another part may be modelled as logic gates.”* (p. 980).

2.1.4. Lessons learned from this genealogy

The situation faced by EO actors seems to directly resonate with some of the aspects described above. The genealogy of co-design especially highlights critical characteristics shared by the various instances of co-design despite their different academic roots:

- **A need for design**, with a more or less innovative character and sometimes directly related to the integration of IT technologies into a given organisation (in historical cases of Participatory Design);
- **A need to involve very heterogenous actors**, with varied practices, competencies, design experiences;
- **The relationships between these actors have to be (re)invented**: in some situations, they have never worked directly together (e.g. customer involvement); in other situations, they might have previously worked together but not in a design regime (e.g. buyer-supplier relationship), or with such a high need of integration (e.g. embedded systems). This need of (re)inventing relationships between actors stems from the “crisis” of the design collective mentioned earlier (Dubois et al., 2014), where actors cannot rely on conventional approaches to collectively design.

These considerations lead us to refine the definition of co-design given in the introduction that merely focused on the two first dimensions, and better outline its specificities compared to other similar words commonly used in literature:

Retained definition of co-design

Co-design will hereafter refer to the organisation of a collective design process that involves the three following aspects:

- i) **A design aspect**, entailing the exploration of innovative objects (e.g. socio-economic applications of EO data)
- ii) **A collective aspect**, entailing the involvement of heterogeneous actors in the design process (e.g. data providers, data users, other relevant actors).
- iii) **A crisis aspect**, involving the need of (re)inventing the relationships between the involved actors.

This third aspect is especially useful to better distinguish co-design from other terms that also entail both design and collective aspects. For example, strategic management has extensively investigated “**collaboration**”, “**cooperation**” or “**coordination**” as core elements for inter-organisational relations (Gulati et al., 2012; Kretschmer and Vanneste, 2017; Sydow et al., 2015). The distinction between these three terms has been largely debated (Castañer and Oliveira, 2020) and is not the focus of our discussion. More interestingly, co-design can be compared to these different terms. Based on an extensive literature review, (Castañer and Oliveira, 2020) propose to redefine these terms as follows: coordination as “the joint determination of common goals”, cooperation as “the implementation of those goals”, and collaboration referring “to voluntarily helping other partners to achieve [common] goals or one or more of their private goals”. To a certain extent, co-design can be indeed associated with these terms as it certainly involves certain forms of coordination, cooperation, and/or collaboration. However, co-design would consider these processes in cases where *additional design efforts are needed to (re)invent the relationships between the involved actors* (possibly moving away from classical forms of cooperation, coordination or collaboration). In the same vein, in innovation management, co-design could also be associated with “**collaborative innovation**” that also includes strong design and collective aspects (Baldwin and von Hippel, 2011; Caccamo, 2020; Ollila and Yström, 2016). In this respect, co-design will be hereafter considered as a *form of collaborative innovation that puts a specific emphasis on the need of (re)inventing the relationships between the involved actors*.

2.2. Building a framework to analyse grand-distance co-design

As exposed in the introduction, literature tends to report on an increasing range of grand-distance situations. Following this tendency, it is also worth noting that co-design has also evolved beyond the aforementioned traditional roots towards new forms that specifically address grand distance.

Co-design has especially been designated as one of the core concepts of transition studies (Grin et al., 2010), that encompass a growing body of research on the long-term socio-technical transformations involved in addressing these grand challenges through so-called “sustainability transitions” (e.g. Zolfagharian et al., 2019; Köhler et al., 2019; Markard et al., 2012). As synthesised by (Loorbach et al., 2017), the crux of the matter for this body of

research lies in considering that “grand societal challenges should be understood as systemic, and that dealing with such challenges is only possible through fundamental systemic changes in societal regimes.” (p. 602). Such transitions for example involve designing policies to deal with water management issues (Pluchinotta et al., 2019), exploring new urban planning practices to imagine the future of our cities (Lavoie et al., 2021; Scherrer et al., 2017) or enhancing the sustainability of agricultural systems (Della Rossa et al., 2022; Berthet et al., 2022; Elzen and Bos, 2019; Berthet et al., 2016a).

Beyond research on transitions, some forms of co-design also clearly appear in other highly-innovative contexts where innovation requires new forms of partnerships. Note that these contexts do not always refer to “co-design” explicitly, but will be considered as such when corresponding to the definition given above, i.e. when involving forms of collective design processes with a crisis dimension. It can concern established actors of a given sector - e.g. in the military sector (Nicolaÿ and Lenfle, 2019) or automotive sector (Ollila and Elmquist, 2011), but also emerging entrepreneurs or actors crossing existing boundaries, e.g. through the development of crowdsourcing initiatives or various forms of innovation contests (e.g. Kokshagina, 2022; Bertello et al., 2021; Porter et al., 2020; Adamczyk et al., 2012). More specifically, forms of grand-distance co-design also appear in the field of digital innovation, as data-driven services are increasingly co-created in an intricate network of actors (Schymanietz et al., 2022).

2.2.1. Three analytical levels to capture the specificities of grand-distance co-design

Compared to the historical forms of co-design described in the genealogy, this growing body of research especially sheds light on a number of specificities related to grand distance. In particular, it can be noted that these specificities unfold at various levels: they involve specific co-design practices seen at a ‘micro’ level, but also specific long-term strategies seen at the ‘meso’ level of a given actor involved in co-design, as well as specific forms of dynamics seen at the ‘macro’ level of the socio-economic ecosystems in which the different actors evolve.

2.2.1.1. Micro level: an increased difficulty in mobilising actors in a long-term perspective

Considering the processes and tools involved, scholars shed light on an intricate arrangement of collective design sessions or workshops. Recent literature has shed light on **workshops taking an increased variety and complexity of forms**. Several workshops are often required, following a rigorous process distributed in time (Della Rossa et al., 2022; Lavoie et al., 2021; Berthet et al., 2020; Pluchinotta et al., 2019; Abrassart et al., 2015). These workshops increasingly need to take into account new forms of time limitation or geographical constraints due the heterogeneity of actors involved (Pluchinotta et al., 2019). Partly addressing these issues, the use of virtual platforms or workshops has flourished, especially since COVID-19 restrictions (Kokshagina, 2022; Bertello et al., 2021).

Interestingly, the nature of the workshop's outcomes also appears to be affected by grand distance, especially leading to a closer attention to the social-organisational forms of outcomes (Dubois, 2015). Indeed, in several situations, co-design has been explicitly depicted as targeting a profound renewal of interactions between actors that sometimes even becomes the primary objective of the process (Della Rossa et al., 2022; Berthet et al., 2020; Abrassart et al., 2015).

Beyond the organisation of the workshops, recent literature also massively reports on a sophisticated range of **pre-workshop actions**. Such activities already existed in more traditional forms co-design, especially including the invitation of participants and preparation of workshop materials. However, the scope of these activities has been dramatically broadened due to grand distance.

Indeed, in traditional occurrences of co-design, both the goal of co-design and the actors to be involved tended to be clearly identified from the beginning of the process, and could be described shortly as "co-design with elderly people to develop concepts for health care services" (Steen et al., 2011). In its traditional form, Participatory Design is indeed explicitly guided by "the aim of designing sustainable uses of IT based on a specific problem within the company" (Bodker et al., 2004, p. 13). Similarly, in the engineering roots of co-design, the design process of embedded systems is driven by a shared list of requirements: "*Whereas performance is the most important design criterion for information processing systems, reliability, availability, and safety are extremely important for control systems*" (De

Micheli and Gupta, 1997, p. 354). The actors to be involved could thus be almost directly derived from the shared issue to be addressed, such as a firm and its customers in the case of customer involvement for mass customisation (Berger et al., 2005), or the employees of a specific organisation in the cases of historical Participatory Design (Simonsen and Robertson, 2012).

By contrast, in grand-distance situations, scholars highlight that co-design cannot necessarily rely on a shared issue from the outset, as actors are likely to have diverging or even conflictual views (Berthet et al., 2016b; Della Rossa et al., 2022; Pluchinotta et al., 2019). In this respect, scholars noticeably agree on the need of undertaking a thorough “diagnosis” of the system at stake (e.g. Della Rossa et al., 2022; Pluchinotta et al., 2022; Lab Ville Prospective, 2021). It especially involves a round of interviews or other forms of inquiries to identify the concerned actors, their relationships, as well as their respective knowledge and perceptions of the system’s boundaries and issues to be addressed (Pluchinotta et al., 2022; Della Rossa et al., 2022; Giordano et al., 2020; Berthet et al., 2020; Pluchinotta et al., 2019).

Scholars also underline the importance of considering **post-workshop actions**, to especially account for the long-term continuity of efforts beyond the limited timespans of workshops. This point has already been highlighted in traditional roots of co-design, especially claiming for taking an evolutionary perspective and considering sustained forms of co-design (Botero and Hyysalo, 2013; Simonsen and Hertzum, 2012). Nevertheless, it takes another dimension in grand distance situations as the long-term commitment of heterogenous actors appears as particularly difficult (Kokshagina, 2022; Porter et al., 2020; Bertello et al., 2021; Ferraro et al., 2015). Moreover, compared to cases of co-design remaining within the boundaries of a given organisation, such as the ones implemented by large firms in the automotive or aeronautics industries (Elmqvist and Segrestin, 2009; Hooge et al., 2016a), co-design tends to face additional **difficulties in mobilising actors and giving direction to the innovation efforts involved in the long-term** (Della Rossa et al., 2022; Pluchinotta et al., 2019).

2.2.1.2. Meso level: towards specific organisational characteristics to sustain co-design efforts over time

Beyond emphasising on co-design practices at a micro level, literature also clearly highlights that co-design in grand-distance situations cannot be fully understood without considering the longer-term actors' strategies. This especially calls for going beyond considering one co-design action as unfolding at one point in time (as mainly appearing at the micro level), but also considering **how adequate organisational conditions are created to continue co-design efforts over time**, here suggesting a shift of focus towards another level of analysis that we will coin "meso".

This aspect was already present in the traditional roots of co-design, where **long-term learning processes involved in co-design** appear as particularly critical (e.g. Simonsen and Robertson, 2012; Stewart and Hyysalo, 2008). In grand-distance situations, scholars have paid a specific attention to the **possible means of creating the conditions for the momentum to develop over time**, especially responding to the difficulty of sustaining co-design efforts beyond the timespan of co-design workshops.

In this respect, co-design needs to consider what actions should be taken and their sequencing in time, how ideas developed jointly can then be anchored in the partner organisations (Ollila and Elmquist, 2011), how to "embed learning back into the [involved] organisations" (Pluchinotta et al., 2019). In a similar vein, Lavoie et al. (2021) emphasise that drawing concrete propositions for future development paths out of the co-design process "*is possibly the most important, underrated, forgotten, and complex step*" (p. 50).

This can also involve expanding the pool of actors involved over time, as illustrated in the case of a crowdsourcing initiative addressing environmental sustainability challenges in the maritime industry: "*generating the engagement of new participants becomes equally important as sustaining the engagement of existing ones*" (Porter et al., 2020, p. 274). It can for example involve multiplying interactions with the actors that could legitimise certain novelties, through dedicated experimentation and demonstration efforts (Elzen and Bos, 2019). In the same vein, several scholars also underline that these efforts can be especially sustained through the formalisation of long-lasting forms of collaborations and structures (Berthet et al., 2022; Elzen and Bos, 2019; Ollila and Yström, 2016).

Following this line, the occurrences of grand-distance co-design in literature also discuss the **specific competencies and organisational forms** required for such long-term endeavours. Developing innovative design capacities within involved organisations appears as a promising way, e.g. through the development of dedicated training programmes (Lavoie et al., 2021; Yström et al., 2021; Rampa and Agogué, 2020; Rampa et al., 2016).

With regard to the organisational forms underpinning co-design in a long-term perspective, (Stewart and Hyysalo, 2008) unveil the role of “innovation intermediaries” that “create spaces and opportunities for appropriation and generation of emerging technical or cultural products by others who might be described as developers and users.” (p. 296-297). These actors have been largely studied by innovation management scholars, building upon different research streams on technology diffusion, systems of innovation, innovation management (Howells, 2006). They typically act as “boundary-crossing” actors involving a large variety of disciplines, actors, interests, value systems, fields of activity and institutions (Boon et al., 2011).

In the context of sustainability transitions, (Kivimaa et al., 2019) suggest that intermediaries can be considered as key catalysts speeding up change towards sustainable development. However, the latter authors specifically call for further considering the **sophisticated variety of intermediary actors whose relations and roles go beyond the ones described in previous developments** (e.g. Stewart and Hyysalo, 2008). This finds echoes with other studies showing that a high degree of unknown calls for specific forms of intermediaries (Agogué et al., 2017, 2013). The latter authors especially shed light on some figures playing the role of “architects of the unknown”, stimulating and driving collective exploration and knowledge creation.

As a possible way of undertaking such intermediary roles, scholars underline the role of so-called “**boundary objects**” (Nicolaÿ and Lenfle, 2019; Abrassart et al., 2015). Indeed, following seminal studies of Carlile (2002) and Star and Griesemer (1989), boundary objects especially allow heterogeneous actors to work together by establishing a shared context that “sits in the middle” (Star, 1989, p. 47). Boundary objects prove to be especially crucial when different kinds of knowledge are dependent on each other: *“First, a boundary object establishes a shared syntax or language for individuals to represent their knowledge. [...] [Second, it] provides a concrete means for individuals to specify and learn about their*

differences and dependencies across a given boundary. [Third, it] facilitates a process where individuals can jointly transform their knowledge” (Carlile, 2002, pp. 451–452). In the context of large-scale innovative projects, and building upon Galison’s work on “trading zones”, Lenfle and Söderlund (2019) show that boundary objects can especially contribute to creating an “interlanguage” that enables the sharing of heterogeneous expertise and disciplinary knowledge and fosters coordination towards the end of achieving a common and unique goal. Boundary objects have also proved to play a significant role in the context of digital innovation and information science research (Huvila et al., 2017). In particular, addressing the involved breadth and degree of new knowledge might require new forms of sophisticated boundary objects, e.g. mixing data, modelling and simulation (Lakemond et al., 2022).

2.2.1.3. Macro level: extending the stakes of co-design to the level of ecosystem dynamics

Grand distance also calls for extending the scope of analysis towards the **larger level of the socio-economic ecosystems in which the actors evolve**, that we will coin “macro”. The shift from the meso to the macro level basically lies in the fact that understanding the stakes and conditions for an actor to undertake co-design also requires considering the role, position and relationships of this actor within a broader ecosystem of actors.

The concept of “ecosystem” has been widely used in management research, leading to a profusion of varying perspectives – for recent and extensive reviews, see (Granstrand and Holgersson, 2020; Tsujimoto et al., 2018). It was initially introduced in the field of strategy by comparison with the biology field (Iansiti and Levien, 2004; Moore, 1993), considering the firm as inhabiting an ecosystem of interdependent and co-evolving actors that affect or are effected by the firm’s strategy. As especially highlighted in (Adner, 2017; Autio and Thomas, 2014), these actors can noticeably go beyond the traditional value chain of suppliers and distributors and potentially span various industries, e.g. including outsourcing companies, financial institutions, technology providers, and regulatory and coordinating bodies.

Following (Ritala and Almpantopoulou, 2017), we will hereafter retain the definition of ecosystems as *“systems that focus on innovation activities [...], involve the logic of actor interdependence within a particular context [...] and address the inherent co-evolution of actors”*. In this respect, our perspective basically aims at going **beyond an actor-centric**

perspective by embracing a broader look at the ecosystems of actors involved in a given innovation process.

Going back to grand-distance situations, scholars have especially shown that co-design strongly involves ecosystem-related aspects beyond the scope of the actor sponsoring the co-design process. For example, (Nicolaj and Lenfle, 2019) show that the co-design process involved in designing a complex service in the military industry has supported the **establishment of a rich and structured ecosystem** for the service, by gradually expanding the community of participating stakeholders and gaining their commitment.

Similar considerations have been especially described the EO field. In this regard, the development of spatial oceanography in the 80s-90s offers a telling example. As thoroughly described in (Le Pellec-Dairon, 2013), the French spatial agency undertook tremendous efforts to create rich forms of interactions with existing and new actors and thus ensure the long-term creation of a vibrant ecosystem that could make use of newly produced space-based oceanographic data. It involved fostering research spanning previously separated scientific and technical expertise in oceanography and remote sensing, especially through the development of training programmes and dedicated PhD projects. It also involved the structuration of entities that could ensure the development and commercialisation of operational services, e.g. through the creation of a new department in a pre-existing commercial company entrusted by the French spatial agency. And last but not least, it also involved the creation of a new organisation (called Mercator Ocean) to sustain oceanographic simulation and forecasting chains on an operational basis. These efforts have had long-lasting results, as attested by the flourishing uses of oceanographic data and the important role that Mercator Ocean has taken on, indeed in charge of operating the marine component of the European landmark EO programme Copernicus since 2014. Interestingly, even in such cases where efforts of growing a rich ecosystem of actors have been successfully carried out, it appears that the process is still on-going to further reach actors that could appear as more and more distant, e.g. actors related to the ocean energy or aquaculture sectors beyond historical weather and climate scientific communities (Le Traon et al., 2019).

As recalled by this example, understanding the transformations occurring at the level of ecosystems especially requires adopting an **evolutionary and long-term perspective**. This

dimension has especially prevailed in the stream of transition studies, that especially draws upon the notion of “socio-technical system”, referring to the actors, institutions and artefacts interacting to fulfil societal functions (e.g. transport, communication, nutrition) (e.g. Geels, 2004, 2002).

In particular, the multi-level perspective (MLP) framework has been especially developed by the latter authors to account for the transformations of these socio-technical systems, conceptualised as “transitions”. In this regard, the concept of “regime” is particularly central: it corresponds to the dominant and stable configuration of a socio-technical systems, especially referring to the rules and practices framing the action of the different social groups involved in transitions (e.g. engineers, users, policy makers). In this view, a transition occurs as a gradual shift from one regime to another. This shift involves non-linear processes resulting from the interactions of the regime with “niches” in which emerging novelties and innovations are nurtured, as well as with changing exogeneous factors referred as “landscape” (e.g. global societal trends putting pressure on the existing regime).

Following this view, the actors involved in co-design are inherently entrenched in the on-going transition dynamics of the socio-technical systems to which they belong. Scholars have also increasingly called for further understanding how co-design is not only influenced by on-going dynamics but could also contribute to influencing their pace and directions, e.g. in the context of supporting the exploration of alternative pathways for the energy transition in Finland (Hyysalo et al., 2019b, 2019a).

Several issues have been more specifically highlighted by scholars, that can be especially linked to a noticeable increase of distance. Indeed, transition mechanisms have proved to occur not only within one single socio-technical system but also between heterogeneous socio-technical systems (e.g. biogas development spanning agriculture and renewable energy systems), calling for further investigations on forms of **multi-system mechanisms** (Sutherland et al., 2015; Papachristos et al., 2013; Raven, 2007; Raven and Verbong, 2007).

Moreover, in the face of grand challenges, contemporary ecosystems tend to be increasingly exposed to turbulent environments undergoing continuous transformations and possibly challenged by unexpected disruptive events (e.g. Pettit et al., 2013; Buganza and Verganti, 2006). This tendency has led to an increasing attention to such concepts as

“resilience”, accounting for the ability of these ecosystems to adequately respond to these disruptive events (e.g. Ramezani and Camarinha-Matos, 2020; Roundy et al., 2017). Initially rooted in ecology, the concept of resilience has found many echoes in a large range of disciplines with varying conceptualisations (Bourcart, 2015). Recent developments have especially considered resilience in an transformative perspective, thus going beyond “*mere resistance to shock and conservation of existing structures, but [involving the ecosystem’s] ability to reorganize, reconfigure, restructure, and even reinvent when appropriate in response to disruptions*” (Ramezani and Camarinha-Matos, 2020, p. 3). Following this transformative perspective, **enhancing the resilience of ecosystems** might especially involve specific design efforts requiring dedicated research investigations, as especially highlighted in Elsa Berthet’s work on the collective design of resilient social-ecological systems (Berthet et al., 2022).

2.2.2. Research questions as investigated in the papers

As depicted above, management research appears as increasingly concerned by situations where collective action is hampered by grand distance. Existing literature already shows how co-design has evolved to address a certain number of issues resulting from grand distance, and how some of them still remain insufficiently addressed.

In this regard, undertaking in-depth investigations in the EO context appears as a promising way of bringing insightful contributions to research with regard to how to further address these issues. Indeed, as exposed in the introduction, the EO context appears as an extreme case of grand distance where collective action seems initially doomed to failure as actors have hardly anything in common. In such a context, the issues pointed out by scholars appear as all the more critical to address. In this respect, the extreme character of grand distance especially drives us to consider **how to address the issues stemming from grand distance all the more explicitly and systematically**.

Our research outcomes have been formalised in three academic papers, each one having a stronger focus on one of the three levels. It is to be noted that the focus of the paper merely indicates the level to which the main contributions of the paper mostly relate. But it does not mean that all aspects related to the two other levels are completely ignored. Indeed, the co-design specificities appearing at a given level are likely to have consequences that can be observed at other levels.

A first paper focuses on the micro-level processes and tools involved in co-design, referred as “co-design methods”. These methods are especially investigated in the perspective of enhancing the resilience of socio-economic ecosystems in the face of grand challenges. This aspect is here taken into account as a contextual element that specifically calls for investigating new forms of co-design methods. In particular, the paper aims to investigate how co-design methods can adapt to the observed tendency towards increased difficulties in mobilising actors and giving direction to the innovation efforts on a long-term basis. These difficulties are hereafter referred as “limited orchestration capacities”. These considerations have led us to address the following research question in Paper 1 (very slightly reformulated to improve the wording):

Research question of paper 1 (focus on co-design at a micro level)

How can co-design methods enhance the resilience of ecosystems facing grand challenges when sponsored by an actor with limited orchestration capacities?

A second paper takes a closer look at meso-related aspects of co-design, by investigating the organisational characteristics of an actor that can be considered as a form of innovation intermediary led to undertake co-design on the long run. However, the paper restricts the scope of this investigation to a particular angle that is more specifically related to digital innovation. It especially delves into a specific case of digital innovation, called “data-push innovation” consisting in stimulating the use of existing data by third-party actors.

In this regard, platform strategies have been extensively described as a promising way of designing complex systems by developing and recombining modular components (Baldwin and Woodard, 2009; Gawer, 2014). In particular, so-called “innovation platforms” consist in building “*a technological foundation upon which a large number of [third-party actors] can build further complementary innovations*” (Gawer, 2020). These strategies have particularly flourished in the digital innovation context, where platforms have become omnipresent as illustrated by the well-known cases of operating system platforms like iOS or Android (e.g. Constantinides et al., 2018; de Reuver et al., 2018; Tiwana et al., 2010).

However by contrast with these historical cases of successful digital platforms, third-party actors are not necessarily able to directly innovate on top of available data by

themselves, as especially highlighted by scholars investigating open data initiatives (e.g. Zuiderwijk and Reuver, 2021; Bonina and Eaton, 2020; Janssen et al., 2012). In this context, the focal actor is analysed as undertaking a specific form of innovation platform strategy, that particularly needs to deal with the initial limited capacities of third-party actors in leveraging data. Going back to grand distance, it is worth noting that it appears in this paper as resulting in a specific issue for data-push innovation – the limited capacities of third-party actors in leveraging data – that requires to be handled in a more explicit and systematic way.

This has led us to address the research question as formulated below (very slightly reformulated to improve the wording):

Research question of paper 2 (focus on co-design at a meso level)

How to manage repeated data-push innovation based on a platform strategy when the capacities of third-party actors in leveraging data are initially limited?

A third paper focuses on co-design seen from a macro perspective. It especially investigates how co-design can interplay with the dynamics of multiple heterogeneous socio-technical systems, by specifically investigating so-called “anchoring” strategies consisting in further connecting a novelty to one or several socio-technical systems (Elzen et al., 2012). A novelty broadly refers to a new technology, a new technical concept or a new socio-technical practice. In this vein, EO data can be considered as a specific form of novelty. Co-design has proved to be a promising way of supporting anchoring strategies with attested effects on transition dynamics (Elzen and Bos, 2019).

However, it still remains unclear how co-design could contribute to such strategies in multi-system configurations, i.e. when the novelty is to be connected to several heterogeneous socio-technical systems. This question seems all the more important as these configurations have already proved to be particularly promising in terms of speeding up sustainability transitions (Sutherland et al., 2015). Paper 3 thus addresses the following question:

Research question of paper 3 (focus on co-design at a macro level)

How can a multi-system co-design framework help the developers of a certain novelty steer an anchoring strategy into multiple socio-technical systems?

2.3. A broader research purpose beyond the papers: unveiling the underpinning model of collective action

By investigating specific research questions related to each level, the three papers contribute to unveiling specific aspects of grand-distance co-design as unfolding at each of these levels. However, beyond the contributions offered by the three papers, the kappa proposes to go one step further towards characterising grand-distance co-design. Indeed, by depicting how co-design unfolds at micro, meso and macro levels, the papers characterise co-design by portraying its manifestations as observable at three different levels. More fundamentally, the kappa of the thesis aims to characterise co-design by further elucidating its internal consistency and inner workings. In other words, it aims to investigate the driving forces that make co-design appear in such or such way at the three micro, meso and macro levels. In particular, because co-design consists in building or rebuilding collective action when the latter is in crisis, elucidating the driving forces of co-design will precisely consist in unveiling the underpinning model of collective action. It remains therefore to elicit a range of foundational dimensions that characterise such a model of collective action.

Management researchers have already proposed theoretical frameworks to describe models of collective action. In particular, the one developed by (Hatchuel and Weil, 1995) appears as particularly relevant for our research. Indeed, their framework was specifically introduced to analyse certain forms of “management techniques”, such as operational research after World War II or expert systems in the 90s, which had witnessed a soaring use in a growing number of organisations similarly to co-design nowadays. (Hatchuel and Weil, 1995) especially showed that the investigated management techniques were fundamentally associated with so-called “rationalisation projects”, that aimed to establish a form of collective action as more efficient and viable (so more “rational”) in a given context. Rationalisation is defined as a *“mythical objective, a figure of progress in [organisations] to which each period, each main management technique, temporarily gives more substance”* (Hatchuel and Weil, 1995, p. 96).

In this regard, it seems relevant to consider **co-design as a management technique that aims for contemporary forms of rationalisation projects, in particular the ones directed towards establishing efficient and viable forms of collective action in grand-distance**

situations. Consequently, the model of collective action underpinning co-design, that will be more shortly designated as the “**model of co-design**”, will be hereafter described as entailing four distinct but interacting dimensions. The three first dimensions are derived from the framework proposed in (Hatchuel and Weil, 1995) and are complemented by a fourth one derived from more recent advances in design research (Le Masson et al., 2017). They can be synthesised as follows:

2.3.1. A management philosophy

The management philosophy is defined as “**the system of concepts that refers to the objects and objectives at which rationalisation is aimed**” (Hatchuel and Weil, 1995, p. 98). For example, in operational research, the underlying management philosophy consisted in optimising each decision by finding different alternatives and selecting the most efficient ones. As for the development of expert systems, it was rooted in a management philosophy considering that knowledge could be automated.

With regard to co-design, existing literature displays different forms of management philosophy. Literature suggests that co-design entails a twofold objective: designing a certain object (e.g. data-based products or services, solutions for grand challenges), but also designing the collective of actors to be involved to reach the first design objective (e.g. Hooge et al., 2016a; Dubois, 2015). Literature also sheds light on a spectrum of management philosophy with more or less focus on these two objectives. In some works, co-design is associated with a management philosophy that is more focused on the object-related objective. Such management philosophy could be qualified as “fit-driven”, i.e. consisting in building a fit between a developed solution and users’ needs (e.g. Steen, 2013) and thus involving “*bridging user-developer innovation domains*” (Stewart and Hyysalo, 2008). In other cases, co-design appear to especially focus on the collective-related objective, e.g. when targeting profound social and organisational transformations (e.g. Berthet et al., 2020; Elzen and Bos, 2019). It also echoes the perspectives taken in (Abrassart et al., 2015) where co-design is seen as a form of “social design”, and in (Dubois et al., 2014) where co-design is seen as a “change management intervention” focusing on strengthening the collective of actors involved in the design process.

2.3.2. A simplified view of organisational relations

This dimension describes **the roles of the most important actors involved in the rationalisation project**. For example, the main protagonists of scientific management artificial intelligence relies on a range of experts and users. (Hatchuel and Weil, 1995) also underline that “all management techniques include the specialist in their particular approach” (e.g. operational researchers and AI specialists). The name of this specialist figure can change over time (e.g. current “methods engineers” are descendants of the scientific management specialists involved in Taylorism). The specialist figure can also “sometimes disappear as the technique spreads, evolves, is popularised or institutionalised as a permanent figure of certain organisations”.

With regard to co-design, a large variety of actors can be involved: users or developers of a given technology, certain forms of innovation intermediaries, citizens and other concerned actors such as regulatory agencies (e.g. Kivimaa et al., 2019; Stewart and Hyysalo, 2008). Concerning the co-design specialist figure, it unfolds differently across cases. This role seems to be taken on either directly by the actors that initiate the co-design process (e.g. manufacturers in the good industry), or by external experts that have a specific co-design expertise (e.g. professional designers or researchers). It seems thus interesting to differentiate between two figures: “*co-design experts*” corresponding to the aforementioned specialist figure and the figure of the “*co-design sponsor*”, i.e. the group of actors that takes the initiative of launching a co-design process but that does not necessarily have all relevant expertise. In grand-distance situations, these two figures frequently appear as distinct, which can be easily associated with the increasing issues associated with co-design. For example, in (Abrassart et al., 2015), co-design is sponsored by local libraries but requires the intervention of external experts - here the researchers playing the role of “social designers”.

2.3.3. A technical substratum

This dimension refers to **the arsenal of techniques, tools and methods involved in shaping collective action**. For example, in past rationalisation projects, such techniques included tables for measurement and planning of actions (e.g. to optimise a production line),

but also computers and algorithms in the context of rationalising artificial intelligence and expert systems.

With regard to co-design, this dimension has been largely covered in the different streams of literature reviewed previously, mentioning a large range of tools and methods supporting the co-design process. It for example includes co-simulation tools in engineering design (Wolf, 1994), prototypes, probes, mappings, toolsets (Hyysalo et al., 2019b; Sanders and Stappers, 2014; Visser et al., 2005), toolkits for mass customisation of products (Franke et al., 2008; Franke and Hippel, 2003; Parmentier and Gandia, 2013; Piller and Walcher, 2006; von Hippel, 2001), guidelines and support materials used in workshops (Abrassart et al., 2015; Lavoie et al., 2021), specific forms of diagrams supporting the representation of a given actor's perception of the system at stake and its possible dynamics (e.g. Pluchinotta et al., 2022; Giordano et al., 2020; Pluchinotta et al., 2018).

2.3.4. A reasoning logic

This dimension refers to the reasoning logic followed by the actors involved in the rationalisation project. It was not present in the first pieces of work related to management techniques, but has later appeared as critical to describe collective action directed towards innovation following a specific “design reasoning logic” (Le Masson et al., 2017). This dimension aims to further highlight the **underlying mechanisms supported by the technical substratum**, by especially eliciting the knowledge bases and innovative ideas that are explored.

Considering this dimension seems all the more important as scholars have explicitly associated co-design with intricate exploration and learning processes (e.g. Stewart and Hyysalo, 2008), that appear as particularly extensive in grand distance situations (e.g. Loorbach et al., 2017; Grin et al., 2010). To describe the reasoning logic dimension, we will more specifically rely on “C-K design theory”, that has already been used in several contexts of co-design, especially in recent grand-distance situations (e.g. Lavoie et al., 2021; Berthet et al., 2020; Pluchinotta et al., 2019; Abrassart et al., 2017, 2015; Berthet et al., 2016a).

C-K design theory describes the reasoning logic underlying a design process, as the interaction and the expansion of two spaces: a space K of knowledge and a space C of concepts (Hatchuel and Weil, 2009, 2003):

- The *K-space* gathers all knowledge bases that the designers activate and progressively acquire during the design process (technical knowledge, user preferences, standards and regulations, etc). Formally, a piece of knowledge is defined as a proposition having a logical status: it is either true or false.
- The *C-space* is the space where concepts are explored. Concepts correspond to “desirable unknowns”, “unknowns” because they are undecidable propositions (neither true nor false) with respect to the propositions available in K-space, and “desirable” because that are judged as interesting to explore by the designer (e.g. “a low-carbon emitting flight”).

C-K design theory especially aims to highlight that any design process involves the intertwined expansion of the two spaces. It is essentially rooted in two important considerations. Firstly, it elaborates on the fact that nothing is designed from scratch, but always from existing knowledge. Yet, it also considers that any design process cannot merely rely on knowledge: the formulation of concepts also plays an important role in driving the design process. On this basis, the activity of designing is described as a process where an initial concept can trigger the formulation of new concepts and/or the exploration of new knowledge, and symmetrically the search for new knowledge can also trigger the generation of new knowledge and concepts. The C-space is thus expanded by the production of new concepts triggered by an initial concept and/or new knowledge. In parallel, the K-space is expanded by the production of new knowledge triggered by previous knowledge and/or new concepts. The interactions between the two spaces have been more precisely described as involving four elementary operators:

- $K \rightarrow C$, referred as the “*disjunction*” operator, that consists in creating new concepts in the C-space based on available knowledge in the K-space. The design process starts with the formulation of an initial concept (C_0) resulting from a disjunction.
- $C \rightarrow K$, referred as the “*conjunction*” operator, that consists in creating new knowledge in the K-space resulting from the concept expansion in the C-space. In particular, this is the operator underlying the end of a design path, when the initial concept C_0 has been partitioned up to a proposition that becomes decidable in K.
- $K \rightarrow K$ that consists in the *self-expansion of knowledge* based on classical operations of inference, deduction, optimisation etc.

- $C \rightarrow C$, referred as a “partition” operator, that consists in generating sub-concepts based on existing concepts. The partition can be either restrictive (if it reduces the space of possibilities without revising the identity of the object, e.g. “a house with a red roof”), or expansive (if it revises the identity of the object to be designed by adding a new property that is not known as a possible property of the object, e.g. “a house without roof”).

Figure 3 synthesises the representation of the mechanisms underlying the design process, following the formalisms of C-K design theory detailed above.

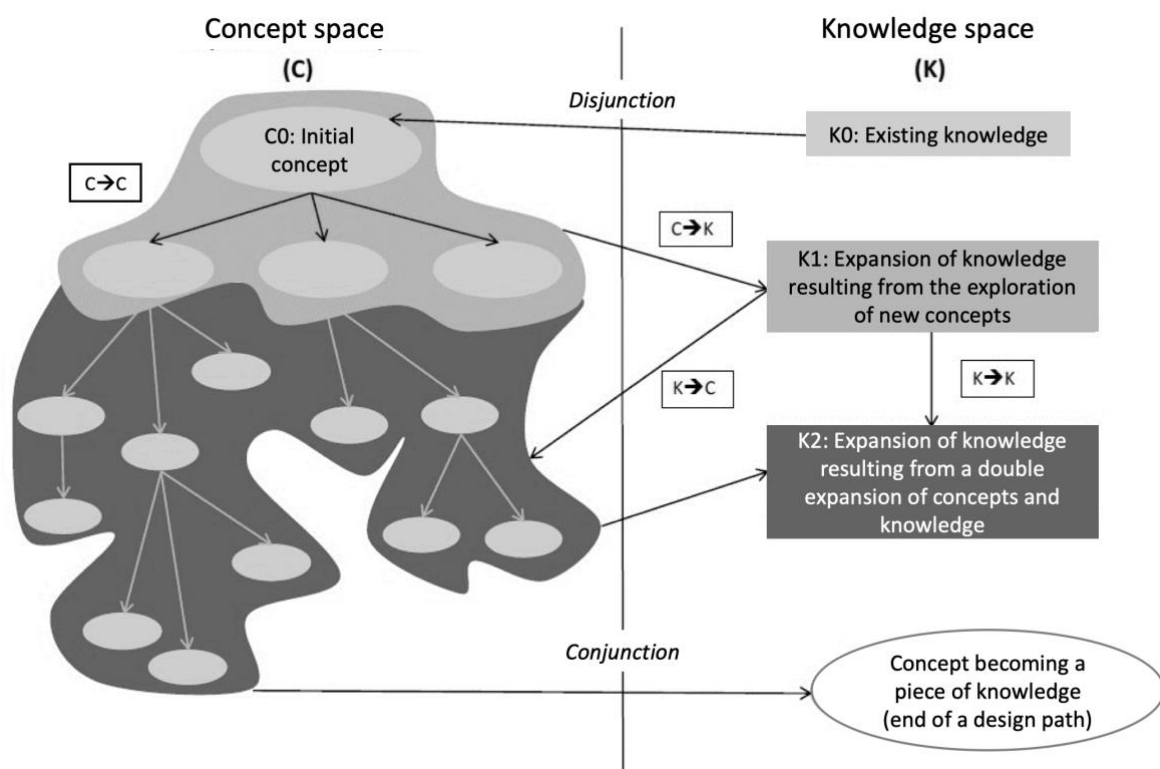


Figure 3: Representation of a design reasoning logic following the C-K theory framework (adapted from (Cabanes, 2017))

Based on this framework, Dubois (2015) has especially highlighted the limits of co-design when merely relying on “**reactive expansion**”, i.e. when the design process is based on a reaction (by analogy with chemical reactions) between each participant’s knowledge. The reaction results in a concept expansion, but no knowledge expansion in addition to the sum of respective participants’ knowledge. In these cases, participants’ satisfaction is mainly related to the fact that they use the knowledge of others and/or others used their knowledge to design a desirable unknown. After several sessions, the participants come to a point where

they have shared their respective knowledge and tend to become weary without new knowledge. To overcome these limitations, Dubois (2015) calls for a continuous management of co-design that would integrate subsequent phases of knowledge expansion.

Note that these C-K design theory principles have especially led to the development of a class of co-design methods named “DKCP” (e.g. Lavoie et al., 2021; Berthet et al., 2020; Pluchinotta et al., 2019; Laousse, 2018; Abrassart et al., 2017, 2015; Berthet et al., 2016a). “DKCP” embraces an overall set of methods and tools, that could be rather designated as a form of technical substratum. However, it is still interesting to comment on the overall process of these methods within this “reasoning logic” dimension, as they directly mirrors the followed reasoning logic, based on C-K design theory. “DKCP” refers to the phases of the process: Definition - Knowledge – Concept – Project (Le Masson et al., 2017):

- DKCP begins with *the D-phase (definition phase)*, consisting in framing the innovation field to be explored and the identification of the relevant actors to be involved;
- Subsequently, *the K-phase (knowledge phase)* focuses on sharing knowledge to prepare the ground for the future exploration of innovative concepts. Participants are expected to share any knowledge (technical, economic, commercial, scientific, legal, use-oriented,...) that might indicate issues in the current solutions, suggesting new potential for development. This phase results in making a “state of the art” (existing solutions) and a “state of the non-art” (anomalies, limits of participants’ expertise), shared by all participants.
- Then *the C-phase (concept phase)* consists in the exploration of original concepts, coined “projector concepts”. These concepts are carefully formulated by the management team to guide the exploration towards counter-intuitive design paths. These concepts aim to be provocative and help the participants to avoid cognitive fixations, i.e. the fact of focusing on design paths that are cognitively easy to formulate.
- *The P-phase (project phase)* focuses on aggregating, recombining and developing the original suggestions from the C-phase to organise a coordinated design process. It does not consist in selecting a couple of feasible ideas but actually consists in building a design strategy that covers very short-term (quick and smart solutions) to very long-term explorations.

The DKCP methods were initially developed for well-established industrial organisations (e.g. Hooge et al., 2016a; Hatchuel et al., 2009; Elmquist and Segrestin, 2009). In grand-distance situations, scholars have been led to adapt these methods to account for the new issues resulting from grand distance, such as the increased complexity of the ecosystem of actors. In such contexts, scholars for example report on the additional efforts needed to build shared unknowns out of the heterogeneous views of participants, as well as the difficulty in going through the process with often stringent time and geographical constraints (e.g. Pluchinotta et al., 2019; Labatut and Hooge, 2016; Berthet et al., 2016a).

2.4. Conclusion on the analytical framework synthesised in a 4x3 table

First, the review of the historical roots of co-design has led us to define co-design as the organisation of a collective design process entailing a specific crisis dimension, i.e. where existing forms of collective action are insufficient to address the design objectives and thus need to be (re)built. Moreover, recent research advances suggest a noticeable tendency towards new forms of co-design that especially deal with a range of issues stemming from grand distance.

In particular, on the one hand, literature suggests that these issues appear at different levels, each one corresponding to a certain timespan and focal point of analysis. **Three levels** can be especially distinguished and are coined 'micro', 'meso', 'macro'. These levels contribute to characterising co-design by showing how it unfolds at the different levels.

On the other hand, to draw the connection between the three analytical levels, literature provides further means of describing the model of collective action underpinning co-design, designated as the "model of co-design". **Four dimensions** are especially relevant to describe such a model: a management philosophy, a simplified view of organisational relations, a technical substratum, a reasoning logic. In order to characterise grand-distance co-design as accurately as possible, we thus ultimately aim to elicit the co-design model following the four dimensions defined above. However, these four dimensions are closely intertwined and difficult to observe separately.

Our research strategy has thus consisted in undertaking several in-depth investigations covering the three different analytical levels. The results of each investigation will be thus discussed with regard to the corresponding analytical level (micro/meso/macro), but also with

regard to how it contributes to shedding light on specific aspects of the four dimensions of the co-design model. The analytical framework used to synthesise our results will thus take a matrixial form (the three analytical levels in columns / the four dimensions of the co-design models in lines). This framework is used to synthesise the first insights on grand-distance co-design drawn from existing literature, as depicted in Table 2 (next page).

Our investigations will lead us to further complete this table, possibly confirming some of the aspects already underlined by literature or unveiling new ones. At this stage, it is not clear yet whether the grand-distance co-design models described in literature are able to address such extreme cases of grand distance as the ones observed in the EO context. Because existing models already address some issues related to grand distance, some aspects of co-design models are likely to be also relevant for the EO context. However, it is also likely that some adaptations and adds-on will be needed to further address the issues resulting from the extreme character of grand distance. The next chapter will clarify the specificities of the context in which co-design has been experimented. The subsequent chapters will then discuss the extent to which the experimented model of co-design aligns with or differs from the identified models of grand-distance co-design.

	Micro level	Meso level	Macro level
Management philosophy	Two-fold design objective: the object and the collective of actors	Fostering the encounter of actors across usual organisational boundaries	Targeting the resilience of ecosystems
Organisational relations	Co-design sponsor with limited orchestration capacities. Potentially supported by co-design experts.	Actors involved in long-term strategies, e.g. playing the role of innovation intermediaries	Involved actors belonging to heterogeneous ecosystems / socio-technical systems
Technical substratum	Combination of workshops, pre-workshop and post-workshops actions	Specific forms of boundary objects	
Reasoning logic	Limits of 'reactive' co-design. Design process steered by a rigorous co-expansion of knowledge and concepts, e.g. DCKP methods adapted to the grand-distance issues.		

Table 2: Analytical framework (boxes in grey) used to synthesise first insights on grand-distance co-design drawn from literature

CHAPTER 3: An intervention research to model and experiment a case of grand-distance co-design in a European project

Summary of Chapter 3

Our inquiry on grand-distance co-design models in the EO context has benefitted from a very rich empirical ground, being directly involved in a large European project called “e-shape”. The chapter first gives a glimpse of the origins of the project and how I ended up embarking on this adventure. The subsequent sections justify the relevance of this project as an empirical field with regard to our research objectives, and expose our methodology based on an intervention-research approach.

Résumé du Chapitre 3

Notre recherche a bénéficié d'un terrain empirique très riche, étant directement impliqués en tant que chercheurs dans un grand projet européen, nommé « e-shape ». Le chapitre donne d'abord un aperçu des origines du projet et comment j'ai été amenée à me lancer dans cette aventure. Les sections suivantes justifient la pertinence de ce projet comme terrain empirique au regard de nos objectifs de recherche, et présentent notre méthodologie basée sur une approche de recherche-intervention.

3.1. A brief look back at the origins of the research work

Our research was initially triggered by a solicitation of another research centre of Mines Paris - PSL University, called “O.I.E.” (Observations, Impact, Energy). Since the 80s, O.I.E. has developed a strong expertise in Earth observation, especially related to the estimation of solar radiation data based on meteorological satellites. Over the years, O.I.E. has gained a renowned position within the EO community, by successfully contributing to the development of various products and services for multiple kinds of users (e.g. energy companies interested in assessing solar energy resources).

In 2018, O.I.E. came to be in charge of structuring a consortium of actors to respond to a call for proposals within the Horizon 2020 programme of the European Commission. The call for proposals defined the scope of the expected project as “*an application-oriented initiative, aimed at showcasing and promoting existing European [GEO (Group on Earth*

observations)] actions [...] relying on existing strengths in Europe. [...]. Based on the core use of a variety of data available within [GEO], actions should scale up and develop a comprehensive suite of products, services or solutions delivering economic, social and policy value to European citizens, making use of state-of-the-art data integration and fusion techniques.” (SC5-15-2018 action described in (European Commission, 2018, p. 66)). A strong emphasis was especially put on developing added-value products and services for and with real users.

At that time, our research centre, the Center for Management Science (CGS) had fairly recently undertaken research on co-design within Louis-Etienne Dubois’ thesis (Dubois, 2015), especially building upon its strong expertise in innovation management and design theory developed within the Chair of Design Theory and Methods for Innovation (DTMI) since 2009. Having identified Dubois’ research, O.I.E. contacted the DTMI team to explore the possibility of bringing a certain co-design expertise to the consortium. Although our lab was completely new to the EO field, the questions at stake appeared as particularly intriguing and stimulating. They especially resonated with past and current research trajectories developed by the lab, on new innovation patterns related to digital and sustainability transitions, associated with new trends in design and innovation methods – see for example Caroline Jobin’s thesis investigating the flourishing use of “POC” (proof-of-concept) in contemporary organisations (Jobin, 2022). The DTMI team thus saw in the project a promising opportunity to advance their own research on these different topics, and joined the consortium to take charge of the work-package dedicated to co-design.

On my side, in 2018, I was finishing my Master’s degree in engineering at Mines Paris, having followed the major “Engineering design and methods for innovation” led by the DTMI team. My final year project consisted in exploring “technology-push” strategies in the context of a company designing motors, sensors, actuators mainly for the automotive industry. I was especially in charge of setting up and implementing a methodology to support the design of applications for a new material developed by the R&D department of the company. Although I was initially not sure of doing academic research later on, I was actually mainly torn between joining the public sector or the spin-off consultancy company of our lab to continue building up my expertise in design and innovation methods and putting it at the service of

organisations and society. However, when I heard of the PhD position opening up within the project in the EO field, I quite quickly decided to take the plunge.

Although I was completely new to the EO field, I saw this PhD subject as a way of going on a stimulating adventure that combined a lot of the aspects I was craving to explore: (i) the stakes related to Earth science and socio-environmental challenges, (ii) the current trends on open data considering data as a common good that could help address these challenges, (iii) the possible contributions of design theory and innovation management methods that I had found particularly powerful during my studies and final year project, and last but not least (iv) the opportunity of working in an international environment gathering teams all over Europe, and witnessing what could be a form of European “public service”. I applied to the position and started this PhD journey in September 2018, before the project officially started in May 2019.

3.2. The project “e-shape”: an empirical field particularly adapted to investigate a case of grand-distance co-design

The consortium gathered under the name of “e-shape”, standing for “EuroGEO Showcases: Application Powered by Europe”, received a 4-year grant (2019-2023) from the European Commission. The context of e-shape has provided us with an exciting and particularly favourable position to investigate a case of grand-distance co-design, in an extreme situation of grand distance as faced by the e-shape partners.

3.2.1. Contextual elements of the project “e-shape”

e-shape was built as a legacy of previous EU projects, bringing together decades of public investment and expert teams, into operational services with high socio economic value for the citizens, the industry, the decision-makers and the researchers. In particular, the project leveraged existing EO resources from the EU Copernicus programme and GEOSS (the Global Earth Observation System of Systems developed by GEO to facilitate the sharing of EO data collected from the large array of observing systems contributed by countries and organisations within GEO). The objectives of e-shape entailed (1) the development of operational EO services with and for the users and creating a conducive environment for addressing societal challenges, (2) but also more profoundly contributing to establishing

EuroGEO, the European component of the intergovernmental organisation GEO (Group on Earth Observations).

e-shape initially gathered a team of 54 experienced partners from academia, industry, institutional entities and user communities to develop 27 pilot applications based on EO data, gathered in **seven showcases (agriculture, health, renewable energy, biodiversity, water resources, disaster resilience and climate)**. This initial pool of partners was expanded within the lifetime of the project through the progressive on-boarding of 5 new pilots in 2020 and 5 others in 2021, finally expanding the **number of partner organisations to 68 and the number of pilots to 37**. Each pilot was in charge of developing a certain set of products or services within a specific showcase. It involved one or several organisations that are members of the project, and was coordinated by one of these organisations designated as the “pilot leader”. As an initial condition for project participation, each pilot interacted with at least one user organisation. These user organisations did not receive direct funding from the project and were thus considered as external actors to the project.

It is here worth noting that the pilots have a specific position in the EO field. They leverage existing ICT resources (especially data produced by available satellites or other measuring instruments, and also increasingly infrastructures offered as a service by certain actors – especially for cloud computing), and focus on building value-added products or services on top of these resources. In this regard, **the pilots have a kind of intermediary position, aiming to bridge the distance between data producers and different forms of data users**. As such, they are directly concerned with the issue of grand distance as depicted in the introduction.

The nature of the considered users might vary depending on the cases. It happens that these pilots target end-users that benefit from the value-added products without using them to design another service for another user (e.g. farmers). But most frequently, the pilots rather target data users that have strong design competencies and will be able to take charge of the last miles up until end-users (e.g. reaching municipalities or other entities developing their own air pollution monitoring and alerting system, rather than directly reaching citizens facing air pollution issues).

One can notice that the organisations involved in the different pilots might also intervene in other spots of the EO landscape. For example some of the e-shape partners also

directly operate their own satellites (such as the company DEIMOS). However, their role within e-shape was mainly related to the value-adding function (see Figure 4).

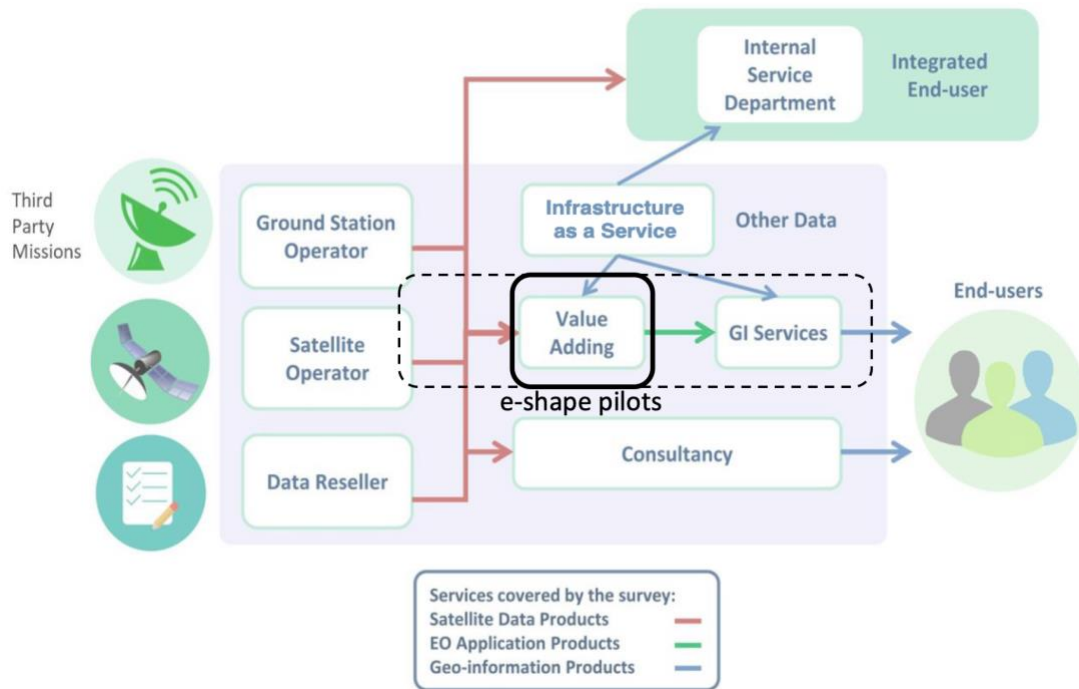


Figure 4: Position of e-shape pilots in the EO field: main focus on the value-adding function although the organisations undertaking the development of pilots might also intervene further upstream or downstream (source of background picture: EARSC Industrial Survey 2021)

The pilots involved various types of organisations, that can be categorised as follows:

1. National meteorological institutes (of Sweden, Finland, Germany, Austria);
2. A various range of public research institutes, such as the National Observatory of Athens (NOA), the Italian Council for National Research (CNR). The public institutes sometimes partner with private partners to take charge of engineering and or commercialisation of the developed EO-based solutions.
3. Other forms of research institutes. Some of them could be described as Research and Technology Organisations (RTOs) such as the Luxembourg Institute of Science and Technology (LIST) or VTT Technical Research Centre of Finland.
4. Well-established commercial firms (such as DEIMOS in Portugal especially developing maritime surveillance systems, CLS in France specialised in delivering value-added products and services for environmental monitoring since 1986).
5. Emerging SMEs and start-up (especially among the last on-boarded pilots).

3.2.2. Role of our research team in e-shape

Throughout the project, the development of pilots has been supported by seven different work packages, respectively in charge of the following activities: (1) project management, (2) co-design, (3) implementation, (4) user uptake, capacity building and liaison activities, (5) sustainability & upscaling, (6) communication and dissemination, (7) ethics requirements (see Figure 5). Our team has been involved in the project as leading the work package dedicated to co-design (WP2). Our role has consisted in building and experimenting a co-design model adapted to the issues faced by the EO field, in interaction with the pilots.

As such, we have benefitted from a **privileged access to the different pilots**, in particular giving us insights on how they have been dealing with the issue of grand distance, and how co-design can possibly address grand distance. Our team entailed three members at the beginning in 2019 (*myself*, in charge of co-leading the work package; *Pascal Le Masson* and *Benoit Weil*, my two PhD supervisors, supporting me in this role). It was completed by a fourth member in 2020, *Skander Ben Yahia*, who joined the team as intern and then research engineer, to help us conduct the various activities of the work package in the project.

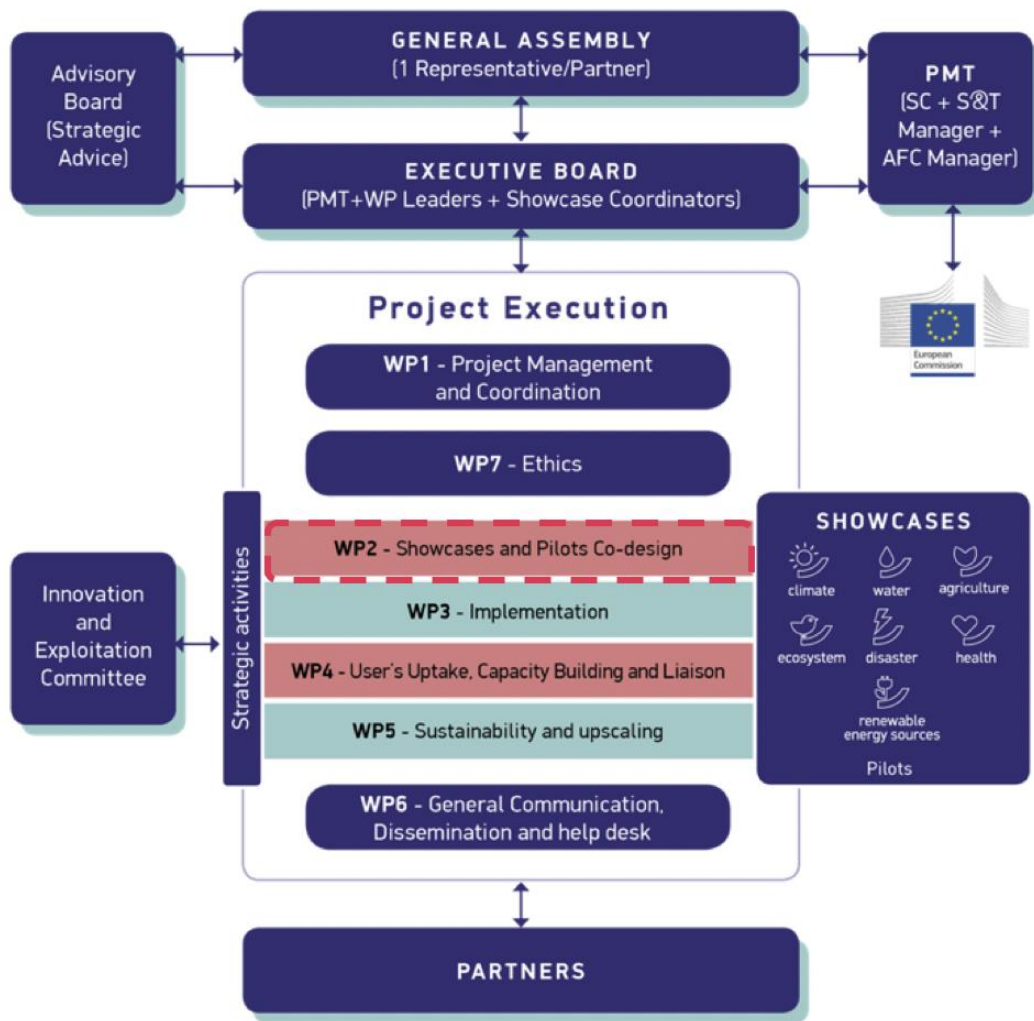


Figure 5: Structure of e-shape project: involvement of our research team in WP2

It is important to highlight here **that our position as co-design work package leaders has been defined as mainly playing the role of a “safety net”**, i.e. letting the pilots lead their overall co-design trajectory, while providing support to the pilots when their own expertise come to be insufficient to address the issues at stake.

Several factors have especially motivated the choice of this configuration. Firstly, from a practical perspective, we could not have afforded undertaking all co-design efforts on the behalf of all pilots given the large number of pilots and our limited human resources. Secondly, the pre-existing co-design experience of the pilots allowed them to be already quite autonomous in their co-design approach.

To illustrate this second point, Box 2 (see next page) details the example of one of the pilots, involved in the biodiversity showcase, aiming at exploring the value of space-based remote sensing techniques for park managers of protected areas. The box especially

summarises the minutes of the meeting organised with this pilot for us to learn about their past experience of co-design. This case illustrates particularly well that:

- Although not explicitly referring to grand distance, a number of issues related to grand distance can be noticed (nature of the problem not known in advance, differing perceptions and languages, relationships difficult to establish and maintain over time).
- They already try to take into account such issues in their co-design approach (organisation of dedicated meetings, specific way of organising the dialogue and asking questions).
- However the success of co-design is acknowledged as nowhere near guaranteed, suggesting that some grand-distance issues remain insufficiently addressed.

To conclude, the empirical context of **e-shape appears as a promising ground to experiment models of grand-distance co-design**. In this context, **the figure of the co-design sponsor is endorsed respectively by the different “pilots”**, i.e. the actors involved in developing EO-based pilot applications for a variety of users’ ecosystems, and thus dealing with an extreme situation of grand distance as highlighted in Chapter 1. In e-shape, this endeavour is recognised as requiring a dedicated form of co-design expertise, hence the involvement of **our research team representing the figure of external co-design experts**, in charge of complementing the respective expertise of co-design sponsors.

Box 2: Extract of the minutes of a meeting between our team and e-shape partners leading a pilot on biodiversity and having past co-design experience (here within the project called “ECOPOTENTIAL”).

In the ECO POTENTIAL project, the rationale of co-design consisted in defining a storyline with a well-identified user community formed by technical staff and park managers mainly working in 26 Protected Areas such as national parks. Inside these parks, the specificities of users’ practices needed to be better understood and taken into account. Co-design especially involved:

- **Going beyond simple questionnaires:** the latter might be interesting for specific questions but only once the contact is well established;
- **In-person meetings** (at least 3 by protected area): the ECO POTENTIAL team especially highlights that gaining the users’ trust by physically and regularly meeting them proved to be critical. Sometimes, it involved finding local scientists speaking the same language.
- **"Storylines" were used** to formalise the outcomes of the interactions with the different areas.

The ECO POTENTIAL scientists have especially underlined what kinds of issues they have been facing and what they have learned from ECO POTENTIAL and previous experiences:

- **The nature of the problem is not known before hand:** efforts are needed to progressively shape a common problem, resulting in a new understanding of the situation. Example of the explanation of population dynamics in a mountainous park: park managers

explained a decrease of population by the coldness of the day. For ECOPOTENTIAL team, it was explained by density and snow cover. Both were right but they did not share the same perception and language.

- **The way of expressing the problem is also biased in a way:** there is a difference between the needs perceived by the ECOPOTENTIAL scientists and those expressed by the park staff. For the ECOPOTENTIAL scientists, the problems were always related to the project they were specifically working on (e.g. biodiversity monitoring and conservation). Whereas, the park managers were also concerned with other kinds of issues, such as the impact of tourism on the area. It had been evolving over time: at the end of the project, the scientists further took into account the practical problems uttered by park managers, but park managers' perception did not change much.
- **Need to be careful when organising the dialogue** between ECOPOTENTIAL scientists and park managers. Indeed, at first, ECOPOTENTIAL scientists were the only ones to speak, then they changed the process to let more space for park managers to speak.
- **Position to have within the interactions is very important:** the ECOPOTENTIAL scientists became especially aware that it was important to refrain from saying "I will tell you what to do", nor say "please tell me what to do" (because sometimes the park managers might not know the problem yet). You have to go with an idea but be ready to tune the idea.
- **Building long-term relationships goes beyond the project lifetime:** in the case of ECOPOTENTIAL, half of the relationships already existed before the beginning of the project and have been maintained afterwards for successful cases. Different means of sustaining these relationships: in-kind resources (even without funding), involvement in new projects, having a Research Infrastructure offering a specific framework in which it's easier to continue.

Out of the 20 or so cases of ECOPOTENTIAL project, around 10 were very successful. The ECOPOTENTIAL team has identified different factors of failure depending on each project: **bad luck, lack of contact with the park staff, poor definition of the problems encountered.**

3.3. Research approach: an intervention research motivated by our research purpose and the favourable conditions offered by e-shape

Having justified the relevance of the project e-shape as an empirical field to investigate grand-distance co-design models, several kinds of research approaches could have been imaginable within this field. The next paragraphs will expose why we have chosen to rely on an intervention-research approach. The latter approach indeed appears especially relevant with regard to our research purpose and strategy, and suitable with the conditions offered by the empirical context of e-shape.

3.3.1. Relevance of intervention research with regard to our research purpose and strategy

To clarify the followed approach, it is useful to rely on the distinction between several approaches in management research proposed in (David, 2012), synthesised in Table 3.

		Objective	
		Mental construction of reality	Concrete construction of reality
Approach	Starting from observed facts or a the reflexive work of a system on its own inner workings	<p><i>Observation (participatory or not)</i></p> <p>Elaborating a model describing the inner workings of the investigated system.</p>	<p><i>Action research</i></p> <p>Helping to transform the investigated system based on its own reflexive action, based on a collaboration with practitioners.</p>
	Starting from an idealised situation or a concrete project of transformation	<p><i>'In-house' design of management models and tools.</i></p> <p>Elaborating potential models and tools without direct link with an empirical field.</p>	<p><i>Intervention research</i></p> <p>Helping to design and implement management models and tools on the ground, drawing from a transformation project that is more or less clearly defined.</p>

Table 3: Various methodological approaches in management research (adapted from David, 2012; p. 133)

The context offered by e-shape has led us to put aside the approaches driven by an objective of “mental construction of reality”. Indeed, our direct involvement in the project directly discards a mere “in-house” approach. Moreover, a mere observation-based approach would not have been consistent with our research purpose. Indeed, it would have consisted in merely describing the models of grand-distance co-design as already implemented by e-shape partners. However, as described previously, the existing co-design practices of e-shape partners prove not to completely address the extreme level of grand distance at stake. Moreover, e-shape partners had barely formalised their practices into a proper co-design model. Drawing a model of co-design from their own description of co-design would not have led to a very convincing conclusion. This is particularly well illustrated by the following verbatim, coming from an e-shape partner depicting its initial view of co-design:

*“When we are preparing the proposals, there are always lists of keywords or buzzwords to use to make them catchy. In EuroGEO, the trend was co-design but, in our minds, [...] **we thought sitting and discussing with stakeholders is just co-design.**”*

These elements have driven us towards a research approach involving a concrete construction of reality through a strong collaboration with practitioners, especially providing researchers with a direct access to the issues at stake. Such approaches basically consider that the collaboration between researchers and practitioners can highly benefit both parties: *“Managers [i.e. practitioners] are continuously acting out models of good management but are not always aware of where the models came from, how they were developed, whether they are robust, or whether they fit the current circumstances. Management scientists are continuously building new models while keenly observing what is going on in the world of business. If the two groups join forces they will have the components necessary for faster and more relevant knowledge creation: model building, testing out models, observing consequences, and analyses of cause and effect”* (Pasmore et al., 2008, p. 9).

To a certain extent, intervention research and action research appear as fairly close (Coghlan et al., 2012). They especially share the following aspects: the objective of fostering changes in organisations while generating scientific knowledge, and a strong collaboration between researchers and practitioners. However, a fine line distinguishes these two approaches. As synthesised in Table 3 and further explained by Radaelli et al. (2014), the main difference lies in the nature of the theoretical objective and the ability to produce knowledge beyond its context of application: in action research, *“scientific knowledge is both produced and applied within the context of application”* (p. 339), whereas in intervention research *“scientific knowledge is [...] produced in a specific context of application, but transferred to the level of a general theory of action”* (p. 339).

In other words, compared to these other approaches, **intervention research is more specifically driven by the theoretical objective of identifying, evaluating and formalising models of collective action** (Hatchuel and David, 2008). In this perspective, intervention research involves detecting and validating innovative management models when already developed by some forms of “pioneering organisations”, but also possibly designing new ones when relevant (Hatchuel and David, 2008, p. 151). The investigated models are progressively formalised based on loops of “stimulus-response” mechanisms (Hatchuel and Molet, 1986). Researchers can indeed propose a tentative formalisation of models that aim to be both actionable in practice and theoretically grounded, especially drawing from their integration into the empirical context and their connection with various academic fields. The proposed

models can then be tested and enriched based on practitioners' responses, creating learning for both researchers and practitioners, and possibly leading to new stimulus-response loops.

As such, intervention research is particularly **aligned with our research purpose** that precisely aims at unveiling and characterising models of grand-distance co-design, i.e. models of collective action underlying co-design in grand-distance situations. Moreover, Radaelli et al. (2014) show that intervention research provides helpful support for multi-level of analysis, by grounding its investigation in collective action and considering that *“the behaviours of individuals, teams and organisations need to be investigated through their mutual interactions”* (p. 340). Consequently, intervention research is also **well suited to conducting our research strategy**, consisting in investigating co-design models at three different levels of analysis.

3.3.2. Relevance of intervention research with regard to the setting offered by e-shape

It is important to note that specific conditions are required to conduct intervention research effectively (Hatchuel and David, 2008). First, the selection of managerial partners for the intervention research needs to be driven by an **“assessed research potential”** (Hatchuel and David, 2008; p. 157). Such potential was already described in previous paragraphs (see section 3.1.). Indeed, it was the factor that precisely led the DTMI team to accept the proposition of joining the consortium.

The activities of the research team and the commitment of practitioners to the research endeavour especially need to be backed up by a **clear contractual agreement** explicitly stating the pursued research objectives. It is important to make clear that the agreement *“is not a consulting contract. [...] The academic team should not commit to [merely] solving a problem or conducting some planned change”* (Hatchuel and David, 2008; p. 152). In e-shape, the involvement of our research team as “co-design work package leaders” provided us with an official mandate legitimising our intervention in interaction with e-shape partners. The grant agreement of the project also clearly indicated that our intervention entailed a strong research objective, and was not to be considered as a mere form of consultancy (that would have consisted in applying off-the-shelf co-design methods to the specific context of e-shape).

Moreover, Hatchuel and David (2008) highlight that intervention research is stimulated by management issues occurring in so-called “pioneering organisations”. In this respect, let us recall that e-shape partners were selected based on their previous credentials and efforts in developing EO-based products and services. As detailed above, they had already experienced some forms of co-design before the project, which yet came to be sometimes insufficient to address the level of grand distance at stake. The pilots could thus be considered as **pioneering organisations already experimenting some forms of grand-distance co-design**, although the underlying model remained not explicitly formalised. **These pioneering organisations were also willing to explore new models of co-design within the project**, to better address the encountered grand-distance issues.

3.3.3. Focus on a few epistemological stances underlying intervention research

From an epistemological perspective, intervention research relies on the stances of collaborative management research (Shani et al., 2008). It basically considers that **the rigour of research is less a matter of reducing the interactions with the investigated object than controlling these interactions in a reflexive way**.

Indeed, management research investigates the organisation of collective action, that is by nature an ongoing and dynamic activity. As eloquently recalled by Pasmore et al. (2008), it is *“difficult or impossible to bring an entire organization into the laboratory where we can control everything that takes place”* (p. 16), and *“the social science researcher, and especially the collaborative management researcher, cannot remain detached from the people under study [...], [they] cannot help but change the phenomena that are being studied, because that is the very nature of organizing.”* (p. 18). The researchers contribute to the construction of the studied reality, thus following a design logic (David, 2012; Hatchuel, 2005). As such, collaborative management research turns away from a merely positivistic stance that would consider the reality as an “out there” territory to be studied in a controllable environment where the bias of researchers can be removed (e.g. Reason and Torbert, 2001; Susman and Evered, 1978).

The rigour of research relies on the acknowledgment of the interactions between the researchers and their object of investigation, and the implementation of methods and processes *“intended to reduce the likelihood of drawing false conclusions from the data*

collected” (Pasmore et al., 2008; p 20). In particular for intervention research, Radaelli et al. (2014) emphasise the need of going beyond the criterion of generalisability that does not well reflect the most important outcomes of intervention research. The authors propose the three following criteria: **(1) accommodation**, i.e. *“the extent to which research results in knowledge that can be used in diverse, comparable contexts where similarities and differences can be assessed”* (p. 341) ; **(2) catalytic validity**, i.e. *“the extent to which the research imbues the people involved in it with novel ways of understanding reality and of using that knowledge for positive change”* (p. 348), **(3) authenticity**, i.e. *“the extent to which research findings represent agreement on what is considered to be true”* (p. 341).

3.4. Setting up a rigorous process to build, experiment and assess models of grand-distance co-design within e-shape

The rigour of our research has been especially ensured by setting up: (1) a collaborative protocol with practitioners aiming at jointly exploring models of grand-distance co-design (section 3.4.1), (2) a joint and continuous monitoring process of research outcomes (section 3.4.2.), (3) a regular confrontation with practitioners and scholars outside e-shape to test the validity of the produced knowledge beyond the boundaries of the intervention (section 3.4.3.). Figure 6 gives an overview of the temporal unfolding of the two first aspects.

e-shape Start Date
 ▲ 01/05/2019

e-shape End Date
 ▲ 30/04/2023

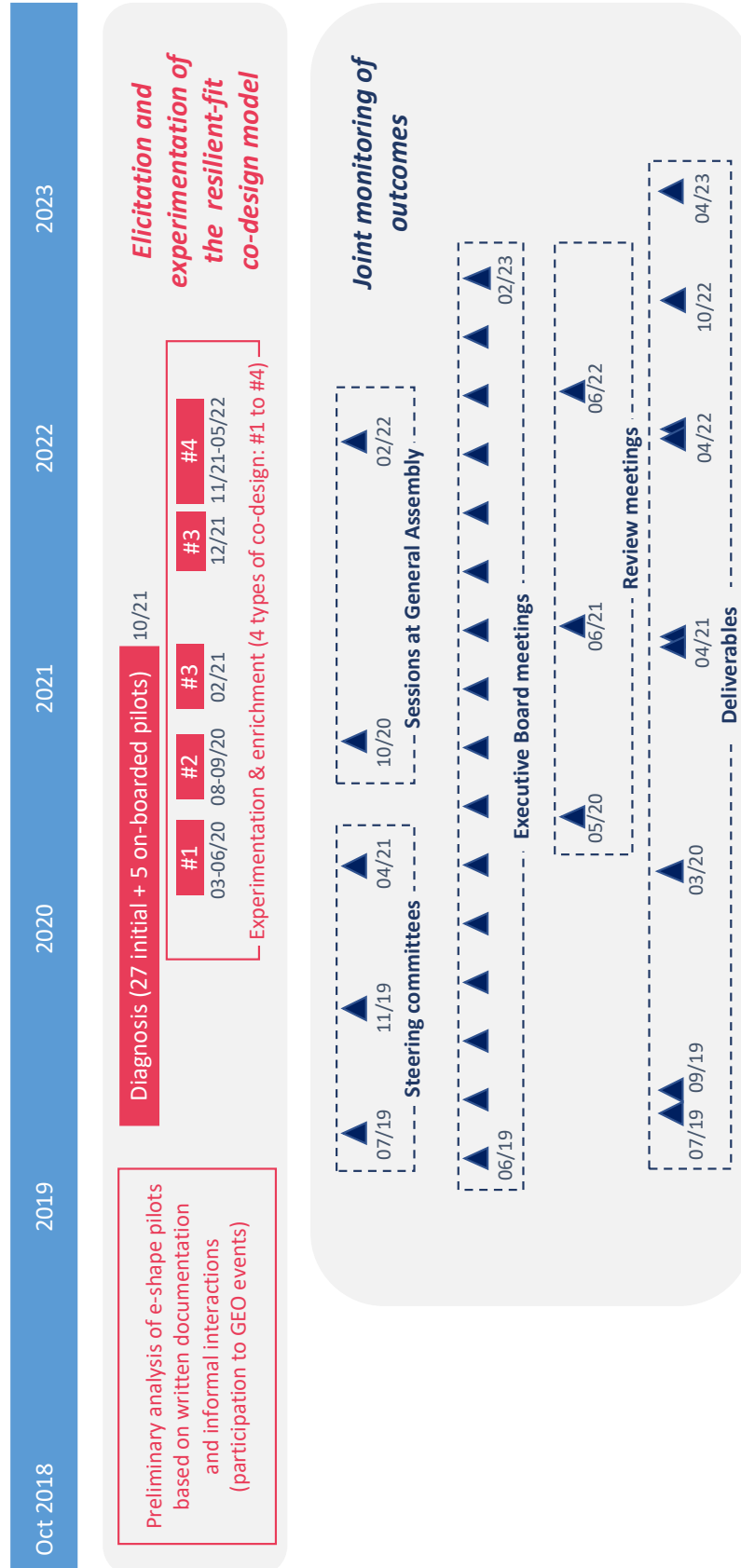


Figure 6: Synthesis of the interactions involved in: (1) the collaborative protocol with practitioners aiming at building and experimenting the resilient-fit co-design model (in pink), (2) the joint and continuous monitoring process of research outcomes (in dark blue)

3.4.1. Collaborative protocol with practitioners focused on jointly exploring grand-distance co-design models, in particular “the resilient-fit co-design model”

Our research followed the typical steps of intervention research, as especially introduced in (Hatchuel and Molet, 1986). The process was initially triggered by a certain “feeling of discomfort”: at the outset, e-shape partners expressed their difficulties in conducting co-design and fostering long-term outcomes. However, it is important to note that **the issue of grand distance was not directly articulated as such by e-shape partners at this stage**. Subsequent phases were thus needed to elicit the nature of the problem and experiment models of collective action addressing this problem, based on loops of “stimulus-response mechanisms” (Hatchuel and Molet, 1986), where the intervention of researchers create a stimulus followed by a response of the practitioners, creating a learning process both for the researchers and practitioners and the different actors of the organization.

3.4.1.1. Diagnosis of the management problem: characterisation of grand-distance situations and associated models of co-design

Following Hatchuel and Molet (1986), a phase needs to be dedicated to *“translating ‘feelings’ into concepts [...], and constituting a theory of the organizational structure associated with the problem”* (Hatchuel and Molet, 1986; p. 181). In the case of e-shape, it consisted in better understanding in which context co-design took place, i.e. the design processes undertaken by the pilots and the encountered difficulties. This investigation took a multi-faceted format, involving a so-called “mini-drill exercise”, focusing on an in-depth investigation of one of the pilots, followed by a thorough “diagnosis campaign” organised with all pilots. Note that the diagnosis campaign followed a twofold objective: a methodological objective by supporting the critical initial steps of intervention research, but also a practical objective with regard to our role of work-package leaders to help the pilots reflect on and possibly transform their own co-design practices (here by enriching their own diagnosis of their respective co-design needs). The next paragraphs will focus on the first aspect, thus describing the diagnosis from a methodological point of view with regard to the intervention-research process. As for the second aspect, it will be further elucidated in Chapter 5 (see section 5.2. related to the “technical substratum” dimension).

Regarding the mini-drill exercise, we chose to focus on the pilot led by the centre O.I.E., given the facilitated access for us belonging to the same research institution, as well as O.I.E.'s specific position in the project. Indeed, not only was O.I.E. in charge of leading a pilot, but the centre also endorsed the role of the energy showcase coordinator and of the project management team. Our investigation on the O.I.E.'s pilot involved:

- Between October 2018 and April 2019, a *tentative formalisation by our research team* of the current status of O.I.E.'s pilot and its place within its overall trajectory (past history and projected future). To this end, several types of materials were used: a 6h interview with the previous O.I.E.'s director exploring the outlines of O.I.E.'s history since the 80s, as well as secondary sources (articles and books written by O.I.E.'s researchers and project archives in which they were involved),
- In April 2019, *presentation of the tentative formalisation to O.I.E.* (organisation within a dedicated one-day meeting), and analysis of their feedback.
- *The tentative formalisation was then updated* based on O.I.E.'s feedback.

The mini-drill exercise with O.I.E. thus enabled us to make a first diagnosis of the situation of O.I.E.'s pilot and the issues at stake. It especially resulted in formalising the issue of “grand distance” as underpinning the co-design difficulties encountered by the actors of the EO community (the concept of distance can be traced back in one of my early presentation to a doctoral seminar in June 2019). Moreover, the mini-drill exercise was also designed as a means of testing and validating the “diagnosis” process to be later organised with the remaining pilots. A steering committee was later organised in July 2019 to discuss and validate the proposed process with all showcase coordinators. This led to a long-lasting campaign of diagnosis with the 27 initial pilots (repeated later on with the 5 new pilots onboarded in 2019). For each pilot, the diagnosis was organised in a similar way to O.I.E., involving for each pilot: *(i) the tentative formalisation of the pilot's situation of grand distance, (ii) the enrichment and validation of this tentative formalisation* by interacting with the pilot (exchanges on the on-line management platform followed by a 1h30 interview), *(iii) the updating of the formalisation in a shareable and synthetic format* (written report shared on the management platform complemented by a visual template of the pilot). Based on the large variety of pilots in e-shape, the diagnosis campaign proved to be especially useful to further characterise the

variety of grand-distance forms and the associated co-design issues. It appeared especially useful to distinguish between four types of co-design, each one corresponding to targeted issues stemming from grand distance. In November 2019, although the diagnosis campaign was not completed yet for all pilots, a second steering committee was held by our team to discuss and validate the preliminary results of the diagnosis phase. We especially presented how a variety of grand-distance issues could be characterised, the underlying model of co-design and how subsequent forms of experimentations could be conducted (corresponding to the four identified types of co-design).

To summarise briefly the conclusions of the diagnosis phase, it has especially led us to formulate the following hypothesis: *the difficulties faced by the pilots in developing added-value data-based solutions cannot be merely explained by the sole characteristics of data (e.g. quantity, quality, availability, cost)*. These elements can of course have an impact. But, EO data already address a large number of these potential hindering factors: a tremendous amount of data already exist, scientifically-validated processing chains are already available to ensure the quality of data, numerous datasets are already easily accessible at low or no cost thanks to open data policies that have been deeply rooted in the development of the international EO community for at least several decades (Harris and Baumann, 2015). As an alternative hypothesis, our analysis of the pilots has led us to assume that *the difficulties of the pilots are likely to stem from co-design practices that tend to underestimate or insufficiently address the grand distance at stake*. Indeed, the analysis has revealed that the pilots are especially at **risk of ending up creating “short fits”**, i.e. relationships with certain relevant partners that are initiated in the short term, that however fade away in the long run due to grand distance. Moreover, as researchers, we were aware of recent advances on co-design suggesting that grand-distance could be at least partly addressed by adapting the co-design process to the nature and level of grand distance at stake. These considerations have led us to propose *an alternative co-design model putting at the forefront the idea of fostering adequate and long-lasting relationships by managing the short-fit risk as systematically and explicitly as possible*. The proposed model was later **coined “resilient-fit co-design model”** to emphasise the pursued endeavour of avoiding short fits by alternatively building up their resilient character.

According to Hatchuel and Molet (1986), the resilient-fit co-design model takes the peculiar status of a “**rational myth**”, combining the functions of a scientific hypothesis and a myth. It is “rational” in the sense that is built upon consistent deductions and inferences, thus appearing as a rigorously built hypothesis. However, it does not necessarily intend to reach the same level of formalisation as a mathematical model. It rather aims at producing an hypothesis that remains open to revision and that is stimulating enough for actors to reconsider and possibly transform their existing model of action. This is where its function of myth comes into play. The term “myth” underlines that it aims at expressing an understanding of reality that might appear as a bit utopic or far-fetched as in stories and fairy tales, but that has the advantage of stimulating imagination and questioning engrained perceptions.

3.4.1.2. Experimentation and enrichment of the “resilient-fit co-design model”

Building on the resilient-fit hypothesis, a second critical phase of intervention research was then designed to transform the rational myth into a set of logics, that can be experimented and enriched with practitioners. In our case, it involved **organising with a few volunteering pilots some pinpointed experimentations**. In particular, we ensured that each co-design type identified in the previous phase (corresponding to a delimited set of issues stemming from grand distance) could be experimented with at least one pilot. An additional experimentation was carried out for one of the types responding to a specific demand.

It is here important to note that by construction, because the experimentations were run on a voluntary basis, they primarily concerned the pilots for which the grand-distance issue appeared as especially critical or hard to manage, thus motivating the exploration of the alternative “resilient-fit co-design model”. Each experimentation involved:

- A dedicated *preparatory step*, consisting in proposing and validating the set of logics to be experimented with the pilot through a series of meetings;
- An *experimental step*, basically consisting in the organisation of co-design workshops;
- A *feedback step*, aiming at identifying the nature of leanings both for the practitioners (how the experimented set of logics proved to be helpful with regard to the objective of building resilient fits); and the researchers (how to further improve the set of logics associated with the resilient-fit co-design model to progress towards the resilient-fit objective)

Chapter 5 will further portray the set of logics associated with the workshops, as well as pre-workshop and post-workshop actions, as resulting from these loops of experimentations. Chapter 5 will also indicate some limitations and perspectives for future experimentations.

Finally, note that the results of these experimentations were then shared and discussed with all project members, especially within a steering committee organised in April 2021. As such, the relevance of the resilient-fit co-design model could be validated beyond the single cases of the volunteering pilots. The various devices that supported the validation process are further detailed in next section.

3.4.2. Focus on the devices supporting the joint and continuous monitoring process of research outcomes

Building a joint and continuous monitoring process of research outcomes plays a crucial role in ensuring a robust collaborative protocol (Hatchuel and David, 2008). Several forms of devices especially enabled us to regularly share and discuss these results with the project partners, including:

- *Written deliverables* (9 in total) progressively formalising and characterising the resilient-fit co-design model (reviewed by at least two external actors, submitted to the European Commission and shared publicly on the project website after validation);
- *Steering committees* organised at the most critical moments of the intervention research (see previous section), to discuss and validate the current status of the investigated resilient-fit co-design model and the next steps to conduct;
- *Other meetings* serving as a way of communicating and discussing our research outcomes, such as: Executive Board meetings aiming to monitor and analyse the project progress gathering the project management team, the work-packages leaders and the showcase coordinators; dedicated sessions at the General Assembly of the project, gathering all e-shape partners, as well as annual Review Meetings dedicated to the assessment of the project progress by the project officer of the European Commission and two external reviewers, and requiring the project management team, showcase coordinators and work package leaders to report on their respective activities.

Table 4 gives an overview of the different types of collected empirical materials throughout the different steps of the intervention research (related to both the collaborative protocol and the joint monitoring of outcomes).

		Contextual elements	Collected materials
Collaborative protocol	Diagnosis	32 pilots, each corresponding to a specific grand-distance situation, categorised in 4 main types.	In total 48h of interviews, leading to around 120 pages of synthesis notes (systematically validated by the interviewees after the interview)
	Experiments	5 pilots (one for each type of co-design + one more pilot for the 3 rd type of co-design)	In total 35h distributed among preparatory steps, experimental steps and feedback steps. Ranging from 4h to 10h for a given pilot. Leading to about 75 pages of intermediary and final synthesis notes (again validated by the participants)
Joint monitoring of outcomes	Deliverables	9 deliverables (8 written + 1 still to come)	About 250 pages in total, tracking the progressive enrichment of the resilient-fit co-design model
	Steering committees	Gathering our research team and main e-shape representatives (at least project management team & showcase leaders)	In total 6h (2h for each meeting) of presentation & feedback discussion. About 3 pages of notes – mainly noting down verbatims.
	Other meetings	Presentation of the status of our work at executive board meetings, general assemblies and review meetings	About 90h in total. Personal notes taken during these meetings, not directly used for data analysis, but for my own understanding of the project. About 20 pages of transcribed discussions.

Table 4: Overview of the collected empirical materials for the different facets of our research process

3.4.3. Focus on the devices managing the “transference” risk of intervention research

Researchers involved in intervention research benefit from a privileged proximity with their object of investigation, giving them access to very rich empirical materials. However, in this proximity, Aggeri (2016) also highlights that researchers might face a “transference” risk, i.e. becoming caught into the specificities of the studied organisations. There is thus a need of organising dedicated mechanisms to counter this form of enclosure, in particular through regular interactions with external actors outside the sphere of the investigated organisations. In my PhD research work, these mechanisms have been put in place through interactions with both academia and practitioners.

3.4.3.1. Interactions with academia

The advances of my PhD work have been regularly presented to the other members of the Center for Management Science and of the Interdisciplinary Innovation Institute (i3):

- Individual thesis committees (June 2019, May 2020, July 2021);
- Doctoral seminars (March 2019, April 2021) ;
- Meetings of the Chair Design Theory and Methods for Innovation (November 2019, October 2020);
- Thematical research day of i3 (March 2021).

More broadly, research results have been frequently shared and discussed with different academic communities (see Table 5).

Type of publication / communication	Academic community / editor	Details
Conference paper	Innovation & Product Development Management	Barbier, R. , Thomas, M., Le Masson, P., Weil, B., (2019). Revisiting the management off technology-push situations by maximizing discovery and inhibiting screening. In: 26th Innovation and Product Development Management Conference (IPDMC 2019), Jun 2019, Leicester, United Kingdom. (hal-02168040)
Conference paper	R&D management	Barbier, R. , Le Masson, P., Weil, B., (2019). Creating value from data in an ecosystem: building and expanding relationships between data and seemingly distant usages. R&D Management 2019, Jun 2019, Palaiseau, France. (hal-02168086)
Journal paper	Revue française de gestion	Le Masson, P., Andrade, T., Barbier, R. , Blanchet, P., Boudier, J., Brunet, S., Caron, P., Demonsant, C., Fourny, A., Gilain, A., Harlé, H., Hatchuel, A., Hida, C., Hooge, S., Jobin, C., Leveque, J., Monnier, H., Pan, S., Parpaleix, L.-A., Prieur de la Comble, I., Quandalle, T., Secher, A., Thomas, M., Valibhay, C., and Weil, B. (2020). L'apport de la théorie de la conception à la gestion de crise : L'exemple d'une war room créative et activatrice face à la Covid-19. <i>Revue française de gestion</i> , 293, 111-126. https://doi.org/10.3166/rfg.2021.00498
Doctoral workshop	Innovation & Product Development Management	Barbier, R. , (2021) Growing a data-based ecosystem to support multiple sectors in tackling grand challenges: the case of Earth observation data. In: 28 th Innovation and Product Development Management Conference (IPDMC), Doctoral workshop, June 2021 (online).
Conference paper	Earth Observation	Barbier, R. , Ben Yahia, S., Le Masson, P., Weil, B., (2021). Expanding Usages of Earth Observation Data: A Co-Design Approach to Grow an Ecosystem of Efficient Service Designers, 2021 IEEE International Geoscience and Remote Sensing Symposium IGARSS, 2021, pp. 296-299, doi: 10.1109/IGARSS47720.2021.9553914.

Conference paper	Earth Observation	Voidrot, M-F., Simonis, I., Barbier, R. , Le Masson, P., Fichaux, N. (2021), Looking for reproducibility for Earth Observation applications at the abstract level. IEEE International Symposium on Geoscience and Remote Sensing (IGARSS), Jul 2021, Brussels, Belgium. <hal-03335895>
Conference paper	Design Society	Barbier, R. , Le Masson, P., Weil, B., (2021). Transforming data into added-value information: the design of scientific measurement models through the lens of design. Proceedings of the Design Society: International Conference on Engineering Design, Cambridge University Press, 2021, 1, pp.3239-3248. https://doi.org/10.1017/pds.2021.585
Conference paper	R&D management	Barbier, R. , Le Masson, P., Lenfle, S., Weil, B., (2021). Building the generativity of data to support the dynamics of multiple ecosystems: the case of Earth-observation data. R&D Management Conference 2021, Jul 2021, Glasgow, United Kingdom. <hal-03356310>
Conference paper	Management	Taupin, L., Barbier, R. , Le Masson, P., Redheuil, E., Segrestin, B., Valibhay, C. (2022). De la validation du business model au patrimoine de création : le scale-up vu par la conception. Cas d'une startup à la frontière avec la deeptech. Association Internationale de Management Stratégique (AIMS), May 2022, Annecy, France. <hal-03708134>
Journal paper	IEEE Transactions on Engineering Management	Barbier, R. , Ben Yahia, S., Le Masson, P., Weil, B., (2022). Co-Design for Novelty Anchoring Into Multiple Socio-Technical Systems in Transitions: The Case of Earth Observation Data. IEEE Transactions on Engineering Management, 2022, doi: 10.1109/TEM.2022.3184248.

Table 5: List of communications and publications in various academic communities

3.4.3.2. Interactions with practitioners beyond e-shape

Several forms of interactions with various practitioners have been regularly organised to confront the preliminary results of our research with their respective contexts. These interactions especially include the annual meetings with industrial partners of the Chair Design Theory and Methods for Innovation, but also numerous interactions with practitioners in the EO field and other industrial sectors facing similar issues (see Table 6).

Type of interaction	Community of practitioners	Details
Presentation and meetings	Earth Observation	Workshop and one-to-one interactions organised by the project officer of e-shape to share e-shape co-design experience with newly funded H2020 projects. Positive feedbacks on the co-design framework that proved to be useful for other projects.
Presentation & follow-up meetings	Automotive industry	Workshop organised by Renault to explore their data-based innovation strategy. Invited as an external expert in 2 sessions where insights gained in the EO field were presented to Renault employees.
Presentation	Earth Observation	Presentation at the Copernicus Horizon 2025 event, organised within the French Presidency of the Council of the European Union.
Webinar session	Earth Observation	Presentation at a webinar gathering several initiatives of the EO community involved in co-design / co-development
Meetings	Earth Observation	Interactions with E2L (several informal meetings followed by a still on-going process of several semi-structured interviews, in collaboration with 2 former CGS PhD students and an additional researcher). E2L is a SME company with the legal status of Cooperative (SCOP) willing to further connect EO science and society. E2L has developed an original co-design approach to connect EO research scientists of the CESBIO laboratory and territorial innovation projects that could benefit from EO data to undertake a sustainable development strategy.
Working group participation	Earth Observation	Appointed as expert in a working group of 26 international experienced members convened to develop the Strategic Mission of GEO (Group on Earth observations) for the period after 2025, to be presented to ministers of GEO Members at the 2023 GEO Ministerial Summit. Participation to 7 meetings of 1-2 days in 2022-2023.
Workshop session & panel speaker	Earth Observation	Participation in several sessions within the EuroGEO 2022 Workshop, the annual event of the European EO community: <ul style="list-style-type: none"> - Organisation of a hands-on session on co-design - Participation as speaker in a panel on <i>“Involving users in different stages of EO solution development”</i>

Table 6: List of main interactions with practitioners beyond e-shape project

3.4.4. Evaluation of the research outcomes

The overall rigour and validity of our research can be checked against the criteria proposed in (Radaelli et al., 2014) for intervention research. Table 7 provides a few tangible elements attesting the validity of the overall research for each criterion. To summarise, **the resilient-fit co-design model has been acknowledged as highly beneficial by e-shape partners** (e.g. see verbatims in the table), **and has also caught a strong attention of the EO**

community beyond the project (attested by some verbatims and the various solicitations of our research team beyond e-shape).

Evaluation criteria	Research outcomes
<p>Accommodation: produced knowledge can be used in diverse, comparable contexts where similarities and differences can be assessed</p>	<p>Following recommendations of Radaelli et al. (2014), the resilient-fit co-design model “[does] not map out a rigid course of action but rather generate guidelines that [organisations] can adapt to specific situations” (p. 348).</p> <p><u>Attested by the very positive feedback of e-shape partners:</u> <i>“This way of doing the co-design is of interest since it provides a guideline to be systematically applied for such an internal co-design approach [i.e. here referring to co-design type 3]. To illustrate the genericity of this co-design approach, we did recently a very fruitful session of co-design with our IT teams [...] for the second round of coding of the pilot, [...], following the same guideline for a resilient-fit approach”.</i></p> <p><u>Also attested beyond e-shape</u> (feedback of other projects of the EO community in which the guidelines were shared): <i>“For me personally, doing co-design with users for years but without reflecting about the methodology, it was very useful to have these guidelines from e-shape. It makes you think about certain aspects of the co-design process. [...] Our conclusions about the e-shape co-design methodology (for now): Has it been useful for NextLand? Yes! Do you have to follow it closely? No, we rather see it as guidelines / best practices which may inspire you when organising co-design activities.”</i></p>
<p>Catalytic validity: inspiring the people involved with a new understanding of reality</p>	<p><u>Within e-shape:</u> <i>“For me it was really eye opening that we could use it in such a broad way to look at all sort of possibilities rather than trying narrow down what we wanted to do.” “We thought sitting and discussing with stakeholders is just co-design. We realised soon that [...] there is a whole science and a frame behind it, a frame that brings many benefits.”</i></p> <p><u>Beyond e-shape:</u> strong interest of the overall EO community for the resilient-fit co-design model built and experimented in e-shape (e.g. attested by several invitations to chair or contribute to dedicated sessions in various events of the EO community, co-design identified as a critical component of the future EuroGEO structure, my nomination as expert in the GEO working group exploring GEO Post-2025 strategy)</p>
<p>Authenticity: agreement on what is considered to be true</p>	<p>Ensured through the regular and collaborative validation of research outcomes (as detailed in previous sections).</p>

Table 7: Validity of the intervention research according to the evaluation criteria proposed in (Radaelli et al., 2014)

3.5. Methodology and materials of the three papers

The three different papers aim at formalising the contributions of such research outcomes to various academic streams. It is important to highlight here that the papers do not systematically point to an intervention-research approach. Indeed, intervention research qualifies the methodological foundation of the overall process, whereas papers reflect only delimited parts of the full reasoning. Intervention research especially entails loops of abductive, deductive and inductive logics. Introducing the resilient-fit co-design model follows

an abductive logic as it provides a tentative explicative hypothesis of problematic facts. However, **the papers do not reflect this abductive phase but rather focus on subsequent phases of deduction** (drawing consequences from the resilient-fit hypothesis), **and induction** (empirical test of the hypothesis, leading to its confirmation or refutation and possible refinement).

As explained in the theoretical background section, each paper consists in investigating co-design at a different analytical level, corresponding to the micro, meso and macro levels suggested by literature. In particular, the levels are delimited in the papers as follows:

1. The *micro-level* paper focuses on the processes occurring within co-design on a relatively short time span. In the context of our research, we have especially focused on the limited number of co-design operations experimented with some of the pilots of the e-shape project.
2. The *meso-level* paper focuses on the organisational characteristics of a given actor undertaking co-design, that need to be considered in a longer-term perspective. To this end, we have focused on one of the e-shape partners that has been involved in such activities for already a long time before the project started.
3. The *macro-level* paper focuses on the dynamics of the socio-economic ecosystems in which the actors related to co-design evolve. In the context of our research, it has involved considering the e-shape partners as belonging to broader socio-technical systems undergoing long-term transformations beyond the project timespan.

Table 8 details the methodology and materials used for each paper accordingly.

	Paper 1 - micro	Paper 2 - meso	Paper 3 - macro
Focal point of analysis	Co-design processes occurring within a limited number of co-design operations (timeline limited to the e-shape project)	Organisational features of a given actor undertaking co-design (timeline going beyond the e-shape project)	Dynamics of the socio-economic ecosystems in which the actors related to co-design evolve (timeline going beyond the e-shape project).
Underlying logic	Mainly inductive: test of the resilient-fit co-design model against empirical cases	Deductive starting point: The resilient-fit co-design model (implicit in the paper) is likely to require a long-term strategy to handle the variety of contexts in which data could be used. Potential strategy derived from existing literature in digital innovation. Mainly inductive: test of such a strategy against an empirical case	Mainly inductive: test of the resilient-fit co-design model against multiple empirical cases (focus on the diagnostic component)
Empirical materials	Multiple case studies 3 case studies corresponding to 3 different e-shape pilots that thoroughly implemented co-design diagnosis and experimented specific forms of co-design workshops in close interaction with us.	Longitudinal case study Long-term history of one e-shape partner (O.I.E. research center), that plays a significant role in the project: leading a pilot, the energy showcase and leading the project management team. O.I.E. has a long record in stimulating the use of EO data by multiple actors, starting in the 80s.	Multiple case studies 27 case studies corresponding to the 27 initial e-shape pilots that all completed co-design diagnosis (the following 10 onboarded pilots were not included in the paper as their diagnosis followed a slightly different process).
Data collection	Based on our interactions with the three considered pilots. Including for each one: - Co-design diagnosis (exchanges of the online management platform and 1h30 interview) - Workshops: sequence of preparatory meetings (1h30 to 3h30), design sessions (total of 3h of workshops), debriefing meetings (30min to 1h30)	- Interviews with members of O.I.E. and its partner company in charge of engineering and commercialisation (11 interviewees in total) - Secondary sources: list of O.I.E.'s past and present projects and scientific publications - Regular informal interactions: visiting periods at O.I.E. (7 weeks in total) - Dedicated "validation" meetings to share and validate research outcomes with practitioners	Based on the co-design diagnosis made with the 27 pilots, especially including: - Secondary sources (pilots' application forms to the project, academic publications, websites) - Field notes (kick-off meeting, informal interactions with project members) - 2h meeting with the seven showcase coordinators, the project management team and the workpackage leaders for preliminary co-design framework validation - 1h30 semi-guided interview with each pilot
Data analysis	Collaborative research protocol resulting in a shared and validated interpretation of outcomes with practitioners.	Collaborative research protocol resulting in a shared and validated interpretation of outcomes with practitioners.	Collaborative research protocol resulting in a shared and validated interpretation of outcomes with practitioners.

Table 8: Research methodology and empirical materials of each paper

CHAPTER 4: Contributions of papers at micro, meso, macro analytical levels

Summary of Chapter 4

The three papers take complementary perspectives on the model of co-design experimented within the thesis. Each one focuses on a different analytical level and draws upon a specific stream of literature. This chapter focuses on briefly synthesising the respective contributions of each paper to the stream of literature specifically addressed by the paper.

Résumé du Chapitre 4

Les trois articles académiques adoptent des perspectives complémentaires sur le modèle de co-design expérimenté dans la thèse, chacun se concentrant sur un niveau d'analyse différent et s'appuyant sur un courant de littérature spécifique. Ce chapitre fait la synthèse des contributions respectives de chaque article au sein du courant de littérature spécifiquement abordé par l'article.

Because each stream of literature is based on different terms and concepts, it might be hard to see the linkages between the different terms used in the papers. To clarify this point, a correspondence table has been built to highlight how the different terms are used across the papers, especially with regard to how they relate to the notions of “grand distance” and “resilient fit” (see Table 9).

	Paper 1	Paper 2	Paper 2
Aspects related to grand distance	Limited orchestration capacities of the co-design sponsor	Long-term strategy required by the data-solution developer to bridge the distance with potential users. Limited capacity of potential data users to support this process on their own.	Interactions between heterogeneous socio-technical systems , that do not share the same regimes and dynamics
Aspects related to the “resilient-fit” characteristics	The resilient-fit objective defines the targeted outcomes of co-design methods	The “ data/uses fit system ” designates the nature of the object designed by the co-design sponsor to make data be used in multiple contexts (i.e. fit into multiple “use contexts”)	Building a resilient fit here appears as “ anchoring ” a novelty (data) into socio-technical systems undergoing transition dynamics

Table 9: Correspondence table showing how the terms used in the three papers relate to each other.

4.1. Contributions of Paper 1: focus on the ‘micro’ analytical level

Title: *‘Resilient-fit’ co-design methods: designing the integration of Earth observation data into ecosystems facing grand challenges*

Authors: Raphaëlle Barbier, Skander Ben Yahia, Pascal Le Masson, Benoit Weil

- *Raphaëlle Barbier*: collected the data, conceived and performed the analysis, identified the relevant literature streams, wrote the paper;
- *Skander Ben Yahia*: participated in collecting the data;
- *Pascal Le Masson & Benoit Weil*: participated in collecting and analysing the data, made feedback on preliminary versions of the paper.

Status: *submitted under revision*

1. V1: conference paper presented at IGARSS 2021
2. V2: extended abstract submitted to *Creativity and Innovation Management*
3. V3: full paper submitted to *Creativity and Innovation Management* in May 2022

Abstract

In the face of grand challenges, socio-economic ecosystems need to undertake profound transformations involving new forms of collaborative and innovative processes. This paper proposes to shed light on a specific class of co-design methods, coined ‘resilience-fit’, that supports an outsider actor (i.e. with extremely limited orchestrating capacities) in enhancing the resilience of ecosystems facing grand challenges. A vivid example of such a situation can be found in the field of Earth observation where data-based solution designers increasingly undertake dedicated co-design efforts to integrate data into multiple ecosystems facing grand challenges. Based on an in-depth empirical investigation of three case studies in this field, the paper describes how ‘resilient-fit’ co-design methods can be built in such contexts, unveiling their similarities and specificities compared to existing ones. The paper especially shows how these co-design methods progressively contribute to enhancing resilience through an original way of shaping the unknown and mobilising actors, that especially lies in building ‘locally-shared unknowns’, related to how data can be used to address certain challenges faced by pinpointed actors of the ecosystem. This research offers several theoretical and practical contributions by enriching the pool of available co-design methods needed to support the transformations of socio-economic ecosystems under the pressure of grand challenges.

Key words: co-design, grand challenges, resilience, innovation ecosystems, open innovation, user innovation, radical innovation, digital innovation

Theoretical background	Literature in design and innovation management on co-design methods : - Long tradition of research related to methods organising collective and innovation design processes - New emerging questions related to the current transformations of industrial ecosystems facing grand challenges
Research gap	Especially issues related to situations when the co-design sponsor has limited orchestration capacities, i.e. a limited ability to influence the direction of innovation efforts and mobilise relevant actors.
Research question	How can co-design methods enhance the resilience of ecosystems facing grand challenges when sponsored by an actor with limited orchestration capacities?
Analytical framework	Co-design methods analysed according to their outcomes related to three dimensions (cognitive, social, dynamic)
Method and materials	Methodology: intervention research Materials: three case studies
Academic contributions	- Enriching the pool of available co-design methods for the (re)design of ecosystems, especially adapted to the limited orchestration capacities of the co-design sponsor - Original configuration of ecosystem dynamics, triggered by actors that are initially external to the ecosystems
Managerial contributions	Guidelines to implement 'resilient-fit' co-design methods when sponsored by actors with limited orchestration capacities.
Limits and perspectives	- Limited temporal scale of analysis preventing us from observing long-term effects of conducted co-design actions - Further research needed on how to establish these methods on an operational basis - Further research needed on the artefacts supporting co-design processes (prototypes, toolkits, etc.)

Table 10: Summarised content of Paper 1

4.2. Contributions of Paper 2: focus on the ‘meso’ analytical level

Title: *Data-push innovation beyond serendipity: the case of a digital platform strategically building up the genericity of Earth observation data*

Authors: Raphaëlle Barbier, Skander Ben Yahia, Sylvain Lenfle, Benoit Weil

- *Raphaëlle Barbier*: collected the data, conceived and performed the analysis, identified the relevant literature streams, wrote the paper;
- *Skander Ben Yahia*: participated in collecting the data;
- *Sylvain Lenfle*: participated in designing and performing the analysis, made feedback on preliminary versions of the paper.
- *Benoit Weil*: participated in designing and performing the analysis, made feedback on preliminary versions of the paper.

Status: *submitted and under revision*

1. V1: Conference paper presented at R&D Management Conference 2019
2. V2: Conference paper presented at R&D Management Conference 2021
3. V3: 1st submission to the journal *Technovation* in February 2022
4. V4: 2nd submission to *Technovation* in August 2022 (after request for major revision)

Abstract

The potential of data in stimulating innovation has been largely acknowledged by practitioners and researchers. In particular, this has given rise to a specific form of data-based innovation, labelled “data-push innovation”, consisting in stimulating the use of existing data by third-party actors. Data-push innovation concerns all organisations willing to create additional value from data that have already been produced internally or by other actors, e.g. firms but also open data platforms. However, how to steer data-push innovation repeatedly for a large variety of actors remains challenging. This paper proposes to investigate this issue by examining the longitudinal case study of an actor that has successfully stimulated the use of Earth observation data by multiple actors over the last 40 years. The paper offers several contributions to research in information systems and innovation management. First, it contributes to advancing research on digital platforms. The case study indeed unveils original platform expansion dynamics, that are especially supported by a non-dominant form of platform leadership focusing more on gaining generative power than controlling power, and eventually resulting in building up the genericity of data, i.e. their ability to be widely used by a large variety of actors. Second, more generally contributing to research on data-based innovation, the paper elaborates on the notion of “data/uses fit system”, shedding a specific light on the elements to be designed to make data circulate beyond their initial context of production towards new contexts of use, adjusting to the existing constraints on data and the practices of the actors that might benefit from their use.

Keywords: data-based innovation; data-push innovation; digital platforms; data genericity; Earth Observation data

Theoretical background	Literature in information systems (IS) and innovation management , especially related to a certain class of digital innovation, coined “data-push innovation”
Research gap	Literature mainly described data-push innovation within a single case where data are made fit-for-purpose for one given actor. An open question remains as to manage data-push innovation repeatedly for a large variety of actors over time.
Research question	How to manage repeated data-push innovation based on a platform strategy when the capacities of third-party actors in leveraging data are initially limited?
Analytical framework	<ul style="list-style-type: none"> - The concept of “<i>data/uses fit system</i>” is introduced to shed light on the set of socio-technical elements that need to be designed to enable data to fit into multiple contexts of use. - The mechanisms underlying the design of the data/uses fit system are described using the framework of <i>digital platforms</i>, composed of a generic core, peripheral use-specific components, and boundary resources serving as interfaces between the generic core and the surrounding platform ecosystem.
Materials and method	<ul style="list-style-type: none"> - Empirical materials: longitudinal case study - Data analysis relying on collaborative research guidelines.
Academic contributions	<ul style="list-style-type: none"> - Contributions to literature on digital platforms: specific forms of platform expansion dynamics - Contributions to literature on digital innovation: “data genericity building” as a promising strategy for data-push innovation. “Data/uses fit system” as a useful concept for other digital innovation strategies beyond data-push innovation
Managerial contributions	Providing practitioners with new ways of structuring their data-push innovation strategies, requiring a specific managerial logic.
Limits and perspectives	<p>Remaining questions deserving further investigation:</p> <ul style="list-style-type: none"> - What are the conditions of emergence and viability of actors that would be able to undertake such strategies? - How can the mechanisms related to the design of the data/uses fit system be coupled with other forms of platform-based mechanisms? - Are there other forms of ‘data genericity building’ strategies, relying on different mechanisms or organisational logics? - Are there other ways of successfully steering repeated data-push innovation, differing from a ‘data genericity building’ strategy?

Table 11: Summarised content of Paper 2

It can be noted that co-design does not seem to be a central element of the paper at first sight. Yet, it appears in the background, as the paper makes a longitudinal study of an actor that has played the role of co-design sponsor in e-shape. As such, the paper especially contributes to describing the organisational characteristics of such an actor taking a long-term perspective.

4.3. Contributions of Paper 3: focus on the ‘macro’ analytical level

Title: *Co-design for novelty anchoring into multiple socio-technical systems in transitions: the case of Earth Observation data*

Authors: Raphaëlle Barbier, Skander Ben Yahia, Pascal Le Masson, Benoit Weil

- *Raphaëlle Barbier*: collected the data, conceived and performed the analysis, identified the relevant literature streams, wrote the paper;
- *Skander Ben Yahia*: participated in collecting the data;
- *Pascal Le Masson & Benoit Weil*: participated in collecting and analysing the data, made feedback on preliminary versions of the paper.

Status: *published in IEEE Transactions on Engineering Management*

1. V1: 1st submission to *IEEE TEM* in January 2021
2. V2: 2nd submission to *IEEE TEM* in September 2021 (after request for major revision)
3. V3: 3rd submission to *IEEE TEM* in March 2022 (after request for major revision)
4. Accepted for publication in June 2022

Abstract:

Tackling grand challenges requires new forms of collaborative innovation to support intricate design processes involving heterogeneous actors. This article specifically investigates how co-design supports the anchoring of promising novelties into multiple socio-technical systems to accelerate their respective sustainability transitions. A co-design framework adapted to this multi-system context is derived from transition research and design and innovation management research. The framework is validated empirically based on 27 case studies where the novelty to be anchored corresponds to Earth observation data. Contributing to transition research, the article shows how this multi-system co-design framework provides novelty developers with a diagnostic tool to clarify their anchoring strategy, by framing the relevant actions to conduct at different time horizons. Several enrichments of the anchoring concept are also proposed, highlighting some complementarities between different forms of anchoring and the endless property of the process. Contributing to design and innovation management research, the article sheds light on co-design in an original perspective by considering a context crossing the usual boundaries of socio-technical systems and focusing on a diagnostic dimension preceding the organization of collective design sessions. The co-design framework also highlights a so-called “resource-based” form of collaborative innovation aiming to build novelty-based resources for heterogeneous actors facing grand challenges. This approach complements more common “challenge-based” approaches aiming to directly address a targeted challenge.

Keywords: anchoring, co-design, collaborative innovation, digital innovation, earth observation data, grand challenges, multi-level perspective, strategic niche management, sustainability transitions

Theoretical background	Transition studies , especially related to “anchoring” mechanisms between multiple socio-technical systems.
Research gap	Insights on the managerial practices supporting such mechanisms are still limited.
Research question	How can a multi-system co-design framework help the developers of a certain novelty steer an anchoring strategy into multiple socio-technical systems?
Analytical framework	Co-design framework synthesised in a table: - In line, 4 types of co-design according to the nature of targeted learning processes - In column, outcomes of co-design analysed according to the kind of anchoring and the kind of interactions with transition dynamics
Materials and method	- Empirical materials: 27 case studies - Inductive logic
Academic contributions	- Contributions to transition research: co-design as a diagnostic tool supporting anchoring mechanisms - Contributions to design and innovation management: providing insights on “resource-based” forms of collaboration innovation towards tackling grand challenges (as opposed to “challenge-based” forms)
Managerial contributions	Providing practitioners with new ways of structuring their data-push innovation strategies, requiring a specific managerial logic.
Limits and perspectives	- Further enrichment of the co-design framework - Further elicitation of the organisational conditions to sustain multi-system anchoring processes - Further investigation on the complementarity between resource-based and challenge-based forms of collaborative innovation

Table 12: Summarised content of Paper 3

CHAPTER 5: Portraying the 4 dimensions of the resilient-fit co-design model

Summary of Chapter 5

The previous chapter has briefly summarised the contributions of each paper to targeted academic debates in specific streams of literature. The present chapter aims to go one step further towards our research purpose, by showing how the three papers contribute to shedding light on a consistent co-design model, “coined resilient-fit”. In this regard, the chapter depicts the four dimensions of collective action underpinning the resilient-fit co-design model, and discusses the originalities of the observed characteristics. The chapter also discusses the validity domain of the model, relying on two conditions: (i) the co-design sponsor is clearly identified from the outset as the holder of an asset that has the potential of being a resource for others, (ii) the nature of the asset is based on data. But the model remains very open with regard to the nature of the grand challenge(s) that the data could potentially be a resource for.

Résumé du Chapitre 5

Le chapitre précédent a montré comment chaque article contribuait à des débats académiques ciblés dans des courants spécifiques de la littérature. Pour répondre à notre objectif de recherche, le chapitre 5 propose de poursuivre l'analyse en montrant comment les trois articles contribuent à éclairer un modèle de co-design cohérent, dit « modèle de co-design à haute résilience ». Le chapitre analyse ainsi les quatre dimensions de l'action collective sous-jacente au modèle de co-design à haute résilience, et examine l'originalité des caractéristiques observées pour chaque dimension. Le chapitre aborde également le domaine de validité du modèle, qui repose sur deux conditions : (i) l'acteur en charge de conduire le co-design est clairement identifié dès le départ comme le détenteur d'un actif susceptible d'être une ressource pour d'autres, (ii) l'actif est ici constitué de données. Le modèle reste par contre très ouvert en ce qui concerne la nature du ou des grands défis pour lesquels les données pourraient potentiellement constituer une ressource.

For a matter of clarity, the dimensions of the resilient-fit co-design model will be presented in a slightly different order as the one introduced in the theoretical background section, looking at successively: the *management philosophy* in section 5.1. (the overall purpose at which co-design is aimed), the *technical substratum* in section 5.2. (tools and processes supporting co-design), the *reasoning logic* in section 5.3. (the underlying design mechanisms based on the intertwined exploration of both concepts and knowledge) and the *simplified view of organisational relations* in section 5.4. (organisational characteristics, roles

and relationships of the involved actors). The validity domain, limits and perspectives of the resilient-fit co-design model are discussed in section 5.5.

5.1. Management philosophy: a “resilient-fit” objective in a “resource-based” perspective

The management philosophy underpinning a given management technique has been previously defined as “the system of concepts that refers to the objects and objectives at which rationalisation is aimed” (Hatchuel and Weil, 1995, p. 98). It basically refers to the purposes followed by the actors when designing and implementing a specific management technique, that here corresponds to co-design. As for the resilient-fit co-design model, the management philosophy is actually directly mirrored in the name used to designate the model of co-design experimented within the PhD: **the resilient-fit co-design model aims at building resilient fits between grandly-distant actors**. The term “resilient fit” was initially introduced to label the specificities of the co-design experimented in the project, especially underlining the need of going beyond reaching “short fits”, i.e. relationships that underestimate the distance at stake and that are bound to easily come to an end. Our research has then allowed us to precise what is exactly meant by “resilient fit” beyond the label.

5.1.1. A “resilient-fit” objective to manage the risk of short fits

To build the notion of “resilient fit”, *Paper 1* draws upon the following definition resilience inspired from the review of studies in different fields: it refers to resilience as the *ability of the considered system* (e.g. ecological ecosystem, individuals, materials, organisations) *to continuously and robustly cope with unexpected disruptive events* (e.g. environmental damage, psychological traumas, mechanical strains, or technological and market transformations). In this perspective, the integration of EO data into users’ ecosystems is seen as such a disruptive event, insofar as these ecosystems are highly familiar with EO data. Note that “disruptive” is only meant to refer to the high degree of unknown related to the event, but not to the promptness of the event. Indeed, the integration of EO data requires tremendous efforts spanning a large period of time, and is thus anything but a prompt event occurring all of a sudden.

It is also worth noting that the disruptive event related to the integration of EO data is fostered by the EO community so as to help the users' ecosystems address other disruptive events related to the grand challenges they face. In this regard, *Paper 1* proposes to define the "resilient-fit" property as combining two forms of resilience: the **resilience of the fit** between data and users' ecosystems, and the broader **resilience of these ecosystems** in the face grand challenges. Mixing these two aspects is questionable. Indeed, co-design more directly appears as related to the first aspect, whereas the impacts of co-design on the second aspect might not be self-evident to observe directly. Moreover, the resilience of the ecosystems in the face of grand challenges certainly extends the only scope of co-design. However, we find it interesting to include this second aspect to underline that co-design is not only driven by the attempt at fitting data into certain user's practices at all costs, which could easily drift towards a form of "data solutionism". But that co-design also targets a knock-on effect on enhancing the overall capacities of actors to address their respective challenges.

Paper 1 further develops this notion by identifying **three dimensions of resilience**, from which three types of outcomes for a resilient-fit co-design model are derived:

- **A cognitive dimension**, associated with outcomes related to the elicitation of a range of concepts (here related to the integration of data into certain users' ecosystems) and associated knowledge;
- **A socio-organisational dimension**, associated with outcomes related to the establishment of relationships between relevant actors to adequately address the transformations involved on the cognitive dimension;
- **A dynamic dimension**, associated with outcomes related to the actors' capacity to handle the continuous evolution of the cognitive and socio-organisational dimensions to ensure the long-term viability of the fit. It especially involves the capacity to undertake intricate learning processes and to deal with the internal and external constraints or opportunities that might occur over time.

It is interesting here to outline how the resilient-fit management philosophy specifically addresses the risk of managing short fits, as summarised in Table 13. The created fits are all the more likely to fade away as co-design only focuses on building one type of product or service with one single actor (thus making the fit very sensitive to the possible transformations or mere disappearance of this given actor), and that the nature of the

relationship and the long-term dynamics are left implicit or out of the scope of co-design. The resilient-fit co-design model aims to move away from these kinds of situations, hence the various efforts on the different dimensions. Note that the “short-fit” model depicted in the table does not mirror the actual co-design practices of e-shape pilots. Indeed, intuitively, the pilots have already undertaken some efforts to overcome short fits, although not as systematically and explicitly as in the proposed resilient-fit model.

	Resilient-fit	Short-fit
Cognitive	Eliciting a range of possible concepts and associated knowledge, with various actors	Agreeing on one single list of requirements with one single actor
Socio-organisational	Eliciting the nature of the relationships to be set up with relevant actors	Implicitly or hardly considered
Dynamic	Eliciting the conditions for a long-term continuation of design efforts over time (especially entailing intricate long-term learning processes)	Implicitly or hardly considered

Table 13: Comparison between "resilient-fit" and "short-fit" co-design models

Let us now further elaborate on each of the three dimensions, and discuss the similarities and differences with existing co-design models. The *cognitive* and *socio-organisational* dimensions are intrinsically rooted in foundational management principles. Indeed, management research describes models of collective action by considering knowledge and relations as fundamentally inseparable: relationships depend on actors’ knowledge and vice-versa (Hatchuel, 2005). These two dimensions also specifically appear in literature on co-design suggesting that it entails a two-fold design objective concerning: (1) the nature of the design object (“design” aspect of co-design), (2) the collective of actors ensuring the design of the object (“co” aspect of co-design) (e.g. Abrassart et al., 2017; Dubois, 2015). Compared to co-design studies that would primarily focus on the first objective for example to design a certain service for an identified group of actors (e.g. Steen, 2013; Steen et al., 2011), the resilient-fit co-design model rather follows the observed trend in grand-distance situations towards **enhanced attention to the outcomes of co-design related to building up or transforming the collective of actors involved in co-design** (e.g. Della Rossa et al., 2022; Berthet et al., 2020; Abrassart et al., 2015).

As for the *dynamic* dimension, it was already mentioned by previous studies as underpinning both cognitive and socio-organisational dimensions, although not necessarily labelled as a distinct outcome dimension. For example in DKCP methods (e.g. Hooge et al.,

2016a), the generation of ideas related to the design object and the creation of partnerships between involved actors are supported by a step-by-step approach involving the exploration of several concepts and knowledge bases. It also involves a dedicated phase to agree on how to continue the design process after the co-design workshops, and especially ensure that participants are able to leverage what they have learnt throughout the process.

Recent advances on grand-distance co-design have further highlighted the issue of ensuring such forms of dynamics over time (e.g. Bertello et al., 2021; Porter et al., 2020; Pluchinotta et al., 2019). It seems all the more critical as scholars largely underline the turbulent and fast-changing character of the environments in which contemporary organisations evolve, possibly disturbed by unimaginable events (Buganza and Verganti, 2006; Elmquist et al., 2019). The evolutions faced by the actors can result for their progressive and long-term familiarisation with each other opening up new perspectives for each of them. But evolutions can also be dictated by external and unexpected factors.

We have witnessed such evolutions during the project, sometimes leading the pilot to completely reconsider its development strategy. For example, a pilot involved in assessing water quality and visibility had previously interacted with diving centres, that unfortunately temporarily or permanently closed due to COVID-19 lockdown. Another pilot had to face the merger of the initial user (a start-up) with a bigger group that no longer considered the partnership as one of its priorities. **Identifying the dynamic dimension as a distinct form of outcomes is a way of further systematising the efforts needed to address these issues.** Going back to the two facets of resilience, it is also a way of putting a strong emphasis on considering the knock-on effect of co-design on the design capacities of the actors in a long-term perspective.

Paper 3 offers a complementary insight on this dynamic dimension, by proposing a **metaphor inspired from the biological world**. The process of creating a resilient fit is here compared to grafting (as an alternative image to “anchoring”), that better underlines the continuous character of the process and the living property of the entities concerned by the fit. Indeed, as a gardening practice, grafting involves adding a tissue of plant to growing plants to make the latter further grow by taking advantage of the characteristics of the grafted tissue. Following this metaphor, EO data could be compared to the grafted tissue and the potential users’ ecosystems to the growing plants on which the add-on tissue is grafted.

Other metaphors could also be helpful to further shed light on other facets of the process, such as the concept of “creolisation” as developed by the French poet and philosopher Edouard Glissant (e.g. Glissant, 1996)⁵. For Glissant, creolisation does not only refer to the creation of a creole language. It more precisely refers to the encounter of two heterogeneous cultures, whose outcomes are unexpected and cannot be merely deduced from one of them: “Creolisation is unpredictable, whereas the effects of interbreeding [of plants or animals] could be intended” (Glissant, 1996, p. 19; my translation). Moreover, Glissant also underlines that “creolisation requires that the heterogeneous elements ‘inter-value’ each other when they come to be connected” (Glissant, 1996, p. 18; my translation). In this regard, besides the grafting metaphor, the creolisation metaphor is helpful to highlight that (1) the outcomes of the fit between grandly-distant actors are largely unknown at the outset, (2) the process involves a mutual metamorphosis of these actors (by contrast with the grafting metaphor that only highlights the effects on the potential users’ ecosystems).

5.1.2. Resource-based perspective on collective action towards grand challenges

Finally, it is also important to note that the resilient-fit objective unfolds here in a specific perspective, that is especially illuminated in *Paper 3*. The paper indeed shows that the investigated model of co-design aims to foster collective action in a so-called “**resource-based**” perspective, by contrast with other forms of co-design that are coined “challenge-based”. The term “resource-based” refers to the fact that co-design is triggered by an asset that has been initially built by a certain group of actors (here EO data produced by the EO community), and that could be further transformed in a resource for other actors having their own challenges to face. In this perspective, the actors of the EO community do not intend to solve themselves the challenges faced by others. But they rather aim to create the conditions into which multiple actors outside the EO community might better tackle their respective challenges.

⁵ I am aware that the concept of “creolisation” has also been used in a slightly different way in science and technology studies, especially in Peter Galison’s work (Galison, 1997). However, I am here merely attempting at using Glissant’s conceptualisation of “creolisation” in a metaphoric way, that I find helpful to shed light on certain aspects that the grafting metaphore leaves in the shadow. An in-depth discussion of Galison’s developments would certainly be of interest, but I will rather keep it for future research efforts.

As such, this co-design model differs from other “challenge-based” models, that are triggered by one or several grand challenges at stake and aim at organising a joint exploration of solution paths responding to or progressing towards addressing these challenges. Literature provides numerous examples of co-design following a “challenge-based” perspective, e.g. co-design aiming at designing policies addressing water management issues in a certain territory (Pluchinotta et al., 2019), imagining new usages of public libraries (Abrassart et al., 2015), designing an application to improve sales and customer in-store experience or creating a new school following the planned merger of two schools (Dubois, 2015).

It is important to note that **the distinction between these two perspectives refers to the nature of the trigger and not the outcomes of co-design**. Indeed, in both cases, the outcomes of co-design entail a better understanding of what exactly constitutes a resource and a challenge for the different involved actors.

In a resource-based perspective, the co-design sponsor is not bound to come with a well identified challenge. And this is precisely where the difficulties lie in: the co-design sponsor needs to make assumptions on the challenges that its asset is likely to contribute to tackling. Making first assumptions is what allows the co-design sponsor to initiate the co-design process by at least identifying some actors that could be potentially interested. However, it is equally important to acknowledge that those assumptions precisely need to be rediscussed through the co-design process. The following dimensions of the model (technical substratum and reasoning logic) will further shed light on these aspects.

5.2. Technical substratum: designing a variety of resilient fits with a strong attention to designing the “co”

The technical substratum refers to the arsenal of techniques, tools and methods involved in shaping collective action. In the context of the experimented form of co-design, it includes the guidelines and protocols developed to drive the co-design process, as well as the support materials used within this process. In particular, we will see in the section how the technical substratum is aligned with the management philosophy, by showing how different elements contribute to progressing towards the objective of building up resilient fits.

In terms of guidelines and protocols, *Papers 1 and 3* shed light on a few essential features of the different aspects related to pre-workshop actions, workshops and post-workshop actions.

To start with, *Papers 1 and 3* highlight that co-design is not limited to the organisation of workshops but involves a sophisticated range of pre-workshop actions. In e-shape, these pre-workshop actions consisted in undertaking a thorough **diagnosis phase** to identify co-design needs, i.e. with whom and for what a pilot might need to co-design. Within the project, this diagnosis phase was run once for each pilot as a preliminary step before the potential organisation of workshops. To ensure a common understanding of the diagnosis outcomes with each pilot, the diagnosis phase was organised following a rigorous process of several steps, that are detailed in *Papers 1 and 3*.

The diagnosis phase was then followed by a so-called “**workshop phase**” (also called “**co-design action phase**” in Paper 1), with the pilots that volunteered for the experimentation of a certain type of co-design with our support. Each type was experimented with at least one pilot. In the following pages, our research team will be designated as “**co-design management team**” or shortly “**co-design team**”, as we have played the role of co-design experts in charge of organising a resilient-fit co-design process with the pilots. The overall co-design process followed by each of the four pilots is detailed in Table 14. The next sub-sections will give an overview of the technical substratum supporting the different phases of the process.

	Diagnosis phase	Workshop phase		
		Preparatory step	Design sessions	Debriefing
Type 1	<p>1st round of template validation & enrichment (July 2019 – Nov 2019): exchanges on the online management platform</p> <p>1h30 interview (January 2020): - 3 management researchers (co-design management team) - 2 pilot's members</p>	<p>2 meetings of 1h30 (March - June 2020) with same participants. <i>+ e-mail exchanges</i> to prepare the support materials for the design sessions</p>	<p>1 workshop of 3h (July 2020); <u>18 participants</u> from: Co-design team (3), Pilot's team (5), Users from 5 different organisations (10)</p> <p><u>Design brief:</u> "Building a health surveillance & air quality platform for current and future operations of Athens' actors"</p>	<p>1h meeting (July 2020) Gathering the co-design team and the 2 pilot's co-leaders just after the workshop;</p> <p>Regular updates during project meetings.</p>
Type 2	<p>1st round of template validation & enrichment (July 2019 – Nov 2019): exchanges on the online management platform</p> <p>1h30 interview (July 2020): - 3 management researchers (co-design management team) - 3 pilot's members</p>	<p>2 meetings of 1h30 & 2h (August - September 2020) with same participants as previous step. <i>+ e-mail exchanges</i> to prepare the support materials for workshops</p>	<p>3 workshops of 1h-1h30 (Nov 2020) <u>3-7 participants</u> from : Co-design team (1-3) Pilot's team (1-3) User organisation (1) – different for each workshop</p> <p><u>Design brief:</u> "Exploring the range of usefulness of the pilot's service and related actors of the ecosystem by leveraging knowledge & experience of User organisation 1/2/3"</p>	<p>15-30min meeting following each workshop between the leader of the co-design team & the pilot leader;</p> <p>1h wrap-up meeting (Feb 2020);</p> <p>Regular updates during project meetings.</p>
Type 3	<p>1st round of template validation & enrichment (April 2019): exchanges in a dedicated one-day 'mini-drill' exercise</p> <p>1h30 interview (June 2019): - 3 management researchers (co-design management team) - 3 pilot's members</p>	<p>1 meeting of 1h30 (February 2021) with same participants as previous step. <i>+ e-mail exchanges & phone calls</i> to prepare the support materials for workshops</p>	<p>1 workshop of 3h (Feb 2021) <u>10 participants</u> from: Co-design team (4), Pilot's team (4), Operationalisation partner (2)</p> <p><u>Design brief:</u> "Clarifying the parts of the service to be operationalised / to be explored and the associated cooperation modalities between the pilot and the operationalisation partner."</p>	<p>30min following the workshop with all participants;</p> <p>Regular updates during project meetings.</p>
Type 4	<p>1st round of template validation & enrichment (July 2019 – October 2019): exchanges in a dedicated one-day 'mini-drill' exercise</p> <p>1h30 interview (September 2020): - 3 management researchers (co-design management team) - 2 pilot's members</p>	<p>3 meetings of 1h-1h30 (Nov, Dec 2021, Jan 2022) with the pilot's leader and the co-design team <i>+ e-mail exchanges</i> to prepare the support materials for workshops</p>	<p>2 workshops of 2h (January & May 2022) <u>7-8 participants</u> from: Co-design team (4), Pilot's team (1-2), User organisation (2),</p> <p><u>Design brief 1:</u> "Building a long-lasting and sustainable relationship between Pilot & User to further stimulate the sargassum ecosystem"</p> <p><u>Design brief 2:</u> "Exploring the business model of meteorological institutes to build a sustainable Pilot-User relationship & further stimulate the sargassum ecosystem"</p>	<p>30min-1h meeting following each workshop, between the co-design team and the pilot leader;</p> <p>Regular updates during project meetings.</p>

Table 14: Details on the co-design process as experimented for each type

5.2.1. Pre-workshop actions

Pre-workshop actions especially involved a thorough diagnosis phase, supported by different forms of technical substratum. First, a **typology of four main types of co-design** has been set up to systematise the outcomes of the diagnosis. Each type basically corresponds to the need of (re)building adequate relationships with a specific class of actors:

- For type 1 (coined "*adjustment between user and solution designer*"), with identified users that have already expressed their interest on a first basis;
- For type 2 (coined "*exploration for usage initiation*"), with potential users that are however difficult to engage or that have not expressed a clear interest yet;
- For type 3 (coined "*engineering for solution operationalisation*"), with actors involved in ensuring the engineering and/or commercialisation of data-based solutions;
- For type 4 (coined "*exploration for usage expansion*"), with users that already benefit from a first delivered version of data-based solutions and are willing to explore future expansions of these solutions.

This typology is more extensively detailed in *Paper 3*, and synthesised in Table 15. It especially draws upon a usual distinction in design literature (Dorst and Cross, 2001; von Hippel and von Krogh, 2015) between two sub-spaces of a given actor's design space: the problem space (here related to the nature of data usages) and the solution space (here related to the nature of the data-based solution addressing identified problems). Following this distinction, each type can be associated with a certain level of unknown for each sub-space of the co-design sponsor's design space. Note that **the diagnosis contributes to the resilient-fit objective** as it especially encourages the co-design sponsor to interact with a wider range of actors than only one single user that could seem interested at first sight.

		Level of unknown - <i>Problem space</i>	
		Low	High
Level of unknown <i>Solution space</i>	Low	<p>Co-design type 1 <i>“Adjustment between user & solution designer”</i></p> <p>Problem-related unknown: identified problems that might need further specification Solution-related unknown: limited development efforts leveraging existing building blocks Learning processes to build problem-solution pairs: slight co-expansion of problem and solution spaces</p>	<p>Co-design type 2 <i>“Exploration for usage initiation”</i></p> <p>Problem-related unknown: unknown or little-known problems to be identified Solution-related unknown: limited development efforts leveraging existing building blocks Learning processes to build problem-solution pairs: large on problem space, limited on solution space</p>
	High	<p>Co-design type 3 <i>“Engineering for solution operationalisation”</i></p> <p>Problem-related unknown: identified problems that might need further specification Solution-related unknown: extensive development efforts Learning processes to build problem-solution pairs: large on solution space, limited on problem space</p>	<p>Co-design type 4 <i>“Exploration for usage expansion”</i></p> <p>Problem-related unknown: unknown or little-known problems to be identified Solution-related unknown: extensive development efforts Learning processes to build problem-solution pairs: large co-expansion of problem and solution spaces</p>

Table 15: Typology of co-design types (support material of diagnosis phase)

In addition to the co-design typology, a **visual template has been also specifically built to represent the pilot’s context in a synthetic way**. When included in the papers, these templates were slightly transformed to be made more easily understandable. Unlike these transformed versions, the initial templates had the specificity of depicting the users’ communities on the left hand side and data sources on the right hand side. This element might appear anecdotal. But interestingly, several pilots told us they found this representation surprising as they would naturally start by positioning data on the left and derive the rest of the pilot’s description from there. Therefore, positioning the users on the left has proved to be an interesting way of triggering a change of mindset. It has indeed pushed the pilots to consider the development of their pilots from another starting point, i.e. their current knowledge about potential users instead of the types of available data sources. Figure 7 depicts the template of a pilot at the end of the diagnosis process, i.e. after completion and validation with the pilot.

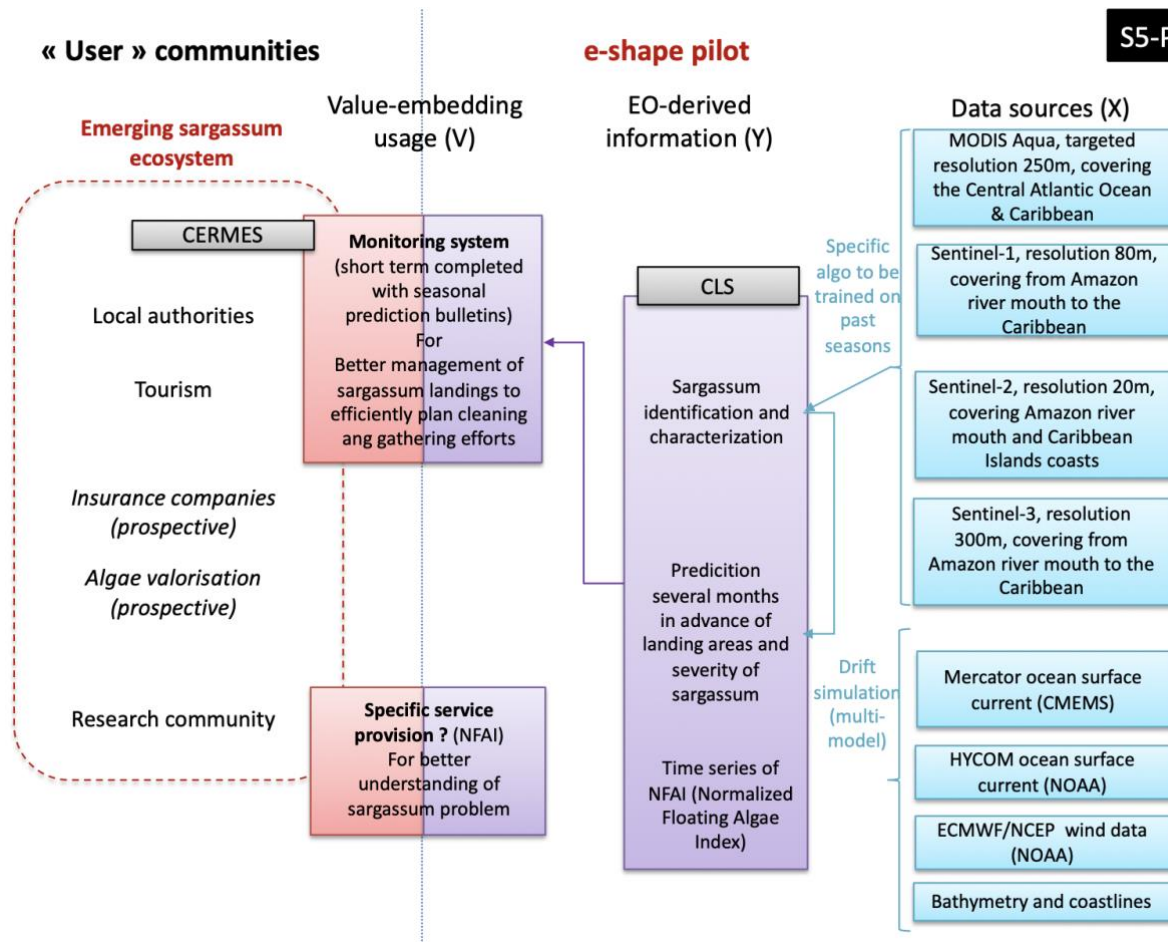


Figure 7 : Example of template supporting the diagnosis process. Case of the pilot "S5-P4" on sargassum detection for seasonal planning (sargassum is a kind of algae that lands massively on Caribbean beaches generating negative impacts over local communities). "CLS" is the name of the organisation leading the pilot. "CERMES" is the targeted user (Centre for Resource Management and Environmental Studies of the University of the West Indies).

5.2.2. Workshops

Concerning the workshop phase, the design sessions relied on quite simple sets of slides that allowed us to ensure that the distinct phases of the session were rigorously followed. These phases are further detailed in the next section related to the reasoning logic dimension. The present paragraph will thus rather focus on a few specificities related to the support materials used during the workshops.

In this respect, it is first worth noting that the workshops have been set up to explicitly address the issues highlighted by literature with regard to the long-term continuation of design efforts (e.g. Berthet et al., 2022). Indeed, it involved **systematising the attention paid to the social dimension of the workshop outcomes**. This dimension was already highlighted as a critical one in various cases of grand-distance co-design (Abrassart et al., 2015; Dubois,

2015). In some cases, a full design session was dedicated to working on building new forms of relationships, e.g. through the use of a computer-aided serious game asking the participants to simulate their respective actions and becoming aware of the forms of relationships appearing as the most relevant for supporting these actions (Della Rossa et al., 2022).

In our case, such sophisticated ways on strengthening the social outcomes of co-design could not be experimented given the limited available time of the participants. However, this dimension was systematically considered as a targeted outcome of each co-design workshop. It was clearly put at the forefront of the initial design brief for each workshop, e.g. in the case of the co-design type 4: “building a long-lasting and sustainable relationship between CLS [pilot] & CERMES [user] to further stimulate the sargassum ecosystem [i.e. the ecosystem of actors involved in tackling the sargassum-related issues]” (see other examples in Table 14). Moreover, each workshop – even the shortest ones of 1h - involved a specific phase to discuss the collaboration modalities between the participants to continue the design efforts after the workshop. The need of systematising the efforts related to the social outcomes of co-design directly is especially strengthened by the extreme character of grand distance. Indeed, the relationships between the co-design sponsor and the participants are nowhere near guaranteed by a few hours of interactions spent in a single workshop. This dimension hence needs to be discussed by the participants as explicitly as possible.

Interestingly, the nature of the relationship can differ from usual buyer-seller relationships. For example, it involved the launch of a common master’s or PhD project to further investigate certain aspects of the developed service (in the experimented type 2), or a specific analysis to study the possible correlations between variables respectively related to air quality and health-related issues (in the experimented type 1).

Specific diagrams were designed to synthesise the outcomes of each workshop. These diagrams aim at **making extremely explicit how the workshop contributes to progressing towards building a resilient fit with the participants**. As discussed above, it involved paying specific attention to the social dimension of the outcomes, but it also involved accounting for the two other dimensions involved in the resilient-fit definition. For illustrative purposes, the diagrams resulting from the different experimented co-design types are respectively shown in Figure 8, Figure 9, Figure 10, and Figure 11.

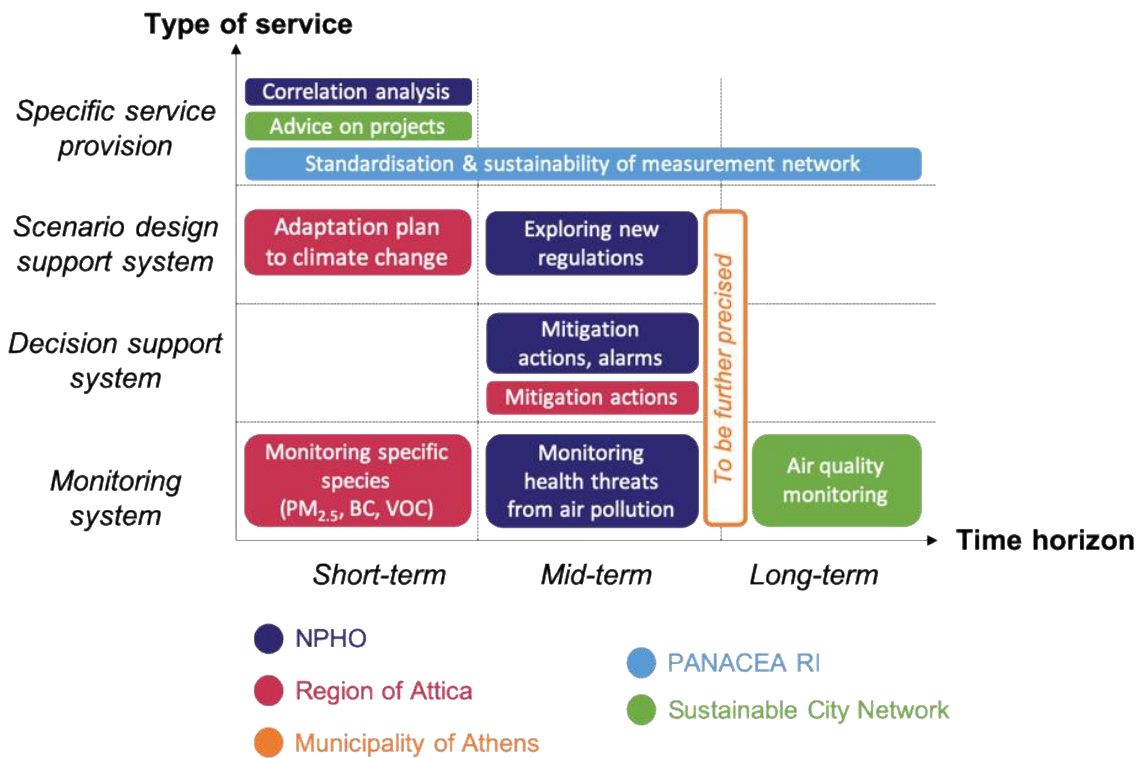


Figure 8: Diagram synthesising the outcomes of co-design type 1 (each colour corresponds to one user organisation)

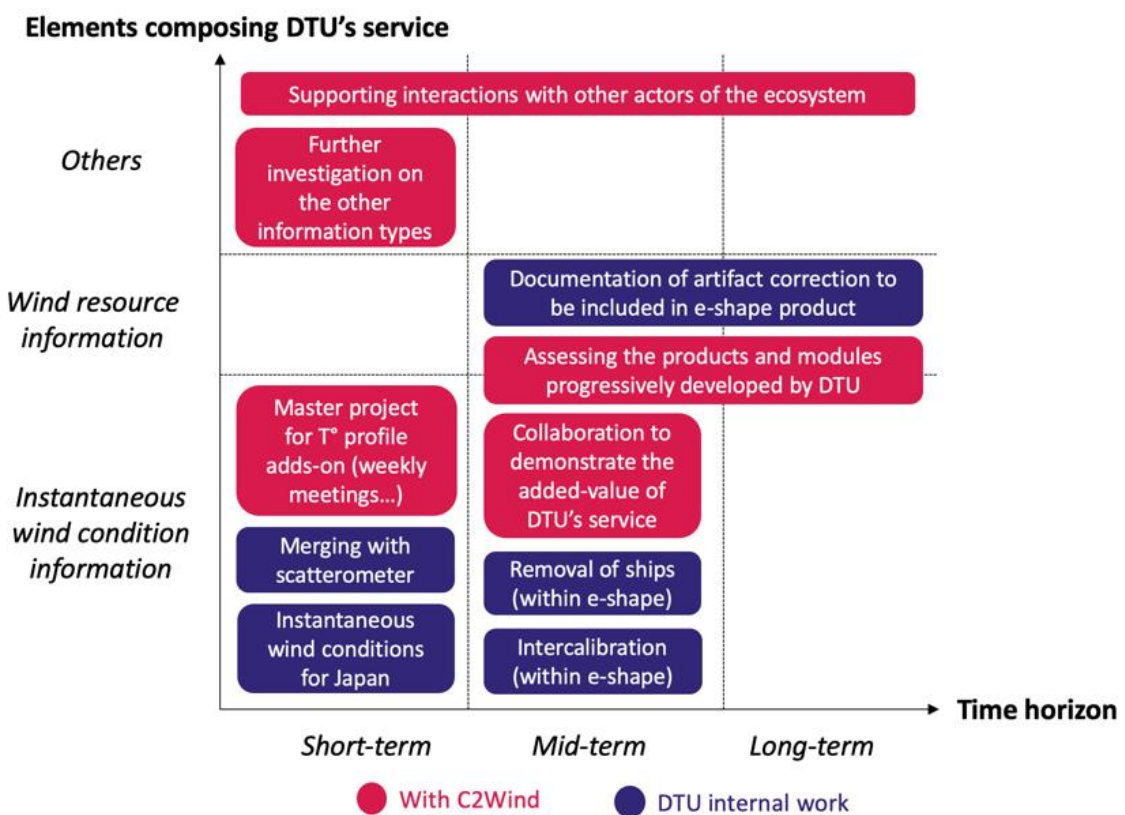


Figure 9: Diagram synthesising the outcomes of co-design type 2 (DTU = pilot's team / C2Wind = one of the three user organisations involved in the process)

	Short-term	Mid-term	Long-term	Cooperation modalities
Modules to be operationalized	Type a' CMV for hindcast - Gridded maps of clear sky index & cloud motion vectors). - Area: starting with Nantes & Oldenburg. Enlarging to Europe & Mediterranean basin	Type a' for nowcast		March 2021: kick-off and working sessions to define inputs & outputs and development planning. TSV: involving Stéphane OIE: beta-testing Milestones for e-shape sprint 2
Modules to be explored	Type b CMV for hindcast with partial processing from O.I.E. (TSV providing maps; O.I.E. processing the algorithm). Same area	Type b CMV for hindcast with processing transferred to TSV	Type b CMV for nowcast	March 2021: technical working session with TSV (Alexandre) on python code developed by O.I.E.
Undetermined	TSV-OIE collaboration for GAN methods	Collaboration on other deep learning methods for long-term forecasting	Commercial service for forecasting at different time horizons	R&D collaboration (joint PhD & internships, specific interest group on forecast between O.I.E. and TSV)

Figure 10: Diagram synthesising the outcomes of co-design type 3 (CMV = Cloud Motion Vector, i.e. the name the service's building block under consideration / O.I.E. = pilot's team / TSV = operationalisation partner)

Actions to expand existing services

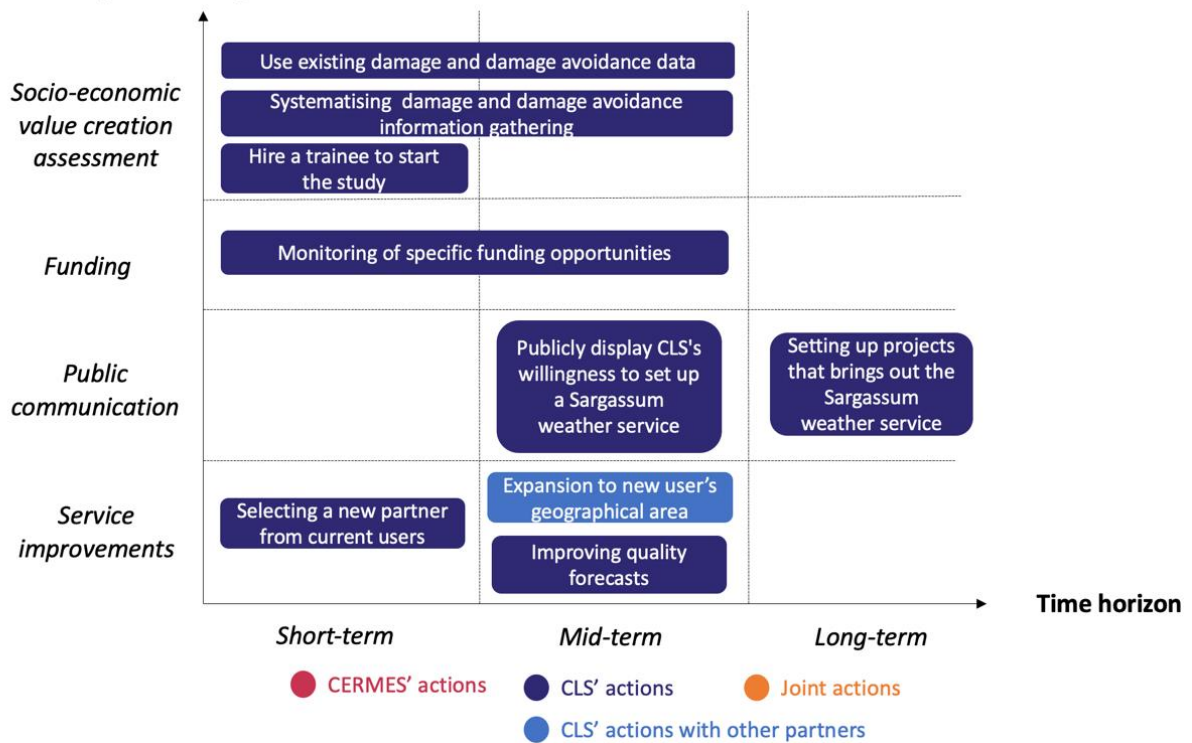


Figure 11: Diagram synthesising the outcomes of co-design type 4 (CLS = pilot's leader, CERMES = user organisation)

Each diagram elicits the three resilient-fit dimensions as follows:

- On the *cognitive* dimension, the diagram represents the range of development paths of data-based solutions identified as promising for given use contexts.
- On the *socio-organisational* dimension, the diagram depicts how the workshop has contributed to designing the relationships between the involved actors, i.e. identifying the cooperation modalities for further interaction between the co-design sponsor and the participants.
- On the *dynamic* dimension, the diagram accounts for the possible advances and learnings made by the different participants in the future. It thus involves mapping the identified development paths at different time scales (short-term / mid-term / long-term).

As already highlighted in other innovation contexts, the use of diagrams is an effective boundary-crossing mechanism that can foster knowledge sharing across organisational boundaries (e.g. Rau et al., 2012). In this particular case, the diagrams seem to especially contribute to setting up a joint structure in which participants can further interact with each other.

During the workshops, **some parts of the support materials were more specifically related to data-related aspects**. Indeed, in some cases, the pilots resorted to specific tools such as Jupyter Notebooks. These notebooks are open-source and browser-based tools that basically offer the possibility to decompose an algorithmic workflow into several steps, interweaving parts of codes, text-based explanations and visualisation of outputs through images or graphs. They have been increasingly used by data scientists as a powerful tool, especially to share research outcomes with other researchers or data scientists in the perspective of open science (Perkel, 2018; Randles et al., 2017).

Interestingly, beyond targeting the scientific community, some pilots have also explored the possibility of using such notebooks to support their interactions with potential users. For example, a Jupyter Notebook has been used by O.I.E. for the development of their pilot related to PV penetration at urban scale (Blanc and Ménard, 2021). Figure 12 gives a little overview of some of its components.

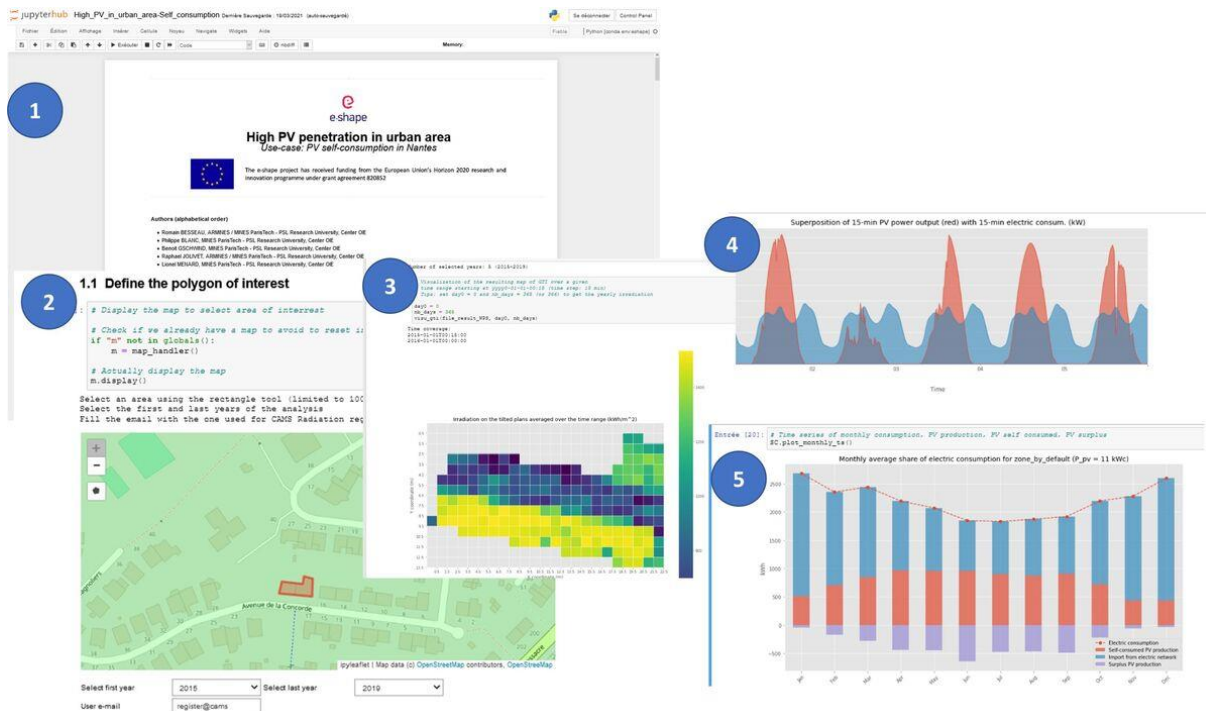


Figure 12: Extracts of the Jupyter Notebook related to the assessment of PV self-consumption capacities: (1) Frontpage of the Notebook, (2) selection of a polygon of interest (here a building), (3) assessment of the annual mean of solar radiation on each m² of the selected roof (kWh/m²), (4) graph representing the PV production (kW) compared to the electricity consumption over a few days (at 15 min intervals), (5) assessment of the monthly electricity consumption (red line) distributed among a self-consumption part (red), a surplus of PV production (pink), and an importation part (blue). Source (Blanc and Ménard, 2021)

A master student from Mines Paris, Elise Costa, worked with our research lab and O.I.E. on a small research project, investigating the role that such Jupyter Notebooks could play in helping O.I.E. to build and/or strengthen their relationships with certain actors. She showed that the Jupyter Notebook had the advantage of eliciting the assumptions made by the pilot on a certain use case, and playing with these assumptions in an interactive way. For example, the Jupyter Notebook built by O.I.E. initially took the view point of an individual investigating the possibility of installing PV panels on its roof. It thus mirrored the initial use case explored by O.I.E. at that time. When O.I.E. later explored other use cases with the national operators of the electricity distribution system (DSO), the Jupyter Notebook were slightly modified to integrate new modules closer to the DSO's operations as assumed by O.I.E.. These assumptions were confirmed by the DSO's positive reactions to the demonstration made by O.I.E. based on the Jupyter Notebook.

In this regard, the Jupyter Notebook can be considered as a certain form of boundary object that allows heterogenous actors to represent, learn about and transform their respective knowledge (Carlile, 2002; Star and Griesemer, 1989). It also aligns with recent

research showing the role of digital technologies for knowledge sharing and fostering stakeholder collaboration (Jalowski et al., 2022). The exact functions that such Jupyter notebooks or alternative technologies could play at different phases would deserve further research.

At this stage, we can at least note that the Jupyter Notebook seems to intermingle several functions. Following the typology of prototyping artefacts developed in (Ben Mahmoud-Jouini and Midler, 2020), it seems to have a strong “stimulator” role in the inspiration phase, insofar as it initiates and helps explore new and unfamiliar knowledge. It also seems promising in playing a “demonstrator” role, at least with regard to the concept selection phase, providing relevant empirical support for the analysis and selection of different concepts. Its role in subsequent phases of development is less clear, for example with regard to its potential in terms of providing a tool for testing the fit of the developed solution with the user’s specifications. Interestingly, scholars have noted that stimulator artefacts are not always needed in co-design, e.g. in cases where the participants already share a common understanding of the issues to be addressed by the co-design process (Nicolaÿ and Lenfle, 2019). In this respect, the role of the Jupyter Notebook as a stimulator is aligned with the situation of extreme grand distance where the participants need to build such common understanding.

Finally, it is worth noting that the **workshops were all organised virtually**, initially due to COVID-19 lockdown. We were indeed led to completely redesign the format of the first design session we had planned with one pilot following the outcomes of the diagnosis phase. This design session corresponded to the experimentation of a co-design type 1 supporting the National Observatory of Athens (NOA) to design a health & air quality surveillance platform with a number of regional partners. Due to the geographic proximity of NOA and the invited participants, the design session had been initially planned as a full-day in-person format. The session was later transformed into a 3h virtual meeting.

Following this first experience, all design sessions were organised by our research team in a virtual setting. Initially imposed by COVID-19 lockdowns, this setting has also proved to be convenient for practical reasons. Indeed, in certain contexts, the participants were not located in the same geographical area. The case of CLS, a company based in Toulouse (France) gives a telling example as the pilot developed by CLS involves interacting with a research

center of the Caribbean region (CERMES). Beyond geographical limitations, time limitations also came into play. In the case of the experimented type 2, the pilot found interesting to interact with a large number of actors of the wind offshore industry, who were scattered across Europe but first and foremost who did not necessarily have much time to dedicate to the interactions. Resorting to short virtual meetings of 1h-1h30 was a good way of organising first interactions with these actors despite their constraints. This also allowed the pilot to have interactions with more actors and thus build a broad understanding of the sector without too much time investment.

This format certainly let little time for broad explorations and informal interactions. But on the other hand, it also better emphasised some critical aspects of co-design. In particular, it became more obvious that one co-design session was certainly not sufficient to address the grand distance issue between involved actors. Hence it further underlined the importance of explicitly designing the relationships that would allow partners to extend their exchanges beyond the design session. This point appeared all the more critical as the virtual settings could not rely on the acknowledged benefits of physical spaces to foster collaborative innovation practices (de Vaujany et al., 2019; Fritzsche et al., 2020).

Therefore, although the virtual setting initially appeared as a constraint, it has actually been beneficial from a research perspective, leading us to explore new ways of conducting co-design. Indeed, so far, our research lab has been mostly used to carrying out in-person and longer workshops, typically organised on several distributed days. These observations seem to resonate with other scholars' experiences, describing virtual settings as an interesting way of increasing participation across distributed actors (e.g. Zimmermann et al., 2021). In several contexts, a combination of physical and virtual settings has proved to effectively support collaborative dynamics (Capdevila and Mérindol, 2022). Further research will be needed to investigate the possible complementarities between these two modes of interactions for grand-distance co-design.

5.2.3. Post-workshop actions

Regarding the post-workshop actions, our involvement as external co-design experts has been relatively limited, letting the pilots continue their development strategy on their own. **One or several “debriefing” meetings** were organised with the participating pilot's

members after the workshops in order to have their views on the direct outcomes of the process, what they had learned in terms of how to organise co-design, how they would consider continuing co-design in the future. These debriefing sessions were also the opportunity for us to recall a few important principles about co-design and share our suggestions in terms of the next relevant co-design actions that the pilots could take on. These discussions aimed at enhancing the capacities of the pilots to undertake resilient-fit co-design in a more autonomous way.

To conclude, the technical substratum entails a rich range of tools and techniques described above, that contribute to making collective action possible by fostering learning and making emerge concrete paths of action between these actors. One can also note that the nature of the technical substratum is consistent with the underlying “resilient-fit” management philosophy, by supporting efforts on the three intertwined cognitive, socio-organisational, and dynamic facets of resilience. The next section will further unveil the consistency of the resilient-fit co-design model by focusing on the underlying reasoning logic.

5.3. Reasoning logic: comparison with the logic underlying DKCP-based co-design in historical and grand-distance contexts

The reasoning logic dimension aims at eliciting the mechanisms involved in the design process followed by the actors when undertaking co-design. This dimension is particularly critical to understand the consistency of the model, as it especially sheds light on the strong interplay between the three other dimensions (management philosophy, technical substratum and organisational relations). Following C-K design theory, this reasoning logic involves the co-expansion of knowledge (i.e. what is known by the participants) and concepts (i.e. the unknown objects that are explored). In this regard, the different papers bring complementary perspectives.

Paper 2 is particularly helpful to shed light on the overall reasoning logic of the co-design sponsor, within which co-design takes place. The paper indeed suggests that **the design space of the co-design sponsor is related to the design of the so-called “data/uses fit system”** (labelled as the concept “ C_0 ” in C-space). Without going into too many details, the data/uses

fit system essentially refers to the set of socio-technical elements that allow data to be used in various contexts (i.e. by various actors with various purposes). In other words, it is what makes data *fit* into a range of multiple *use contexts*. The adjective "socio-technical" elements refers to the fact that making data used in various contexts involve building a wealth of "technical" elements, such as sophisticated algorithms and processing chains. But it also involves building some forms of "social" elements, such as forging relevant partnerships with actors in charge of maintaining the technical infrastructure or providing computing capacities (e.g. cloud computing providers).

Let us now go back the elicitation of the reasoning logic using C-K design theory. Associated with the C_0 concept "designing the data/uses fit system" (in C space), one can roughly distinguish between several broad categories of knowledge bases (in K space): a *data-related knowledge base* (e.g. knowledge about the available measuring instruments, the characteristics of the instruments, the available methods to derive data from these instruments, the limits of these methods), a *use-related knowledge base* (overall understanding of potential sectors in which data could be used, identification of potential users within these sectors, knowledge about these actors' existing practices and competencies), and a *fit-engineering knowledge base* (involving all knowledge and know-how required to ensure the engineering of the data/uses fit system, such as ensuring the maintenance of a robust processing chain providing a guaranteed level of data availability, or ensuring commercial relationships with potential clients). These aspects will be later represented in a synthetic way (see Figure 13 in a few pages).

Within this overall context, one can say that **co-design plays the role of supporting the expansion of the co-design sponsor's design space by focusing on specific parts of its design space**. This aspect is especially developed in *Paper 3* showing that the diagnosis phase allows to identify the types of co-design that seem to be relevant given the status of the co-design sponsor's design space, each type addressing specific unknowns and learning processes. As such, the diagnosis appears as a moment where the co-design sponsor elicits its knowledge related to the different knowledge bases mentioned above (especially the fit-engineering and use-related ones) and interrogates them to identify which ones would need to be further expanded with the help of external actors that seem relevant for this endeavour.

The different workshops then come as a way of opening up temporary design spaces with these pinpointed actors, each one exploring different forms of concepts and knowledge. The new concepts and knowledge coming out of the workshops finally feed back into the co-design sponsor's design space, producing expansions in both concept and knowledge spaces. *Paper 3* further highlights that the types of co-design ought to be seen as highly complementary: several types might not appear relevant at a given moment in time but later on, given the evolutions of the co-design sponsor's design space. This especially suggests a recursive implementation of different types of workshops, distributed over time. These different aspects are also schematically represented in Figure 13 (next page).

We have primarily focused here on depicting the co-design sponsor's design space. However, it is important to note that co-design also has an effect on the respective design spaces of the other participants (i.e. potential users or operationalisation partners). These design spaces are not driven by the same objectives as the co-design sponsor's ones which primarily lie in designing the data/uses fit system.

For example, in the co-design workshop related to the use of EO data for air quality & health surveillance, the Greek National Public Health Organisation invited as a potential user explained that they were currently undertaking the development of an environmental data observatory on a national scale, gathering all potential data on parameters that could affect health of Greek citizens. This organisation was thus interested in seeing whether EO data provided by the co-design sponsor could fit into and possibly enrich their own design space driven by the C₀ "*designing an environmental data observatory for all of Greece*".

The workshops have proved to play a role in enriching the respective participants' design spaces with new knowledge and concepts, as attested by the identification of several possible paths and relationships that the participants agreed on further exploring (see the outcomes depicted in section 5.2.2.). However, we could only get limited hints on the respective participants' design spaces, as we had no direct access to these participants outside the workshops, hence our main focus on the co-design sponsor's design space.

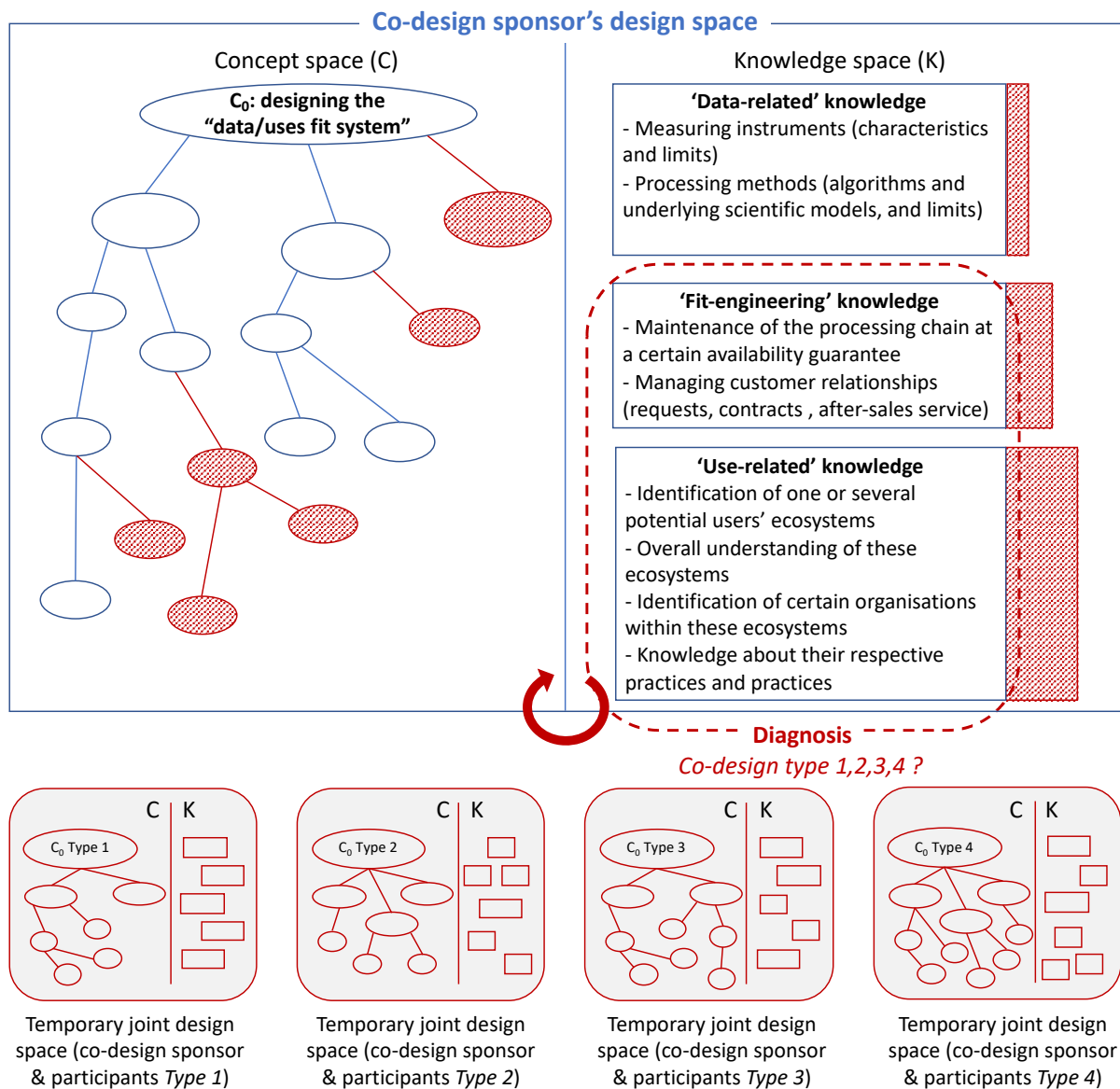


Figure 13: Representation of the reasoning logic based on C-K design theory, seen from the view of the co-design sponsor. The diagnosis and workshops are two complementary ways of expanding the co-design sponsor's design space. The diagnosis helps the co-design sponsor to elicit its current knowledge, especially related to the potential data uses and the engineering of the fit system. The diagnosis results in identifying which types of co-design could be relevant. The workshops related to each type then consist in creating a temporary joint design space between the co-design sponsor and the invited participants, each one driven by a specific type of initial concept (C₀) and exploring different forms of concepts and knowledge. The outcomes of each workshop contribute to enriching the co-design sponsor's design space (red circle arrow) with new concepts and knowledge (represented in gridded red), with a strong emphasis on the 'use-related' knowledge.

Paper 1 brings complementary insights on the **design mechanisms unfolding within each type of co-design**. In this respect, it seems especially helpful to compare these mechanisms to the ones usually unfolding in so-called "DKCP" methods. The next paragraphs will thus focus on highlighting the commonalities and differences of the resilient-fit co-design process, compared to historical cases of DKCP methods developed in the context of well-established industrial companies (Elmqvist and Segrestin, 2009; Hatchuel et al., 2009; Hooge

et al., 2016a), as well as in more recent cases of grand distance (e.g. Della Rossa et al., 2022; Berthet et al., 2020; Lavoie et al., 2021; Lab Ville Prospective, 2021; Pluchinotta et al., 2019; Labatut and Hooge, 2016; Berthet et al., 2016a). Note that some elements of comparison might also appear as part of the “technical substratum” dimension, as DKCP entails a range of methods and tools guiding the overall process. However, certain aspects of these methods are particularly helpful to enlighten us about the nature of the underlying reasoning logic, hence our choice of rather describing them under the reasoning logic dimension.

It can be first noted that the resilient-fit co-design process follows a similar structure to DKCP, directly rooted in C-K design theory principles. In particular, the structuration of the process in distinct phases is crucial, especially to avoid cognitive fixations by guiding the exploration beyond easily accessible design paths (Hatchuel et al., 2009). In this respect, the resilient-fit co-design process relies on the same distinction of phases, including: (1) the *D (definition) phase*, consisting in setting up the frame in which the collective exploration will be held, (2) the *K (knowledge) phase*, consisting in setting up a common cognitive ground for the exploration by sharing existing and new knowledge, (3) the *C (Concept) phase*, consisting in exploring a range of innovative concepts, and (4) the *P (Project) phase*, consisting in transforming explored ideas into concrete action plans and strategies. The content and sequencing of these phases were however adapted to the situations at stake. Table 16 (see next pages) synthesises the comparison between the experimented co-design process and the ones derived from DKCP in historical cases and more recent cases of grand distance. A few noteworthy aspects are hereafter detailed.

Similarly to other recent cases of grand distance (Berthet et al., 2016a; e.g. Della Rossa et al., 2022; Lab Ville Prospective, 2021; Labatut and Hooge, 2016; Pluchinotta et al., 2019), the definition phase involved a thorough diagnosis of the socio-technical system at stake. However, by contrast with the aforementioned cases, **this diagnosis was made by the co-design management team in an asymmetrical way**. Indeed, it focused on mirroring the understanding of the situation from the pilot’s perspective. This mainly stemmed from the fact that neither the pilot nor our research team had easy access to the other actors of the ecosystem. This especially prevented us from exhaustively mapping the cognitive fixations of all these actors prior to the workshops, except in cases where the invited participants were already very well-known by the pilot (e.g. in the experimented type 3 where the invited

participants belonged to the engineering company that had been partnering with the pilot for a long time).

Still within the definition phase, the preliminary training of the participants constitutes another interesting comparison point. Scholars report on the long-term benefits of training actors about innovative design principles (Yström et al., 2021; Rampa and Agogué, 2021; Rampa et al., 2016). However, in our case, due the constraints of the project and the limited availabilities of participants, **no thorough training of participants was organised prior to co-design**. Nevertheless, the process included a minimal form of training to avoid certain identified issues. In this regard, prior to the workshops, a preliminary phase involved one or several meetings with the pilots. During these meetings, a brief explanation made by our team to the pilots about the specificities of the design process related to the considered co-design type. It especially included warning the pilots about the risk of cognitive fixations, taking different forms depending on the co-design type. These cognitive fixations were briefly formulated as such:

- *Type 1: considering that the user already knows what to do with EO (thus risk of missing different ways of using EO data, beyond monitoring purposes)*
- *Type 2: considering the user as already a client (thus risk of overlooking the learning efforts required to better understand the potential users' ecosystem)*
- *Type 3: considering the operationalisation as a mere transfer from R&D to engineering entity (thus risk of overlooking remaining exploration efforts that could need efforts from both the R&D and engineering entities)*
- *Type 4: focusing on the dreams of one specific user to build future solutions (thus risk of relying on a single user that might later disappear, and long-term risk of lock-ins)*

The post-workshop debriefing sessions also contributed to strengthening the learning made during the experimented process.

DKCP in historical industrial contexts	DKCP adapted to recent cases of grand distance	Resilient-fit co-design
<p>Overall context</p> <p>30 participants or so coming from different divisions of the same company.</p>	<p>Overall context</p> <p>15-40 participants spanning heterogeneous organisations.</p>	<p>Overall context</p> <p>3-10 participants spanning heterogeneous organisations.</p>
<p>“D” (Definition) phase</p> <p>Consisting in identifying the innovation field to be explored, mapping current design paths, cognitive fixations, identifying the actors to be subsequently involved. These actors typically belong to the same organisation within which DKCP takes place.</p>	<p>“D” (Definition) phase</p> <p>Initial diagnosis made more complex to realise due to the increased heterogeneity of participants:</p> <ul style="list-style-type: none"> - It especially requires the management team to gain a thorough understanding of the initial issues at stake, the heterogeneous views of the actors, and the relevant actors to be invited as participants (Della Rossa et al. 2022; Lavoie et al. 2021; Lab Ville Prospective 2021; Pluchinotta et al., 2019; Labatut and Hooge, 2016). - It possibly requires a long preliminary phase to strengthen the legitimacy and orchestration capacities of the co-design sponsor within the community of actors, e.g. 16 months (Labatut and Hooge, 2016). - It possibly requires training the participants about innovative design principles at the outset (Lavoie et al. 2021; Lab Ville Prospective 2021). 	<p>“D” (Definition) phase</p> <p>Initial diagnosis of the actors, their design paths and cognitive fixations limited to the view of the co-design sponsor (asymmetrical access to the different actors).</p> <p>No preliminary phase to further establish the legitimacy of the co-design sponsor: the process is run based on its current level of orchestration capacities (that can take varying degrees depending on the type of co-design).</p> <p>Training of pilots limited to a brief presentation of design theory principles, especially explaining the main cognitive fixations to be avoided within each co-design type.</p>
<p>“K” (Knowledge) phase</p> <p>Consisting in setting up a common cognitive ground to further explore innovative concepts. It usually involves expanding the initial knowledge of actors with external knowledge to avoid cognitive fixations.</p> <p>Typically organised as several seminars of a few hours distributed over time, e.g. 7 full-day workshops organised over 3 months in (Hooge et al. 2016)</p>	<p>“K” (Knowledge) phase</p> <p>Similarly to historical cases, injection of new knowledge by the management team or external experts, e.g based on the knowledge shared individually by the different actors (Pluchinotta et al., 2019), or based on the identification of current trends and their extrapolation in the future (Lavoie et al., 2021).</p> <p>K-phase often limited by time or space constraints, thus leading to alternative formats, typically held on one day, such as:</p> <ul style="list-style-type: none"> - the organisation of several cycles of K-C phases, where K-phase and C-phase are held on the same day (Labatut and Hooge, 2016), - individual interactions of the participants with the management team & time for knowledge sharing at the beginning of the C-phase (Pluchinotta et al., 2019). 	<p>“K” (Knowledge) phase</p> <p>Knowledge sharing mainly based on the respective knowledge of the participants, that are already highly unconnected by nature.</p> <p>No external knowledge brought by the management team, except slightly in co-design type 4 (as participants are already familiar with each other and are willing to embrace more exploratory efforts).</p> <p>K-phase combined with the C-phase and P-phase in very reduced timeslots (1h-3h).</p>

DKCP in historical industrial contexts	DKCP adapted to recent cases of grand distance	Resilient-fit co-design
<p>“C” (Concept) phase</p> <p>Consisting in the exploration of a pool of concepts within the defined scope of exploration. Relying on the formulation of projector concepts, that encourage the participants to explore counter-intuitive design paths, e.g. “a cost-saving green car” (Elmqvist and Segrestin, 2009). Typically organised as several full-day workshops (Hooge et al., 2016)</p>	<p>“C” (Concept) phase</p> <p>Similar use of projector concepts, e.g. “water resource production by transporting water from other planets” (Pluchinotta et al. 2019).</p> <p>Sometimes taking more sophisticated forms, e.g. formulated as prospective scenarios (Lavoie et al. 2021; Lab Ville Prospective 2021).</p> <p>C-phase tends to be more limited in terms of time, e.g. a 1-day workshop (Pluchinotta et al. 2019).</p>	<p>“C” (Concept) phase</p> <p>Projector concepts are not formulated as unsettling disruptive ideas. However, following a similar logic, guiding questions are systematically formulated to encourage the exploration of a range of alternative design paths.</p> <p>Reduced timeslots (see K-phase)</p> <p>C-phase merely relies on “reactive expansion” as described in (Dubois, 2015).</p>
<p>“P” (Project) phase</p> <p>Consisting in setting up different strategies that would allow the participants to further work on the development of the identified promising ideas.</p> <p>Typically organised through dedicated working groups active for at least several months, e.g. 18 months in (Hooge et al. 2016)</p>	<p>“P” (Project) phase</p> <p>Scholars report on issues related to transforming explored ideas into concrete action plans (Lavoie et al., 2021), and sustaining the momentum over time (Berthet et al., 2022).</p> <p>Use of original tools to overcome these difficulties, e.g. a serious computer-assisted game to simulate the implementation of several ideas coming from the C-phase and encourage the players to form new relationships (Della Rossa et al., 2022)</p>	<p>“P” (Project) phase</p> <p>A specific attention is paid to setting up the collaboration modalities between the participants and potentially identifying new relevant actors to be involved in the future. This phase is systematically integrated at the end of every design session, and not as a separated slot after the K-phase and C-phase.</p>

Table 16: Comparison of the resilient-fit co-design process and associated design mechanisms, with regard to DKCP-based processes in historical and grand-distance contexts

The organisation of subsequent K, C and P phases underwent quite important changes compared to historical and more recent cases of DKCP. **The phases were indeed organised in a more combined way and shortened format.** In historical DKCP cases, each phase included several full-day workshops distributed over time. In the experimented co-design, the workshops were stringently shortened and each workshop included all three phases. In this respect, it resonates with a noticeable evolution of DKCP methods when addressing grand-distance situations (e.g. Pluchinotta et al., 2019; Labatut and Hooge, 2016). In our case, although the content differed from one type of co-design to another, the workshops basically followed the following sequence of parts:

- Part 0 – Introduction of the workshop, presenting the overall context (pilot) and the followed process (co-design team)
- Part 1 – Knowledge shared by the pilot [+ by the co-design team in type 4] (*K-phase*)

- Part 2 – Knowledge shared by the other participants (*K-C phase*)
- Part 3 – Agreeing on the concepts to be further explored and relationships to be built (*P phase*)

It is here worth noting that the C-phase was not organised as a very distinct phase from the K-phase, given the very short format of some workshops (sometimes lasting only 1h-1h30). Although closely intertwined with the K phase, some forms of concept expansion could still unfold. It especially relied on the “**reactive expansion**” mechanisms described in (Dubois, 2015), where the concept expansion results from the reaction between the existing participants’ knowledge, without the injection of external knowledge. The participants were indeed invited to share their knowledge in reaction to what was previously presented by the pilot, leading to the potential emergence of shared unknowns, i.e. concepts that would bridge EO-data aspects with and usage-related aspects.

Dubois (2015) highlighted the limits of such a “reactive expansion” process. It indeed resulted in limited outcomes with regard to the innovativeness of the concepts, and the participants tended to become weary throughout the process. In the experimented co-design, these limits did not result in consequential issues. The potential weariness effect was limited thanks to several factors: the participants were initially selected because there was a pinpointed will of learning from both parties, and the duration of workshops was considerably shortened. As for the first aspect related to innovativeness, several factors justify the actual relevance of reactive expansion.

First, it relates to the **nature of innovativeness** considered in our case. Previous research has indeed shown that innovativeness could be effectively assessed by mapping the different innovation paths followed by the actors of a given field, e.g. innovation paths addressing road safety for two-wheeler vehicles (e.g. Agogu  et al., 2012). In those cases, a concept is considered innovative if it differs from the paths currently followed by the actors. Recent research developments in grand distance situations have proposed an alternative assessment of innovativeness, being rather **defined relatively to one given actor’s design space and not to a field-wide reference mapping** (Meinard and Pluchinotta, 2022). The latter authors especially call for considering innovativeness as “*a matter, for the individual attributing the property, of becoming aware of new possibilities that the innovative item exemplifies or hints at*” (p. 4). The experimented co-design follows the latter individual-based

way of considering innovativeness, by contrast with the view taken by Dubois (2015) mainly relating to the field-based way. Indeed, in our case, the process did not aim at reaching radically new ideas with regard to the EO field, but at triggering innovative ideas in the view of participating actors. For the potential users who are hardly familiar with EO data at the outset, innovative concepts relate to the possibilities of improving their existing practices or inventing new ones with the help of EO data. Symmetrically, for the pilots, innovative concepts emerge if new possibilities arise from the knowledge and capacities brought by the users or operationalisation partners.

Second, and drawing on this view on innovativeness, the relevance of reactive expansion for our case can be further explained by considering how cognitive fixations unfold. Indeed, according to design theory principles, innovativeness results from the possibility of overcoming cognitive fixations, which requires the use of independent knowledge bases (e.g. Agogu  et al., 2014). This is precisely what calls for the injection of new external knowledge in the K-phase of DKCP. However, in the EO context, the knowledge bases respectively owned by participants are already highly independent by nature. In this respect, the knowledge shared by the pilot has the potential to extend the design space of the other participants and vice-versa. Sharing the existing knowledge of participants is thus an efficient way of triggering the **mutual defixation of the actors**, without necessarily injecting external knowledge. In this respect, mutual defixation involves creating hooks between independent knowledge bases that were previously too unconnected to be shared. One can note that co-design type 4 did involve the injection of external knowledge. It was motivated by the fact that participants were already familiar with each other and it was thus not guaranteed that their respective knowledge bases could effectively defixate their counterparts.

To foster defixation, the K-C phase was rigorously guided by a set of questions prepared in advance by the co-design team and the pilots (synthesised in Table 17). These **guiding questions had a similar role to “projector concepts”**, that are generally used in DKCP to stimulate the exploration of a range of alternative design paths beyond the most expected ones. The questions were however not formulated as proper disruptive ideas as it is normally the case, e.g. “water resource production by transporting water from other planets” (Pluchinotta et al. 2019). Indeed, such concepts tend to be quite unsettling for the participants in the first place and require sufficient time to be adequately explored, as already noted in historical cases of DKCP (Hooge et al., 2016a; Elmquist and Segrestin, 2009). Those conditions

were hard to meet in our case, leading us to adapt these projector concepts. We thus kept their underlying function of guiding the exploration towards various directions but transformed them in the more easily accessible forms of questions.

Co-design type	Guiding questions (although not formulated as unsettling disruptive ideas, same function as projector concepts: fostering the exploration of a range of alternative design paths)
Type 1	<ul style="list-style-type: none"> - <i>Opening question to the participants following the pilot's demonstration</i>: What are your current operations that would potentially benefit from the pilot's service? - <i>Detailed use case of the service (1/2)</i>: According to what was presented by the pilot, what would you do with this service? Which division would be concerned? To what extent would you be able to use the provided service on your own? <ul style="list-style-type: none"> - If you use the service for <i>monitoring purposes</i>, what information would you like to monitor? Ex: pollutant concentrations - What types of actions in your operations would it potentially support (<i>decision support system</i>)? Ex: triggering certain actions when a threshold is exceeded - Beyond using the service for your current workflows, how could the service help you to develop new operations or services on a longer-term perspective (<i>design support system</i>)? Ex: exploring new mitigation actions, regulations - <i>Detailed use case of the service (2/2)</i>: What would be the constraints, drawbacks and risks of using the pilot's service? - <i>Dream of future EO services</i>: If you forget the current technological/resource constraints, what EO applications would you dream of?
Type 2	<ul style="list-style-type: none"> - <i>Opening question to the participants following the pilot's demonstration</i>: What potential do you see in what was presented by the pilot? - <i>Guided exploration</i> by breaking down the pilot's service in several building blocks and asking 3 questions for each: <ul style="list-style-type: none"> • Could you detail a <i>potential use case</i> for this information: for which use? Added-value of this information? What would be the constraints of using it? • <i>Same questions for other actors of the ecosystem</i> you are interacting with. • If you <i>forget the current technological/resource constraints</i>, what EO services would you/other actors dream of?
Type 3	<p>Each participant (the pilot on the one side, the operationalisation partner on the other side) is asked to depict the service to be developed from its own view. To this end, each participant is asked to <i>explicitly express a range of alternatives (ideal / quick & smart / in-between versions)</i>.</p>
Type 4	<p>Following a presentation made by the management team about the "weather forecast funding model", the participants were asked to <i>explore different design paths corresponding to different aspects of the weather forecast model, and to systematically elicit the potential contributions of the participants for each path</i> :</p> <ul style="list-style-type: none"> - What would be the equivalent of meteorological institutes' monopoly positions? - What would be the equivalent of the three main points of the 159 programme (meteorological safety of people and property, research work and support to armed forces)? - How would you justify the collective value of sargassum forecasts? In particular: How would you assess damages of an extreme event related to sargassum? How would you assess the effectiveness of actions preventing these damages? How would you assess the contribution of forecasting?

Table 17: Examples of questions guiding the K-C phase in the four experimented co-design types

Another noticeable element lies in the **chosen order for knowledge sharing**. The question of starting with the pilot or with the other participants is indeed not completely neutral. Starting with the invited participants seems indeed more appropriate to avoid the pitfalls of data solutionism, i.e. the tendency to systematically consider data as a solution

while overlooking the broader issues that need to be addressed (Green, 2019). However, the experimented cases followed the other option of starting with the pilots. This choice was made in accordance with the pilots for a question of legitimacy. Indeed, in e-shape, co-design was organised without requiring a certain level of legitimacy to be first established, by contrast with other cases of grand-distance co-design where time was spent beforehand to strengthen the legitimacy of the co-design sponsor within a relevant ecosystem of actors (e.g. Labatut and Hooge, 2016). In this respect, by initiating the exchanges, the pilot could more easily set the scene and position itself as an important player. Although not completely addressed, the risk of data solutionism was at least partly balanced with the subsequent phases, encouraging the participants to give details on their day-to-day operations beyond feasibility considerations related to what was presented by the pilots.

To conclude, we can see that the consistency of the co-design model is particularly well highlighted in this reasoning logic dimension. The “resilient-fit” management philosophy is indeed mirrored in the co-design sponsor’s design space, driven by the design of the data/uses fit system. It involves continuously expanding knowledge and concepts related to the uses of data or the engineering of the fit, thus leading the co-design sponsor to continuously build and rebuild relationships with multiple actors over time. The section has also highlighted how the technical substratum is directly linked with the underlying reasoning logic (e.g. workshops drawing on reactive expansion mechanisms). Finally, the elicitation of co-design sponsor’s reasoning logic has also pointed to some aspects of the “organisational relations” dimension. Indeed, different figures of actors have come into play: the pilots, whose role within the co-design process is directly linked to its longer-term strategy, as well as the co-design (management) team. These latter elements will be further detailed in the following section.

5.4. Organisational relations

In the theoretical background section, organisational relations were defined as describing the roles of the most important actors involved in the rationalisation project, here directed towards the creation of collective action in grand-distance situations. In the context of co-design, existing literature has led us to distinguish between the *co-design sponsor*, i.e. the group of actors that takes the initiative of launching a co-design process but that does not necessarily have all relevant expertise, and the *co-design experts* that might provide this

additional co-design expertise when needed by the co-design sponsor. The different papers contribute to further clarifying some organisational characteristics of these two figures involved in the resilient-fit co-design model. Besides these two figures, the different papers also indirectly shed light on *institutional actors* such as policy makers and public bodies, especially the European Commission in our case. It especially leads us to discuss their role in ensuring the long-term viability of both co-design sponsors and experts.

It is worth noting that we will not discuss the other actors participating in co-design besides the co-design sponsor (e.g. users or operationalisation partners) as a separate figure. Several studies have especially underlined the rich and multifaceted role of users (Hyysalo et al., 2016), e.g. taking the different hats of co-designers, promoters, decision-makers (Nicolaÿ and Lenfle, 2019). However, the configuration of our research has not allowed us to have a direct and in-depth access to them, but only through the mediation of the co-design sponsors involved in the project. Therefore, while acknowledging the important role of these actors, they will mainly be depicted through the lens of their relationships with the co-design sponsor, reflecting the position we had access to as researchers.

5.4.1. Co-design sponsor

The figure of the co-design sponsor appears in the different papers through different angles. *Papers 1 and 3* mainly depict how it unfolds within the co-design process. By contrast, *Paper 2* does not focus on co-design but aims at understanding the organisational characteristics of an actor that has been playing the role of co-design sponsor in e-shape. To this end, *Paper 2* focuses on the longitudinal case study of “O.I.E.”, leading one of e-shape pilots as well as the energy showcase, and also holding the role of project management team of e-shape. The case of O.I.E. is particularly interesting as it has been involved in stimulating the use of EO data by a large variety of actors since the 80s. Although co-design does not appear as a central element of the paper, it is mentioned as one of the resources that contribute to building up the long-term strategy of this actor. The paper contributes to drawing a portrait of the co-design sponsor figure, shedding light a few noticeable traits, with regard to its expertise, its interactions with various actors, and its competencies. It is to be noted that some of these traits will appear as mainly linked to questions related to digital innovation. In this respect, by focusing on other literature streams, the two other papers offer

complementary ways of considering how these traits resonate with other contexts beyond digital innovation.

In *Paper 2*, the distinctive expertise of the co-design sponsor is described as building up the so-called “data/uses fit system”. The paper especially highlights that such expertise involves building a **rich and diverse range of interactions with various actors**. In addition to the interactions with potential users, the co-design sponsor might be led to interact with actors having the ability to ensure the engineering of the developed solutions. In the case of EO-based products and services, it especially involves operationalising and maintaining the processing chain (possibly to be available 24/7 with a guaranteed percentage of reliability) and ensuring the day-to-day relationships with existing users.

The co-design sponsor might have these operationalisation capacities internally. Meteorological offices tend to belong to this category, having already robust technical infrastructures and dedicated teams for managing their relationships with users. But in some other cases, the co-design sponsor might need to partner with external actors, typically in the case of research institutes whose objectives primarily lie in advancing research. O.I.E. gives a telling example of such a configuration. O.I.E. has indeed partnered with a commercial entity in charge of the engineering, maintenance and commercialisation of products and services based on O.I.E.’s research.

Finally, the co-design sponsor might also have interactions with other “peer” actors taking on similar endeavours in the same or different areas. In the case of O.I.E., this type of interactions has been especially important to deal with questions related to standards allowing heterogeneous systems to be interoperable one with another. In this regard, O.I.E. has been participating in working groups and other activities of the Group on Earth Observations (GEO). It has especially allowed O.I.E. to become aware of the importance of standards to further enable the use of EO data by a large variety of actors. In this respect, O.I.E. has dedicated tremendous efforts to comply with them (going through a complete redesign of their algorithms and associated products and services). But beyond their own trajectory, O.I.E. has also endeavoured to support other EO actors in progressing towards further compliance with standards.

Interestingly, the case of O.I.E. shows that **these interactions can intertwiningly unfold in several modes: an adaptive mode and a stimulation mode**. In an adaptive mode, the co-design sponsor adapts to the on-going transformation dynamics followed by the different actors. In some case, O.I.E. has indeed been led to design or redesign components of the data/uses fit system, e.g. to respond to certain demands or foreseen trends on the usage side, or to leverage new data or IT capacities on the data side.

However, by progressively building its expertise, the co-design sponsor might also gain the ability of stimulating certain transformations within the ecosystems of actors with whom it interacts. For example, in the perspective of estimating solar radiation at an increasingly fine-grained resolution, O.I.E. was the one building the bridge between the founders of an energy start-up interested in developing a business for photovoltaics penetration at urban scale, with the French national mapping agency having key data sets. Indeed, on the one side, O.I.E suggested to the start-up that making solar cadasters at urban scale would be feasible provided the integration of a high-accuracy digital surface model. On the other side, O.I.E. suggested to the national mapping agency that their digital surface model could be valorised (while it was considered at that time as a mere side-product of existing aerial images). But these stimulation actions were only made possible because O.I.E. had already accumulated a large experience in solar radiation estimation and could thus leverage existing building blocks.

The different papers also show how these two modes of interactions occur within the co-design process. *Paper 3* especially shows that each co-design type tends to focus on a certain type of interaction: type 1 mainly involves supporting an identified usage-related dynamics, type 2 mainly involves identifying and linking-up with on-going usage-related dynamics, type 3 mainly involves leveraging or influencing data-related dynamics, and type 4 mainly involves identifying and stimulating future promising data-related and usage-related dynamics.

Moreover, *Paper 1* highlights that **these interactions can occur despite the limited orchestration capacities of the co-design sponsor**, by setting up and running the co-design process in a adapted way. In this regard, the co-design sponsor could be considered as having **a certain form of leadership**, when considering leadership as “the exertion of influence in order to ‘make things happen’ [...] despite a lack of formal authority” (Müller-Seitz, 2012, p. 429).

Paper 2 further describes this form of leadership as “**non-dominant**”, in the sense that it does not aim at becoming a central entity taking the controlling power over a whole ecosystem as in historical cases of technological platforms (Gawer and Cusumano, 2002), or digital platforms (Eaton et al., 2015; Ghazawneh and Henfridsson, 2013). In this respect, *Paper 1* underlines that this leadership rather unfolds in a “**localised**” way, in the sense that it only concerns a pinpointed group of one or several actors. In this respect, the leadership of the co-design sponsor do not consist in directing the core activities of the actors, as it could be the case in cases of hub firms having strong orchestration capacities (e.g. Dhanaraj and Parkhe, 2006). Interestingly, co-design appears to progressively contribute to enhancing the co-design sponsor’s overall orchestration capacities, not necessarily by strengthening its orchestration capacities within a given sphere, but by aggregating more and more local spheres of influence.

These considerations suggest that the co-design sponsor can have a role in fostering innovation processes across heterogeneous actors, and as such could be considered as a **form of innovation intermediary** (e.g. Howells, 2006). Agogu  et al. (2017) summarise the core functions of innovation intermediaries as such: (i) connecting actors; (ii) involving, committing, and mobilising actors; (iii) solving, avoiding, or mitigating potential conflicts of interests; and (iv) stimulating the innovation process and innovation outcomes. In this respect, the previous paragraphs describing the co-design sponsor reflect well these different functions.

Agogu  et al. (2017) also show that the content of each function depends on the degree of unknown addressed by the innovation intermediaries. A high degree of unknown especially calls for specific figures of intermediaries, such as the “architects of the unknown” (Agogu  et al., 2013). These actors are called “architects” to underline their active role in structuring collective exploration activities, beyond merely brokering someone else’s knowledge or offering a platform for networking. In this respect, the comparison of the co-design sponsor with this figure is interesting.

To a certain extent, similarly to an architect of the unknown, the co-design sponsor takes an active role in the process of joint exploration and creation of knowledge as already depicted above. However, following the results already shown on the reasoning logic dimension, it is worth noting that this process does not unfold in the same way as the cases explored by Agogu  et al. (2013). Indeed, the latter fall into the field-based view of innovativeness described in the reasoning logic section. In this perspective, the role of the

architect of the unknown involves building a reference mapping of the innovation paths followed by the different actors involved in addressing a certain issue, such as “two-wheeler road safety”. By contrast, in the resilient-fit co-design model, the co-design sponsor does not embrace such an objective. It rather lies in making emerge new shared concepts, that remain very “local” in the sense that they only concern the co-design sponsor and a limited group of participants involved in a given co-design action. In this regard, the co-design sponsor mainly plays with the knowledge and concepts that the actors can respectively bring in the process at a certain moment in time.

As a result, the metaphoric figure of the “architect” appears not be the most appropriate one to do justice to the specificities of the co-design sponsor’s role. To continue the biological-ecological metaphor of “grafting” developed in the management philosophy section, **the figure of the co-design sponsor could be alternatively depicted as a “gardener of the unknown”**. As the architect, the gardener has an active designer role. However, instead of sketching the overall design plan from the outset, the gardener’s design process is more progressive and the designed garden is constantly in the making. Indeed, as advocated by the well-known gardener Gilles Clément (e.g. Clément, 2017), the gardener has to play with the on-going and possibly unexpected transformation dynamics occurring within a limited part of the landscape delimited by the garden. Again, the metaphor does not aim at embracing all facets of the co-design sponsor’s role but at further highlighting that the co-design sponsor also has to play with a moving limited part of the landscape, composed of changing knowledge and concepts as the different participants evolve and learn over time.

To support such a rich set of activities, the paper also suggest that **a broad range of competencies is required**. As developed in *Paper 2*, the long-term strategy of O.I.E. clearly involved among others: the mastery of data processing techniques involving both mathematical and physical knowledge, the ability to ensure the engineering of the data/uses fit system, the ability to understand the on-going and possibly future dynamics of multiple ecosystems of actors, and to this end the ability to circulate across a large variety of organisations. This latter aspect also appears in *Paper 3*. It indeed sheds light on the required capacities of the co-design sponsor to circulate across different levels within a given socio-technical system (as the “hybrid actors” described in (Elzen et al., 2012)), but also across multiple socio-technical systems. The ability of understanding the ecosystems’ dynamics also

echoes studies related to multi-stakeholder innovation networks where some actors act as “environmental scanners who track collaborative dynamics and intervene to address emerging challenges by altering between [several] orchestration modes” (Reypens et al., 2021, p. 78).

These competencies are likely to result from the **complementarity between the individuals of the co-design sponsor’s team**, as well illustrated in the case of O.I.E. (see Table 18). To a certain extent, the profiles of these individuals highly resonate with literature on “boundary spanners”, referring to individuals who have the capacity to work across disciplines spanning usual boundaries and who can play a strong role in binding heterogeneous actors together (e.g. Haas, 2015; Fleming and Waguespack, 2007; Levina and Vaast, 2005). Some hints of such boundary spanning capacities are illustrated in Box 3, featuring some extracts of an interview conducted at the beginning of my thesis with Lucien Wald, member of O.I.E. since the 80s, as researcher and then director until 2018.

Lucien	Previous director of O.I.E., he had been involved in solar radiation research at O.I.E. from the 80s up until he retired in 2018. He initially had a theoretical physicist background, that had played a critical role in the way O.I.E. had developed its algorithms, based on a deep understanding of measuring instruments and underlying physical phenomena. At some point, he experimented some entrepreneurial projects in parallel with his research activities, especially at the beginning of remote sensing development. Willing to focus on research, he eventually put them aside when the research activities of the lab increased in scale, especially related to solar radiation data that later gave birth to “SoDa” (Solar radiation Data) services. As researcher and director of the lab, he especially put at the forefront the idea of making research have an impact for society, while ensuring that he could stick to his equations and remain at the cutting edge of research.
Thierry	Current director of O.I.E., Thierry did his PhD at O.I.E. on data fusion techniques (1991 – 1993) and has been researcher at O.I.E since 1995. He has been strongly involved in different groups and instances of the intergovernmental organisation GEO since 2005: co-chair of a community of practices on energy (2006 – 2015), co-chair of the GEO user interface committee (2007-2014), member of the GEO Societal Benefits Implementation Board and GEO Institutions & Development Implementation Board (2012-2015), chair of the “GEO VENER” initiative (since 2015), representative of France in the programme board (since 2015), alternate representative of France at the GEO Executive Committee (2023-2024).
Lionel	Involved in the team since the 80s as a research scientist, he brings to the team an in-depth knowledge of management of Information System and Spatial Data Infrastructure. Since 1996, he has been involved in numerous European Commission funded projects playing key role in advocating, designing, prototyping, developing and monitoring cutting-edge information systems (e-shape (2019-2023), NextGEOSS (2016 - 2020), ConnectinGEO (2015-2017), EnerGEO (2009-2013), ENDORSE (2011- 2013), MESoR (2007-2009), SoDa (2000-2003)). In particular, since 2005-2006, Lionel has been highly involved in leading O.I.E. to comply with standards. In the 2010s, he especially took an important role in the complete redesign of SoDa services, shifting from web pages coded in their own XML language towards Web services compliant with OGC standards.
Benoit	He received his PhD in computer science in 2009 and has been working as a research engineer at O.I.E. since 2010. His specific expertise in ICTs proved to be critical in redesigning SoDa services as standard-compliant Web services. He also played a significant role in the interaction with the team of engineers of Transvalor (O.I.E.’ s partner ensuring the engineering and commercialisation of SoDa services). Indeed, he would frequently transform the algorithms originally coded for research purposes in more robust codes that could be more easily handled by Transvalor.

Philippe	Head of the research group involved in renewable energy resource assessment within O.I.E., Philippe has built a strong expertise in both remote sensing and the solar energy sector. He did his PhD at O.I.E. (1996 – 2000) and then worked as a research engineer in the spatial industry (2000-2007) in signal and image processing and data fusion for Earth Observation systems and various projects where scientific support in signal and image processing, statistics, algorithmic prototyping and applied mathematics is required. He joined back O.I.E.'s team in 2007. Since then, he has been involved in multiple projects in the solar energy sector, progressively becoming a shrewd observer of current and future trends of the sector.
Yves-Marie	He joined O.I.E. more recently in 2017, to further support O.I.E. with regard to its activities related to renewable energy sectors. Indeed, he has built a strong experience in linking meteorology, renewable energies and their integration into the network. He obtained a PhD degree in 2016 at University of Kassel (Germany) on the modeling of regional PV power generation from meteorological data. He previously worked for several research institutes with a strong tradition of interactions with the industry, such as CEA (French Alternative Energies and Atomic Energy Commission) and Fraunhofer in Germany.
Mireille	She worked for O.I.E. between 1996-1997 and joined back in 2001. She holds a PhD degree in remote sensing, especially applied to oceanography. Since 2001, she has especially been involved in developing the Heliosat methods laying the foundation of SoDa services. She is also in charge of monitoring the quality of the inputs that O.I.E. provides to the Copernicus Atmospheric Monitoring Service (CAMS) on an operational basis.

Table 18: Profiles of individuals belonging to O.I.E., an organisation playing the role of co-design sponsor in e-shape

Box 3: Extract of an interview with Lucien Wald, director of O.I.E. retired in 2018 and involved in the team since the 80s.

Lucien: Back in the 80s, remote sensing was only an emerging field. [...] Our lab benefitted from computing means that were quite unique in France and Europe at that time. So a lot of scientists from various backgrounds would come to visit us and use our tools and infrastructures. [...] **So right from the start, we operated in a multi-domain atmosphere**, spanning geology, forestry, agriculture, meteorology, oceanography, in parallel of remote sensing. [...] So all our developments tended to be quite generic, [...] we were bound to conceptualise a lot of things: what is exactly considered in the algorithm? What are the underlying mathematical theories? So then, one can more easily apply the algorithm to one case or another. Here physics also plays an important role, to spot what can be considered as negligible in the sophisticated equations.

[...]

With the same idea as the one underlying Heliosat [name of the set of algorithms developed by O.I.E. to assess solar radiation based on data coming from meteorological satellites], **we explored a large range of applications:** monitoring systems for **forest fires**, [...] but also **counting vehicles on highways**. They all relied on the same core idea: detecting an anomaly [cloud for Heliosat, fire smoke, vehicles] with regard to a reference environment. [...] I even went to see motorway companies to sell them the idea of counting vehicles. [...] They were very interested but it would have required us to actually design the whole system, including the pylons with onboarded cameras, as well as the whole image transmission and processing processes. But I didn't want to play this game, only for the sake of selling an algorithm. I understood that there was a missing intermediary here. If I had an entrepreneurial ambition, I could have built my own business out of it, but I didn't want to. I wanted to keep doing research. [...] Later on, **we worked on human health**. Keep in mind

that when you start investigating a new field, you need at least 3-4 years what it's all about before starting contributing to it. But I had accumulated this experience of entering into new fields and human health seemed to offer promising perspectives.

[...]

Raphaëlle: but all these activities were run in parallel of your activities on solar radiation?!

Lucien: Yes, you only need to have many competent little hands for each one! [laughs]

[...]

Overall, I've been always driven by this desire of doing research, but with the will of doing something useful and used. So all these activities of meeting people, understanding their needs etc were the responsibilities implied by my job as researcher.

5.4.2. Co-design experts

In addition to the figure of the co-design sponsor, the figure of co-design experts has also played an important role in the resilient-fit co-design model. During e-shape, the figure of “co-design experts” was played by our research team leading the work-package on co-design. As highlighted in Chapter 3, the co-design sponsors in e-shape also had a certain expertise of co-design. Indeed, e-shape was built as a legacy of previous EU projects, gathering teams with a strong track record of developing EO-based products and services within one or several application domains. Therefore our role as co-design experts has not been to take charge of all co-design efforts to be carried out by each e-shape pilot. We rather positioned ourselves as helping to unlock some critical blocking points, thus mostly intervening when the pilots' own co-design expertise proved not to be sufficient to address the issues at stake. The additional support brought by our team as external co-design experts can be especially summarised as follows:

- In the diagnosis phase (done for all pilots), we helped the pilots to make explicit the status of their knowledge about the assumed users' ecosystems and the possible gap between their current knowledge and the targeted objectives. In this respect, the pilots underlined that the “third-eye” view provided by our external co-design team proved to be particularly helpful.
- In the workshop phase (done for a limited number of voluntary pilots), we helped the pilots to structure their interactions with a targeted set of actors, especially helping them to explore forms of relationships that could differ from the ones they might expect in the first place.

Design theory expertise proved to be important in both phases. Indeed, our experience has especially led us to **chase and unveil the cognitive fixations that the co-design sponsor might be prone to**, with regard to its perception of the ecosystems of actors and its place within those (in the diagnosis phase), and with regard to the nature of its relationship with a certain type of actors (in the workshop phase).

In the future, **the distribution of co-design expertise across the co-design sponsor and external co-design still remains an open question**. Having co-design experts as a separate figure from the co-design sponsor was acknowledged as very beneficial in e-shape. But for future developments, it will be interesting to question what forms co-design expertise might be possibly handed over to the co-design sponsors, and what other forms would necessitate being taken over by an external figure of co-design experts.

Training co-design sponsors to design theory principles and specificities of resilient-fit co-design could be a possible way of helping the co-design sponsors to deal with an increasing range of co-design situations in autonomy. This first path is especially encouraged by studies showing the promising results of training employees in organisations willing to undertake large transformations in the face of grand societal challenges (Yström et al., 2021; Rampa and Agogué, 2021; Rampa et al., 2016).

In parallel, a team of external co-design experts could remain helpful to support the co-design sponsors with the most intricate aspects, especially concerning the diagnosis phase (given the difficulty of making alone a diagnosis of one's own fixations), and the cases of workshops where the co-design sponsor has difficulty addressing the level of grand distance at stake.

5.4.3. Institutional actors

Although less apparent than the two previous figures, it is also worth acknowledging the important role of institutional actors. The historical case of oceanography has already well highlighted the role of space agencies in fostering the growth of a vibrant ecosystem of data users (Le Pellec-Dairon, 2013). In our case, the configuration of e-shape has rather led us to observe **the role of a public funding actor, here the European Commission, in the development trajectory of the co-design sponsors**.

Paper 3 suggests that the role played by institutional actors such as the European Commission goes beyond establishing a new form of regime (e.g. entailing specific rules and regulations) that would bridge the respective regimes of EO and usage-related socio-technical systems. In e-shape, the financial support provided by the European Commission proves to contribute to developing the capacities of grandly distant actors to weave robust and beneficial relationships. This kind of support appears to **play a critical role in the long-term development strategy of the co-design sponsors**. It is for example well illustrated by the case of O.I.E. in *Paper 2*, that has been involved in numerous EU-funded projects along its trajectory. For example, the origins and developments of certain building blocks used by O.I.E. in e-shape can be traced back to past European projects, such as the Jupyter Notebook previously developed by O.I.E. in the project 'NextGEOSS' (2016-2020). More generally, the co-design diagnosis phase carried out with the different pilots revealed that many of them had been involved in other EU-funded projects before e-shape.

While suggesting the important role of funding actors, the pilots' project-to-project trajectories also raise the question of how to ensure that each project helps the pilots progress towards building a viable operating model over time, without merely relying on a never-ending project-based funding. Addressing this question would deserve further research, especially aligning with recent calls for considering renewed forms of innovation policies especially in the face of supporting sustainability transitions (e.g. Boon et al., 2022; Robinson and Mazzucato, 2019; Kuhlmann and Rip, 2018).

The results of our research nonetheless call for a few preliminary remarks. First, they suggest that managing grand distance turns out to be a complex and long endeavour that certainly extends the scope of a single project. Second, and as a consequence of the first remark, it seems particularly important to use **adapted key performance indicators (KPIs) to assess the results of such projects with respect to the grand-distance issue**.

In this regard, *Paper 1* allows us to have a few preliminary thoughts on this question, drawing from the notion of resilient fit. KPIs could especially aim to reflect the progress made by the pilots towards building resilient fits. To assess whether a resilient fit or a short fit is built, it is probably insufficient to only count the number of requests on a given web-based platform or the number of paying users. Although the latter elements are important, they indeed do not reflect well the intermediate steps that might be required to reach these points,

nor the dynamics in which the pilot is engaged. Our results suggest that KPIs could, among others, involve assessing at the beginning and at the end of the project:

- *Number and nature* of the considered users' ecosystems;
- *Knowledge about the overall context of these ecosystems* (ability to tell how the ecosystem is structured, what are the enforced rules and regulations, the current dynamics, etc);
- *Number of contact points* within these ecosystems;
- *Degree of relationship robustness for each contact point*: nature of exchanges (from one-off interactions to strong relationships possibly involving past collaborations), form of formalisation (no formalisation / informal formalisation / contractual formalisation);
- *Ability of the pilot to ensure the operationalisation of the developed solution* (in-house / already existing operationalisation partner / relationship with an operationalisation partner to be (re)built).

At the end of the project, the assessment could also entail identifying the types of co-design carried out during the project. Each co-design type indeed refers to a well-pinned issue that the pilot needs to address. In this respect, it appears more informative than only counting a number of co-design sessions. By considering the different types of co-design undertaken by a given pilot over time, the trajectory and strategy followed by a given pilot could be made more explicit. The proposed KPIs will of course need to be further refined and tested.

To conclude, we can see that again the “organisational relations” dimension is strongly linked to the other ones. The respective fields of expertise of the co-design sponsor and co-design experts were already apparent in the “technical substratum” and “reasoning logic” dimensions and have been further elicited here. These different fields of expertise appear as especially critical to lay the foundation for reaching resilient fits, hence the link with the “management philosophy” dimension. In this respect, the figure of the institutional actors also appears to play a key role in creating the enabling conditions of resilient fits.

Note as well that, for each dimension, various aspects could be unveiled thanks to the complementarity of views provided by the different papers. The respective contributions of the papers to unveiling some aspects of the resilient-fit co-design model are synthesised in Table 19.

	Paper 1 - <i>micro</i>	Paper 2 - <i>meso</i>	Paper 3 - <i>macro</i>
Management philosophy	Objective of building “ resilient fits ” involving building shared unknowns (<i>cognitive dimension</i>), dedicated interactions with targeted actors (<i>socio-organisational dimension</i>), strengthening the capacities of actors to sustain design efforts over time (<i>dynamic dimension</i>).	<i>Implicitly present</i> : building resilient fits implies being able to repeatedly fit data into multiple use contexts (hence the focus on the data/uses fit system).	Emphasis on the dynamic dimension of the resilient fit (<i>grafting</i> metaphore). Resource-based view on collective action for grand challenges (as opposed to a ‘challenge-based’ view): co-design aiming to build resources for others to better address their respective challenges
Technical substratum	Sophisticated range of tools & methods : - Pre-workshop (diagnosis phase): diagnostic visual template , framework of four co-design types - Workshop guidelines and templates for each type - Post-workshop: focus on the co-design sponsor’s learning curve	Further insights on certain data-related boundary objects such as Jupyter Notebooks.	Framework of 4 co-design types , each one being defined by a certain delimited form of learning
Reasoning logic	Adaptation of the DKCP logic. Each type of co-design contributes to designing locally shared unknowns with pinpointed actors of the ecosystems . The processes basically relies on the mutual defixation of actors stemming from their respective highly unconnected knowledge.	The design space of the co-design sponsor is related to the overall long-term objective of designing the data/uses fit system .	The diagnosis phase plays the role of a diagnostic tool helping the co-design sponsor’s to set up and steer future expansions of its design space (identifying the relevant types of co-design to be implemented with certain actors at a certain time horizon)
Organisational relations	The <i>co-design sponsor</i> proves to be able to implement co-design despite extremely limited orchestration capacities The <i>co-design experts</i> especially play a role in helping the co-design sponsors to overcome their cognitive fixations . Further insights on KPIs to help institutional actors better assess the trajectory of the funded pilots towards bridging the distance, especially towards building resilient fits.	As designer of the data/uses fit system, the <i>co-design sponsor</i> is led to build rich and diverse interactions with multiple actors (in an adaptive or stimulation mode) Designing the data/uses fit system involves a broad range of competencies Role of <i>institutional actors</i> in supporting the long-term continuity of the efforts needed to design the data/uses fit system	The <i>co-design sponsor</i> needs to be able to circulate between niches and regimes of several socio-technical systems (hybrid actors) To further build on the <i>grafting</i> metaphore, the <i>co-design sponsor</i> could be seen as a “gardener of the unknown” Role of <i>institutional actors</i> going beyond implementing new rules and regulations but focusing on developing the capacities of actors to manage grand distance.

Table 19: Synthesis of contributions of each paper to unveiling certain aspects of the resilient-fit co-design model

5.5. General discussion on the resilient-fit co-design model, its limits and perspectives

The previous sections have already touched upon a range of discussion elements, limits and further perspectives related to each dimension of the resilient-fit co-design model. The subsequent paragraphs will complete the picture by considering elements of discussion applying to the overall model.

5.5.1. How the resilient-fit co-design model addresses grand distance

In line with our research purpose consisting of characterising grand-distance co-design models, it is first important to reflect on how the resilient-fit co-design model addresses grand distance. As already touched upon above, grand distance has led us to integrate specific elements in the co-design model from the outset of our experimentation (designated as “effects of grand distance on resilient-fit co-design”). Moreover, once experimented, it is also noticeable that resilient-fit co-design has an effect on grand distance and contributes to reducing it. Table 20 summarises how grand distance is addressed in these two perspectives.

Distance dimensions	Effects of grand distance on resilient-fit co-design	Effects of resilient-fit co-design on grand distance
Cognitive	Segmentation of learning processes (each co-design type focusing on delimited aspects), and distribution over time.	Enrichment of each actor’s design space, especially relying on mutual defixation .
Social and organisational	Typology of co-design mirroring the diversity of the actors to be involved. Systematisation of efforts directed towards eliciting the nature of the relationships to be (re)built .	Actors becoming more familiar with each other. Actors agreeing on various forms of relationships , possibly beyond traditional forms of buyer-seller relationships.
Institutional	Co-design sponsor encouraged to learn about the overall context in which the actors evolve , including the rules and regulations of the considered ecosystems.	Difficult to observe directly after one or several co-design sessions. But appearing as a long-term endeavour .

Table 20: Summary of how the experimented co-design model addresses grand distance, considering grand distance as an input and as an output of co-design

Regarding the first perspective, the effects of grand distance on resilient-fit co-design have already been highlighted when considering the different dimensions of the model. It is especially interesting to note that the extreme character of grand distance in the EO context has especially led us to introduce a few original features, while reusing some properties of existing grand-distance models. On the one side, strong systematisation and elicitation efforts

have been made on some aspects already noted as critical by scholars, e.g. eliciting the socio-organisational outcomes of co-design as suggested in (Abrassart et al., 2015; Dubois, 2015), but in every single design session whatever its duration can be and in a very explicit way. On the other side, new forms of requirements have emerged, such as the introduction of an extended typology of co-design types to further sequence learning efforts over time.

Regarding the second perspective, the effects of resilient-fit co-design on reducing grand distance are also interesting to discuss. These effects are especially apparent on the socio-organisational and cognitive dimensions of grand distance (see Table 20), but tend to be less straightforward on the institutional dimension. Indeed, institutional effects are hard to directly observe after one or several co-design sessions. They were nonetheless touched upon during the co-design process, for example appearing as a long-term development path to be further explored by the participants. For example, these institutional aspects were discussed in the experimented co-design type 2 related to the integration of EO data into the wind offshore industry. At the end of the design sessions, it clearly appeared that subsequent long-term efforts would be needed to make EO data recognised as a legitimate source of information, complementing the other sources of data already used by the industry. One of the participating user was especially identified as a potential partner to work on this issue. Further research embracing a longer time span will be required to assess the actual effects of co-design on this dimension.

By combining these different effects of grand distance, the resilient-fit co-design model has proved to be especially efficient to lay the foundation for collective action to happen, despite the actors being separated by a grand distance. Some issues however remain with regard to the question of possible lock-ins. Indeed, how can we ensure that once a resilient fit is created, it will not reinforce path-dependences of respective actors and eventually evolve into lock-in situations (i.e. situations where the actors can hardly transform their practices and invent new action paths)? If a user indeed makes large investments in integrating data into its own practices, this could play as a hindering factor for later redesigning these practices, e.g. in the perspective of better tackling grand challenges.

Going back to the experimented co-design types, it is true that data tended to be primarily considered as a possible way of improving existing practices of users, while designing

new ones was rather postponed to longer-term horizons. In this regard, it could appear at first sight that the risk of subsequent lock-ins has not be fully managed. However, it is here important to note that these limitations are inherent to the initial grand distance separating the actors. When the pilots are not familiar enough with a given usage ecosystem, they are not in a position of designing themselves new action paths to be followed by the users. It is actually not even clear whether or not the potential users need to consider new action paths. Symmetrically, the users cannot envisage how data could potentially help them if they do not understand what they can or cannot do with data.

Managing the risk of lock-ins thus appears as a long term endeavour that would deserve a close attention beyond the scope of what could be experimented during my PhD. Nevertheless, it is worth highlighting that the resilient-fit co-design model already takes some precautions to limit the risk of lock-ins. It indeed puts a strong emphasis on progressively enhancing the design capacities of both all involved actors. The co-design sponsor enhances its understanding of the ecosystems of potential users, thus enhancing its ability to stimulate these ecosystems within the limits of its current capacities. Symmetrically, the potential users also enhance their capacity of understanding and handling data, thus benefitting from an additional resource for their reflections on how to organise their own practices. As such, the actors are more likely to avoid lock-ins by progressively becoming aware of their previous fixations and the other possible paths overcoming them.

In a way, the resilient-fit co-design model does not necessarily aim to undertake broad exploratory efforts that would target a thorough redesign of participants' practices in the first place. It indeed rather aims to create a durable fit between highly distant actors that would allow them to enhance their respective design capacities in the long term. But in this regard, it also lays the foundation for more ambitious joint design efforts that could be potentially required in the future.

On this aspect, the other grand-distance co-design models aimed at highly exploratory joint design efforts (e.g. Lavoie et al., 2021; Pluchinotta et al., 2019) could offer promising means of complementing the resilient-fit co-design model. Indeed, the resilient-fit co-design model contributes to reducing the degree of grand distance. In theory, it thus progressively make relevant the other models that were developed for lower degrees of grand distance.

Ambitious exploratory efforts are indeed all the more likely to succeed as the participants can benefit from strong design capacities and a pre-existing common ground.

These considerations suggest that the resilient-fit co-design model could benefit from being followed by other complementary forms of co-design. In the other way round, it could also be interesting to consider how the resilient-fit co-design model could potentially serve as a follow-up tool of other forms of co-design. It could be for example helpful to manage the remaining issues of mobilising the actors on a long-term basis, especially after the end of the design sessions (e.g. Berthet et al., 2022; Della Rossa et al., 2022; Pluchinotta et al., 2019). This could serve as a way of further building the relationships between the relevant identified actors in a more continuous and not too demanding time frame.

To summarise, **the results of our research confirm the relevance of the experimented resilient-fit co-design model to address grand distance**. Further research will be needed to investigate the possible combination and complementarity of the resilient-fit co-design model with the other available models of co-design (adapted to grand distance but also possibly to a lesser degree of distance).

5.5.2. Validity domain of the resilient-fit co-design model

Another critical aspect to discuss lies in the validity domain of the resilient-fit co-design model. The validity of the model has been indeed tested in a specific context of investigation, thus inevitably leading to a form of contingency. In this respect, the following elements are worth noting:

- The resilient-fit model heavily relies on the **existence of an actor willing to ignite and sponsor the co-design process** (i.e. the pilots in e-shape). This aspect is especially linked with the resource-based setting of co-design. The actor igniting and sponsoring co-design is the one holding a specific resource that could potentially benefit others. This condition might however be harder to meet in other contexts. For example, in a challenge-based approach when co-design starts with a given challenge (e.g. addressing water management issues in a given territory, or reinventing the packaging industry), additional efforts might be needed to identify which actor(s) could take on this role.

- The co-design sponsor leverages a **resource of a specific nature, i.e. data**. In this respect, we have to acknowledge that certain aspects of the model are directly linked to the specific properties of data (e.g. types of boundary objects, organisational form and competencies of the co-design sponsor).
- The resilient-fit model seems suitable with a **very large variety of grand challenges, here corresponding to the potential domains of data application**. This assertion is especially backed by the outstanding range of application domains addressed in e-shape. The project indeed included 7 thematic areas, within which each of the 37 pilots focused on a sub-challenge related to a given thematic area.

To summarise, the validity of the resilient-fit co-design model has been verified in the domain defined by **two critical conditions**: (1) **the co-design sponsor is clearly identified from the outset** as the **holder of an asset** that has the potential of being a resource for others, (2) the nature of the asset is based on **data**. By contrast, **the nature of the addressed grand challenge(s) appears as an open variable** of the model, thus making the validity domain of the model already quite large. Further research will be needed to investigate whether the resilient-fit co-design model can be applied to broader validity domains, especially with regard to the two critical conditions described above.

5.5.3. Operationalising the resilient-fit co-design model: variety of possible forms yet to be explored

Remaining within the tested validity domain of the resilient-fit co-design model, an open question also remains as to how such a resilient-fit co-design model could be further operationalised beyond the context of e-shape. Several efforts have already been made in that direction, especially involving numerous discussions with practitioners in the EO field. These interactions confirm the relevance of the model beyond e-shape. But several questions remain quite open at this stage and will deserve further investigation.

Concerning the typology of co-design, it is important to note that we do not claim for exhaustivity. The typology has been introduced to reflect the diversity of issues to be addressed in co-design, and thus adapting the co-design process within each type accordingly.

In other contexts than the ones represented in e-shape, new issues might appear as deserving a specific co-design effort. **The typology of co-design and the pool of associated workshops will thus deserve being progressively enriched**, according to the other and possibly new issues encountered by the co-design sponsors. In particular, it might come out that each type is actually worth being divided into sub-types. It could for example be worth for co-design type 4, corresponding to a case where the co-design sponsor had already built a certain product for a given user. In the type 4 experimented in e-shape, the expansion of the product beyond this initial user actually boiled down to jointly exploring the way of ensuring the viability of the product over time. Indeed, although acknowledging the usefulness of the product, the initial user could not pay for it. But in other contexts, we could also imagine forms of co-design type 4 that would be closer to forms of “prospective co-design” (Lavoie et al., 2021; Lab Ville Prospective, 2021; Abrassart et al., 2017). The exploration could here entail a more prospective stance and possibly involve multiple users, so as to explore future scenarios related to the users’ contexts and the possible contributions of data.

Moreover, **the organisational forms taken by the figures of the co-design sponsors and co-design experts remain very open**. The e-shape project shows that the role of co-design sponsor can be endorsed by private or public actors of different profiles (mainly meteorological institutes, public research institutes, other forms research institutes such as research and technology organisations, commercial firms, emerging SMEs and start-ups). It also appears that these actors tend to face a number of issues when undertaking such a long haul endeavour, with slightly different concerns depending on their profiles.

Without being exhaustive, the research institutes have especially to deal with the issue of continuing doing good research without becoming overwhelmed by the activities entailed in co-design. It might here require to build specific forms of public-private relationships to adequately distribute the tasks across partners with complementary expertise and capacities (as illustrated in the case of O.I.E.). But the effort might be worth it for science as well. Recent studies suggest that scientists can benefit from the interactions with potential users, as they can lead to open up new promising research paths in addition to having a societal impact, following a so-called “double-impact” model of research-industry coupling (Plantec, 2021). Such considerations might require to further legitimise the place of co-design in research activities, echoing the calls of other scholars: *“[Producing scientific knowledge for sustainable*

transitions] may also require a renewal of research governance, giving more space to participatory processes and allowing research to adopt a new position in the setting of societal goals.” (Berthet et al., 2022, p. 10).

For commercial companies, building sustainable business models appears as a difficult issue, here echoing other management research in the EO field (Lages, 2022). It especially relies on a range of capacities that might be difficult to combine, involving the capacity to understand and integrate into users’ ecosystems, strong engineering capacities, as well as strong scientific capacities to understand the phenomena that data are able to capture.

The organisational form of the co-design experts figure remains very open as well. It could take the form of a specialised unit in charge of implementing co-design on the behalf of a certain group of one or several co-design sponsors. Such forms already exist, for example the cooperative company E2L playing the role of co-design experts for a given research institute specialised in remote sensing techniques for biosphere monitoring (E2L, 2016). Alternatively and probably in a complementary way, we could also think of other forms of co-design expertise at the broader level of the EO community, that could be conveyed by existing institutional forms supporting the development of the EO community, such as the Group on Earth observations (GEO) and specifically its European component (EuroGEO). Such expertise could be for example fostered by a constitution of a trained team of co-design experts, intervening on-demand for the actors needing it.

CHAPTER 6: The resilient-fit co-design model opening up new forms of collective action in times of digital and sustainability transitions?

Summary of Chapter 6

This concluding chapter aims to further reflect on the main contributions and perspectives offered by our research. It especially contributes to literature on co-design, by expanding the range of grand-distance situations where co-design proves to be a powerful means of creating collective action, even in situations where collective action seems initially unthinkable. A few additional contributions are also discussed, especially in the context of digital and sustainability transitions. The chapter especially highlights that the cases investigated in the EO field exemplify an intriguing form of collective action towards sustainability transitions, which unfolds in a “resource-based” way, as opposed to a more usual “challenge-based” way. In a “challenge-based” way, collective action towards sustainability transitions starts with a given challenge (for example, mitigating air pollution) and consists in bringing together a whole range of different actors to address this challenge collectively. By contrast, in a “resource-based” way, that could also be referred to as “capacity-based” perspective, collective action starts with heterogeneous actors that are concerned by different types of sustainability-related challenges (e.g. mitigating air pollution, preserving biodiversity, building meteorological satellites), and that might already have some capacities to partly address them. In this “resource-based” perspective, collective action consists in building bridges between these heterogeneous actors, drawing upon their respective fields of expertise to build new “resources” for transitions (here useful and usable data). These resources are aimed at enhancing the capacities of these actors to address their respective challenges, and expanding the imaginable scope of future individual and collective actions. In the context of designing data as meaningful resources for sustainability transitions, the chapter also further reflects on the risk of “data solutionism”, where data would be value for their own sake and considered as a panacea. This risk can be partly mitigated by adequate forms of co-design, but still requires further efforts and a close attention.

Résumé du Chapitre 6

Ce chapitre de conclusion vise à approfondir la réflexion sur les principaux apports et perspectives de notre recherche. Elle contribue notamment à la littérature sur le co-design, en augmentant l'éventail des situations de grande distance où le co-design s'avère être un

puissant moyen de créer de l'action collective, même dans des situations où l'action collective semble a priori impensable. Quelques contributions complémentaires sont également abordées, notamment dans le contexte des transitions numériques et écologiques. Le chapitre souligne en particulier que les cas étudiés dans le domaine de l'observation de la Terre illustrent une forme intrigante d'action collective pour les transitions, qui suit une approche « basée sur les ressources », qui diffère d'une approche qualifiée de « basée sur les défis ». Dans une approche « basée sur les défis », l'action collective part d'un certain défi (par exemple, lutter contre la pollution de l'air) et consiste à réunir toute une palette d'acteurs différents pour agir collectivement en vue de ce défi. Dans une approche « basée sur les ressources » (qu'on pourrait également qualifier de « basée sur les capacités »), l'action collective commence avec des acteurs hétérogènes qui sont concernés par des défis différents (par exemple, lutter contre la pollution de l'air, préserver la biodiversité, construire des satellites météorologiques), et qui peuvent déjà avoir la capacité de les aborder de façon partielle. L'action collective consiste alors à relier ces acteurs hétérogènes, et construire de nouvelles « ressources » pour les transitions (ici des données utiles et utilisables) en s'appuyant sur leurs expertises respectives. Ces ressources ont pour vocation d'augmenter les capacités des acteurs à agir en vue de leurs défis respectifs, et d'imaginer de nouveaux champs d'actions futures, individuelles et collectives. Dans la perspective de concevoir des données comme des ressources pour les transitions, le chapitre discute également du risque de « solutionnisme de la donnée » qui valoriserait l'usage des données de façon systématique et considérerait les données comme une solution miracle. Le co-design peut contribuer à atténuer ce risque, mais des efforts supplémentaires et une attention particulière sont encore nécessaires.

Let us first go back to the starting point of our journey. It started with an enigma faced by contemporary organisations and managers, lying in the issue of what we have coined “grand distance”. Simply said, the grand-distance issue boils down to the following question: **how to create collective action between highly distant worlds that have hardly anything in common from the outset, thus appearing as largely unknown to each other?** From a management perspective, this question could appear as almost paradoxical, or at least highly problematic. Indeed, all the conditions that usually lay the foundation for collective action are no longer guaranteed. How to bridge people who belong to heterogeneous professional spheres, who might even not know the existence of each other, who barely share any common knowledge, expertise and set of rules and norms to comply with? Given all these obstacles, would managing grand distance not be only doomed to failure? Is it even worth trying?

One can at least argue that the effort is justified by the high stakes involved. Indeed, grand distance seems to become more and more prevalent, to reach increasing levels, and as such to be all the more critical to manage. The field of Earth observation (coined “EO”), that has been specifically studied in this thesis, provides a vivid example. But beyond the EO context, we are already witnessing similar attempts at bridging digital and sustainability transitions within open-data movements, especially calling for public administrations to make their data available for others (e.g. Berrone et al., 2016; Brunswicker and Johnson, 2015), but still struggling to make these data used in practice (e.g. Zuiderwijk and Reuver, 2021). Contemporary organisations are also increasingly facing the need of building new forms of collective action bridging distant worlds, especially in the perspective of better tackling grand challenges and accelerating sustainability transitions (Konrad et al., 2008; e.g. Sutherland et al., 2015). This thesis does not intend to give a definite answer to these questions, as tremendous research and managerial efforts are certainly yet to come. **Our approach has rather consisted in going down a rabbit hole, investigating the potential contributions of “co-design” to organising collective action in grand-distance situations, and endeavouring to make some contributions and draw stimulating perspectives from there.** This is precisely what we would like to outline in the following paragraphs.

6.1. Down the rabbit hole: summary of the main lines of inquiry

The journey started off in the EO field, where the issue of grand distance unfolds in a particularly extreme way, as especially described in *Chapter 1*. Indeed, for more than forty years, tremendous efforts and investments have been made to generate high-quality data on the status and evolution of our planet Earth (e.g. composition of the atmosphere, status of vegetation, sea levels, temperature of objects), for example, leading to significant advances in meteorology and climate sciences. In the last years, these efforts have been extended to the attempt at bridging the digital transition in which the EO community has been involved (with new cutting-edge technological and scientific advances providing a wealth of data), and the sustainability transitions that actors outside the EO community have been increasingly urged to progress towards (such as municipalities seeking to develop tools for climate change adaptation or pollution mitigation, but also companies for example involved in the development of renewable energies). Could EO data help these actors in their pursuit? If yes,

how? Such questions are not self-evident to answer as **the potential new users of EO data are bound to be largely unknown by EO data providers in the first place**. In this context, “co-design” has started to flourish in the EO community as a potential way of bridging the distance. However, the EO community still calls for further formalisation, improvement, and generalisation of co-design beyond the buzzword (e.g. Goodess et al., 2019).

Our navigation through state-of-the-art co-design research in *Chapter 2* has highlighted an observed tendency towards situations of increasing distance, and its consequences on co-design at three different levels (micro, meso, macro). Existing studies on grand-distance co-design have confirmed the **potential role of co-design in addressing grand distance, and have also underlined the need of adapting co-design to the distance involved**.

Moreover, the chapter has highlighted that our understanding of co-design goes beyond a mere view on the range of tools and methods supporting the organisation of some forms of workshops and collective design sessions, **hence the use of the term “co-design model”** embracing several dimensions. Indeed, not only have we described these tools and methods (referring to the “technical substratum” dimension of the co-design model); but we have also sought to unveil the underpinning model of collective action, by characterising the overall purpose at which co-design is aimed (“management philosophy” dimension), the organisational characteristics, roles and relationships of the involved actors (“simplified view of organisational relations” dimension), and the underlying design mechanisms based on the intertwined exploration of both concepts and knowledge (“reasoning logic” dimension).

The chapter has underlined how existing research on grand-distance co-design already points to a variety of co-design models with different characteristics for each dimension. At this stage, an open question remained so as to the adequacy of these models to situations of extreme grand distance, as, for example, is faced by the EO community. As suggested by previous developments, some adaptations were foreseeable, but how and whether they would actually unfold remained open to investigation.

Taking this investigation further, *Chapter 3* has exposed the empirical context in which such co-design models for cases of extreme grand distance could be explored. The chapter shows that we have benefitted from a **particularly favourable empirical setting, by being directly involved in the European project called e-shape**. Indeed, e-shape provided us with a

very rich empirical ground, embracing 37 different pilot applications covering 7 thematic areas (agriculture, health, energy, biodiversity, water, natural disasters, climate), each one aimed at developing a range of EO-based products or services for one or several types of users. In this context, the co-design sponsors, i.e. the actors in charge of initiating and undertaking co-design in the long run, were EO data providers involved in the development of these pilot applications (also shortly called “pilots”).

Moreover, as a prerequisite of e-shape, these EO data providers were top-level experts that had already been involved in such developments for at least several years. As such, the majority of them already had some experience of co-design, but their existing co-design practices proved to be sometimes insufficient to address the extreme grand distance involved. The EO providers were thus kinds of “pioneering organisations”, that could provide us with interesting insights to start with, but that were also willing to explore new forms of co-design. We thus endorsed the role of “co-design experts” bringing additional co-design expertise to complement those held by e-shape partners. In this context, **we were led to build and experiment a new form of co-design, coined “resilient-fit co-design model”**, in strong collaboration with e-shape partners.

Chapter 4 and, more importantly, *Chapter 5* have contributed to portraying the resilient-fit co-design model. Chapter 5 has especially discussed the characteristics and peculiarities of the model for each dimension. The resilient-fit co-design has also proved to be relevant for addressing extreme grand distance, at least within the tested **validity domain of the model** relying on two critical conditions: (i) the co-design sponsor is clearly identified from the outset as the holder of an asset that has the potential of being a resource for others, (ii) the nature of the asset is based on data – the model remaining very open with regard to the nature of the grand challenge(s) that the data could potentially be a resource for.

Beyond the overall ability of the model to address extreme grand distance, the resilient-fit co-design model also sheds light on original patterns of collective action appearing at the four dimensions of the model. These different elements offer several contributions and perspectives for various streams of literature and for practice, which we would like now to further reflect on.

6.2. Academic contributions and perspectives

6.2.1. Main contributions to management research: resilient-fit co-design to organise collective action in extreme cases of grand distance by designing a resilient 'co'

The thesis primarily contributes to the management research stream on co-design, rooted in different research traditions in industrial design, engineering design, and innovation management. In particular, recent studies have shown that co-design can especially contribute to managing grand distance, e.g. related to policy design supporting the energy transition of Finland (Hyysalo et al., 2019a, 2019b, 2019c), policy design for water management issues in a given region (Pluchinotta et al., 2019), the need of imagining the future of cities (Lavoie et al., 2021), or the design of agroecological systems (Berthet et al., 2022, Elzen and Bos, 2019). However, the relevance of co-design was *a priori* not guaranteed in situations of extreme grand distance, as for example encountered in the EO case. In this respect, by unravelling the resilient-fit co-design model, our research confirms that co-design can indeed help manage an extreme level of grand distance, of course provided that specific efforts are made to explicitly address the issues involved at such an extreme level. In this respect, our research brings two first contributions: (i) showing that **collective action can be organised even in situations of extreme grand distance** and (ii) **expanding the distance spectrum within which co-design is proved to contribute to organising collective action despite the distance at stake.**

Moreover, investigating an extreme case of grand distance has led us to set up a form of co-design that displays some peculiar characteristics, that contribute to offering fresh perspectives on the range of possible co-design forms. It can first be noted that the resilient-fit co-design model aligns with the observed tendency towards an increased attention to the socio-organisational outcomes of co-design (e.g. Della Rossa et al., 2022; Berthet et al., 2020; Dubois, 2015; Abrassart et al., 2015). The latter authors have indeed highlighted that not only can co-design result in designing innovative objects, but it can also have an effect on the collective of actors by creating or strengthening relationships between the involved participants.

In this respect, the resilient-fit co-design model belongs to the range of co-design forms considering **co-design as entailing the “design-of-the-co”** and not only referring to designing collectively, as especially suggested by Dubois (2015). The “design-of-the-co” formula aims at emphasising that “co” in the word “co-design” “is not to be simply considered as the means of designing innovative objects (*“let us design something innovative by doing it in a collective way”*), but as a proper object of design (*“let us design the collective (the ‘co’), i.e. build the adequate relationships between the involved actors involved, so as to further design collectively”*).

Importantly, Dubois (2015) further highlights that the “design-of-the-co” perspective does not set aside the “designing collectively” facet. Indeed, these two facets are actually strongly linked. Designing the collective does not only stem from putting heterogeneous people together, but it is actually strongly supported by the fact that these people undertake a process of designing collectively. In other words, designing collectively is a way of making people forge a robust collective of actors. In this respect, Dubois (2015) suggests that the scope of design ambitions and the strength of the collective can be progressively expanded in an intertwined way by repeating co-design over time. Starting with a weak collective, co-design might result in modestly-innovative ideas, but could at least strengthen the collective, and lay the ground for future exploratory efforts.

This “design-of-the-co” perspective can be especially found in recent advances on grand-distance co-design models, e.g. in (Berthet et al., 2020) where co-design is described as a matter of “fostering social learning and designing new solutions *to enhance interactions between participatory breeding stakeholders*” (p. 3-4; our emphasis)”. It seems consistent with the issues resulting from grand distance. Indeed, the further the distance between participants at the outset, the less likely they are to form a collective naturally, and the more efforts are needed to explicitly design the collective. While aligning with the previous developments, **the “design-of-the-co” facet has taken on a new dimension in the resilient-fit co-design model**, which is again consistent with the fact that going from grand distance to extreme grand distance undermines further the usual enabling conditions of collective action.

Let us now elaborate on how some characteristics of the resilient-fit co-design model play a key role in designing the ‘co’ in extreme grand distance. It can be first noted that the resilient-fit co-design model puts a strong emphasis on systematising and eliciting as much as

possible the “design-of-the-co” objective. By merely drawing on the name of the model, one can say that the resilient-fit co-design model basically aims to **design the ‘co’ in a resilient way.**

To elicit further what is meant by that, it is worth commenting on the term “resilient-fit”. The resilient-fit co-design model has been labelled as such to directly mirror the underlying management philosophy, i.e. the overall purpose at which co-design is aimed. The “fit” refers to the objective that largely prevails in all forms of co-design: creating a fit between heterogeneous actors - whether it be for developing a fit-for-purpose product or service for given users, or designing certain forms of collective action to tackle an identified challenge. “Resilient” refers to the nature of this fit, highlighting that co-design does not end when one fit is reached with one actor at a certain moment in time, but that it involves ensuring the long-term viability of these fits. In particular, in cases where actors are separated by a grand distance, a fit is likely to be very tenuous in the first place. In other words, without sufficient precautions, there is a risk of merely building “short fits”, i.e. relationships that underestimate the distance at stake and that are thus likely to quickly fade away. By contrast, **the resilient-fit co-design model puts at the forefront the objective of managing the “short-fit” risk. It especially involves designing adequate forms of relationships that would enable sustainable and fruitful interactions in the long term, and progressively lay the foundation for more and more exploratory endeavours.**

This objective has important consequences on how the resilient-fit co-design process is structured. It especially involves **two components that both contribute to designing a resilient ‘co’: (1) a diagnosis component and (2) a workshop component.** The articulation of these two components appears all the more critical as the co-design sponsor does not know initially with whom it would be interesting to design a collective with. For example, taking the view of a provider of data related to wind energy resources exploring the potential of data for the offshore wind industry, it is not *a priori* self-evident whether it would be interesting to discuss with wind farm manufacturers, consultants, energy companies, banks funding windfarm projects, or other actors among the rich ecosystem of offshore wind industry. Similarly in the agricultural sector, should the EO data provider co-design with farmers, cooperatives, scientists, industrial companies? Should all these actors be invited to co-design altogether? And for a given type of actors, which organisation should be contacted as a priority? And which person in this organisation?

We can see here that many unanswered questions make the process of designing the ‘co’ particularly challenging. In this respect, both diagnosis and workshop components participate in progressively elucidating these questions, by playing the following roles:

The *diagnosis* component consists in the co-design sponsor pinpointing the actors that seem the most relevant to organise co-design with, among a rich ecosystem of actors (potentially several different ecosystems). Within e-shape, the templates and materials supporting the diagnosis (see section 5.2. “technical substratum”) were precisely built by our research team to help the co-design sponsors to elicit their current status of knowledge about the considered ecosystems, including their overall understanding of the ecosystems’ organisation and dynamics, their existing contact points, their previous experiences, the encountered issues, etc. In a way, the diagnosis component aims at helping the co-design sponsor to formulate first answers to the questions raised above, based on the co-design sponsor’s existing knowledge. It especially results in identifying several possible types of co-design to be conducted with various actors, distributed over different time horizons. However, at this stage, these questions remain only answered on the basis of the co-design sponsor’s existing knowledge, but might need to be refined through the learning made during the interactions with the pinpointed actors. This is where the second component plays an important role.

The *workshop* component consists in the co-design sponsor attempting at designing the ‘co’ with the pinpointed actors invited to join a given workshop. It especially involves working on three intertwined aspects:

- i) *Building a range of locally shared unknowns related to how data could be a potential resource for the pinpointed actors.* It can involve identifying draft ideas of possible topics or subjects of interest to be further explored (e.g. correlation analysis between air pollution and health related issues). These unknowns are designed as only “locally shared” because they only intend to be shared between the participants of a given workshop, that represent only a small part of the overall ecosystem of actors.
- ii) *Building multi-faceted forms of relationships* that are not necessarily taking the form of buyer-seller relationships (e.g. participating in a common project,

hiring a student to explore the possibility of adding temperature profiles to wind resource assessment data);

- iii) *Strengthening the actors' design capacities over time*, especially allowing them to pursue the efforts on the first two aspects in the long run, especially involving the ability to undertake intricate and long-term learning processes.

These three aspects are not inherently new and are especially consistent with the usual conditions of what makes a good design process (Le Masson et al., 2017), embracing a form of *variety* (several forms of resource-related unknowns and relationships), *originality* (resource-related unknowns and relationships appearing new with regard to each participant's design space), *value* (the knowledge acquired respectively by the participants contribute to opening up new forms of value for data to become a resource for the pinpointed actors), *robustness* (here basically relying on the enhancement of design capacities).

More originally, the workshops seem to take a quite unusual function here compared to other forms of co-design. Indeed, in our case, when the co-design sponsor invites people to participate in the co-design workshops, it is actually not yet certain that these participants will prove to be the relevant ones. The workshops thus directly serve as a way of validating or invalidating the relevance of further designing the 'co' with the invited participants. In other words, **the workshops endogenise a diagnostic function, that usually tends to be considered as exogenous to the workshops and fully embraced by a separate diagnosis phase**. Indeed, in most grand-distance co-design models, the participants are identified through an initial diagnosis process that is done beforehand, and essentially by the co-design experts getting involved in a time-demanding process of mapping the different actors and relationships and their respective knowledge and cognitive fixations. (e.g. Della Rossa et al., 2022; Lavoie et al., 2021; Pluchinotta et al., 2019). In our case, there was also a dedicated phase of diagnosis organised prior to the workshops, but it did not intend to map the different actors of the ecosystem(s) at stake by taking a third-party view, but rather intended to formalise the co-design sponsor's own view on the(se) ecosystems. As such, the diagnosis phase was rather to be seen as a first initialisation of the diagnosis, only constituting a very partial view of the considered ecosystems, that ought to be progressively expanded by the subsequent workshops.

To depict the situation in an imaged way, we could say that the co-design sponsor can only see the various ecosystems from the outside, through tiny little keyholes. Workshops

could then be seen as attempts at knocking on some doors and see whether these doors lead to dead ends or could be good entry points in the considered ecosystems. In this respect, the workshops contribute to progressively enriching the diagnosis made initially by the co-design sponsor.

The diagnosis and workshops thus appear as closely intertwined components that should be conducted in a recursive way. This aspect is more precisely described from the view of the co-design sponsor's reasoning logic in *section 5.3*: "diagnosis" and "workshops" appear as two different types of moments in the overall reasoning logic of the co-design sponsor, that can be alternatively and repeatedly activated by the co-design sponsor to progressively expand its design space directed towards designing the system, allowing data to be used in a large variety of contexts (the so-called "data/uses fit system"). The diagnosis component corresponds to a moment of elicitation, making explicit the learning made during multiple workshops and other activities that the co-design sponsor might have. As for the workshops, they are the engines of the diagnosis process triggering new learning with various actors, that can be progressively elicited at each implementation of the diagnosis component.

It is worth noting here that in some chapters of the thesis, "diagnosis" and "workshop" are rather described as two subsequent "phases". Indeed, this directly reflects how it actually unfolded during the project: a diagnosis phase was carried out by all e-shape pilots, a workshop phase then followed for a few volunteering e-shape pilots, but we did not have time to run a second round of diagnosis after the workshops. I propose here to use the term "component" instead of "phase", precisely to move away from a mere linear view of the articulation between diagnosis and workshops .

Said in a metaphorical way, **the co-design sponsor can be seen as a "gardener"** who makes the garden grow by leveraging the on-going dynamics of nature and especially pinpointing plants whose specific properties make them play a specific role in the ecosystem. In this respect, designing a resilient 'co' relies on the combination of two combined aspects: **(1) launching the "design-of-the-co" in multiple directions**, by reaching out to a variety of pinpointed actors of the considered ecosystems, chosen for their specific characteristics and roles in these ecosystems, **(2) ensuring that these various attempts carry with them the seeds of long-term fruitful collectives of actors** supporting the growth of the ecosystems. It

is worth noting here that the collectives of actors do not refer to one global collective but a multiplicity of little “localised” collectives between the co-design sponsor and pinpointed actors of the considered ecosystems.

Main contributions to management research

To summarise, our research has elicited the resilient-fit co-design model that has proved to help organise collective action in an extreme case of grand distance, as witnessed in the EO context. The thesis does not claim that every situation of extreme grand distance could be addressed by the resilient-fit co-design model. It does not claim either that there is no other co-design model that could also address a situation of extreme grand distance. However, by eliciting this specific model, our research already contributes to management research, and especially to the stream of studies on co-design, by:

- (1) Showing that **collective action can be organised even in extreme cases of grand distance**, where it seemed highly improbable at the outset,
- (2) **Extending the validity domain of co-design** as a potential means of organising collective action **to situations of extreme grand distance**,
- (3) **Extending the range of possible co-design forms to address situations of grand distance**. In particular, within the perspective of considering co-design as “design-of-the-co”, we have shed light on original characteristics that can especially foster the **design of a resilient ‘co’**, by (i) reaching out a variety of pinpointed actors of the considered ecosystems, chosen for their specific characteristics and roles in these ecosystems, (ii) ensuring that these various attempts carry with them the seeds of long-term fruitful localised collectives of actors supporting the growth of the ecosystems.

Of course, these contributions will deserve further developments. The resilient-fit co-design model could especially benefit from being tested and enriched in multiple other empirical contexts, in the EO field and beyond. It will also be interesting to investigate whether one or several characteristics of the resilient-fit co-design model could also be relevant at different levels of the distance spectrum, not only for situations of extreme grand distance but also possibly for situations of shorter distances.

Finally, the notion of “grand distance” itself will certainly require further elaboration. The thesis has defined a situation of grand distance as a situation that combines a large degree of distance on a large number of dimensions. One could here argue that the boundaries between situations of short distance, grand distance, and extreme grand distance remain a bit vague. Indeed, at which stage shall we consider that there is a large degree of distance, and that the number of dimensions is large? I do not have a clear answer to this question for the moment. Defining some exact thresholds appears difficult and a bit arbitrary to me. Yet, at this stage, I would like to highlight that **the grand-distance definition has at least proved to be operative in a comparative perspective**, i.e. highlighting that some situations face a grander distance than others, and that it is a critical aspect to take into account when attempting to organise collective action. In this vein, we have underlined that contemporary managers and organisations tend to face situations of increased distance with an increased frequency, compared to early developments in the management field. We have also shown that the EO field even goes one step further in the grand distance spectrum compared to these contemporary forms of grand distance. Another possible path of further elaboration could also concern the possible interplays between the different dimensions of distance. Previous studies have indeed highlighted that all dimensions of distance might not have the same status (e.g. Mattes, 2012). In this respect, one could question whether a large distance on some dimensions but a shorter distance on some others would raise different forms of issues. One could also wonder whether some dimensions play a more critical role than others.

Let us now consider how these main contributions to management research also pave the way towards subsidiary contributions and perspectives in other streams of literature, starting with the ones related to collective action for tackling grand challenges.

6.2.2. [Subsidiary contributions and perspectives for collective action in the face of grand challenges](#)

A growing body of management research has highlighted that tackling contemporary grand socio-environmental challenges calls for deeply transforming organisations and inventing new forms of collective action, that would especially involve heterogeneous actors spanning usual sectorial boundaries (e.g. George et al., 2016; Eisenhardt et al., 2016; Ferraro et al., 2015). In this context, it appears that there is a clear need for collective action between

actors that are likely to belong to grandly-distant worlds, but that it proves to be tremendously difficult to organise.

In this respect, the thesis offers a first contribution. It shows in its own way that **despite the intricate issues at stake, there is still some hope to cling on to: organising collective action between actors that hardly know each other is not wholly wishful thinking**, provided that adequate objectives, organisational models, tools and reasoning logics are imagined and put in place. Of course, the thesis does not claim that the resilient-fit co-design model will provide the magic solution to any kind of grand-distance situation, but showcasing one case is sufficient to tell us that such endeavours are possible, and definitely worth trying.

Moreover, the resilient-fit co-design model has also unveiled original patterns of collective action that can hopefully offer some fresh perspectives. First, as detailed in *section 5.1. "Management philosophy"*, the resilient-fit co-design model is driven by a so-called **"resource-based" perspective on how collective action can contribute to tackling grand challenges**, that consists of starting with an existing asset (e.g. EO data) and investigating how collective action could be organised to transform this asset into a resource, which would help others to progress along their respective trajectories towards sustainability transitions.

This perspective suggests interesting ways of organising collective action towards grand challenges, differing from the "challenge-based" perspective that seems to largely prevail. Indeed, numerous studies rather focus on starting with one or several targeted grand challenges and investigating how collective action could be organised to address the targeted challenges, e.g. studies on how cooperatives can play a role in addressing challenges such as water management, fertiliser and pesticide use in the agri-food system (Callagher et al., 2022), how firms could implement new forms of strategies involving a strong engagement with stakeholders to support a transition towards renewable energy (Dodd and Nelson, 2019), how crowdsourcing platforms can contribute to imagining solutions for sustainable oceans (Porter et al., 2020).

Although seemingly less common, the resource-based perspective seems nonetheless relevant beyond the EO context. Existing research already provides us with a few examples. For example, Ayrault (2022) reports on the case of an energy company investigating the possibility of supporting sustainability transitions of local actors based on a certain asset, i.e. its historical expertise of providing local and collective heat delivery infrastructures. The latter

research aligns with our observations that the value of this asset as a possible resource for sustainability transitions is not given in advance, and that its elicitation requires dedicated efforts, especially involving forging specific forms of relationships with heterogeneous actors and building up “locally-anchored” expertise. Such a resource-based pattern seems thus to offer promising ways of building collective action towards sustainability transitions, and would deserve closer attention in a larger variety of contexts and with various forms of assets beyond data (such as existing infrastructures, expertise, spheres of influence, etc.).

Moreover, I would find it particularly interesting to investigate the **possible complementarity between challenge-based and resource-based perspectives**, that are probably not to be considered as incompatible approaches but as two modes of collective action which organisations could alternatively play on.

Secondly, as detailed in *section 5.4. “Organisational relations”*, the resilient-fit co-design model sheds light on a form of collective action for grand challenges that does not rely on a form of centralised orchestration steered by one legitimate influential actor, but rather relies on the **existing orchestration capacities of actors that tend to be only limited to very localised spheres**. Said briefly, although these actors do not have the position to give the direction for a whole field or system towards sustainability transitions, they can still trigger local transformations by building upon the range of already available expertise distributed among heterogeneous actors.

However, our research suggests that these transformations might be difficult to unfold in practice, especially due to a multi-faceted and high level of distance that might make the actors seem highly unknown to each other. In this respect, our research calls for paying specific attention to the way relationships are adequately built and rebuilt between these actors over time, possibly going beyond classical forms of buyer-seller relationships. Such forms of collective action resonate with existing studies, e.g. calling for polycentric forms of climate governance (e.g. Cole, 2015), or distributed actorhood (e.g. Gehman et al., 2022).

In particular, Gehman et al. (2022) suggest that collective action for grand challenges can be especially supported by a form of “scaffolding”, metaphorically referring to the term commonly used in the construction industry designating the temporary structures that support the building or repairing of more permanent physical structures. In the context of

collective action for grand challenges, scaffolding consists in building the temporary structures providing heterogenous actors with enriched possibilities of actions to tackle grand challenges in their own respective ways: *“scaffolding points to a collective but distributed learning process. Those involved are likely to attain different learning outcomes: some might learn to rig up scaffolds for future projects; others might connect dots in new and innovative ways. Actors do not need to know the same thing [...] but they do need to know and create their own knowledge for the success of their own projects and how it connects to the larger enterprise”* (Gehman et al., 2022; p. 270). In other words, scaffolding contributes to transforming and shaping local patterns of behaviours and interactions, as for example illustrated in the context of addressing inequality patterns in small-scale societies in India (Mair et al., 2016).

Some echoes with our research are noticeable here. Indeed, aligning with Mair et al. (2016), the resilient-fit co-design model has contributed to transforming local patterns of interactions between pinpointed actors of the involved ecosystems. Moreover, resonating with the definition given by Gehman et al. (2022), it has involved an important and distributed learning process, aimed at opening up new pathways for the respective development outlooks of participants. In this respect, **the resilient-fit co-design model could be seen as a possible means of supporting scaffolding processes in certain situations of grand distance.**

Interestingly, the role of co-design in building scaffolds was already highlighted in early developments of co-design, especially considering that it should focus on creating the infrastructure for co-design to continue over time (Botero and Hyysalo, 2013). However, the actors considered in the latter study (a community of elderly people) were not concerned by the issue of grand distance. Our research thus aligns with and extends these previous developments, by shedding light on possible forms of mechanisms supporting scaffolding in situations of grand distance. It suggests that these mechanisms could especially involve the multiplication of localised co-design actions aimed at “designing the co”, i.e. progressively building up multiple localised collectives gathering pinpointed actors of the considered ecosystems. The thesis also suggests that the way these actors are pinpointed plays an important role. Indeed, it is not only a matter of designing collectives with all possible kinds of actors, which could quickly become overwhelming. It is rather a matter of **pinpointing the actors that would have the highest capacity to trigger transformations in their own sphere of influence.**

This is precisely where integrating a strong diagnostic function in co-design seems especially relevant: these actors might be difficult to pinpoint right away. As such, the diagnostic function of co-design appears as a promising feature, providing means of identifying the actors to build scaffolds with in priority. Further research could explore the different forms that this diagnostic function could take, depending on the considered situation.

Finally, our research also illuminates a noteworthy form of innovation policy. In times of grand challenges, scholars especially call for imagining the “next-generation of innovation policy” (e.g. Edler and Boon, 2018; Kuhlmann and Rip, 2018). In particular, the latter authors advocate a form of public action that would move away from an overly prescriptive position where the directions to be taken by the actors would be identified and planned by the public authority itself. By contrast, they argue that public action towards grand challenges should rather be focused on fostering “meta-governance”, i.e. creating the conditions for others to self-organise and experiment around societal problems.

The role played by the European Commission in e-shape seems to provide an **interesting example of how such form of “next generation innovation policy” could look like in practice**. Indeed, by funding such projects, the European Commission has not prescribed how solutions should be designed to address certain grand challenges. However, it has played a crucial role in allowing numerous actors of the EO community and various sectors to strengthen their respective capacities of organising collective action towards tackling grand challenges. In this respect, although not being overly prescriptive, such forms of public action remain highly interventionist, in line with several studies advocating the role of public policy in supporting market formation and transformative innovation (e.g. Boon et al., 2022; Mazzucato and Robinson, 2018).

In the EO context, the intervention of public action seems all the more critical as it appears that collective action cannot be solely driven by markets. Indeed, these markets do not exist yet or are only emerging. The value of EO data is not *a priori* given, neither by the EO data experts and nor by the actors outside the EO community. Hence, there is neither supply nor demand yet. In this context, the form of public action supported by the European Commission has consisted in allowing collective action in situations where it seems promising in terms of potential societal impacts (e.g. bridging digital and sustainability transitions), yet highly unlikely to happen without any support. Aligning again with Kuhlmann and Rip (2018),

such forms of public action seem to be especially critical to ensure the continued and targeted investment required to foster learning and the development of new capacities, that are then likely to have a large knock-on effect in the perspective of better tackling grand challenges. In particular, our research suggests that co-design could be considered as such a new critical capacity having large knock-on effects. It would be interesting to further investigate whether and how supporting the development of co-design capacities could be established as a long-lasting form of public action, beyond e-shape and possibly beyond the EO community.

6.2.3. Subsidiary contributions and perspectives for digital innovation research

Given the nature of the investigated empirical context, some of our results also contribute to research on digital innovation. Indeed, the figure of co-design sponsors was endorsed by EO data providers seeking to enable the use of EO data by multiple people who might possibly benefit from these data despite being not familiar with them. Investigating the organisational characteristics of the actors involved in co-design has thus led us to better understand the strategies of these EO data providers (see especially *Paper 2* and *section 5.4.1. “co-design sponsor”*). At the core of their strategies, these actors are all faced with a similar question: *how to make data produced for a given context of use* (i.e. for historical – mainly scientific - uses of EO data) *be useful and used in other contexts of use* (i.e. related to the operations of the new potential users outside the EO community)? This question is actually intrinsically linked to the core essence of data. Indeed, scholars point out that data are never completely “raw”: what we consider as “data” at least reflect the purpose for which they have been initially produced (e.g. Gitelman, 2013). In such a perspective, scholars describe data as incomplete objects or intentionally unfinished technologies (e.g. Alaimo et al., 2020; Kallinikos et al., 2013).

In this respect, the capacity of data to circulate across organisations and sectors is actually not an intrinsic property of data but results from additional efforts to design a wealth of technical as well as social elements. For instance, it can involve building robust processing chains, but also building specific forms of interactions with various actors of the ecosystems, e.g. to learn about a given use context or make data recognised as a legitimate source of information complying with the regulations of a given sector. Such efforts have already been subtly coined as the “recontextualisation” of data, i.e. making data initially used in a given

context, be used in another different context (e.g. Aaltonen et al., 2021; Alaimo et al., 2020; Aaltonen and Tempini, 2014). Drawing on these studies, our research has extended these considerations from a single case of recontextualisation towards multiple repeated cases of recontextualisation over time. Additional issues are raised here: how to learn about these potential use contexts? How to handle their variety? How to avoid being overwhelmed by the accumulation of design efforts involved in each case of recontextualisation?

Our research especially contributes to shedding light on the specific managerial logics taking into account the close interdependence between data and use contexts and supporting the extension of the contexts in which data can be used. These **managerial logics are described as involving the design of the “data/uses fit system”**, precisely referring to the set of socio-technical elements allowing data to be used in multiple contexts beyond its initial context of production. To a certain extent, such managerial logics find some echoes with previous research in other technological sectors, e.g. in the context of designing “generic technologies” having a wide range of potential applications (e.g. Hooge et al., 2016c; Kokshagina et al., 2016) or other forms of innovative technologies where “market-pull” and “technology-push” are described as complementary approaches to foster innovation (e.g. Maier et al., 2016; Brem and Voigt, 2009). However, the fundamental interdependence between data and its use contexts calls for specific processes and logics, where data and its use contexts are intimately linked and jointly designed, probably in a more intertwined and systemic way than a technology and its markets.

These considerations also offer some perspectives to the specific stream of research on open data. The EO context is indeed particularly interesting in this respect: tremendous efforts have already been undertaken to make EO data largely shared and open to all for at least several decades (Harris and Baumann, 2015). In this respect, the EO community has already dealt with multiple issues that are commonly held responsible for impeding the uptake of open data (e.g. Smith and Sandberg, 2018; Janssen et al., 2012). Without being exhaustive, data sharing principles and standardisation have been widely encouraged in the community since the early 2000s, and have been especially supported through the creation of the intergovernmental body GEO. The EO community has also benefited from investments on data production instruments providing a large quantity of data (e.g. satellites), and has been largely involved in building and maintaining good-quality and up-to-date data sets out of these instruments.

This particular setting interestingly underlines that **despite data already being open from a technical and regulatory perspective, there are still a number of issues related to making data actually able to circulate across organisations and sectors**. Such issues were already acknowledged by scholars (e.g. Bonina and Eaton, 2020; Ruijer et al., 2017; Goeta, 2016). Our research offers a little contribution here by shedding light on one possible way of addressing them, by fostering the development of actors building bridges between data and their uses through the design of “data/uses fit systems”. The figure of such actors could be seen as a specific kind of intermediary (e.g. Janssen and Zuiderwijk, 2014), that would neither intend to be a mere provider of data marketplace facilitating the transactions between buyers and sellers (e.g. Bergman et al., 2022), nor to become a dominant digital platform as contemporary examples of big tech companies such as Google or Apple (e.g. Gawer, 2022). These first observations especially call for further investigating the different **possible figures of actors playing a critical role in our digital economy**, that might tend to remain in the shadow of the most visible and dominating players.

6.2.4. Subsidiary contributions and perspectives for design research

Finally, our research has also shed light on intriguing patterns related to the nature of the design process (as especially appearing in section 5.3. “Reasoning logic”). In particular, C-K design theory appears not sufficiently well equipped to capture certain aspects of the design process. Following the formalisms of C-K theory, the co-design sponsor’s design space has been described as entailing a concept (C) space (including the concepts, i.e. the “unknowns” explored by the co-design sponsor), and a knowledge (K) space (including the knowledge bases leveraged and expanded by the co-design sponsor throughout the process). Basically, the knowledge bases comprise knowledge about available data sources, processing methods and techniques, engineering infrastructures, but also a “use-related” knowledge base including knowledge about potential users, their identities, their design capacities, their positions within a broader ecosystem (e.g. the offshore wind industry), and about the organisation of this broader ecosystem.

Compared to early C-K developments, this “use-related” knowledge base appears as particularly critical and takes a more complex form. Indeed, in early C-K developments, it tended to be seen as a rather static knowledge base: the designer (e.g. of innovative cockpits)

took into account its knowledge about users but this knowledge remained almost the same during the whole design process as the users were already well known (e.g. pilots of helicopters). By contrast, in the resilient-fit co-design, **the use-related knowledge base and the associated concepts rather appear as radically dynamic**, as the co-design process precisely aims at helping the co-design sponsor to dramatically and continuously enrich its knowledge about possible use contexts. Moreover, the potential users also have the capacity to learn from the interactions with the co-design sponsor, and to change what they can consider as an interesting use.

These dynamics of knowledge and associated concepts cannot be fully captured by C-K theory at this stage, as already highlighted by several studies (e.g. Ravier et al., 2018; Cerf et al., 2012). These limits certainly call for further developments. The latter authors have for example proposed to consider the “use space” as a distinct space from the K-space and C-space. Another possible path would consist in enriching the K-space with a structure that could take these dynamics into account more adequately.

6.3. Contributions for practitioners

Beyond these different academic contributions and perspectives, our research has also brought about significant outcomes for practitioners. As detailed in the methodology section (see *section 3.4.4.*), our research has directly contributed to providing actors of the EO community with an enriched way of undertaking co-design, by better addressing the extreme grand distance at stake. The benefits of the resilient-fit co-design model have been strongly underlined by the members of e-shape. The relevance of the model has also been acknowledged by the EO community beyond e-shape, e.g. providing useful guidelines to other projects funded by the European Commission, and becoming a strong priority within the intergovernmental organisations supporting the community (GEO at the global scale and EuroGEO focusing on the European part of GEO).

It is important to recall here that **our main contribution to practitioners has not consisted in building hands-on solutions to specific problems, but has rather consisted in providing a model of collective action that can help practitioners to better understand their own practices and improve their ability to transform them.** This aspect lies at the core of our research methodology, based on an intervention-research approach. As highlighted by

Radaelli et al. (2014), hands-on solutions “may be valuable for a while but then leave organisations in need of further consultancy” (p. 348). By contrast, intervention research intends to “foster managerial awareness of the models, tools and procedures which can improve the capacity [of practitioners] to enact actual changes” (p. 341).

In this respect, I find the following testimony particularly telling, showing that the resilient-fit co-design model is not to be taken as a mere one-size-fits-all recipe fully customised for a specific problem. The testimony comes from the person in charge of framing the co-design approach in another EU-funded project and with whom we shared some input on the resilient-fit co-design model experimented in e-shape:

“For me personally, doing co-design with users for years but without reflecting about the methodology, it was very useful to have these guidelines from e-shape. It makes you think about certain aspects of the co-design process. [...] Our conclusions about the e-shape co-design methodology (for now): Has it been useful for [our project]? Yes! Do you have to follow it closely? No, we rather see it as guidelines / best practices which may inspire you when organising co-design activities.”

As detailed in 5.4.3. section “*Institutional actors*”, our results could also provide useful insights for funding agencies such as the European Commission. We indeed suggest that new forms of KPIs could be imagined to assess the success of projects over time. There is probably a fine line to be found between (i) acknowledging the fact that these efforts take time and might need prolonged support over time, but (ii) without falling into the trap of ever-lasting funding without improved perspectives on bridging the distance. In this regard, it seems interesting to more explicitly **track the trajectory of funded pilots towards bridging the distance and building resilient fits with relevant actors.**

The success of a pilot application should probably go beyond assessing the success or failure of developing a viable product or service for a given user within the project lifetime. Indeed, in some cases, even if the interactions with a potential user do not lead to conclusive agreements, they might still play a key role in the pilot’s learning process, e.g. allowing the pilot to identify other people with whom it would be more relevant to interact in the future. In this respect, it seems especially interesting not to consider the success of a given co-design action taken one by one, but to rather consider the progress made by the pilot on its ability to

pinpoint relevant actors in one or several ecosystems (e.g. by eliciting its knowledge about these ecosystems at the beginning and at the end of a project), and its ability to design the adequate relationships with these pinpointed actors (e.g. counting the number of possibly multi-faceted, commercial or non-commercial, agreements made with these actors).

6.4. Possible lines of inquiry for future research

Various perspectives for future research have already been opened up in previous sections, suggesting a few possible lines of inquiry for future research.

A first line of future inquiry could consist in extending our present results on the resilient-fit co-design model. In this respect, as a natural extension of what I have already tried to initiate during the thesis, bridging the EO empirical context and other contexts faced with grand-distance issues seems to me particularly promising.

First, continuing research in the EO empirical context would especially provide us with an interesting and stimulating ground to **further enrich and operationalise the resilient-fit co-design model**. Considering the operationalisation perspectives, the forms to be taken by the resilient-fit co-design model remain very open. Indeed, how the model has been built and experimented during the project does not mirror the possible forms it might take in the long run. Within e-shape, our research team has endorsed the figure of co-design experts, complementing the pre-existing expertise of e-shape partners. However as researchers, we do not aim to play this role on a long-term operational basis.

Further investigation seems thus especially critical with regard to the **possible governance and engineering of co-design expertise**, i.e. elucidating who will hold such a co-design expertise and how it will be possibly distributed and organised through a consistent governance. At this stage, it seems relevant to consider a combination of various forms of co-design expertise held by various actors. As highlighted above, public authorities could play a key role by providing an original form of “co-design public service” directed towards supporting the development of co-design capacities among a wide range of actors, although the form it could take remains to be defined. In parallel, we could also think of building up a “co-design squad” involving certain actors specifically trained as co-design experts, that could then provide a kind of on-demand support focused on specific cases of co-design. Finally, more specifically concerning public research organisations involved in the development of EO data,

it could also be interesting to consider how co-design could be further legitimised as an important aspect of research practices, which could provide an interesting way of creating both societal impact and new research directions (Plantec, 2021).

Moreover, beyond governance and engineering considerations, **the content of the resilient-fit co-design model will certainly deserve further enrichment.** These enrichments will certainly be required to account for the on-going transformations of the EO field and the potential users' ecosystems, that are likely to generate a larger variety of grand-distance configurations than the ones identified in the project. New digital-transition dynamics will certainly open up new ways for data to be handled, visualised, transformed and used. There is for example a growing trend on "digital twins" of Earth combining EO data and simulation tools, offering new means of monitoring and predicting environmental change and human impact (Bauer et al., 2021), and possibly enabling the invention of new forms of collective action towards sustainable transitions. Moreover, other trends could lead us to investigate whether and how the resilient-fit co-design model could also be relevant for cases that would not only explore how data could be used, but also how new relevant data sources could be produced. This second aspect has been largely set aside in our research so far, as the objective of e-shape merely lied in leveraging existing data sources (e.g. made available through the Copernicus programme). However, this point will certainly need to be addressed, e.g. in the new trends of "citizen data" aiming at involving citizens in the production of data complementing other traditional sources of data (e.g. Jollymore et al., 2017). Finally, given that the resilient-fit co-design model progressively contributes to reducing the grand distance at stake, it will be interesting to investigate how it could be complemented by other co-design models that have proved to be beneficial in shorter grand-distance contexts.

Beyond the EO field, it will certainly be interesting to **extend these investigations to other kinds of empirical contexts, especially the ones that are likely to face grand distance.** Indeed, it would allow us to possibly extend the validity domain of the resilient-fit co-design model, and certainly also lead us towards investigating alternative co-design models. I would be genuinely curious to consider all kinds of contexts involving profound transformations of existing socio-economic ecosystem, be they involved in challenge-based or resource-based collective action towards addressing grand challenge. But the most natural first steps would probably be to consider the contexts that at least share some commonalities with the tested validity domain. For instance, it could include empirical contexts corresponding to a resource-

based setting where the considered resource is no longer data-based, as for example in the aforementioned case of the energy company involved in building district heating infrastructures (Ayrault, 2022).

In parallel with this first line of inquiry, primarily focusing on the nature of co-design models, it seems also interesting to further investigate **the nature of “bridging” between digital and sustainability transitions**. This second line of inquiry actually underlies the first one, as co-design intrinsically poses and addresses the question of building these bridges. It is worth noting that **some echoes can be found with historical cases related to the development of large-scale infrastructures**, such as the development of electricity and power systems in the late nineteenth century and early twentieth century (Hughes, 1993), or the development of generic instruments *“oriented towards the production and theorising of open devices which potentially serve multiple spheres”* (Joerges and Shinn, 2001, p. 3), such as high-precision mechanics and optics developed in the late nineteenth century, or technologies for liquid scintillation counting that became ubiquitous in molecular biology and medicine laboratories in the 1970s.

These historical examples shed light on what could be considered as different facets of “bridging”, not between digital and sustainability transitions per se, but between the different communities involved in the development of the infrastructures or instruments. Similarly to what has been described in the thesis, these historical cases followed original design strategies intertwining the design of sophisticated technical components and the design of their usages. This aspect is well illustrated by the logic followed by Edison, the “inventor-entrepreneur” involved in the early developments of electric lighting and power systems. As depicted by Hughes (1993), Edison especially focused on *“bridging the gap between resources and demand”* (p. 20). However, it did not merely involve responding to an actual or anticipated demand: *“[the inventions] that were not demand oriented were ingenious utilization of available resources, including existing technology”* (p. 20). In a similar vein, Shinn (2001) depicts the development of high-precision instruments by the University of Berlin professor Helmert as follows: *“His devices were not designed with a specific, local end-user in mind. Rather, Helmert elaborated broad instrument capacity”* (p. 45). Moreover, these endeavours also involved building upon specific forms of organisations: the birth of companies in their modern forms in the case of power systems (Hughes, 1993), sophisticated relationships

between state, science and industry in the case of the generic instruments described by Joerges and Shinn (2001).

The comparison with these historical examples will certainly deserve further investigation. Besides the similitudes depicted above, the specificities of data will certainly lead to unravelling some new forms of bridging. The exact difference between data and other forms of technologies remains difficult to grasp. Nevertheless, I will try to outline here a few preliminary intuitions and questions.

Compared to the development of electricity and power networks or the liquid scintillation technology, there is probably a specific form of relationship between data and a certain representation of the world in which society evolves. To a certain extent, technologies were already recognised as reflecting the organisation of society. Indeed a core tenet of the social and technology studies lies in considering that technologies embody the social organisation constructing them, as for example highlighted by Hughes (1993): *“Electric power systems embody the physical, intellectual, symbolic resources of the society that constructs them [...]. In a sense, electric power systems, like so much other technology, are both causes and effects of social change”* (p. 2). However, one can note that electric power systems were certainly not built with the primary objective of eliciting certain aspects of society. This point might precisely be one of the critical differences with data. Indeed, as I understand it so far, data do not only embody some aspects of the society constructing them, but they are especially **aimed at producing a certain vision or understanding of our world by making some specific phenomena visible, which are not only social but also physical, biological, chemical, etc.** Indeed, as highlighted by information systems scholars (e.g. Alaimo et al., 2020), data are produced to describe and characterise some aspects of reality. It may be marketing data, indicating the profiles and behaviours of customers; sport mobile application data, giving performance and health indicators to the app users; or air quality data, measuring the concentration of certain particles in a given area.

Although I am not able to draw very clear consequences yet, these considerations certainly point to further investigating the **peculiar relationship between data, our current world and our future possible worlds.** Going back to the EO example, data make global Earth-related phenomena visible for a given group of actors, i.e. unveiling the weather, possible geological hazards, air quality, or potential energy resources in more or less extended areas.

As such, data also have the potential to help these actors envision some forms of action with regard to these phenomena, considered within their current worlds, but also possibly within future worlds which they could potentially evolve towards. In other words, EO data could be seen as a way of enriching the current and future world representations of various actors with a better understanding of certain phenomena related to human and Earth systems.

These peculiarities can probably act as a doubled-edged sword. On the one side, data appear as a powerful tool for heterogeneous people to reflect on their current courses of action and possibly the new ones to imagine. It especially echoes what has already been highlighted by Alaimo et al. (2020): data provide *“lenses through which people construct and share the realities they confront”*. It may also call for extending the notion of distance beyond what has been developed in the thesis⁶. Indeed, beyond considering the distance separating data providers and users, one could also consider data as providing ways of managing the distance between given actors and the current and future worlds in which they live. On the other side, scholars warn us about the risk of *“data solutionism”*, which consists of seeing the world exclusively through the lenses of data, considering them as the answer to all our contemporary challenges, while forgetting that data only provide a partial vision of our world (e.g. Green, 2019).

In this regard, there is probably a fine line to be found, that could be formulated as the following question: **while avoiding falling into the trap of data solutionism, how could we make the best use of the already existing data-related expertise and competencies to imagine ways of progressing towards sustainability transitions?** In this respect, further research is certainly still needed to investigate the various ways of adequately bridging digital and sustainability transitions. To a certain extent, the resilient-fit co-design model developed in the thesis has contributed to drafting one particular way. Indeed, it has especially focused on providing the holders of data-related expertise and competencies (EO data providers) with appropriate tools and expertise to build bridges with sustainability transitions (here the ones concerning the potential EO data users), with specific attention on not imposing data as a ready-to-use magic solution.

⁶ I owe this reflection to a discussion with Charles Lenay, who works on the question of *“distance”* in cognitive sciences, especially studying the experience of perception between spatially distant individuals or objects (e.g. Lenay, 2021).

In these various attempts at bridging grand-distant worlds, there is probably no one single way. The resilient-fit co-design model is far from being a panacea, all the more as grand-distance situations are likely to flourish and diversify in the coming years. Nonetheless, I hope that this thesis will contribute to providing a few possible starting points...for the next exploration efforts yet to come!

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PART B- PAPERS

*BUILDING BLOCKS
OF THE THESIS*

‘Resilient-fit’ co-design methods: designing the integration of Earth observation data into ecosystems facing grand challenges

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Status: under revision in *Creativity and Innovation Management*

Abstract

In the face of grand challenges, socio-economic ecosystems need to undertake profound transformations involving new forms of collaborative and innovative processes. This paper proposes to shed light on a specific class of co-design methods, coined ‘resilience-fit’, that supports an outsider actor (i.e. with extremely limited orchestration capacities) in enhancing the resilience of ecosystems facing grand challenges. A vivid example of such a situation can be found in the field of Earth observation where data-based solution designers increasingly undertake dedicated co-design efforts to integrate data into multiple ecosystems facing grand challenges. Based on an in-depth empirical investigation of three case studies in this field, the paper describes how ‘resilient-fit’ co-design methods can be built in such contexts, unveiling their similarities and specificities compared to existing ones. The paper especially shows how these co-design methods progressively contribute to enhancing resilience through an original way of shaping the unknown and mobilising actors, that especially lies in building ‘locally-shared unknowns’, related to how data can be used to address certain challenges faced by pinpointed actors of the ecosystem. This research offers several theoretical and practical contributions by enriching the pool of available co-design methods needed to support the transformations of socio-economic ecosystems under the pressure of grand challenges.

Key words

Co-design, grand challenges, resilience, innovation ecosystems, open innovation, user innovation, radical innovation, digital innovation

I. Introduction

In the face of so-called “grand challenges”, referring to “complex problems with significant implications, unknown solutions, and intertwined and evolving technical and social interactions” (Eisenhardt et al., 2016) – e.g. associated with climate change, poverty, food and water security, scholars increasingly call for a profound renewal of management research and practices (Etzion et al., 2017; Ferraro et al., 2015; George et al., 2016) to face these new types of unknown (Elmquist et al., 2019), especially requiring new forms of collective and innovative design processes that could contribute to addressing these challenges.

Design and innovation management literature has a long tradition of research on tools and practices supporting such processes, including so-called co-design or participatory design methods – e.g. (Bjögvinsson et al., 2012; Sanders and Stappers, 2008), and a range of methods supporting collaborative innovation processes by leveraging knowledge and competencies of users and customers (Berger et al., 2005; Hienerth et al., 2014; Magnusson, 2009; von Hippel, 2005) or all voluntary individuals from the ‘crowd’ (Lebovitz et al., 2019; Malhotra and Majchrzak, 2014); but also by unleashing radical innovation capabilities within organisations (Elmquist and Segrestin, 2009; Hooge et al., 2016b; Rampa and Agogué, 2021), or in collaborative innovation arenas (Hooge and Le Du, 2016; Ollila and Elmquist, 2011).

In the particular perspective of tackling grand challenges, a large range methods have been develop to organise a collective exploration of solution paths responding to targeted challenge-related issues, as illustrated by the recent flourishing number of events or platforms leveraging the crowd (Bertello et al., 2021; Cai et al., 2019; Hellemans et al., 2022; Kokshagina, 2022; Porter et al., 2020; Vermicelli et al., 2020), or various participatory methods involving local communities under the pressure of grand challenges – e.g. related to energy (Hyysalo et al., 2019b) or agriculture (Berthet et al., 2022; Elzen and Bos, 2019; Pluchinotta et al., 2019; Prost et al., 2017).

However, other streams of works shed light on situations where collaborative innovation is not triggered by a specific challenge-related objective but by the potential of a given technology or novelty in helping a large variety of actors better address their own challenge-related issues. A vivid example can be found in the Earth observation (EO) field, where data coming from a variety of sources (e.g. from satellites, in-situ sensors, IoT, citizen data) give insightful information on the status and evolution of our natural or man-made environment

(e.g. land cover and urban development, air pollution, water resources, renewable energy resources), and are thus considered as having the potential of opening up new ways of progressing towards a sustainable planet (Giuliani et al., 2020; Guo et al., 2020; Nativi et al., 2020), as also explicitly noticed by management scholars (Chandy et al., 2017; George et al., 2020; Lenfle and Söderlund, 2022). In this context, co-design methods are increasingly being developed to support the integration of EO data in a large variety of socio-economic ecosystems that might benefit from their use (Bremer et al., 2019; Chiputwa et al., 2020; Daniels et al., 2020; Goodess et al., 2019; Vincent et al., 2018). These efforts are especially encouraged by public institutions, e.g. in Europe by the European Commission (Robinson et al., 2020) and the European Space Agency (Robinson and Mazzucato, 2019), more specifically in the perspective of strengthening the “resilience” of the European industries, as outlined in both EU Strategic Foresight Report (European Commission, 2020) and ESA Agenda 2025 (European Space Agency, 2021). In this context, the co-design process is sponsored by actors - the designers of EO data-based solutions - that have evolved outside the considered ecosystems, thus having extremely limited orchestration capacities within these ecosystems, i.e. being hardly able to influence the direction of innovation efforts and mobilise relevant actors. This situation leads us to reconsider existing co-design methods through this specific lens and assess their compatibility with the design objective at stake, thus investigating the following question: *how co-design methods can effectively enhance the resilience of ecosystems facing grand challenges when sponsored by an actor with extremely limited orchestration capacities?*

First, to analysis the expected performance criteria of these methods, the paper defines resilience enhancement of ecosystems as involving different aspects on three dimensions - cognitive, social, dynamic. The existing co-design methods are consequently screened by considering their contributions on resilience enhancement, distinguishing between situations of strong and limited orchestration capacities. Based on an in-depth investigation of three case studies in the EO field, the paper then shows how so called ‘resilient-fit’ co-design methods can effectively be built in a case of extremely limited orchestration capacities. The paper especially a specific way of shaping the unknown and mobilising actors, despite the initial absence of common ground for the emergence of a shared unknown and little knowledge on the actors to be involved.

This research thus contributes to advance research on design tools and practices supporting the (re)design of socio-economic ecosystems, extending the pool of available co-design methods towards situations where the co-design sponsor has extremely limited orchestration capacities. The paper also contributes to practice, underscoring the specificities of these methods compared to existing ones thus offering guidelines to implement such co-design methods beyond the Earth observation context.

II. Theoretical background

This section is organised in two main parts: (1) clarifying the performance criteria used to assess the contributions of co-design methods in the perspective of enhancing the resilience of ecosystems; (2) examining the contributions of existing co-design methods according to the orchestration capacities of the co-design sponsor.

1) Performance criteria of investigated co-design methods: resilience aspects associated with cognitive, social and dynamic dimensions of ecosystems

Formulated from the aforementioned perspective of practitioners, the performance criteria expected from co-design methods lie in *enhancing the resilience of ecosystems under pressure from grand challenges and experiencing the introduction of EO data*. These ecosystems are hereafter coined “data use ecosystems” or merely “use ecosystems”. However, both terms of ‘ecosystem’ and ‘resilience’ have been widely used with a large variation of meanings. The following paragraphs thus aim at stabilising the meanings of these terms as considered in our research work, by intentionally taking quite large definitions that can find echoes with most of the existing perspectives. Several dimensions are first derived from the ‘ecosystem’ construct. A certain meaning of resilience is then associated with each of these dimensions, consistently with both literature on ecosystems and resilience.

Inspired from the biology field, the ‘ecosystem’ concept was introduced in the management field in the 90s (Moore, 1993), putting a specific emphasis on the interdependency and co-evolution of different actors in a certain value creation process, potentially spanning various industries and including “participants from outside the traditional

value chain of suppliers and distributors: e.g. outsourcing companies, financial institutions, technology providers, competitors, customers, and regulatory and coordinating bodies” (Autio and Thomas, 2014). This construct has been significantly used in the innovation management field in the last years as summarised in recent literature reviews (Granstrand and Holgersson, 2020; Tsujimoto et al., 2018). It has also been specifically used in the context of grand challenges, accounting for the intricate and collective nature of the processes involved, as featured in different research streams related to transition studies (Walrave et al., 2018), open innovation (McGahan et al., 2021), entrepreneurship and business model innovation (Audretsch et al., 2022; Boldrini and Antheaume, 2021; George et al., 2020; Khavul and Bruton, 2013; Konietzko et al., 2020; Pankov et al., 2021). Responding to criticisms on this prolific and fragmented use (Oh et al., 2016), scholars have recently suggested that “innovation ecosystem should ideally be used in respect of systems that focus on innovation activities (goal/purpose), involve the logic of actor interdependence within a particular context [...] and address the inherent co-evolution of actors” (Ritala and Almpantopoulou, 2017). Following this definition, the paper proposes to retain three distinctive dimensions of ecosystems: a *cognitive dimension*, related to the nature of the concepts and knowledge explored within the innovation activities defining the purpose of the ecosystem – also called ecosystem value proposition by some scholars (Adner, 2017; Walrave et al., 2018); a *social dimension*, related to the actors involved and their interactions; a *dynamic dimension*, related to the co-evolution of cognitive and social dimensions.

The concept of ‘resilience’ is used in a large array of fields, such as ecology (Holling, 1973; Walker et al., 2004), psychology (Rutter, 1985; Werner and Smith, 1992), engineering (Hoffman, 1948), as well as different streams of management research - e.g. (Buliga et al., 2016; Burnard and Bhamra, 2011; Duchek, 2020; Gharehgozli et al., 2017; Grandori, 2020; Gulati, 2010; Lengnick-Hall et al., 2011; Lengnick-Hall and Beck, 2005; Weick and Sutcliffe, 2011a). Despite a variety of definitions and contexts, these different works share some similar perspectives, basically considering resilience as *an ability of the considered system* (e.g. ecological ecosystem, individuals, materials, organisations) *to continuously and robustly cope with unexpected disruptive events* (e.g. environmental damage, psychological traumas, mechanical strains, or technological and market transformations). In this paper, the integration of data into existing ecosystems (the ‘use ecosystems’) can be seen as such a disruptive event, that has the peculiarity of opening up new possible ways of addressing other

disruptive events related to grand challenges (Chandy et al., 2017; George et al., 2020). In this perspective, the *investigated co-design methods are characterised as 'resilient-fit'*, considering 'fit' in a double sense including the fit between data and the ecosystem into which they are integrated, as well as the overall ecosystem's fitness ensuring its long-term viability in particular in the context of facing grand challenges. Different aspects of resilience can be more specifically associated with each of the three dimensions of ecosystems defined above.

Regarding the *cognitive* dimension, our paper associates resilience with *the elicitation of a range of concepts (here related to the integration of data into certain use ecosystems) and the ability to undertake substantial learning processes*. This definition is aligned with the views on organisational resilience fostered by a broad and diverse knowledge base (Duchek, 2020), continuous learning and innovation (Buliga et al., 2016), as well as a form of 'generalism' (rather than 'specialism'), that is envisioning different alternative action paths based on polyvalent resources (Grandori, 2020). This is also consistent with previous literature on innovation ecosystems shedding light on how the emergence and growth of ecosystems can be driven by a range of innovative concepts based on the exploration sociotechnical imaginaries emulating cross-industrial learning processes (Hooge and Le Du, 2016), or by reopening innovation paths when actors are locked into a form of cognitive path-dependence, e.g. in the case of orphan innovations (Agogu  et al., 2012).

Regarding the *social* dimension, our paper associates resilience with *the establishment of relationships between relevant actors to adequately address the transformations involved on the cognitive dimension*, i.e. in our case actors willing to take part in supporting the integration of data into use ecosystems. This echoes the perspectives on resilience underlining the importance of social resources possibly through the form of cross-functional collaborations and strategic alliances (Duchek, 2020; Lengnick-Hall et al., 2011), or decentralised and networked organisation (Grandori, 2020; Gulati, 2010; Weick and Sutcliffe, 2011b). This is also consistent with literature on innovation ecosystems, as scholars largely underscore the specific efforts needed to adequately align actors (Adner, 2017), potentially requiring dedicated kinds of experimentation (Overholm, 2015; Walrave et al., 2018), and continuously renew the diversity of actors to support innovativeness in the value creation process (Hienerth et al., 2014; Ketonen-Oksi and Valkokari, 2019; van der Borgh et al., 2012).

Regarding the *dynamic* dimension, our paper associates resilience with *the ecosystem's capacity of handling a continuous evolution of the cognitive and social dimensions*

to ensure its long-term viability, given internal and external constraints or opportunities that might occur over time. This corresponds to an important aspect of resilience that is acknowledged in the majority of aforementioned perspectives, e.g. in psychology where the individual finds a new development path after a trauma (Cyrulnik and Jorland, 2012; Werner and Smith, 1992), or in management research where organisations are able to adapt to turbulent environments and possibly capitalise on unanticipated changes (Buliga et al., 2016; Lengnick-Hall et al., 2011). This also goes in line with the dynamic view of innovation ecosystems, e.g. recalled in the synthetic definition provided by (Ritala and Almpantopoulou, 2017), and also stressed by (van der Borgh et al., 2012) referring to the reconfiguration of ecosystem's business model as an "essential asset in securing its long-term viability".

2) Review of existing co-design methods: contributions and underlying conditions

These definitions allow us to analyse how existing co-design methods already contribute to reaching such performance criteria, without necessarily making an explicit mention to grand challenges or resilience. To better integrate contributions of various literature fields, co-design methods are here broadly considered as methods supporting a collective design process, including both a *design* aspect, entailing the exploration of new knowledge and innovative concepts, and a *collective* aspect, entailing the involvement of heterogeneous actors in the design process. The existing co-design methods are screened through a specific lens, considering their contributions on resilience enhancement depending on the orchestration capacities of the co-design sponsor, referring to the actor initiating the co-design process. We especially compare situations where the sponsor tends to have rather *strong orchestration capacities*, i.e. the ability to impose the direction of cognitive and social transformations and to mobilise a large number of actors; with situations where the co-design sponsor tends to have more *limited orchestration capacities*, i.e. if the ability to trigger cognitive and social transformations is less authoritative but requires more negotiating and coordinating efforts, and the ability to mobilise actors is more limited (in terms of scope, i.e. number and diversity of actors, and time, i.e. maintaining actors' engagement over time). Although in reality there is a continuum of multiple degrees of orchestration capacities, distinguishing between two broad categories allows us to identify noticeable trends on the effects of these capacities on the co-design methods.

a) Methods for a co-design sponsor with strong orchestration capacities

A co-design sponsor with strong orchestration capacities can typically correspond to a well-established organisation in a given ecosystem. Several papers offer examples of such situations: good manufacturers with an already large installed customer base (Berger et al., 2005; Hienerth et al., 2014), retailers (Overdiek and Warnaby, 2020) large industrial firms in the automotive or aeronautics industries (Elmqvist and Segrestin, 2009; Hooge et al., 2016b), public organisations operating public transport in a given area (Hatchuel et al., 2009), or a collective of actors of the maritime industry sponsoring a crowdsourcing initiative to develop innovations for the sustainable use of oceans (Porter et al., 2020). These methods shed light on different mechanisms that contribute to enhancing resilience as defined previously.

On the cognitive dimension, the methods explicitly state their ambitions of extending the design space of the co-design sponsor and increasing the innovativeness of developed products or services through different means. Numerous works highlight the benefits of leveraging heterogeneous knowledge and expertise of distributed actors, that can be individuals willing to share their ideas in a crowdsourcing initiative (Porter et al., 2020), users or customers (Franke et al., 2008; Franke and Piller, 2004; Magnusson, 2009; von Hippel, 2005), possibly including “lead users” playing a kind of pioneering role thanks to their ability to leverage an adequate combination of technological and use knowledge (Hienerth et al., 2014; von Hippel, 1986). Knowledge sharing and exploration of concepts can unfold in different ways. Some cases leverage a kind of ‘reaction’ mode, by evaluating or enriching certain ideas proposed by others (Magnusson et al., 2016; Porter et al., 2020). Other works underscore the importance of steering a joint exploration of concepts and creation of new knowledge (Elmqvist and Segrestin, 2009; Hooge et al., 2016b), especially to avoid so-called “fixations effects” (Agogu  et al., 2014; Ezzat et al., 2018; Jansson and Smith, 1991), i.e. the tendency of actors to merely consider directly accessible knowledge, thus leading to a limited range of innovation paths. In these situations, the overall design goal is defined and imposed by the co-design sponsor, although not preventing it from being reformulated during the process to account for participants’ inputs (Porter et al., 2020).

Regarding the social dimension, these methods also include elements that specifically aim to establish forms of relationships that are adapted to undertake the targeted cognitive

transformations. In radical innovation contexts, the methods can for example include the elicitation of new organisational principles or partnerships possibly with new key players (Hooge et al., 2016b). In cases of user innovation, implementing mass customisation co-design with customers can also involve building new modes of cooperation with retailers or intermediate actors (Berger et al., 2005). In the ‘Saving Our Oceans’ crowdsourcing initiative, specific phases are dedicated to the creation of robust links between idea owners and funding partners that have the relevant knowledge and resources (Porter et al., 2020).

Considering the dynamic dimension, it is not systematically mentioned in all methods, as the co-design sponsor is implicitly assumed to have the capacities to support the long-term development of the promising ideas developed within the co-design process – e.g. in cases of user innovation (Hienerth et al., 2014; Magnusson, 2009). (Hienerth et al., 2014) especially highlight that the orchestration capacities of the pioneering producer firm (e.g. including strong “community management” competences) is a key enabling factor of the “continuous exploration and exploitation of business opportunities”. Other methods explicitly mention how long-term dynamics can be more specifically fostered, e.g. by “getting new actors involved throughout the process [...] or stakeholders who help to implement and legitimise solutions in the industry” (Porter et al., 2020), or identifying of a range of short-term and mid-term actions that can be implemented to advance towards longer-term objectives with the overall ambition of enhancing the capacity of actors to sustain these transformations over time (Elmqvist and Segrestin, 2009; Hooge et al., 2016b).

b) Methods for a co-design sponsor with limited orchestration capacities

In other contexts, the co-design sponsor appears to have more limited orchestration capacities, thus requiring further coordination or intermediation efforts to mobilise actors. Such situations can be found in the cases of “open innovation arenas” aiming to trigger new forms of collaborations between heterogeneous actors that have their own respective strategies (Ollila and Elmqvist, 2011; Ollila and Yström, 2016), in certain forms of crowdsourcing or hackathon events, e.g. when the targeted challenge includes numerous aspects involving different industries exceeding the expertise domain of the co-design sponsor, such as in the recent case of Covid-19 crisis (Bertello et al., 2021). This perspective also applies to cases of policy design sponsored by a regional public authority having to deal

with water management issues (Pluchinotta et al., 2019), or participatory design approaches led by agro-ecology research organisations to enhance the sustainability of agricultural systems – e.g. (Berthet et al., 2018, 2016a; Bos and Koerkamp, 2009; Della Rossa et al., 2022; Elzen and Bos, 2019). In these different contexts, similitudes can be noticed with previously reviewed methods, but also new aspects related to the limited orchestration capacities of the co-design sponsor.

On the cognitive dimension, as for previous cases of strong orchestration capacities, the methods contribute to building a variety of concepts and learning processes through different forms of mechanisms or devices. However, it can be noted that the preparatory phases before the actual phase of participants' interactions appear to entail additional aspects to address an increasing level of complexity. In the context of strong orchestration capacities, 'KCP' methods already included an extensive preparatory phase, consisting in identifying the fixation effects of involved actors (Elmquist and Segrestin, 2009; Hooge et al., 2016b). However, additional issues stem from the fact that these actors belong to different organisations with possible diverging or conflictual views (Berthet et al., 2016b; Della Rossa et al., 2022; Pluchinotta et al., 2019). Consequently, scholars mention the need of adding a thorough "diagnosis of the socio-technical system" (Della Rossa et al., 2022), or rounds of interviews to pre-consolidate the knowledge to be shared and explored, explicitly underlining the "time-demanding" character of this process and the difficulty of identifying the relevant stakeholders (Pluchinotta et al., 2019). The RIO approach also entails an intricate preparatory phase of problem and system analysis, aiming to help actors derive long-term needs from their expressed short-term interests (Bos and Grin, 2008; Bos and Koerkamp, 2009; Elzen and Bos, 2019). These methods suggest that significant efforts are needed to build a so-called "shared unknown" driving the design process, but it is worth noting there is at least an identified issue serving as an initial common ground (e.g. improving traffic safety, tackling water management issues), unlike other reported cases of cross-industry partnerships (Gillier et al., 2012).

On the social dimension, as in previous category, the methods allow the establishment of relationships adapted to the considered design purpose. Nevertheless, in the case of limited orchestration capacities, the mobilisation of actors appears to be more difficult to handle, especially requiring to deal with a high heterogeneity of actors that have their own perspectives or interests, even sometimes leading to conflictual situations (Berthet et al., 2016b; Labatut and Hooge, 2016; Pluchinotta et al., 2019). The methods thus tend to target a

profound renewal of interactions between actors (Berthet et al., 2020; Della Rossa et al., 2022), that sometimes even becomes the primary objective of the process, as for example stated in (Bos and Koerkamp, 2009) where the final output is not so much the designed technical product as “the structure in which a new technique or new practice is to prosper, designing strategic connections with and among allies, and positioning that innovation in society”. Comparatively to the previous category of methods, it appears that additional efforts are required to make emerge a design goal out of diverging views, by searching longer-term goals that are shared (Elzen and Bos, 2019), building a shared knowledge base on the issue at stake (Berthet et al., 2016b; Pluchinotta et al., 2019), or putting forward a shared identity (e.g. building a world-leading expertise on traffic safety) that serves as a “joint platform” enabling collaborative innovation between potential competitors (Ollila and Yström, 2016). Moreover, these works extensively highlight the difficulty in getting the actors engaged, thus having to restrain some phases of the design process to adapt to location or time constraints – e.g. (Della Rossa et al., 2022; Pluchinotta et al., 2019).

Regarding the dynamic dimension, various elements contribute to fostering the long-term sustainment of cognitive and social transformations. Some aspects appear as quite similar to the contexts with strong orchestration capacities, e.g. anchoring the ideas developed jointly in the partner organisations (Ollila and Elmquist, 2011), launching new projects to further work on the identified issues (Berthet et al., 2016b), or increasing the capacities of actors that can “embed learning back into their organisations” (Pluchinotta et al., 2019). However, the sustainment of these actions over time appears as globally more fragile or uncertain, and co-design actions taken individually might not be enough to overcome limited orchestration capacities (Bertello et al., 2021). The RIO approach has for example been recently enriched to better account for the uptake of novelties from the initial design phase, by multiplying interactions with the actors that could legitimise these novelties, supported by specific experimentation and demonstration efforts (Elzen and Bos, 2019). Several scholars also underline that these long-lasting efforts need to be sustained by combining multiple forms of actions within long-lasting collaborations and structures (Berthet et al., 2022; Elzen and Bos, 2019; Ollila and Yström, 2016).

3) Research question

Our literature review has outlined that existing methods already give important guidance on how to progress towards the considered performance criteria of resilience enhancement, depending on the orchestration capacities of the co-design sponsor, as summarised in Table 1. The analysis of the methods in two broad categories unveils a trend of increasing difficulties on the different cognitive, social and dynamic dimensions when the co-design sponsor cannot rely on strong orchestration capacities. The case of extremely limited orchestration capacities lies in the continuity of this trend but raises additional issues: there is no initial common ground that could facilitate the generation of shared unknowns, and the relevant actors to be involved are hardly identified at the beginning of the process due to a very limited knowledge of the ecosystem and. To be noted, that in some cases described in literature, one of these additional difficulties could also occur, but to our knowledge not combining both of them - e.g. cross-industry exploratory partnerships where partners have to define collective projects for exploring the potential of an emerging technology while having very different strategic objectives, however in this context the actors were already identified by the innovation platform organisation (Gillier et al., 2012, 2010). Our research question is thus formulated as follows: *how co-design methods can effectively enhance the resilience of ecosystems facing grand challenges when sponsored by an actor with extremely limited orchestration capacities?*

	Methods for a co-design sponsor with <i>strong</i> orchestration capacities	Methods for a co-design sponsor with <i>limited</i> orchestration capacities
Orchestration capacities	Ability to impose the direction of cognitive & social transformations and to mobilise numerous actors	Ability to trigger cognitive and social transformations with more negotiating and coordinating efforts; and to mobilise actors in a more limited way (scope and time)
Main references	Examples: cases of well-established organisations in given ecosystems involved in user innovation (Berger et al., 2005; Hienerth et al., 2014), radical innovation (Elmquist and Segrestin, 2009; Hooge et al., 2016b), crowdsourcing (Porter et al., 2020)	Examples: open innovation arenas (Agogué et al., 2013; Ollila and Elmquist, 2011; Ollila and Yström, 2016), policy design (Pluchinotta et al., 2019), agricultural system design (Berthet et al., 2022; Bos and Koerkamp, 2009; Elzen and Bos, 2019)
Cognitive resilience <i>Eliciting a range of concepts on how data can be integrated into certain use ecosystems and ability to undertake substantial learning processes</i>	Design goal defined by the sponsor (involving possible reformulations) Enlarging the sponsor’s design space by integrating heterogeneous knowledge. Carried out in a reactive mode and/or through dedicated processes to avoid “fixation effects”	Extensive efforts to build a “shared unknown” despite diverging views , but at least common ground related to the issue to be addressed (e.g. traffic safety, water management) Similar attention to the extension of the design space. Additional difficulties related to the preparatory phases (problem-system analysis, diagnostic of socio-technical system, mapping fixation effects of heterogeneous actors)

<p>Social resilience <i>Establishing relationships between relevant actors to adequately address the transformations involved on the cognitive dimension</i></p>	<p>Transforming organisational principles or partnerships, possibly with new actors</p>	<p>Tendency to target profound renewal of existing interactions, while facing difficulties in engaging actors</p>
<p>Dynamic resilience <i>Sustaining the continuous evolution of the ecosystem's cognitive and social dimensions to ensure its long-term viability given internal and external constraints or opportunities that might occur over time</i></p>	<p>Long-term development efforts implicitly sustained by the sponsor, Potentially supported by the elicitation of follow-up projects or actions and enhancement of the sponsor's capacities</p>	<p>Integration of a long-term sustainment perspective from the initial design phase (anchoring strategy including multiplying experimentation and demonstration efforts), Calling for repeated actions within long-lasting collaborative structures</p>

Table 1: Synthesis of contributions and underlying operational conditions of existing co-design methods according to cognitive, social and dynamic dimensions of resilience enhancement – depending on the orchestration capacities of the co-design sponsor

III. Methodology and empirical material

Our research mobilises multiple case studies (Yin, 2009) in which co-design methods have been built to support the integration of Earth observation data into various use ecosystems in a ‘resilient-fit’ perspective. This context corresponds well to a situation where the co-design sponsor has extremely limited orchestration capacities. Indeed, the data-based solution designers are new comers in the potential use ecosystems as they have historically mainly been involved in designing and operating data production chains of measuring instruments (satellites, in-situ sensors etc.). Consequently, they are not able to clearly identify on their own the critical issues that could be addressed in the use ecosystems based on data, and for which actors. And on the other side, the potential users are highly unfamiliar with these data and independently carry out their day-to-day operations, without spontaneously formulating unknowns in relation with data. Hence, the data-based solution designers and potential users do not initially have a shared unknown, but not even a shared issue to be addressed that could serve as a common ground for the formulation of shared unknowns driving the design process. Moreover, the data-based solution designers have limited knowledge on these ecosystems thus hindering their ability to identify and mobilise the relevant actors for the design purpose.

1) Empirical setting: three case studies in a unified project context

The case studies are derived from our involvement in a large research project, that received a 4-year grant (2019-2023) from the European Commission under the Horizon 2020 programme. This project, called e-shape, is specifically dedicated to “creating a conducive

environment for addressing societal challenges, fostering entrepreneurship and supporting sustainable development” by encouraging the use of EO data by a large variety of actors (T. Ranchin et al., 2021). It gathers a team of 69 experienced partners from academia, industry, institutional entities and user communities to develop 37 pilot applications based on EO data, gathered in seven showcases (agriculture, health, renewable energy, biodiversity, water resources, disaster resilience and climate). Each pilot aims at developing a range of EO-based products or services for various users, involves one or several organisations participating to the project coined “pilot members”, and is coordinated by one representative of these organisations designated as the “pilot leader”. As an initial condition for project participation, each pilot interacts with at least one user organisation. These user organisations do not receive direct funding from the project and are thus considered as external actors to the project. All authors of the present paper are involved in the project, in charge of a specific work package dedicated to co-design, consisting in providing the pilots with processes and tools that are progressively designed and experimented in interaction with the pilots. This setting is thus particularly favourable to conduct multiple case studies, in the unified context offered by the project. The present paper focuses on the analysis of three case studies corresponding to three different pilots, selected because they correspond to contrasted archetypal situations where co-design appeared as especially critical in overcoming certain bottlenecks hindering the pilot’s development process. The names of the pilot-leading organisations are anonymised and respectively coined AIR QUALITY, SOLAR and WIND.

a) Empirical context for AIR QUALITY case study

AIR QUALITY is part of a major research center, the oldest in Greece created in 1842, playing an important role in the European space sector with renowned research activities in astronomy, astrophysics, space applications and remote sensing, environmental research and sustainable development as well as geodynamics. Within the institute for environmental research and sustainable development (of about 25 permanent researchers and 30 non-permanent technical and research staff members), AIR QUALITY team is more specifically specialised in atmospheric physics and chemistry and leads the “Health Surveillance Air Quality” Pilot (HSAQ), within the Health Surveillance showcase. The pilot aims to create a modular platform for surveillance of air quality and related health issues both globally and in

certain urban areas (Athens, Munich, Vienna and several Finish cities), especially bridging past (trends), present (analysis) and future (air quality scenarios) to provide a reference space for users and stakeholders to gain thorough insight into urban air quality. Our research work has more specifically delved into the Athens component of this service, aiming to combine several data layers: a high-resolution air quality model providing pollutant concentrations at a resolution of 100mx100m developed by AIR QUALITY; along with local health, land use and socioeconomic data layers that could be provided by complementary actors to develop a range of added-value products, e.g. information on population exposure for all pollutants by relating the concentration fields with population characteristics.

b) Empirical context for WIND case study

WIND is a research section belonging to the wind energy department of a large Danish public research organisation, one of the largest public research organisations for wind energy in the world with about 250 staff members. WIND gathers about 20 researchers with more than 15-year experience in leveraging remote sensing techniques to assess wind energy resources. Resource assessment is indeed an important task for the development of wind farm projects, undertaken prior to the siting of wind farms. Different observation means already exist for this assessment: on the one hand, in-situ measurements are the most accurate but the installation and maintenance of offshore meteorological masts is of high cost and their spatial distribution is limited; on the other hand, offshore wind atlases retrieved from space-borne 'scatterometer' or 'SAR' (Synthetic Aperture Radar) instruments are currently available online with lower frequency and accuracy but with a larger spatial distribution and over longer timespans. Within e-shape, WIND leads the "Merging offshore wind products" pilot, within the Renewable Energy showcase, aiming to create a new and unified wind product especially merging satellite-based data to provide the offshore wind industry with improved offshore wind resource estimates. The new product is expected to cover at least all the European Seas, i.e. North Sea, Baltic Sea, Mediterranean Sea, and several time scales (to be tested for daily, monthly and longer-term-time-scale production).

c) Empirical context for SOLAR case study

SOLAR is a research lab of about 24 researchers that has developed strong expertise since 1976 in the fields of renewable resource evaluation (e.g. solar and wind), meteorology for energy, interoperability and diffusion of information through data bases and Web services, and environmental impacts of energy uses. Within e-shape, SOLAR leads the “High photovoltaic (PV) penetration at urban scale” pilot, within the Renewable Energy showcase. Rooftop PV systems in urban areas appear as a promising source of electricity production as this electricity is consumed where it is produced and resorts to already built-up areas such as unused urban roofs. But, due to complex shading effects in urban context (vegetation, surrounding buildings, superstructures of roofs, etc.) and local atmospheric and meteorological effects, the massive penetration of PV systems in urban areas also induces a significant variability in space and in time of the energy injected in the electric grid. This pilot thus aims to create GIS (Geographic Information System) tools to plan, monitor and nowcast (i.e. short-term forecast below 1 or 2 hours) the spatiotemporal variability of the electric consumption and the production of fleet of PV rooftop systems. These tools are meant to offer an enriched urban energy modelling system that could benefit a variety of actors (such as grid operators, aggregators for energy trading, local communities, urban planners and developers of individual or collective PV self-consumption projects).

2) Data collection and analysis

For each case study, empirical data were collected and analysed through an intervention-research methodology (Hatchuel and David, 2008; Radaelli et al., 2014), that aims to generate actionable knowledge fostering changes in organisations while producing theoretical knowledge that is scientifically relevant for academia. This setting especially allowed us to collect rich empirical material including secondary sources of data (mainly websites of the involved organisations and scientific publications), observation notes taken during project meetings, as well as thorough interactions with pilots for the design and implementation of co-design methods. The investigation of each case study followed a similar protocol, defined and conducted in close interaction with practitioners (i.e. the project partners), in line with general guidelines for collaborative management research (Shani et al., 2008). This protocol

ensured a progressive and joint building of a shared model of co-design, validated by all researchers and practitioners through two main phases:

Phase 1: establishing a shared diagnosis of potential co-design needs for each pilot

This phase consisted in thorough back-and-forth exchanges between the research team and the pilot to identify the co-design needs of the pilot, defined as the issues faced by the pilot in establishing adequate forms of relationships with particular actors that need to be involved in the development or operationalisation of data-based solutions. For this purpose, the research team first drafted a synthetic view of the pilot's situation and objectives, leveraging secondary sources of data and first informal interactions during the project kick-off meeting. This preliminary analysis was visually formalised in a dedicated template representing data sources, the type of information derived from these data, their expected uses and associated actors (other pilot members or users). This first understanding of the pilot's situation was then shared with the pilot on the project online management platform complemented by the research team's pre-diagnosis of co-design needs based on this first understanding. An interview of at least 1h30 was then organised on a virtual meeting application (due to geographic distance) with several representatives of the pilot-leading organisation to enrich this preliminary analysis and eventually validate a shared diagnosis of co-design needs. A report was systematically written by the research team after the meeting (precising the overall analysis of the pilot's situation and identified co-design needs) and validated by all participants of the meeting. To simplify the outcomes of this phase, four types of co-design needs were distinguished, each corresponding to a certain kind of bottleneck associated with the establishment of an adequate relationship with particular actors: (1) with identified users that have already expressed their interest on a first basis, (2) with would-be users that are however difficult to engage or that have not expressed a clear interest yet, (3) with actors involved in ensuring the engineering and/or commercialisation of data-based solutions, (4) with users that already benefit from a first delivered version of data-based solutions and are willing to explore future expansions of these solutions. Moreover, these different co-design needs were distributed over two time horizons to account for their respective level of priority: short-term for the co-design needs considered as the most urgent and longer-term for the co-design needs that would be addressed at a later stage.

Phase 2: design and implementation of co-design actions

Following the results of the first diagnosis phase, the three pilots examined in this paper expressed their willingness to undertake co-design actions to address the bottlenecks identified in the diagnosis phase. The content of the process varied accordingly to the considered co-design type, however a similar sequence of steps was systematically followed in all cases, including:

- A preparatory step consisting in one or several meetings between our research team (also referred to as 'co-design team') and the pilot to jointly prepare the process to be conducted, especially clarifying the pilot's expectations and time resources, the specific issues to be overcome, the relevant participants to be involved, the agenda and practical details (e.g. number of sessions, format – especially in-person or virtual, timing), and the respective contributions of the research team and the pilot.
- A cycle of one or several collective design sessions (taking the forms of one-to-one meetings or workshops with varying number of participants) involving our research team, the pilot and the identified relevant actors.
- Debriefing sessions between our research team and the pilot to exchange on the concrete outcomes for the pilot on the one side (learning, surprises, and advances with regard to the initial expectations), and the pilot's feedbacks on the process itself on the other side.
- Formalisation of the outcomes in a written report, validated by all participants.

Following scholars' recommendations (Hatchuel and David, 2008), our research protocol also included a joint and continuous monitoring process of research outcomes, beyond the validation process undertaken for each individual pilot. These outcomes were indeed regularly shared and discussed with the other project members and more broadly with the Earth observation community, especially through five written deliverables (reviewed by at least two external actors, submitted to the European Commission and shared publicly on the project website after validation); three steering committees gathering our research team, the project management team and representatives of showcases and pilots (recorded and transcribed for the exchange parts); and regular presentations or webinar sessions organised for the Earth observation community (all recorded and transcribed for some of them).

Data collection & analysis	AIR QUALITY	WIND	SOLAR
<p>Diagnosis of co-design needs:</p> <ul style="list-style-type: none"> - <i>Template</i> built on secondary sources of data - <i>1h30 virtual meeting</i> with the relevant pilot's members - <i>Written report</i> to formalise the diagnosis outcomes (validated by all participants) 	<p>1st round of template validation and enrichment (July 2019 – Nov 2019): exchanges on the online management platform</p> <p>1h30 interview (Jan 2020): - 3 management researchers (co-design work package) - Research director of the department for environmental research & sustainable development (pilot co-leader) - Researcher in the same department (pilot co-leader)</p>	<p>1st round of template validation and enrichment (July 2019 – Nov 2019): exchanges on the online management platform</p> <p>1h30 interview (July 2020): - 3 management researchers (co-design work package) - 2 senior researchers in remote sensing & wind energy (including pilot leader) - Technical lead of wind resource assessment applications</p>	<p>1st round of template validation and enrichment (April 2019): exchanges in a dedicated one-day 'mini-drill' exercise</p> <p>1h30 interview (June 2019): - 3 management researchers (co-design work package) - Research director of SOLAR (also project leader) - Senior researcher in remote sensing & solar energy (pilot leader) - Research engineer expert in databases and web services</p>
<p>Implementation of co-design actions:</p> <ul style="list-style-type: none"> - <i>Preparatory step</i> (co-design team and pilot members) - <i>Cycle of collective design sessions</i> (co-design team, pilot members and invited actors) - <i>Debriefing sessions</i> (co-design team and pilot members) 	<p>Preparatory step (March - June 2020): <i>2 meetings of 1h30</i> with same participants as above. <i>E-mail exchanges</i> to prepare the support materials for the workshop</p> <p>Design sessions (July 2020): <i>1 workshop of 3h;</i> <i>18 participants</i> in total: 3 from co-design team, 5 from AIR QUALITY team, 10 from 5 user organisations</p> <p>Debriefing: <i>1h meeting</i> with co-design team and the 2 pilot's co-leaders just after the workshop; <i>Regular updates</i> during project meetings and co-design sessions (cf next line)</p>	<p>Preparatory step (August - September 2020): <i>2 meetings of 1h30 and 2h</i> with same participants as above. <i>E-mail exchanges</i> to prepare the support materials for workshops</p> <p>Design sessions (Nov 2020): <i>3 workshops of 1h-1h30;</i> <i>Participants:</i> same as above + one invited actor from offshore wind industry for each workshop</p> <p>Debriefing: <i>15-30min</i> between leader of co-design team and pilot leader following each workshop; <i>1h wrap-up meeting</i> (Feb 2020); <i>Regular updates</i> during project meetings and co-design sessions (cf next line)</p>	<p>Preparatory step (February 2021): <i>1 meeting of 1h30</i> with same participants as above. <i>E-mail exchanges & phone calls</i> to prepare the support materials for workshops</p> <p>Design sessions (Feb 2021): <i>1 workshop of 3h;</i> <i>10 participants</i> in total: 4 from co-design team, 4 from SOLAR team, 2 from invited partner (director + 1 R&D engineer)</p> <p>Debriefing: <i>30min</i> taken at the end of the workshop with participants; <i>Regular updates</i> during project meetings and co-design sessions (cf next line)</p>
<p>Joint and continuous monitoring process of the research outcomes</p>	<p>Written deliverables submitted to the European Commission (July 2019, Sept 2019, May 2020, May 2021 x2)</p> <p>Steering committees organised by our research team leading the co-design work package: three meetings of 2h (May 2019, Nov 2019, April 2021) involving at least the project management team and showcase leaders (optionally opened to pilot leaders & other work-package teams)</p> <p>Interactive sessions to discuss e-shape advances on co-design with project members and the broader Earth observation community: e-shape General Assemblies (2020, 2021, 2022), various events in the Group on Earth Observation community</p>		

Table 2: Data collection and analysis for the three case studies (AIR QUALITY, WIND, SOLAR). The "co-design team" refers to the management researchers in charge of the co-design work package within e-shape.

IV. Detailed analysis of case studies

This section aims to describe in more details the co-design methods as designed and experimented in each case study, especially eliciting how such co-design methods contributed to strengthen the resilient-fit of ecosystems in which data are integrated. These methods are evaluated following the performance criteria defined in the theoretical background section, i.e. resilience on the cognitive, social and dynamic dimensions of ecosystems, considering successively the two phases of co-design: the diagnosis process and the implementation of dedicated actions.

1) AIR QUALITY case study

The outcomes of the diagnosis process are synthetically represented in Figure 1, based on the template used as a diagnostic support tool. The template shows that the pilot is organised in several sub-components that have different development stages, objectives and co-design needs. The pilot includes a global component, for which a number of intergovernmental agencies such as the United Nations or the World Health Organisation (WHO) were identified based on the pilot's assumptions that monitoring urban development globally and the related air pollution and health issues would be of interest for them. However, at the time of the diagnosis process, the pilot had still little knowledge on these organisations, thus further requiring some co-design of type 2 (following the definitions given above) to explore this little-known community of users. Beyond this global component, the pilot integrates four local components - each of them having already identified a number of user organisations with regard to a certain focus on the air quality issue (e.g. monitoring emissions of refineries in Finland). Each local component was associated with a co-design need of type 1 as these user organisations had already clearly stated their interests, but an adequate relationship with these identified users still needed to be established to further specify the lists of requirements for the data-based solutions. Regarding the temporal distribution of co-design needs, the type 1 was considered as the most urgent (with a first priority on the Athens sub-component, managed by AIR QUALITY being also the overall pilot-leading organisation), whereas the type 2 for global component would be addressed at a later stage.

A co-design action was thus conducted to address the co-design need of type 1 for the Athens sub-component, following the different steps detailed in the methodology section. Given AIR QUALITY time constraints and expectations, it was decided to organise a 3h workshop (held virtually due to Covid-19 restrictions), with the dual objective of (1) assessing and enhancing the list of requirements of data-based solutions for the different users, (2) setting-up the future relationships with the users. The workshop was organised in three distinct phases with assigned roles for each participant (as detailed in Figure 2) while our research team was especially in charge of ensuring the structure and timing of the exchanges. The outcomes of the workshop were synthesised in a specific chart representing the potential development perspectives for the pilot at different time horizons depending on the assessed level of priority for initiating a collaboration on a certain topic (highest level for short-term and lowest for long-term). Each box indicates a certain type of solution to work on, at a certain time horizon and the stakeholders concerned.

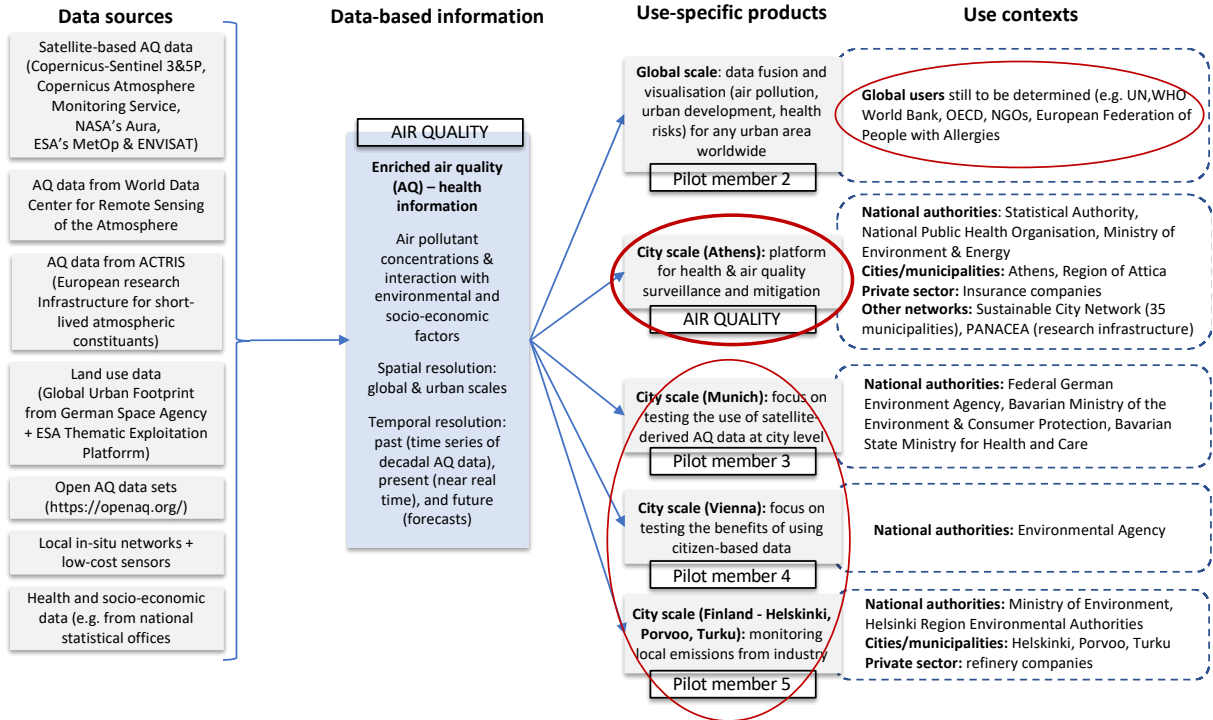


Figure 1: Template synthetically representing AIR QUALITY context (precising the sources of data, the type of information derived from them, the type of data-based solutions developed for given use applications, and the use contexts) and the outcomes of the diagnosis process (bottlenecks identified in red circles – the bold circle indicates the bottleneck addressed in the subsequently experimented co-design action)

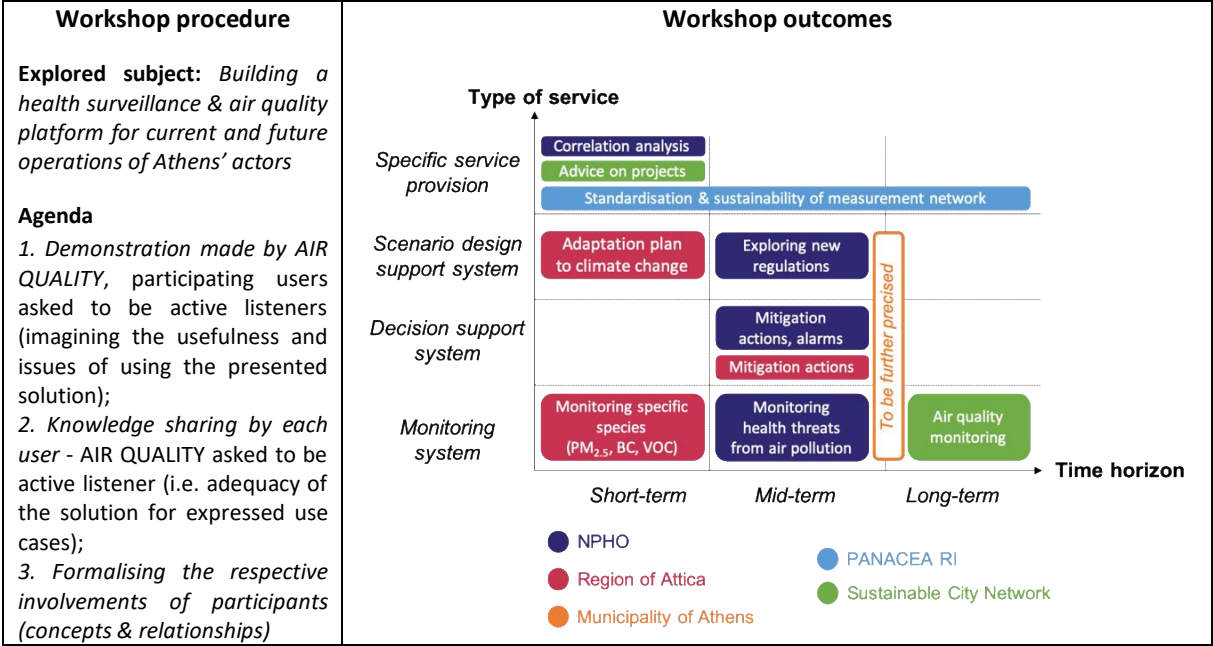


Figure 2: Overview of workshop procedure and outcomes within the co-design action of AIR QUALITY targeting the clarification of the lists of requirements for the developed solution by establishing adequate forms of collaboration with identified users.

2) WIND case study

The outcomes of the diagnosis process are synthetically represented in Figure 3, based on the template used as a diagnostic support tool. At the time of the diagnosis process, WIND had already developed a website delivering wind-field data for free and had interacted with some actors of the wind industry. However these interactions had remained punctual relationships, mainly consisting in selling on-demand wind resource assessments used in the tendering process of wind farm projects. WIND was thus struggling to transform these opportunistic and punctual relationships into longer-term partnerships and more generally to further stimulate the use of EO data in this industry, especially because these data were not yet considered as a legitimate source of information by investors. A co-design need of type 2 was thus identified as the main priority, while also identifying a future need of type 3 (as WIND’s main interest concerns the research aspects, there might be a need of partnering with another entity to be in charge of the engineering and commercialisation aspects of future solutions).

A co-design action was thus organised to address the co-design need of type 2. This involved a couple of internal meetings between WIND and our research team (preparatory step) and a cycle of three short one-to-one meetings (of about 1h30), between WIND and a given user (as well as our research team in support): two with specialised consultants (one

doing yield assessments for wind energy projects, and one more focused on the mere provision of wind resource data for such assessments), and one with a wind farm developer (research and technology department). Every meeting followed the same structure in three phases detailed in Figure 4, driven by the objectives of (1) expanding the usefulness of the developed solution by enriching the pilot’s representation of the use ecosystem, (2) expanding the pool of relevant stakeholders to interact with. The outcomes were synthesised for each meeting in a dedicated chart giving an overview of the different paths for WIND’s development efforts, that could be considered at different time scales, either on WIND’s side or in interaction with the interviewed actor. Figure 4 also displays one of the three charts that came out of the process.

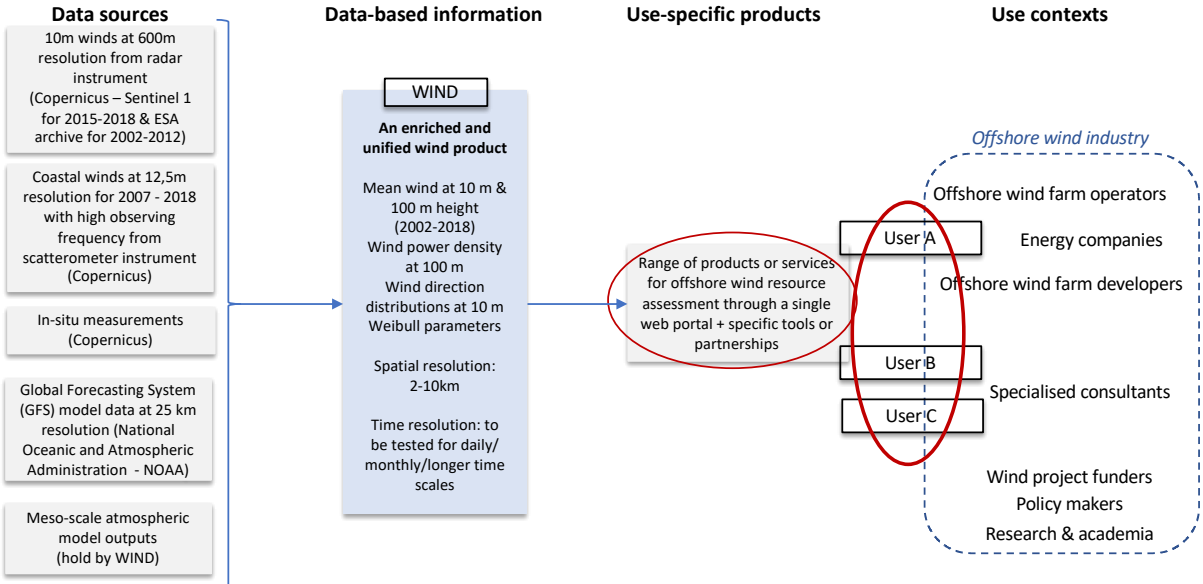


Figure 3: Template synthetically representing WIND context (precising the sources of data, the type of information derived from them, the type of data-based solutions developed for given use applications, and the use contexts) and the outcomes of the diagnosis process (bottlenecks identified in red circles – the bold circle indicates the bottleneck addressed in the subsequently experimented co-design action)

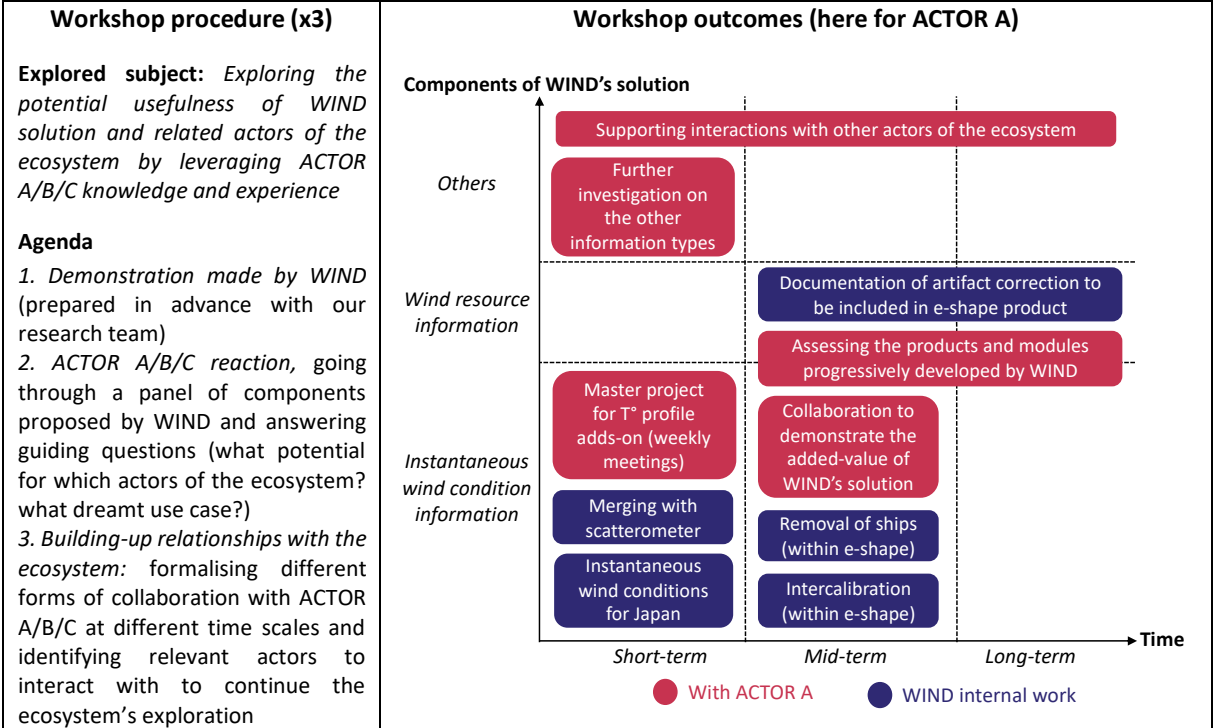


Figure 4: Overview of workshop procedure and outcomes within the co-design action of WIND targeting the identification of relevant entry points in the offshore wind industry with the help of identified actors (A/B/C).

3) SOLAR case study

The outcomes of the diagnosis process are synthetically represented in Figure 5, based on the template used as a diagnostic support tool. The pilot's objective appeared to consist in expanding the developments already made by SOLAR on assessing solar resource at urban scale, by further considering the spatiotemporal variability of this energy resource. SOLAR had already developed a first solution in partnership with a start-up that aimed to facilitate the installation of PV systems designing a simulation tool for private individuals based on maps of solar resource provided by SOLAR and operationalised by SOLAR's historical partner (taking charge of the engineering and commercialisation of the products and services stemming from SOLAR research activities since 2009). By enriching this solution with variability aspects, SOLAR expected to broaden the range of actors that could benefit from this solution and had already identified some interested actors (such as grid operators). The main issue for SOLAR was to redesign the relationship with its historical operationalisation partner, so that it would be more adapted to the envisioned future developments (co-design need of type 3). Other issues were also identified for further expansion of the solution at longer-term, including the exploration of alternative sources of data covering larger geographical areas, renewed

interactions with existing and new users, and potential complementarities with another part of the pilot led by a partner in Germany.

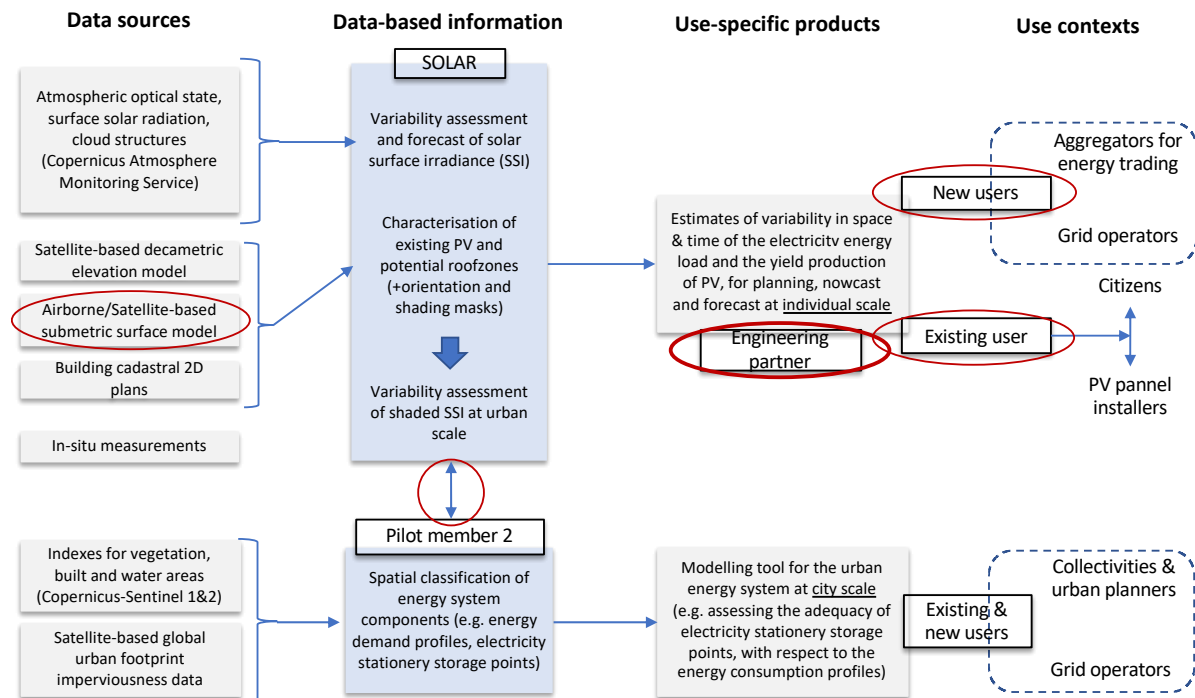


Figure 5: Template synthetically representing SOLAR context (precising the sources of data, the type of information derived from them, the type of data-based solutions developed for given use applications, and the use contexts) and the outcomes of the diagnosis process (bottlenecks identified in red circles – the bold circle indicates the bottleneck addressed in the subsequently experimented co-design action)

Following the diagnosis process, a specific action to address the need of co-design type 3 was conducted. A preliminary session was organised to identify concrete cases where the existing relationship between SOLAR and the operationalisation partner seemed to face some difficulties and would thus need to be redesigned. Following this session, it appeared that it would be critical to work on a specific module, called ‘Cloud Motion Vector’, to improve solar forecasting algorithms, while the respective involvements of SOLAR and operationalisation partner were not clearly defined. A 3h workshop was then organised to (1) build a common understanding of the parts of the module to be operationalised or to be further explored, (2) establish adequate relationships to deal with each category of modules. Figure 6 gives an overview of the workshop agenda and shows the synthesis table of the main outputs.

Workshop procedure				
<p>Explored subject: based on the concrete cases identified in the preparatory phase (‘Cloud Motion Vector’ - CMV - module), clarifying the parts to be operationalised/to be explored & the associated collaboration modalities between SOLAR and OP</p> <p>Agenda</p> <ol style="list-style-type: none"> 1. CMV module seen by SOLAR (sharing critical knowledge and considering different concepts that might be envisaged from ideal to quick&smart alternatives) 2. CMV module seen by OP (same process) 3. Clarification of the parts to be operationalised/to be explored and the associated collaboration modalities to be put in place between SOLAR and OP (type a’, type b corresponding to different sorts of CMV) 				
Workshop outcomes				
	Short-term	Mid-term	Long-term	Cooperation modalities
Modules to be operationalised	<i>Type a’</i> CMV for hindcast - Gridded maps of clear sky index & cloud motion vectors). - Area : starting with Nantes & Oldenburg. Enlarging to Europe & Mediterranean basin	<i>Type a’</i> for nowcast		March 2021 : kick-off and working sessions to define inputs & outputs and development planning (OP: involving Stéphane, SOLAR: beta-testing) Milestones for sprint 2
Modules to be explored	<i>Type b</i> CMV for hindcast with partial processing from SOLAR (OP providing maps; SOLAR processing the algo). Same area	<i>Type b</i> CMV for hindcast with processing transferred to OP	<i>Type b</i> CMV for nowcast	March 2021 : technical working session with OP on python code developed by SOLAR
Undetermined	SOLAR-OP collaboration for GAN methods	Collaboration on other deep learning methods for long-term forecasting	Commercial service for forecasting at different time horizons	R&D collaboration (joint PhD & internships, specific interest group on forecast between SOLAR and OP)

Figure 6: Overview of workshop procedure and outcomes within the co-design action of SOLAR targeting the redesign of the relationship with OP (standing for Operationalisation Partner).

4) Cross-case analysis of co-design contributions to resilience enhancement

a) Co-design diagnosis

On the cognitive dimension, the diagnosis process helped the pilots to formalise the explored concepts (e.g. the imagined data-based solutions for which actors and for what purposes), as well as the status of the pilots’ knowledge on aspects related to the use ecosystems (regarding the overall ecosystem organisation such as related rules and regulations, and regarding the day-to-day operations of identified users) and also on aspects related to data production (e.g. identifying the resources available to ensure the operationalisation and commercialisation of the data-based solutions). This diagnosis process played a kind of “defixating” role, in the sense that it helped the pilots to overcome their own fixation effects and thus clarify their organisation and development strategy on an expanded basis. Several elements of the process contributed to this effect. First, the visual template representing each pilot’s overall objectives and associated actors was first drafted by our research team with available information (especially the pilots’ application forms to the

project formulating their initial ambitions), thus offering a kind of third-eye view to the pilots that proved to be extremely useful for them to clarify their own ambitions. Second, providing an analytical grid with different co-design types also contributed to making the pilots aware of the variety of learning efforts to be considered, going beyond agreeing on the specifications of the data-based solutions with existing users (that appeared as the most evident to the pilots), but also consisting in exploring more deeply a certain use ecosystem (e.g. the offshore wind industry for WIND), or the means of ensuring a long-term viability of data-based solutions (as for SOLAR). A few verbatims illustrate well this defixating effect:

“Once you showed the graph of the pilot and its complexity it was very interesting. I think no one in our team had this overall vision so we were missing that. In fact, the fact that it is a team [i.e. the research team on co-design] outside the development team [i.e. the pilot] is very good because it reveals what we said to you and you put it in a clear graphical way and it helped us to formalise what we wanted to do.” (SOLAR)

“Sometimes you say to yourself: ‘hmm I haven’t thought about this before’. It really helped us actually make clear what was the initial intention, what is visible now, what the users actually want. So, it wasn’t only about the users’ needs but also about our own needs in order to better coordinate our pilot. So yeah it was really helpful for us.” (AIR QUALITY).

On the social dimension, the diagnosis process also contributed to progressing towards resilience, having an impact on the pilot’s network of external actors and also possibly on the pilot’s internal team. Regarding the external actors, the diagnosis process played a form of targeting role for shaping the pilot’s network, helping the pilots to assess the robustness of established points (e.g. when questioned by our research team about users’ competencies and position in the overall ecosystem) and identify the weak points of the network, i.e. the critical relationships that would need dedicated efforts to be established or further strengthened to ensure the viable integration of EO data into given use ecosystems in a long-term perspective. Moreover, concerning the pilot’s internal team, the diagnosis process also contributed to formalise a shared understanding of the pilot’s overall vision, thus strengthening the internal consistency of the pilot. The template used to represent each pilot has proved especially useful in systematically eliciting the actors associated with the different parts of the data-information-value chain envisioned by the pilot.

On the dynamic dimension, the diagnosis process played a role on building bridges between existing and future dynamics. The diagnosis process indeed resulted in identifying the future dynamics to be triggered by precisising the types of co-design efforts to be undertaken at different time horizons. But it is important to note that the identification of

these future-oriented dynamics was made possible by a crucial elicitation work of the *existing dynamics into which ecosystems were already engaged*, both related to data use aspects (e.g. the reluctance of the offshore wind industry related to the use of other sources of data than the ones commonly used for wind farm projects in WIND case), or data production aspects (e.g. the current trends of developing algorithms for solar resource forecasting in SOLAR case, later leading them to work on a generic ‘Cloud Motion Vector’ module that could benefit several developers of solar-forecasting solutions).

b) Co-design actions

On the cognitive dimension, the synthesis outcome charts of the design sessions reflect well that the data-based solution to be designed does not consist in a single concept but rather involves the exploration of a variety of concepts. To reach this rich range of concepts, a specific attention has been paid on overcoming potential fixation effects of both pilot members and the actors invited to participate to the design sessions (users for WIND and AIR QUALITY and operationalisation partner for SOLAR). From the pilot’s perspective, two important aspects are worth being highlighted: one aspect that was expected by the pilots themselves and one aspect that was less self-evident. The first aspect concerns the *fixations related to the pilots’ knowledge on the invited actors*. The design sessions resulted in better understanding the context of action of these actors, sometimes dismissing initial assumptions of the pilots, as for example illustrated in the case of WIND that changed its initial assumptions on the relevant geographical coverage of the developed solution:

“We also expanded our coverage because in the beginning we only focused on the Seas of Europe but one of our users reminded that the Asian seas and the US offshore areas are really the hotspots for wind energy development at the moment so we decided to expand and generate data sets for those areas as well.”

(WIND)

A second form of defixation for the pilot has consisted in *moving away from its representation of the kind of relationship to be established with the invited actors*, i.e. the roles that the pilot would naturally endorse itself and assign to the others. Dedicated efforts have thus been carried out at the preparatory step of the design sessions in which our research team explicitly exchanged with the pilots on the risk of facing such fixations, their possible nature given the considered case, and the specific precautions to be taken accordingly. In the case of AIR

QUALITY, the main fixation consisted in considering that the users would be directly able to express lists of requirements on their own while they might be still highly unfamiliar with EO data. To address this issue, a set of guiding questions was prepared and sent to the users prior to the workshop, encouraging them to think of several use configurations, such as using data for monitoring purposes (merely following the concentration of pollutant concentration), decision-support purposes (triggering certain identified actions when a threshold is exceeded), or scenario-design purposes (exploring new forms of pollution mitigation actions). In the case of WIND, the main fixation was to put itself in a seller position, merely considering the actors of the offshore wind industry as potential clients. Such a position would lead the pilot to limit its investigation on a mere validation of specific features of the solution, thus insufficiently fulfilling the large learning need on the use ecosystem encountered in situations of co-design type 2. The preparatory step between our research team and WIND was thus crucial to emphasise this point and help WIND to move away from a seller position towards considering the actors as partners for learning and exploration. This element has been later highlighted as a crucial learning made by WIND during this co-design process:

“For me it was really eye opening that we could use it in such a broad way to look at all sort of possibilities rather than trying narrow down what we wanted to do. [...] The way we ask questions during the workshops – not just in this context but also in our other projects and activities – has changed to be more exploratory and focused on the potential seen by each stakeholder rather than on the willingness to test or buy our services.”
(WIND)

In the case of SOLAR, the main fixation was to consider the relationship with the operationalisation in a simple valorisation logic based on transferring modules from R&D to operationalisation. However, it appeared during the preparatory phase that some modules of the explored solution actually needed further exploration, with the help of the operationalisation partner. This led us to focus the objective of the workshop on eliciting two types of modules – to be operationalised/to be further explored – and agreeing on the respective roles of the R&D and operationalisation actors on both types of modules, rather than restricting the scope of activities of each actor to either R&D or operationalisation.

Regarding the invited actors' perspective, the design sessions were also designed to help them overcome their potential fixations related to the integration of the considered solution in their own operations. When the invited actors were potential users (in AIR QUALITY and WIND), the session systematically started with a demonstration phase made by the pilot that aimed to show the potential of EO data, thus providing users with a new kind of

knowledge and encouraging them to think of new forms of actions, different from what they could have imagined on their own without EO data. Moreover, for all cases, the phases dedicated to the invited actors' knowledge sharing were systematically guided by a certain number of questions, that forced the actors to consider the presented solution from different perspectives (e.g. using data for monitoring, decision support, scenario-design support, as detailed above for AIR QUALITY), and especially imagine an ideal or dreamt case of data integration without accounting for existing or foreseen obstacles. This latter element proved to have a positive effect on the richness of the exchanges, retroactively broadening the pilot's overall understanding of the invited actors. This has been especially highlighted in the case of AIR QUALITY and WIND:

*"We then broadened the discussion a bit and asked the users to imagine what they would want if no barriers existed and a lot of interesting inputs and ideas came out of that."
(WIND)*

"I would like to comment that I really enjoyed the last bullet that you mentioned, the one about this free mode free Dreamers you know. why? because it was really done in a very relaxing way so everybody had its craziest idea put on the table but it was useful because it worked like a slider so we know where we stand and they gave us the other hand so we have a slider and this is where we can go with e-shape. How did that help us? Now, we can organise the first part and it gives us the vision for the next steps and engage further discussion with stakeholders on organising the next steps and next operations." (AQ)

On the social dimension, the synthesis outcome charts outline that the design sessions triggered transformations of the existing relationships between the pilots and the actors that participated to the design sessions. These relationships were better defined as possibly involving a variety of collaboration modalities, e.g. a joint master or PhD student project to explore identified research aspects as well as an exchange of data (WIND), a preliminary correlation analysis before working on a potential monitoring system of health threats from air pollutions as well as punctual advice provision on certain projects (AIR QUALITY). It is also interesting to notice that the role taken by the actors were sometimes multifaceted, e.g. in the case of AIR QUALITY, the users were also expected to be data providers (e.g. the National Public Health Organisation providing data related to cardio-vascular or respiratory diseases). These outcomes resulted from a specific attention paid on this social dimension during the preparation and execution of the design sessions. Indeed, at the preparatory step, the pilots were systematically questioned on the existing status of the relationship and their expectations. And in each design session, a final phase was systematically dedicated to a discussion on the forms of relationships to establish between participants.

On the dynamic dimension, the co-design actions contributed to establishing new forms of routines within the pilot's organisations, enhancing their ability of sustaining these dynamics over time by either replicating the same types of workshops on their own or to complement them with other types of co-design. The enhancement of the pilots' capacity of handling these dynamics over time in a more autonomous way has been explicitly acknowledged by the different pilots:

"We have enquired the possibility to replicate some of the aspects we did in e-shape in other projects for similar thematic (health and air quality) [...]. It was a big benefit for us and now from onward it is easier for us to look for new stakeholders and to approach them." (AIR QUALITY)

"We will continue to organise user workshops so we maintain a co-design cycle and continue to improve our insights in the ecosystem in the future." (WIND)

"This way of doing the co-design is of interest since it provides a guideline to be 'systematically' applied for such internal co-design approach. To illustrate the genericity of this co-design approach, we did recently a very fruitful session of co-design with our IT teams [...] for the second round of coding of the pilot, following the same guidelines." (SOLAR)

These results were encouraged through different aspects of the process. First, to build the synthesis outcome chart, the pilots were asked to consider the concepts to be explored and the relationships to be established in a dynamic perspective, with varying focuses on short-term, mid-term and long-term time scales. In certain cases (especially WIND type 2), the final workshop phase dedicated to the social dimension also included the identification of future relevant actors to interact with, e.g. investors in wind farm projects or other contact persons from relevant departments within the interviewed energy company (WIND). More largely, the pilots were also invited to continue co-design cycles on their own, either for the same co-design type or for others, as already identified in the diagnosis process or to address newly identified issues coming from the outcomes of the design sessions. These outcomes are summarised in Table 3.

Resilience	Co-design diagnosis	Co-design actions
<p>Cognitive <i>Eliciting a range of concepts on how data can be integrated into certain use ecosystems and ability to undertake substantial learning processes</i></p>	<p>Outputs: elicitation of the <i>pilot's explored concepts and status of knowledge</i> Process: overcoming the pilot's fixations through a third-view representation of the pilot on a <i>visual template and the analytical grid</i> with different co-design types</p>	<p>Outputs: elicitation of a <i>variety of concepts</i> including both data & use aspects (i.e. range of development paths of data-based solutions for given use contexts) Process: overcoming <i>fixations of the pilot</i> - related to the invited actors' context of action (users or operationalisation actors) and the possible nature of their relationships; overcoming <i>fixations of the invited actors</i> (demonstration phase for users, envisioning data integration from different perspectives, question on an ideal/dreamt case)</p>
<p>Social <i>Establishing relationships between relevant actors to adequately address the transformations involved on the cognitive dimension</i></p>	<p>Outputs: <i>targeting role for shaping the pilot's external network</i> (robustness assessment and identification of weak points) & strengthening the <i>pilot's internal consistency</i> Process: systematic <i>mapping of the actors</i> on the different parts of the data-value chain represented on each pilot's template</p>	<p>Outputs: <i>(re)design of the relationship between the pilot and the invited actors</i>, involving a variety of collaboration modalities Process: <i>initial assessment of the current status of the relationship</i> and the pilot's expectations (preparatory step), integration in each design session of a <i>final phase dedicated to establishing collaboration agreements</i> between participants</p>
<p>Dynamic <i>Sustaining the continuous evolution of the ecosystem's cognitive and social dimensions to ensure its long-term viability given internal and external constraints or opportunities that might occur over time</i></p>	<p>Outputs: building <i>bridges between existing and future dynamics</i> Process: identification of <i>future co-design efforts</i> based on a preliminary elicitation of <i>existing dynamics into which ecosystems are already engaged</i> (on data use & data production sides)</p>	<p>Outputs: new forms of <i>routines within the pilot's organisations</i>, enhancing their capacity to sustain the co-evolution of cognitive and social dimensions over time Process: pilot asked to map the outcomes of each design session at <i>different time scales</i>, potentially asked to identify future relevant actors to interact with, and encouraged to <i>continue cycles of co-design on their own</i> (following initial diagnosis or the outcomes of implemented co-design actions).</p>

Table 3: Contributions of the experimented 'resilient-fit' co-design methods to the cognitive, social and dynamic dimensions of resilience enhancement, precisising the obtained outputs and the elements of the process aiming to foster these outputs.

V. Discussion

To summarise the main results of our research, the three investigated case studies confirm that 'resilient-fit' co-design methods can effectively be designed, despite the extremely limited orchestration capacities of the co-design sponsor (here the data-based solution designers). The 'resilient-fit' co-design methods consist in organising a sequence of actions helping the co-design sponsors to *progressively build shared unknowns* (cognitive dimension), *dedicated interactions with targeted actors* (social dimension), and *ultimately contribute to strengthening the capacities of actors to sustain cognitive and social transformations over time* (dynamic dimension). These outcomes can recall the 'infrastructuring' perspective encouraged in design literature, aiming at building the conditions enabling 'design after design' (Bjögvinsson et al., 2012; Botero and Hyysalo, 2013; Iversen and Dindler, 2014; Simonsen and Hertzum, 2012) and other works calling for further considering the important relational outcomes of co-design and considering co-design as a sequence of several interactive sessions in the perspective of fostering the formation of creative communities

(Dubois et al., 2016, 2014). However, the extremely limited orchestration capacities of the co-design sponsor leads to an original situation where there is initially no common ground for the emergence of shared unknown and little knowledge on the relevant actors to be involved. The similarities and specificities of these methods compared to existing ones are thus discussed in the following paragraphs, especially considering the nature of the outputs and the mechanisms underlying the process.

1) Co-design sponsor with extremely limited orchestration capacities: ‘resilient-fit’ outcomes and mechanisms compared to existing methods

Considering the outputs, it is worth noting that the shared unknowns resulting from the co-design process *are built ‘locally’*, i.e. specifically to each relationship of the data-based solution designer with a given actor, referring to how data can be used to address certain challenges faced by this actor. In this respect, it differs from the situations described in literature where the co-design sponsor seeks to build a global overarching design goal common to all the actors, especially in cases of diverging views e.g. (Berthet et al., 2016b; Ollila and Yström, 2016; Pluchinotta et al., 2019). These shared unknowns do not aim either at exhaustively mapping the innovation paths followed in a given field, as sometimes done by specific actors playing the role of “architects of the unknown” guiding the collective exploration of innovative paths and associated creation of knowledge (Agogué et al., 2017, 2013). In the same vein, *the mobilisation of actors also unfolds in a ‘localised’ way*, in the sense that the design sessions do not gather all actors at once but separately mobilise targeted pools of actors, as pinpointed within each type of co-design action. In this respect, the co-design process differs from certain approaches that open up the participation to a broad range of actors regardless of who they are and what competencies they have – e.g. in crowdsourcing initiatives (Hellemans et al., 2022; Kokshagina, 2022; Porter et al., 2020; Vermicelli et al., 2020). Consequently, regarding the dynamic dimension, it appears that the experimented ‘resilient-fit’ co-design methods more specifically result in *locally strengthening the orchestration capacities of the co-design sponsor, by multiplying localised spheres of orchestration* (corresponding to the relationships created with the pinpointed actors) in which the co-design sponsor can suggest innovation directions and mobilise actors more easily.

To reach these outputs contributing to resilience enhancement on all three cognitive, social and dynamic dimensions, the process of the methods has been carefully built by

combining various mechanisms, showing some similarities with existing co-design methods, as well as specificities linked to the investigated situation. First, the overall structure of the process is quite similar to what has been already emphasised in the works concerned with limited orchestration capacities, including a thorough diagnosis process followed by a sequence of design sessions – e.g. (Bos and Koerkamp, 2009; Della Rossa et al., 2022; Elzen and Bos, 2019; Pluchinotta et al., 2019). This diagnosis process entails a detailed analysis of the problem and actors at stake, similarly to RIO approach (Bos and Koerkamp, 2009; Elzen and Bos, 2019), but does not consider all the actors in a symmetrical way. Indeed, in our case, *the diagnosis is asymmetrical as it aims to mirror the understanding of the situation from the perspective of the data-based solution designer*. This mainly stems from the fact that neither the data-based solution designer nor our research team has easy access to the other actors of the ecosystem. These actors might be willing to participate to design sessions but still have limited time to devote to the process until they show a confirmed interest for EO data. This aspect has also prevented us from exhaustively mapping the fixations of all these actors prior to the design sessions, that would have required either in-depth interviews or previous knowledge gained through past interactions as indicated by scholars – e.g. (Berthet et al., 2022, 2016b; Della Rossa et al., 2022; Pluchinotta et al., 2019).

Given the impossibility of having in-depth interactions with participating actors before the co-design sessions except the co-design sponsor, the protocols of these sessions have also been adapted accordingly, combining elements from different existing approaches. Drawing on KCP methods, each co-design session has followed a similar structure including a sequence of distinct phases entailing the following aspects: (1) a “K” (Knowledge) phase, consisting in expanding the initial knowledge of actors to set a common cognitive ground for further exploration of innovative concepts, to (2) a “C” (Concept) phase, consisting in the exploration of a pool of concepts within the defined scope of exploration, and (3) a “P” (Project) phase, consisting in setting up different strategies that would allow the participants to further work on the development of the identified promising ideas (Elmquist and Segrestin, 2009; Hatchuel et al., 2009; Hooge et al., 2016b). However, each co-design session has been stringently time-limited (lasting between 1h30 to 3h) compared to usual KCP workshop (lasting one day to several days), leading us to significantly modify the content of each phase. Indeed, the main objective does not so much lie in undertaking a wide exploration of creative ideas, but rather as triggering the minimal necessary cognitive and social transformations for establishing

adequate relationships between participants, in the perspective of sustaining subsequent and repeated design efforts in a long-term perspective. In other terms and drawing upon the ‘resilient-fit’ labelling of these methods, the objective lies in *triggering a fit between designers and partners and ensuring its resilience over time*. In this regard, the session has conducted K and C phases in a partly overlapping way, introducing no external knowledge unlike usual KCP methods (Elmqvist and Segrestin, 2009; Hatchuel et al., 2009; Hooge et al., 2016b), but *organising the mutual defixation of actors based on their respective knowledge* that are highly unconnected by nature, i.e. considering how the knowledge brought by data-based solution designers can extend the design space of users and trigger the emergence of shared unknowns and vice-versa. This especially resonates with the ‘reactive’ mode of exploration prevailing in crowdsourcing initiatives where participants are asked to react on and enrich each other’s ideas (Hellemans et al., 2022; Porter et al., 2020), and in certain co-design approaches gathering heterogenous participants with little design credentials and no prior relationship (Dubois, 2015), or between actors with stronger design competencies in the perspective of building cross-industry exploratory partnerships (Gillier et al., 2010). Concerning the P phase, it has mainly consisted in setting up the collaboration modalities between participating actors and potentially identifying new relevant actors to be involved in the future.

More specifically considering the mechanisms related to the interactions with users, a specific attention has been paid on guiding them to consider long-term needs beyond short-term interests or technical constraints (e.g. by being questioned on their dreamt use case). This is consistent with insights provided by the RIO approach (Bos and Koerkamp, 2009; Elzen and Bos, 2019), and user innovation literature suggesting that providing users with “too much technology information and restrictions on potential feasibility” can potentially hinder the generation of innovative ideas (Kristensson and Magnusson, 2010). However in the investigated case valuing resilient fit over creativity, there is a need of providing enough technology information to create a fit and expand the users’ design space, while ensuring that but it does not fixate the reflection of users on given solutions. This aspect has especially been integrated in the pilot’s demonstration phase, aiming at showcasing the overall expertise of the pilot and presenting data-based objects that do not appear as turn-key solutions but remain open ended in respect of the use application.

2) Enriching the pool of available co-design methods for the (re)design of ecosystems

The comparison with existing methods shows that a context with extremely limited orchestration capacities can still be the ground for collective design processes, provided that specific efforts and adaptations of existing methods are made. There is probably no one-size-fits-all method and the paper does not claim that the elements described above will apply to all co-design contexts with extremely limited orchestration capacities. However, our results highlight the importance of reflecting on the initial orchestration capacities of the co-design sponsor, assessing the compatibility of existing methods with these capacities and potentially adapting the process accordingly. Moreover, it is important to note that the different categories of methods depending on various degrees of orchestration capacities should rather be seen as permeable. Indeed, a same actor can have strong orchestration capacities within an initial sphere (e.g. within its historical ecosystem of users and partners), but might face situations where its orchestration capacities are much more limited e.g. when moving from internal forms of collaborative innovation towards new forms of cross-organisational or cross-industry co-design (Hooge and Le Du, 2016; Rampa and Agogu e, 2020). In this perspective, the different co-design methods could be considered as *complementary and potentially distributed in time*, to overcome an initial low level of orchestration capacities and progressively leverage a broader range of methods adapted to a higher level of orchestration capacities.

In particular, our research has underlined the potential benefits of undertaking co-design actions in a 'localised' way, targeting locally-shared unknown for pinpointed collective of actors. Although some collective design sessions might require to be conducted at a global scale, it would be interesting to investigate how 'localised' actions could be more adapted in certain circumstances, possibly in situations where mobilising a large number of highly heterogeneous appears as particularly difficult due to geographical constraints and time limitations of participating actors scholars - e.g. in (Pluchinotta et al., 2019). Further research could help better understand the possible complementarities between these forms of actions.

Finally, the experimented 'resilient-fit' methods also contribute to offer fresh insights on the (re)design of ecosystems by shedding light on an original configuration where the dynamics are triggered by actors that are initially external to the ecosystems (here data-based solution designers). These dynamics are not directly enforced by these actors but stimulated in a collaborative setting through the creation of robust relationships with internal actors of

the ecosystem. In this process, co-design methods especially support the data-based solution designers in defining their roles beyond classical patterns of interactions (e.g. user-provider in the case of AIR QUALITY and WIND or research-commercialisation in the case of SOLAR. Once introduced in these ecosystems, the data-based solution designers seem to hold an intriguing position, consisting in progressively strengthening a position that allows them to influence ecosystem dynamics locally, without striving for a strong leadership position. In this regard, it differs from other perspectives where actors strive to gaining global orchestration capacities to shape the ecosystem dynamics to their advantage, as it can be the case for focal firms (Adner, 2006) or platform leaders (Gawer and Cusumano, 2002).

3) Limits and further perspectives

A major limitation of the research lies in the temporal scale of the analysis. Indeed, establishing large collective design processes and undertaking the associated cognitive and social transformations require long-time efforts to be realised, e.g. vividly illustrated by the longitudinal analysis of a social-ecological research infrastructure aiming at collectively designing a resilient agri-food system (Berthet et al., 2022). It will be thus fruitful to pursue our research over a longer time period to examine the long-term effects of the methods and progressively enrich them. In particular, specific efforts are required to further explore how such ‘resilient-fit’ co-design methods could be operationally managed over time. In the investigated context, the co-design process has been steered through a close interaction between data-based solution designers (co-design sponsors) and our research team. This interaction has been a way of providing data-based solution designers with additional expertise on design theory and progressively enhancing their own capacities of continuing the process further. However, further research is still needed to progress towards installing all required conditions for a full operationalisation of these processes in a long-term perspective. Indeed, although recognising the positive effects of the first experimentations carried out so far, some data-based solution designers have especially pointed out the difficulty of integrating these practices on an operational basis:

“I tried to do this again more independently [...] and it was more difficult to do it alone [...] and to convince my colleagues this was a good idea and to explain the concepts to them as I didn't have the same foundation you have.” (WIND)

To address this issue, organising some forms of co-design training could offer promising means of progressively catalysing a community of actors that share a common language on the exploration efforts to be conducted, similarly to what has been experimented in firms striving to undertake dramatic transformations towards sustainability transitions (Rampa et al., 2016; Rampa and Agogué, 2021; Yström et al., 2021).

Another important aspect requiring further investigation consists in questioning the role of a third-party in the process, as played by our research team in e-shape project. The pilots highlighted that a “third-eye” view proved to be particularly helpful for the diagnosis process and would probably be more difficult than co-design actions to undertake autonomously, thus raising the question of what organisational structures could further support such a third-eye view without necessarily relying on our research team:

“[For the workshops] it’s maybe not mandatory to have a third eye. I think the initial phases are way more complex but once you have these initial phases, having just a graphical representation of the workshop helps to be sure that we are following the guidelines. For e-shape it was mandatory to have you assisting these workshops [...] but for the future I think the workshop could be done in an autonomous way.” (SOLAR)

“I think we learnt how to do it more or less but I fully agree with Philippe [SOLAR pilot leader] that we need this third-eye, this psychiatrist. It is important because no matter what we think we are surely biased because we are dealing with our own things. We are replicating the same obstacles without being aware of them. A third eye would be useful to help us see and interpret the findings of this discussion.” (AIR QUALITY)

Finally, this paper does not focus on analysing the artefacts supporting the co-design process. A large panel of works in design and innovation management research has already highlighted the role of a large range of material artefacts in effectively supporting innovation processes, such as probes, prototypes, toolkits - e.g. (Ben Mahmoud-Jouini and Midler, 2020; Chen et al., 2020; Franke and Piller, 2004; Sanders and Stappers, 2014; Zenk et al., 2021). In particular, the artefacts supporting the demonstration phase of the data-based solutions appear to have a crucial role. They need to integrate specific properties to showcase the potential of data while integrating a form of ‘incompleteness’ regarding the applications for which data could be used (Garud et al., 2008). These artefacts could be more closely examined by comparing them with certain kinds of digital design tools such as Computer-Aid-Design tools already examined in literature (Fixson and Marion, 2012), further investigating their role as potential ‘boundary objects’ to support the interaction between actors that hardly share the same language (Carlile, 2002; Huvila et al., 2017; Star and Griesemer, 1989), or as forms

of ‘proof-of-concepts’ supporting both cognitive and social transformations (Jobin, 2022; Jobin et al., 2019).

VI. Conclusion

The paper aims to advance research in innovation management and design by enriching the pool of available co-design methods that can adequately support the (re)design of ecosystems in the context of socio-environmental grand challenges. Based on three case studies in the field of Earth observation, the paper has provided insights on a specific class of so called ‘resilient-fit’ co-design methods that is characterised by (1) the objective of enhancing the resilience of ecosystems considering three dimensions - cognitive, social, and dynamic, (2) the external position of the co-design sponsor initiating the approach, thus having extremely limited orchestration capacities within these ecosystems, i.e. being initially hardly able to influence the direction of innovation efforts and mobilise actors.

Our research work contributes to theory and practice in several ways. First, it sheds light on how the existing co-design methods already provide insights on different ways of enhancing the resilience of ecosystems, and how they differ depending on the degree of the co-design sponsor’s orchestration capacities. Moreover, our research shows how a co-design sponsor with extremely limited orchestration capacities can effectively implement ‘resilient-fit’ co-design methods that contribute to resilience enhancement, despite the initial absence of common ground for the emergence of a shared unknown, and little knowledge on the actors to be involved. The methods result in a specific way of shaping the unknown and mobilising actors, insofar as shared unknowns are only built locally rather than globally (i.e. specific to the relationship with a given actor rather than common to all participating actors), for pinpointed actors of the ecosystem. To foster these outcomes, the process of the methods was built on a number of mechanisms inspired from existing methods and adapted to the specificities of the context of extremely limited orchestration capacities. In this perspective, each co-design session consists in mutually defixating participating actors leveraging their respective knowledge, to trigger the minimal necessary cognitive and social transformations for establishing adequate relationships between participants, in the perspective of sustaining subsequent and repeated design efforts in a long-term perspective.

Finally, this research contributes to practice as it proposes guidelines for these ‘resilient-fit’ co-design methods sponsored by actors with extremely limited orchestration capacities. These protocols already support in practice the actors in the Earth observation field, but could also be helpful for other actors facing similar issues of ecosystem design. The paper especially suggests to further investigate how such a class of methods could be complementary to the other classes of methods, in the perspective of providing co-design sponsors with a panel of methods adapted to a given level of orchestration capacities and progressively fostering the strengthening of their orchestration capacities.

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Data-push innovation beyond serendipity: the case of a digital platform strategically building up the genericity of Earth observation data

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Status: under revision in *Technovation*

Abstract

The potential of data in stimulating innovation has been largely acknowledged by practitioners and researchers. In particular, this has given rise to a specific form of data-based innovation, labelled “data-push innovation”, consisting in stimulating the use of existing data by third-party actors. Data-push innovation concerns all organisations willing to create additional value from data that have already been produced internally or by other actors, e.g. firms but also open data platforms. However, how to steer data-push innovation repeatedly for a large variety of actors remains challenging. This paper proposes to investigate this issue by examining the longitudinal case study of an actor that has successfully stimulated the use of Earth observation data by multiple actors over the last 40 years. The paper offers several contributions to research in information systems and innovation management. First, it contributes to advancing research on digital platforms. The case study indeed unveils original platform expansion dynamics, that are especially supported by a non-dominant form of platform leadership focusing more on gaining generative power than controlling power, and eventually resulting in building up the genericity of data, i.e. their ability to be widely used by a large variety of actors. Second, more generally contributing to research on data-based innovation, the paper elaborates on the notion of “data/uses fit system”, shedding a specific light on the elements to be designed to make data circulate beyond their initial context of production towards new contexts of use, adjusting to the existing constraints on data and the practices of the actors that might benefit from their use.

Key words

Data-based innovation, data-push innovation, digital platform, Earth Observation

I. Introduction

In recent years, the development of IoT, increasingly low-cost sensors and computational capacities has dramatically increased the flow of data in almost every business, industry and research area. This “big data” phenomenon has been largely described in both innovation management literature – e.g. (Cappa et al., 2021; Appio et al., 2021; Bharadwaj and Noble, 2017; Blackburn et al., 2017; George et al., 2014) - and information systems (IS) literature – e.g. (Günther et al., 2017; Abbasi et al., 2016; Gandomi and Haider, 2015; Chen et al., 2012).

Scholars have especially highlighted different forms of data-based innovation strategies to take advantage of the new possibilities offered by data. Among these different possibilities, scholars have especially unveiled certain forms of “data-push innovation” (Han and Geum, 2022; Trabucchi and Buganza, 2020) starting with existing data and focusing on stimulating the use of these data by third-party actors outside the organisation’s boundaries, also similarly referred as “outbound data-based innovation” (Trabucchi et al., 2018). For example, Uber created a service called Uber Movement, providing anonymised data collected through their service of matching riders and drivers to help urban planning around the world, for example by offering insights to avoid traffic congestion caused by specific events or holiday traffic (Trabucchi and Buganza, 2020). In this respect, literature in information systems has precisely described the operations required to transform data into commodities, involving an intricate process of “recontextualisation” to adapt the data produced in a given context to a new context of use (Aaltonen et al., 2021; Alaimo et al., 2020; Alaimo and Kallinikos, 2020).

However, beyond their recontextualisation in one given context, data are acknowledged to be highly ‘portable’, thus having the broader potential of being used and re-used across a large variety of contexts across organisations and industries (e.g. Günther et al., 2017; Lycett, 2013b). This property thus lays the foundation for data-push innovation strategies that organise the recontextualisation of data for new actors repeatedly, resulting in generating a wide variety of new uses over time. These strategies are coined “repeated data-push innovation” throughout the rest of the paper. Such strategies have especially started to be investigated in the context of “open data” approaches, consisting in fostering innovation across multiple actors by opening up the access to data produced by given actors, either public

authorities following open government data policies (e.g. Gupta et al., 2020; Charalabidis et al., 2018; Berrone et al., 2016; Zuiderwijk and Janssen, 2014), or private actors considering data sharing as a promising path of value creation (e.g. de Prieëlle et al., 2022; Mosterd et al., 2021; Zeng and Glaister, 2018; Perkmann and Schildt, 2015).

However, the understanding of these strategies is still in its infancy and requires further investigation. In particular, recent works raise concern about a number of unsolved theoretical and managerial issues. Regarding the theoretical dimension, on the one hand, scholars formulate the assumptions that platform strategies, that have extensively been described for successful digital platforms such as Apple's iOS operating system, could also be relevant for systems in which modules are made of datasets rather than software components (Bonina et al., 2021; Bonina and Eaton, 2020; Karhu et al., 2018; Ruijter et al., 2017). Such strategies rely on a logic of recombinant innovation based on the modularisation of a complex system in various components fostering opportunities for distributed innovation (Baldwin and Clark, 2000). But on the other hand, a growing stream of research also warns us about the specificities of data compared to other digital artefacts (e.g. Aaltonen et al., 2021; Alaimo et al., 2020; Monteiro and Parmiggiani, 2019). In this perspective, creating value from data cannot be merely understood following the recombinant logic usually applying for digital platforms, as underlined by (Alaimo et al., 2020): "though closely associated, digital and data-based innovation should not be conflated with one another. Data in the way we describe them here are not software modules". Those two perspectives on data-push innovation, labelled respectively "platform perspective" and "artefact perspective", thus raise a theoretical issue calling for further enriching our understanding of platform strategies supporting data-push innovation by taking into account the specificities of data as particular digital artefacts.

In addition to this theoretical issue, scholars also shed light on specific managerial issues. It especially appears that data-push innovation strategies seem far less diffused than other platform-based innovation strategies because of the "challenging nature of the effort for identifying the potential [users of data]" (Trabucchi and Buganza, 2020, p. 9). So far, these strategies thus seem to be "more a matter of serendipity" (Trabucchi et al., 2018, p. 52), triggered when potential customers are able to identify a "different hidden value within existing databases" (Trabucchi et al., 2018, p. 51). These considerations also echo the issues

faced by open data platforms. Indeed, fostering the use and re-use of open data still remains eminently challenging (e.g. Zuiderwijk and Reuver, 2021; Jetzek et al., 2019; Zuiderwijk et al., 2016, 2012; Janssen et al., 2012). Scholars especially warn us about the misleading assumption “that open data users have the resources, expertise and capabilities to make use of the data” (Janssen et al., 2012). In this context, it appears that relying on serendipity can only lead to a limited uptake of data, that is restricted to the users having strong and dedicated competencies to identify value dimensions in exiting data and leverage them (Huber et al., 2020; Magalhaes and Roseira, 2020; Jetzek et al., 2019).

This paper thus aims to contribute to this growing body of research investigating the strategies supporting repeated data-push innovation. In particular, the paper proposes to pay a specific attention to the theoretical and managerial issues described above, addressing the following research question: *how to steer repeated data-push innovation based on a platform strategy when the capacities of third-party actors in leveraging data are initially limited?* To respond to the theoretical difficulty described above, the paper introduces the notion of “data/uses fit system”, defined as the set of socio-technical elements enabling data to fit into in a certain range of use contexts, where a “use context” refers to the specific context of an actor having certain purposes for which data eventually appear to be helpful (e.g. urban planning departments willing to better address traffic issues in the case of Uber Movement). Drawing on existing literature, the composition of such a system can be more precisely described as including technical components (e.g. curation of produced data into databases, algorithms to create meaningful metrics), organisational components (e.g. contract with a certain user), and cognitive components (e.g. knowledge on the sensors producing data and the potential uses). This notion allows us to enrich the platform perspective with the artefact perspective, that brings complementary insights on data-push innovation. Following the artefact perspective, the data/uses fit system designates the object that ensures the process of meaning construction inherent to the recontextualisation of data unlike other digital artefacts. Following the platform perspective, the data/uses fit system also designates the nature of the platform components that need to be designed to foster repeated data-push innovation. In this respect, the data/uses fit system can be designed following a modular architecture entailing a generic core common to a large variety of uses, peripheral components with a higher specificity to certain uses, and interfaces.

Following recommendations for further longitudinal empirical research capturing how data-based value creation processes unfold over time (Günther et al., 2017), this theoretical elaboration is then used to analyse the longitudinal case study of an actor that has successfully steered repeated data-push innovation based on Earth observation data, i.e. data that aim to capture the different phenomena related to the planet Earth's physical, chemical and biological systems, and are considered as a promising open data resource (Borzacchiello and Craglia, 2012).

Our research thus offers several contributions. First, the longitudinal case study analysis contributes to enriching our understanding of digital platforms, through the elicitation of an original logic of platform expansion that cannot rely on a pre-existing community of third-party developers. In this respect, the investigated platform owner fosters a non-dominant platform leadership, steering the co-expansion of the platform architecture and the capacities of the overall ecosystem to progressively enhance the genericity of data, i.e. their ability to fit into a large range of use contexts. Second, the notion of the data/uses fit system also offers interesting insights on data-based innovation beyond data-push innovation. This notion indeed sheds a specific light on the elements to be designed to make data circulate beyond their initial context of production and fit into more or less distant and numerous use contexts, accounting for the constraints limiting the possibility of deeply disrupting how data are produced and the practices of the actors that might benefit from their use.

II. Theoretical background

This section aims at building a theoretical framework adapted to the strategies aiming to steer repeated data-push innovation, especially accounting for the fact that data can be used and re-used by a large variety of organisations across heterogeneous sectors. To do so, our framework will leverage research works in both IS literature and innovation management literature, recognised as bringing complementary insights on digital innovation (Autio and Thomas, 2020). The section is organised in four parts. A first part details the insights brought by the research works based on a platform perspective. A second part exposes the complementary contributions of the research works based on an artefact perspective. A third

part elaborates on the notion of “data/uses fit system” bridging both perspectives. A fourth part derives our research question based on the developed analytical framework.

1) Platform perspective on data-push innovation

Platform strategies have been extensively described as a promising way of designing complex systems by developing and recombining modular components (Baldwin and Woodard, 2009). Generally applying for technological platforms in different industrial sectors (Gawer, 2014), such strategies have particularly flourished in a digital innovation context, where platforms have become omnipresent as illustrated by the well-known cases of social media platforms like Facebook, or operating system platforms like iOS or Android (e.g. Constantinides et al., 2018; de Reuver et al., 2018; Tiwana et al., 2010).

The class of platforms investigated in this paper more specifically aims at *supporting repeated data-push innovation*, fostering the use of existing data by multiple third-party actors. They thus rather correspond to *innovation platforms* that serve as “a technological foundation upon which a large number of [actors] can build further complementary innovations”, rather than transactional platforms that “create value by facilitating the buying and selling of existing goods and services” such as social networks or online marketplaces (Gawer, 2020).

A platform architecture basically comprises three main elements: a generic core made of low-variability components, a periphery of complementary modules addressing the variety and variability of specific needs, and interfaces setting the rules of interactions among components (Baldwin and Woodard, 2009). In IS research, the interfaces have been comprehensively described through the concept of “boundary resources” (Gawer, 2020). In the case of Apple (Eaton et al., 2015; Ghazawneh and Henfridsson, 2013), they typically consist in Application Programme Interfaces (APIs) and Software Development Kits (SDKs) allowing the platform owner to manage the tension between generativity and control that characterises digital platforms (Yoo et al., 2010). Generativity has been indeed largely recognised as a fundamental attribute of digital platforms, defined by (Zittrain, 2006) as the “overall capacity of a technology to produce unprompted change driven by large, varied, and uncoordinated audiences”. On the one hand, boundary resources foster generativity by

allowing third-party actors to contribute to the expansion of the platform through the development of complementary modules. On the other hand, they secure the control over the strategic components of the platform, e.g. through licenses defining what is allowed and what is not.

Recent research works have more specifically extended this platform model to the cases of open data platforms (Bonina et al., 2021; Bonina and Eaton, 2020), defining the architectural focus of the platform as “the provision of modules as datasets, rather than as functionality, to third-party developers who then innovate services based on these open datasets” (Bonina and Eaton, 2020, p. 1). In this contexts, boundary resources have been more largely defined as “the rules and tools that serve as the interface to govern the arm's-length relationship between the platform owner and different members of the platform ecosystem” (Bonina and Eaton, 2020, p. 4), where the platform ecosystem basically refers to the broad set of actors that contribute to the functioning of the platform (Wareham et al., 2014). It especially appears that these rules and tools can take a larger variety of forms than APIs and SDKs, such as web portals or hackathons to further stimulate the use of data sets, as well as dataset templates providing data producers with guidelines to ensure that data are shared in an appropriate form.

Regarding the platform ecosystem, (Bonina and Eaton, 2020) propose to differentiate between a supply side entailing the providers of datasets, and a demand side entailing third-party actors developing apps and services in the periphery based on the platform core. However, other research works also highlight the possible connection between different platform developers (Mosterd et al., 2021) or other forms of actors bridging data producers and users in a variety of ways, such as data aggregators, infomediaries or service developers (de Prieëlle et al., 2022; Magalhaes and Roseira, 2020; Janssen and Zuiderwijk, 2014). Therefore, in this paper, we will relate to the ecosystem as entailing three main categories of actors, in line with the model of open data ecosystem described in (Zuiderwijk et al., 2014):

- *Supply side*, i.e. data producers or other providers of technical means needed to build the platform;

- *Demand side*, i.e. third-party actors leveraging the generic core of the platform to develop innovative products, services or internal uses of data (corresponding to the peripheral use-specific components of the platform);
- *Other players*, i.e. actors that are not using the generic core developed by the platform owner, but that are still contributing to the overall data ecosystem, e.g. by bridging data producers and users in different sectors and through different ways.

2) Artefact perspective on data-push innovation

In complement of this platform perspective on data-push innovation, it is also important to consider the parallel developments made on understanding the mechanisms of data-based innovation considering data as a peculiar artefact. Indeed, expanding previous works on digital artefacts (Ekbia, 2009; Kallinikos et al., 2013; Yoo et al., 2012, 2010), a little but growing stream of IS research has recently emphasised the specificities of data compared to other forms of digital objects, such as software modules, computer programmes, digitalised books or videos (Aaltonen et al., 2021; Mikalsen and Monteiro, 2021; Alaimo et al., 2020; Alaimo and Kallinikos, 2020; Østerlie and Monteiro, 2020; Monteiro and Parmiggiani, 2019; Aaltonen and Tempini, 2014).

Scholars have particularly underlined the ambivalent and complex ontology of digital artefacts (Ekbia, 2009; Faulkner and Runde, 2019), that thus need to be distinguished from other forms of technological objects. According to (Kallinikos et al., 2013), digital artefacts can be characterised as:

- *Interactive*, enabling different forms of interactions with human agents;
- *Editable*, involving a continuous and repeated update of their content;
- *Reprogrammable*, being accessible and modifiable by other programmes than the one underlying their initial generation;
- *Distributed*, being not limited within the boundaries of a single source or organisation.

These features also largely hold for data, as data are also described as “steadily revisable, pliable, renewable and expandable” and “portable across settings, platforms and organisations” (Alaimo et al., 2020).

However, these authors also call for a specific attention to the peculiarities of data that are not to be conflated with any other form of digital artefacts. (Alaimo et al., 2020) especially stress that data should not be considered as ready-to-use components that could be directly assembled into larger entities. These authors thus propose to describe the data-based value creation process as a meaning creation process, going beyond the simple recombinant logic that mainly prevails in digital innovation (e.g. Henfridsson et al., 2018; Yoo et al., 2010). Data are indeed initially produced as “data tokens” conveying an abstract representation of a certain phenomenon of interest (Aaltonen et al., 2021; Alaimo et al., 2020; Mikalsen and Monteiro, 2021; Monteiro and Parmiggiani, 2019). In the case of a telecommunication operator, these data tokens correspond to the recording of every click, call and message of the network subscribers, and are initially produced for basic management tasks of the network infrastructure. These tokens encode the identity of the subscriber, the time and type of the network operation and other details through the form of alphanumeric characters, e.g. 097369D2D7372762D31080000000000000001;1;33668741168;3322208;6;20081101004923 ;20081101004923;20081101004923 (Aaltonen et al., 2021). Data tokens thus individually appear as meaningless until they are combined in “data-based objects”, such as records of audience members, that can be eventually transformed in “data commodities”, such as metrics of advertising audiences, sold by the telecommunication operator to advertisers (e.g. Aaltonen et al., 2021; Alaimo et al., 2020). These transformations thus eventually result in making the data produced for an initial purpose (e.g. records of clicks initially used for network management) fit into a new use context (e.g. advertising companies interested in assessing its advertising audiences). In this artefact view, *data-push innovation involves designing a range of socio-technical elements to recontextualise data from an initial context to new use contexts* – e.g. curating and storing data tokens into databases, setting up an algorithm to calculate valuable metrics, agreeing with relevant actors on the meaning of the metrics, possibly building consensus across the industry about the legitimacy of the chosen metrics (Aaltonen et al., 2021; Alaimo et al., 2020; Aaltonen and Tempini, 2014).

The artefact perspective thus extensively enriches our understanding of data-based innovation mechanisms beyond considering data as simple modules to be recombined. Therefore, in the present paper, we propose to enrich the platform perspective with this artefact perspective by introducing the notion of “data/uses fit system”.

3) Conceptualising the missing link between artefact and platform perspectives: the notion of data/uses fit system

Following the artefact perspective, *the data/uses fit system is defined as the set of socio-technical elements enabling data to be used in a certain range of contexts, i.e. to fit into a certain range of use contexts*, where a “use context” refers to the specific context of an actor having certain purposes for which data eventually appear to be helpful. For example, in the cases developed in (Aaltonen et al., 2021; Aaltonen and Tempini, 2014), a use context can refer to the advertising company willing to assess its advertising audiences and for which data from the telecommunication operator eventually prove to be helpful. In this regard, fitting data into a given use context means making data used by a given actor with certain purposes. In this view, the data/uses fit system is *what enables data to gain a certain meaning in use contexts that are different from the ones for which data were initially produced*.

Moreover, the artefact-view stream of works clearly indicates that *the data/uses fit system is not automatically generated when data are produced but needs to be built through dedicated design efforts*. Drawing upon these works, the elements composing the data/uses fit system can be more thoroughly described in three broad categories of components:

- *Technical components*, that widely embrace the technical infrastructure required for collection, storage, processing and distribution of data, as well as the analytical methods used to process data;
- *Organisational components*, referring to the various forms of relationships to be built with relevant actors. It might refer to internal relationships to create commitment between various individuals of the team, but also external relationships with data producers and users, or other relevant actors of the ecosystem, e.g. “to negotiate the adoption of metrics and their meanings, eliminate ambiguities, and build consensus across the industry or ecosystem in which they operate” (Aaltonen et al., 2021).
- *Cognitive components*, especially including knowledge and know-how on the contexts of data production and uses. Indeed, concerning the data production context, data can never be considered as completely “raw”, and are always formatted by the particular conditions under which they are produced (e.g. Gitelman, 2013). The representation of reality conveyed by data is guided by an initial purpose (Aaltonen et al., 2021;

Mikalsen and Monteiro, 2021), that ultimately “sets the boundaries” of what can be later derived from data (Aaltonen and Tempini, 2014), hence “circumscribing the opportunities and limitations of data as resources” (Aaltonen et al., 2021). Moreover, regarding the understanding of new potential use contexts, other authors have especially emphasised the crucial importance an “industry-specific expertise” (e.g. Schymanietz et al., 2022; Urbinati et al., 2019), consisting in knowledge on sectors and organisations that might benefit from data. This especially includes understanding the political, environmental, economic, and social aspects that might influence the relevance of data for a given organisation or sector.

To be noted that these categories of components are not to be considered separately as they are closely intertwined. Indeed, both technical and organisational components require adapted knowledge to be constructed. Moreover, technical and organisational components are also closely linked (e.g. standards requiring relationships with the industry to be defined and implemented). All three dimensions thus require a synchronous evolution as noted by (Aaltonen et al., 2021): “maintaining data-based objects requires keeping several data sources, analytical tools, and organisational practices in sync”.

From the *platform perspective*, the data/uses fit system offers an interesting way of describing the rationale underlying *the specific class of digital platforms directed towards repeated data-push innovation, as involving the design of the data/uses fit system adjusting to the existing constraints, thus limiting the transformations on the sides of data and use contexts*. Indeed, in data-push innovation, the platform owner primarily seeks to capitalise on existing data to the highest possible extent, especially “to exploit the value of the assets that are already within the company (the gathered data)” (Trabucchi and Buganza, 2020). This might include the integration of relevant additional data sets in complement of existing ones (Han and Geum, 2022), but the rationale still lies in leveraging existing data sources rather than creating brand new ones. On the side of use contexts, the platform owner is also constrained in its ability to trigger large transformations (i.e. dramatic changes of actors’ practices or reorganisation of a whole sector). Indeed, the uses of data concern actors that are out of the platform’s boundaries and might be even hardly predictable in advance by the platform owner on its own, as especially highlighted in the case of open data (e.g. Ruijter et al., 2017; Janssen, 2011). Therefore, the investigated platform-based mechanisms differ from the ones that focus on

producing new data that are directly fit for a given purpose, e.g. in “data-driven innovation” cases described by (Trabucchi and Buganza, 2018). In the same vein, the investigated platform-based mechanisms differ from the ones that target large transformative effects on the use contexts, such as Uber that has radically changed the existing practices of drivers and citizens. In an extreme case of highly constrained environment, the data/uses fit system could thus be metaphorically compared to a travel adapter plug, connecting a piece of electrical equipment of one country (here data as produced for an initial purpose) to the electricity supply of another (here a new use context): the data/uses fit system as the adapter plug plays a bridging role between two sides that could not be connected directly and that could not be easily changed either, being constrained by the norms and practices applying to each side.

Some platforms might combine several of these mechanisms, e.g. IoT platforms combining a focus on data production and data-push innovation (de Prieëlle et al., 2022; Mosterd et al., 2021), or Uber combining a focus on data-push innovation and transformation of use contexts (Trabucchi and Buganza, 2020). However, in order to more specifically investigate the mechanisms enabling repeated data-push innovation beyond serendipity (Trabucchi and Buganza, 2020; Trabucchi et al., 2018), the paper will specifically focus on *the platform-based mechanisms supporting the design of the data/uses fit system, set apart from the other types of platform-based mechanisms targeting deep transformations on the supply and/or demand sides*. In this view, the generic core of the platform is made of the components of the data/uses fit system that are common to a large variety of use contexts, such as a calculation algorithm that could be reused for several use contexts. As for the periphery of the platform, it corresponds to the components that are more specifically designed to address the specificities of a limited range of use contexts, such as a highly customised mobile application delivering a certain service to the end-user. This conceptualisation is especially consistent with the socio-technical view on digital platforms defined by (de Reuver et al., 2018) as “a sociotechnical assemblage encompassing the technical elements (of software and hardware) and associated organisational processes and standards”. Figure 1 synthetically represents the model of the data/uses fit system bridging the artefact and platform perspectives on data-push innovation.

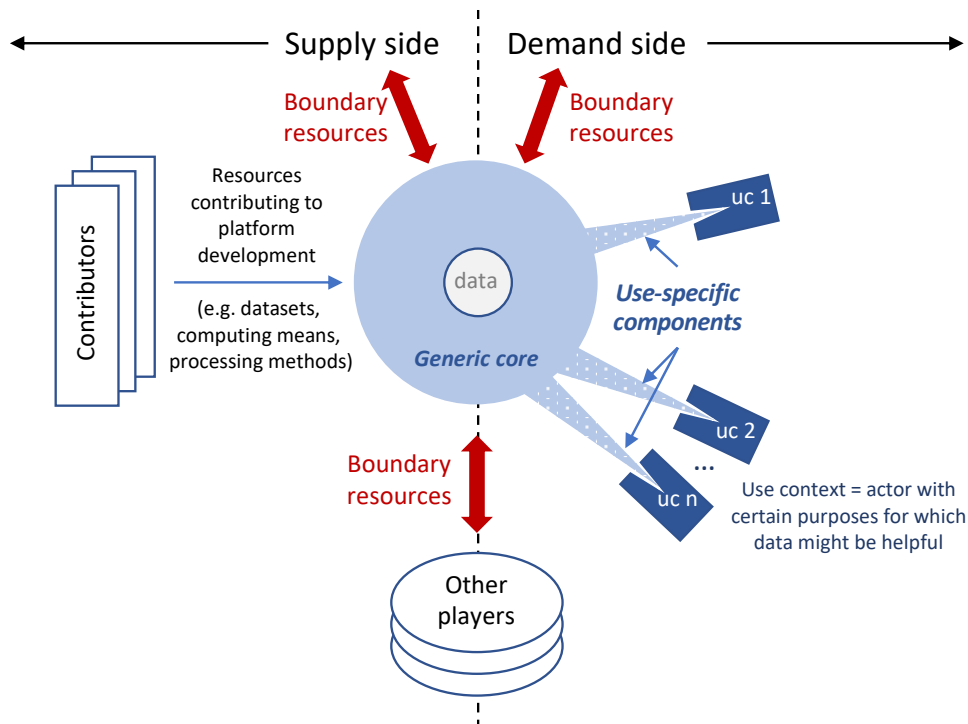


Figure 1: Representation of the data/uses fit system following a platform architecture. The data/uses fit system entails a generic core (i.e. components that are common to several use contexts) and a periphery made of use-specific components (dotted blue spikes). The dark blue boxes represent the use contexts into which data are eventually used thanks to the design of the data/uses fit system. Boundary resources are represented in red and support the interfaces between the platform and the different actors of the ecosystem (supply side, demand side and other players)

4) Managerial issues in the perspective of designing the data/uses fit system to steer repeated data-push innovation

Based on this conceptualisation, we can now further precise the managerial issues occurring in designing the data/uses fit system to support repeated data-push innovation, that especially requires taking a dynamic view. In this vein, (de Reuver et al., 2018) describe boundary resources as crucial elements to understand the expansion dynamics of digital platforms. Moreover, scholars especially highlight a difficulty in dealing with the tension between genericity and adaptation to specific use contexts. This point is especially underlined in the case of open data platforms by (Ruijter et al., 2017), noting that “an issue that needs to be explored further is whether there can be a tension between catering the open data platforms to context-specific user requirements and the objective of meeting generic needs that cannot even be predicted yet.” The mechanisms involved in managing this kind of tension have been investigated in other empirical contexts (e.g. Monteiro et al., 2013; Henfridsson and Bygstad, 2013; Hanseth et al., 1996). In particular, in the context of developing Enterprise Resource Planning (ERP) systems, scholars have unveiled so-called “generification”

mechanisms supporting the design a global generic software that remains compatible with diverse organisational users (Gizaw et al., 2017; Silsand and Ellingsen, 2014; Monteiro et al., 2013; Pollock et al., 2007). In particular, (Gizaw et al., 2017) describe these mechanisms in an open and distributed context of innovation for the development of an open-source health information system, describing “open generification” as “establishing the necessary resources [...] that enable locally situated developers to perform local innovations”. Taking a dynamic view, (Gizaw et al., 2017) especially show that generification involves two intertwined processes: *disembedding*, defined as “the process of lifting out local software requirements out of their contexts and abstracting them to serve diverse user needs across space and time” and *embedding*, defined as “pinning down the disembedded system back to situated realities”. Considering the design of the data/uses fit system, these definitions could be adapted as follows: *disembedding* as the process of making certain elements of the system serve diverse use contexts; *embedding* as the process of adding use-specific peripheral components to the system in order to better fit data into a given use context.

However, in the case of open generification described in (Gizaw et al., 2017), the generification mechanisms can rely on already well-established design capacities of local developers, although these competencies might require to be enhanced (Silsand and Ellingsen, 2014). The context of data-push innovation thus raises an additional difficulty: the potential users might not be familiar with data and thus not be able to play the role of third-party developers (Janssen et al., 2012). This is also consistent with the comparison of different open data platforms made by (Bonina and Eaton, 2020), especially suggesting that their development is all the more successful as it can benefit from an active and strongly-tied network of third-party innovators, which is sometimes missing. In this paper, we will thus examine the following question: *how to steer repeated data-push innovation based on a platform strategy when the capacities of third-party actors in leveraging data are initially limited?* In particular, the theoretical framework developed above leads us to closely examine the two following aspects: (1) *how the generification mechanisms of embedding and disembedding unfold in the design of the data/uses fit system;* (2) *how specific forms of boundary resources support these mechanisms.*

III. Methodology

This research uses a qualitative methodology, relying on a longitudinal case study (Yin 2009). We investigate the case of an organisation that has steered the development of a platform fostering the use of Earth Observation data across various types of actors (industries, public bodies, research communities) for more than 40 years.

1) Overview of the Earth observation data ecosystem

Earth observation (EO) refers to the gathering of data about planet Earth's physical, chemical and biological systems collected through in-situ instruments, satellites and computed from large models such as the ones used in meteorology. EO data were initially produced mainly for scientific goals to monitor the planet and its environment, e.g. to measure and monitor ocean, solar radiation reaching the ground, the composition of the atmosphere, the status of vegetation. Different kinds of instruments are used for this purpose: in-situ sensors (for example floating buoys to monitor ocean currents, temperature and salinity; or land stations that record air quality and rainwater trends), airborne sensors, or satellites. In recent years, the development of remote-sensing satellites and increasingly high-tech "in-situ" instruments has generated an increasing amount of data. Moreover, the European Union has significantly invested to make these scientific data a common good, freely accessible to all potential users, through dedicated "open-data" policies. Socio-economic applications of this data are diverse and promising. They could benefit not only the EO scientific community but also public authorities, private companies, industry, universities, citizens. In particular, EO data have the potential to help these different actors face contemporary socio-environmental grand challenges, e.g. by providing the means of monitoring and responding to natural disasters (fires, floods, earthquakes and tsunamis), assessing the potential of renewable energy sources, managing freshwater supplies and agriculture, addressing emerging diseases and other health risks. However, the actors of the EO community currently face difficulties in further stimulating the use of EO data in such a large variety of evolving use contexts and acknowledge the need of going beyond mere open-data policies through different types of capacity building activities and new projects targeting the development of services based on

EO data that could be more easily integrated into users' practices (Goor et al., 2021; Thierry Ranchin et al., 2021).

2) Empirical materials: the case of an organisation that has successfully steered repeated data-push innovation based on an innovation platform strategy

This paper focuses on the longitudinal case study of the research center *O.I.E. (Observation, Impacts, Energy)* from MINES Paris – PSL (France). Currently gathering 24 researchers. O.I.E. has developed several research activities since 1976, based on the exploitation of EO data in the fields of renewable resources evaluation (solar, wind, ocean, etc.), meteorology and climatology for energy, methodological development about environmental impacts assessment of renewable energy uses, and interoperability and dissemination of information through data bases and Web services. The activities related to solar radiation illustrate particularly well the successful efforts of O.I.E. in continuously stimulating the use of EO data in a large variety of use contexts, different from the one EO data were initially produced for. Indeed, the work of O.I.E. has basically consisted in taking satellite data initially developed for climate and meteorology purposes (Meteosat series of satellites) and transforming them into solar radiation data that can be further used in multiple other contexts. These research works on solar radiation started in the 80s, as the center was involved in a project supported by the Solar Energy R&D Programme of the European Commission (Grüter et al., 1986). The project aimed at assessing solar radiation reaching the ground more precisely and reliably, especially by taking advantage of new data coming from Meteosat satellites, whereas at the time solar radiation was mainly derived from networks of in-situ solar instruments (installed in a limited number of locations). This project gave birth to a first version of the so-called Heliosat methods (Cano et al., 1986), i.e. scientific models and algorithms estimating solar radiation at ground level based on Meteosat data. Since then, Heliosat methods have been continuously revised to take advantage of new technical and scientific advances (e.g. development of new instruments or computation means), sometimes completely rebuilding the underlying structure of the algorithm. In addition to these research works, O.I.E. has also dedicated tremendous efforts in progressively building a capacity of developing and providing operational products and services based on solar radiation data. This approach took a new dimension with the so-called SoDa (SOlar radiation DAta) project funded by the European Commission from 2000 to 2003. SoDa aimed at broadening the use of solar radiation data to

new user communities by building a “one-stop-shop” easy access based on web-service technologies and specific interfaces (Rigollier et al., 2000). This approach successfully aroused the interest of actors belonging to heterogeneous sectors, such as solar energy, astronomy, air quality, building engineering, climatology, education, health, materials, meteorology, oceanography, agriculture, or agroforestry (Gschwind et al., 2006). These promising results led O.I.E. to dedicate significant efforts in sustaining this collection of services after the official end of the project, thus officially creating “SoDa Service” in 2003. Rapidly overwhelmed by the growing number of user demands, O.I.E. decided to entrust the SoDa Service to the company Transvalor from April 2009, that would be in charge of operating, maintaining and commercialising the services, and ensuring a more robust and reliable provision 24/24 hours and 7/7 days. Based on a freemium business model, these services include the provision of free basic solar radiation data at a limited spatial and temporal resolution and more sophisticated paid-for services. These services are currently used by thousands of users (76 000 unique visitors in 2020) and about 100 clients of paid-for services, spanning various sectors (e.g. solar energy industry agriculture, construction industry, health industry). The users of SoDa service are usually companies that leverage SoDa for their own purposes or to build new services. In this perspective, the services developed by O.I.E. can be considered as an innovation platform laying the foundation for others to innovate.

Moreover, it is important to note that the case of O.I.E. offers a particularly interesting situation to study the specificities of the platforms targeting repeated data-push innovation through the design of the data/uses fit system. Indeed, O.I.E. corresponds to an extreme case where the constraints on supply and demand sides are particularly stringent. They are not in a position allowing them to trigger the launch of new satellites in response of certain demands (constrained transformations on the supply side). This role is indeed taken by other industrial players that develop the scientific instruments producing EO data, such as Airbus or Thales Alenia Space. Moreover, given the nascent position of EO in the different sectors that might benefit from EO data, O.I.E. cannot trigger deep reorganisations of these different sectors, thus having to account for the practices of the already well-established actors of these sectors (constrained transformations on the demand side). Therefore, investigating the long-term history of O.I.E. seems particularly interesting for our research question, as it corresponds to a form of “pure” case, almost exclusively focusing on the design of the data/uses fit system.

3) Data collection and analysis

Our empirical materials were collected from September 2018 to July 2022. Different forms of empirical evidence were exploited, to ensure triangulation between sources (Yin, 2009), that are listed in Table 1. The interviews allowed us to build an in-depth understanding of O.I.E.'s activities over time. Secondary sources of data were used to enrich some aspects discussed during the interviews, especially to validate the temporality and exact content of O.I.E.'s activities. Regular informal interactions were also used as a way of enriching our interpretation of O.I.E.'s activities and precisating some points of analysis.

Interviews	<p>Interviewed members of O.I.E.</p> <ul style="list-style-type: none"> - Emeritus researcher and previous director of O.I.E. (involved in solar radiation research at O.I.E. from the 80s): <i>6h in 2018 to go through the overall O.I.E. history and origins</i> - Senior researcher and director of O.I.E. (PhD at O.I.E. 1991 – 1993, researcher at O.I.E since 1995): <i>2h in Nov 2018, 2h in Nov 2021, regular informal interactions since 2018</i> - Senior researcher in remote sensing & energy sector (PhD at O.I.E. 1996 – 2000, research engineer in the industry 2000-2007, O.I.E. researcher since 2007): <i>1h in Nov 2018, 1h in Nov 2019, 2h in Nov 2021, regular informal interactions since 2018</i> - Research scientist with specific expertise in data infrastructures and Web services (involved in the team since the 80s): <i>2h in July 2019, 2h in Nov. 2021, regular informal interactions since 2018</i> - Researcher with specific expertise in ICTs (involved in the team since the 2000s): <i>2h in July 2019</i> <p>Transvalor's team involved in SoDa (in 2021)</p> <ul style="list-style-type: none"> - Manager of the team since 2009: <i>2h in Nov 2018</i> - Technical support and sales engineer: <i>2h in Nov 2018</i> - 2 researchers in remote sensing for longer-term research projects: <i>2h in Nov 2018 (only one of them)</i> - 2 R&D engineers for maintenance and operations: <i>2h in July 2019 (only one of them)</i>
Secondary sources	<p>List of past and present research projects: 56 projects extracted from O.I.E. website (related to solar resource assessment, interoperability and dissemination of data, instruments for Earth observation)</p> <p>Scientific publications (conferences and journal papers) accessible through the HAL open-access platform:</p> <ul style="list-style-type: none"> - Related to Heliosat methods, especially (Cano et al., 1986; Rigollier et al., 2004; Blanc et al., 2011b; Lefèvre et al., 2013; Blanc and Wald, 2015; Tournadre et al., 2022) - Related to SoDa project and Web services, especially (Rigollier et al., 2000; Gschwind et al., 2006; Thomas et al., 2013) - Related to solar cadasters developed for different use contexts, especially (Blanc et al., 2011a; Ménard et al., 2013; Callegari et al., 2017; Blanc and Ménard, 2021)
Informal interactions	<p>1st author visiting periods in O.I.E. research team: 3 weeks in July-August 2019 & 4 weeks in November 2021 (notes taken during these periods, used to enrich an overall understanding of O.I.E.'s activities)</p>

Table 1: Sources of empirical data

These data were analysed in a collaborative research setting, involving both researchers and practitioners - here members of O.I.E. and other relevant partners such as Transvalor (Shani et al., 2008). This setting especially aims to “reduce the likelihood of drawing false conclusions from the data collected, with the intent of both proving performance of the system [of action]

and adding to the broader body of knowledge in the field of management” (Pasmore et al., 2008, p. 20). Following guidelines for collaborative research (Cirella et al., 2012; Pasmore et al., 2008), the analysis procedure consisted in *progressively building a shared interpretation of empirical data and findings between researchers and practitioners*. The analysis procedure thus involved two intertwined forms of actions: (1) continuously enriching an in-depth understanding of O.I.E.’s activities on the basis of interviews, notes taken after informal interactions, and secondary sources of data; (2) validating this understanding with practitioners through dedicated collaborative meetings, resulting in a shared interpretation of empirical data and findings as detailed in Table 2. These meetings were organised as follows: a first phase consisted in a presentation made by our research team on our current understanding of O.I.E.’s activities and remaining questions and blind spots, a second phase consisted in a semi-structured discussion with the participating practitioners starting with their reactions on what was presented in the first phase. To support this process, two analytical strategies were more specifically used: a visual mapping strategy, allowing the “simultaneous representation of a large number of dimensions” (Langley, 1999, p. 700), and a narrative strategy, involving the “construction of a detailed story from the raw data” (Langley, 1999, p. 695); as especially recommended for research aiming at “understanding how things evolve over time and why they evolve in this way” (Langley, 1999, p. 692). The visual mapping strategy especially involved two main forms of visual mapping templates, respectively giving a static and dynamic view of the data/uses fit system, as illustrated in Figure 2.

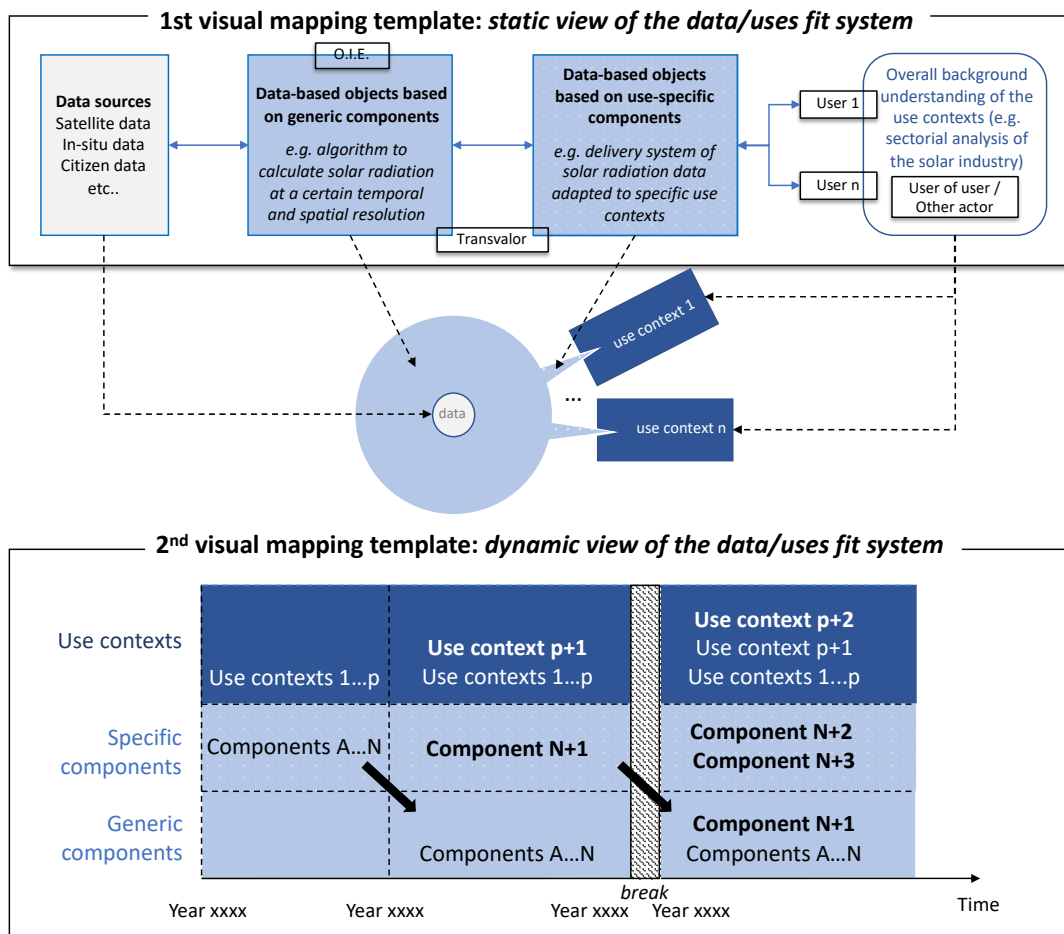


Figure 2: Visual mapping templates used as supportive tools of the collaborative research process. The completed versions of these templates are later shown in the “Case study analysis” section (Figures 4 and 6)

	Collaborative validation meetings	Formalisation of a validated and shared interpretation of data and findings
April 2019	<p>Objective: validating with O.I.E. a first interpretation of empirical data and findings (built on secondary sources of data and interviews)</p> <p>Participants:</p> <ul style="list-style-type: none"> - 3 members of O.I.E.: lab director, senior researcher in remote sensing & solar energy, research scientist expert in data infrastructures and Web services - 3 management researchers (including 1st & 4th authors) 	<p>Visual mapping strategy: 1st template representing the current status of the data/uses fit system as developed by O.I.E.</p> <p>Narrative strategy: document written by our research team, revised and validated by the participants, and additionally validated by two external reviewers (one expert of the EO field and one innovation management researcher)</p>
June 2019	<p>Objective: validating with Transvalor the interpretation of empirical data and findings previously discussed with O.I.E.</p> <p>Participants:</p> <ul style="list-style-type: none"> - 3 members of O.I.E.: same members - 3 members of Transvalor: team manager, 2 researchers - 3 management researchers (including 1st & 4th authors) 	<p>Visual mapping strategy: 1st template representing the current status of the data/uses fit system as developed by O.I.E.</p> <p>Narrative strategy: document written by our research team, revised and validated by the participants, and additionally validated by two external reviewers (one expert of the EO field and one innovation management researcher)</p>

January 2022	<p>Objective: validating with O.I.E. an updated interpretation of empirical data and findings (enriched through interviews and regular informal interactions)</p> <p>Participants:</p> <ul style="list-style-type: none"> - 3 members of O.I.E.: same members - 1 management researcher (1st author) 	<p>Visual mapping strategy: 2nd template representing the evolving composition of the data/uses fit system</p> <p>Narrative strategy: preliminary version of the present paper, revised and validated by O.I.E.</p>
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Table 2: Synthesis of the validation meetings implemented for data analysis

IV. Case study analysis

The activities of O.I.E. on solar radiation are analysed through the lens of the framework proposed in the theoretical background section. The present section starts by describing a recent successful case of fitting EO data into a given use context. This allows us to precisely describe the components of the data/uses fit system in this context. The section then goes back in time to further investigate past O.I.E. activities from the 80's, thus shedding light on the expansion dynamics of the data/uses fit system, based on dedicated generification mechanisms and the progressive development of boundary resources.

1) Describing the data/uses fit system taking the example of a recent successful case of data recontextualisation

Since 2014, O.I.E. has developed so-called “solar cadasters” at urban scale for the start-up *In Sun We Trust* (ISWT). Created in 2015 following first interactions of the founders with O.I.E, this start-up aims at providing private individuals with a free support service facilitating the installation of photovoltaic (PV) systems on their roofs. This includes a simulation tool of economic profits provided by the installation of PV systems allowing electricity self-consumption or sell to the electric-grid at the feed-in tariff, and the connection of interested clients with local PV installers, selected by ISWT for their validated trustworthiness. ISWT makes profits by taking margins on the transactions between the clients and PV installers when a contract is eventually signed thanks to ISWT service. At this stage, ISWT provides all the administrative and legal services required by the local public services and the French electricity provider EDF (declaration of the building work for the PV installation, connection to the grid, etc.). From 2015, ISWT has progressively deployed its services all over the French territory, triggering more than 3500 installations and became exclusive partners of more than 80 local collectivities in five years. In 2019, ISWT merged with Otovo, a leader company of PV energy in Scandinavia. Our analysis focuses on the first years of ISWT development (from 2015

to 2019), in which O.I.E. and Transvalor played a critical role by providing ISWT with the solar cadasters used as a basis of ISWT simulation tool (Callegari et al., 2017) – see *Figure 3*.

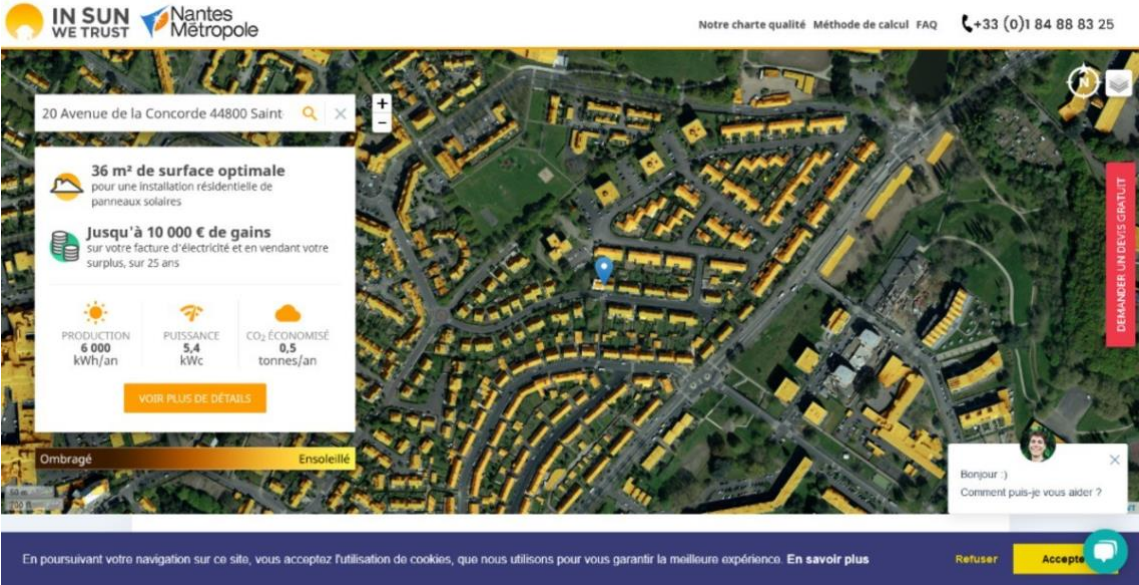


Figure 3: ISWT simulation tool based on solar cadasters at urban scale (Source: Blanc and Ménard 2021)

Following our theoretical framework, *Table 3* more specifically describes the composition of the data/uses fit system enabling solar radiation data to fit into the use context of ISWT, that is synthetically represented in *Figure 4* based on the static-view visual mapping template.

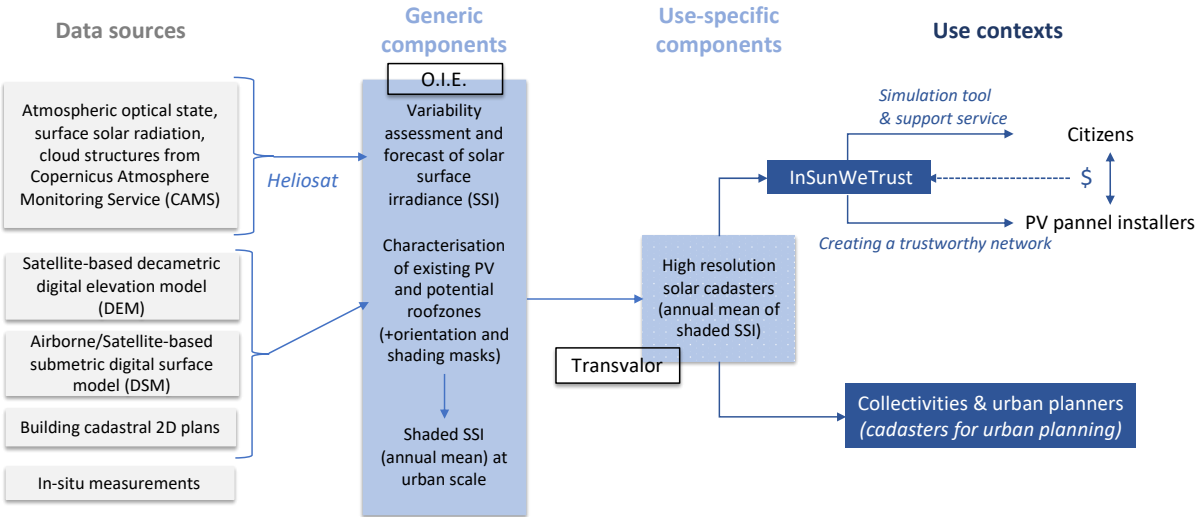


Figure 4: Static view of the data/uses fit system as appearing in the case of ISWT (data sources used as inputs, their transformations into data-based objects based on generic and use-specific components of the data/uses fit system, and the use contexts into which these data-based objects are used)

	Components of the data/uses fit system
Technical	<p>Long-term solar resource datasets, based on the Helioclim-3 database or the CAMS radiation database of solar irradiation values (i.e. the amount of energy received per unit area during a given duration – measured in Wh/m²), with a 4 to 5 km spatial resolution estimated from data provided by ‘Meteosat Second Generation’ satellite. This database is built and updated based on the Heliosat-2 algorithms developed by O.I.E. (Rigollier et al., 2004). The satellite-based dataset can be also calibrated with local in-situ measurements from meteorological stations.</p> <p>Downscaling algorithms to enhance spatial resolution from 5km up to a few meters (required when considering roofs at urban scale). This especially requires taking into account the spatial and temporal variability of irradiation values due to the altitude, the local orientation, and the shadowing effect of the horizon caused by the surroundings orography (e.g. mountains, but also buildings, vegetation and roof superstructure in a urban area). To calculate these so-called “shadow masks” (see Figure 5), two models were used: a decametric resolution digital elevation model (DEM) describing the natural orography (mountains, hills, valley etc.), and a high-accuracy decimetric digital surface model (DSM) giving 3D description of buildings, vegetation and superstructures (provided by the IGN French national mapping agency).</p> <p>Roof location algorithms, based on another dataset provided by IGN (high-accuracy map of building footprints to provide location and contours of corresponding roofs).</p>
Organisational	<p>Relationship with Transvalor: O.I.E. in charge of designing the algorithms. Transvalor providing the Helioclim-3 database on an operational basis for a large range of actors, and in charge of operating the processing chain providing a city-scale solar cadaster as a final output based on the technical components, on an operational and repeated basis following the deployment of ISWT spreading to the whole French territory.</p> <p>Relationship with IGN and ISWT: IGN supporting ISWT and providing them with data. O.I.E. providing their technical expertise on how to process these data.</p>
Cognitive	Knowledge of O.I.E. on the solar energy sector and on the data sources and processing techniques , based on its long-time experience in the field.

Table 3: Composition of the data/uses fit system enabling solar radiation data to fit into the use context of ISWT

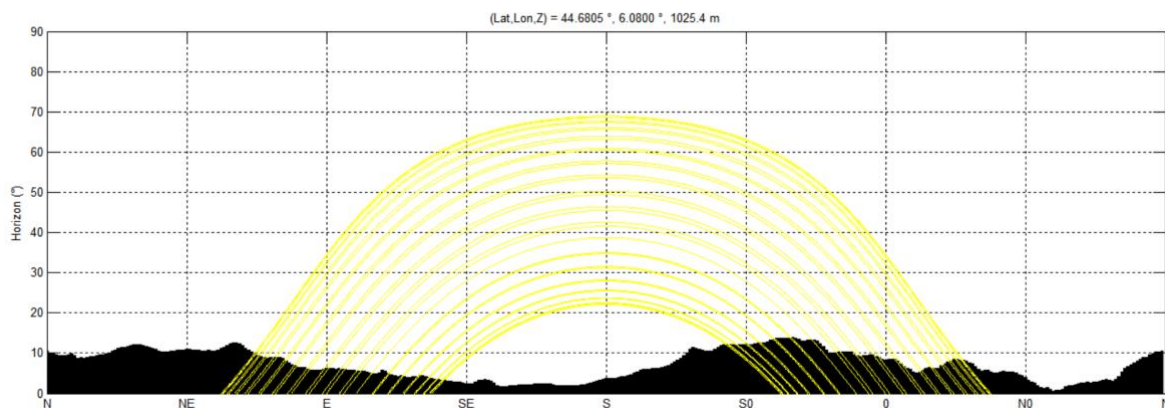


Figure 5: Example of horizon (black area) computed from the digital elevation model ‘SRTM’ at the location (44.6805°N, 6.08°E). The daily trajectories of the sun are represented in yellow (three trajectories per month along the year). The x axis is the azimuth orientation, beginning from the North. The y axis is the elevation angle, in degrees. (Source: Blanc et al. 2011)

However, considering only the case of ISWT alone is not sufficient to understand what has made O.I.E. successful in designing the data/uses fit system over time so that data could fit into multiple use contexts. This point will be clarified by going back to the history of O.I.E. to more specifically examine the generification mechanisms involved in the design of the data/uses fit system and the associated boundary resources.

2) A dynamic view on the design of the data/uses fit system for solar radiation data: generification mechanisms and boundary resources

The longitudinal analysis of O.I.E. highlights how the data/uses fit system has been designed over time through dedicated generification mechanisms contributing to progressively enriching a generic core, and by building a range of boundary resources directed towards the different actors of the ecosystem. O.I.E. clearly sets its objective as the enrichment of a generic core rather than the development of use-specific components, as formulated by an interviewed member of O.I.E.:

“Our role is to crystallise basic building blocks at the highest level, and not to develop components that are too much oriented towards a specific domain”.

In order to progressively built this generic core, O.I.E. has conducted a sequence of (re)embedding and disembedding processes, that are hereafter described mixing the *technical and organisational components of the data/uses fit system*, and synthesised in Figure 6. Initially in the 80s, O.I.E. started to develop Heliosat methods to transform Meteosat top of atmosphere radiance images into surface solar radiation data, in the perspective of building a first European Solar Radiation Atlas for the European Commission (*embedding*). Since 2003, the development of SoDa Service has enabled these solar radiation data to address diverse use contexts beyond this initial one (*disembedding*). The activities of Transvalor when operating and commercialising SoDa Service can also be described as a sequence of embedding-disembedding processes, providing slight adaptations of the service to the specific requests of users (*embedding*), but also identifying the future evolutions of SoDa Service that seem to be promising based on the overall analysis of these requests (*disembedding*). This disembedding process has also been supported by the complete redesign of SoDa Service to make it interoperable with other products or systems, complying with the standards recommended by the Open Geospatial Consortium (Thomas et al., 2013). Similar patterns apply for the downscaling algorithms leveraging the digital elevation model. Indeed, when O.I.E. first met ISWT founders, O.I.E. had already developed them in another context, i.e. the development of 200 m resolution solar cadaster for the Provence-Alpes-Côte d’Azur region in France (Blanc et al., 2011a; Ménard et al., 2013) that had been initially supported and funded by local and regional organisations and councils from 2008 to 2012 (*embedding*). Beyond this initial demand, O.I.E. later put significant efforts on linking these solar cadasters to a larger

pool of use contexts, e.g. by enriching them with additional data (e.g. the distance to the nearest electric grid line), and integrating them into standard-compliant webservices, especially in the framework of a FP7 European project called ENDORSE (*disembedding*). This leads us back to the development of solar cadasters at urban scale for ISWT especially through the additional integration of a high-accuracy digital surface model (*embedding*). The current attempts of O.I.E. at exploring how these urban solar cadasters could potentially fit into a larger pool of use contexts, e.g. grid operators managing the increasing integration of PV in the grid (*disembedding*).

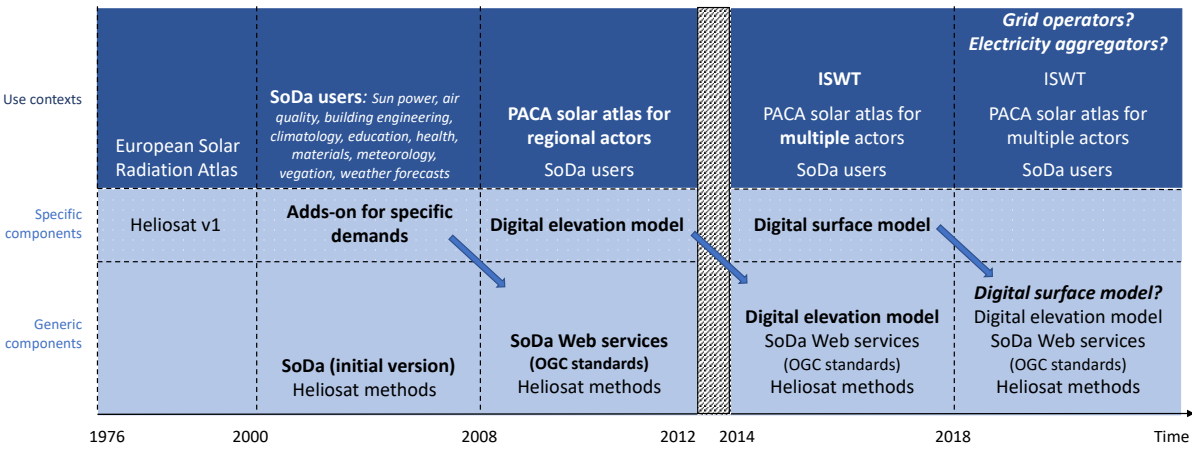


Figure 6: Evolutions of the data/uses fit system of solar radiation data (technical and organisational components) undertaken by O.I.E. since the 80s (evolutions are highlighted in bold characters and arrows especially highlight disembedding operations)

Regarding the *cognitive components* of the data/uses fit system, an interviewed member of O.I.E. highlighted that their success has largely relied on a high complementarity of the individuals of the team:

“Practically speaking, our success is hardy relying on the complementarity of profiles in our lab and their capacities to discuss and consider the whole range of activities that we have been implementing over time.”

O.I.E. members have especially demonstrated their ability to circulate across a large variety of organisations, including data producers, data users and other players of the ecosystems. This ability allows them to continuously identify promising avenues to create new uses from data, while also ensuring a continuous watch on available technical means such as data production instruments, algorithms and IT capacities. Some of these competencies have been deeply rooted in the activities of O.I.E. from the creation of the research center, while some others have evolved in reaction to the evolution of the field, such as recently the competencies

related to the use of cloud computing means. A few examples of these different competencies are outlined by interviewed members of O.I.E. as follows:

“At the creation of our lab, we benefited from computation means that were quite unique in France and even Europe. A lot of scientists from various backgrounds used to come visit us to process their images, based on the tools that had been installed here. [...] So we were working in a multi-domain atmosphere: geology, forestry, agriculture, meteorology, oceanography, and also data processing. [...] So all the developments we made tended to be quite generic, we needed to conceptualise a lot of things.”

“From the beginning of our research activities, we have been used to integrating several observation measurements, processing 15-20 data sources, and we have always kept that.”

“I constantly ensure a double watch. A methodological watch, that is: ‘given these data, how to take advantage of them?’ And another watch that is: ‘what are the available data sources that I could use to further fill in the gaps I currently have in my methods and that could improve the service?’”

“Now a few members in the team are getting used to book a few GPUs on the cloud. We try to progressively adapt ourselves to these new computing means, while still keeping our in-house infrastructures for the moment.”

To support these mechanisms, O.I.E. has developed a number of *boundary resources* that structure the relationship of O.I.E. with the different actors of the platform ecosystem, that were previously described in three main categories: supply side, demand side and other players. These boundary resources have been progressively created and enriched and are listed in Table 4.

Starting date	Boundary resource description	Supply side	Demand side	Other players
2004	Licenses granting access to Heliosat and derived methods Starting with Heliosat-2 method but later concerning the other methods developed by O.I.E., different software libraries have been made available under licenses allowing users to freely use, share and adapt these products and tools, provided that they give credit to the licenses (Creative Commons or equivalent in the EO community, e.g. GEOSS Data Core Sharing principles)		X	
2006	Lead of a group on renewable energies in the intergovernmental organisation Group on Earth Observations (GEO) Aiming at sharing best practices among players aiming to bridge EO and energy sectors (later transformed in the GEO-VENER initiative)			X
2006	Contribution to the International Energy Agency’s implementing agreements related to solar energy Supporting the emergence of a common vision of what defines the quality of solar resource assessment and forecasting methods, or develop standardised and integrating procedures for data bankability. Currently participating to the PVPS programme (task 16) that aims “to lower barriers and costs of grid integration of PV and			X

	lowering planning and investment costs for PV by enhancing the quality of the forecasts and the resources assessments” (http://www.iaa-pvps.org/index.php?id=389)			
2008	Webservice-energy SDI (Spatial Data Infrastructure) The SDI aims at gathering, promoting and spreading EO data for the development of renewable energies based on open standards. The SDI ensures the access to these resources to potential third-party users based on open standards. But is also plays a facilitating role for other players of the data ecosystem, as it gathers the services and products developed by several tens of organisations.		X	X
2009	Help desk for SoDa service Allowing users to express specific requests		X	
2013	Solar Training A training session on the basics of solar radiation organised for 30-40 international participants every year		X	
2019	JupyterNotebooks Offering the possibility to play with parts of codes and visualise them through images or graphs. Initially implemented by O.I.E. in the EU-funded project ‘NextGEOSS’, these notebooks have been further developed by O.I.E. as a way of supporting their interactions with potential users, serving as demonstration tools to explore new use cases based on the temporal variability of solar radiation (Blanc and Ménard, 2021)		X	
2022	Data Management Plan self-assessment tool Tool developed by O.I.E. within the EU-funded ‘e-shape’ project (Thierry Ranchin et al., 2021) to help data-based service or platform developers to assess their current status and trajectory towards compliance with data sharing principles supporting standards.			X
2022	Web application to visualise the homogeneity of data provided by the network of in-situ measurements Developed in order to facilitate the access and the use of in-situ measurements by different players of the ecosystem, in compliance with standards but also compatible with other non-standard formats still used in the field – see (Ménard et a. 2022) for further details on how the web app could be developed by leveraging previous expertise and building blocks built by O.I.E. over time. Also intended to be used by O.I.E. as a demonstration of what can be done with in-situ data encoded in standards, and potentially further convince the managers of in-situ networks to better comply with standards.	X		X

Table 4: Summary of the boundary resources developed by O.I.E. over time

V. Discussion

The longitudinal analysis of O.I.E. unveils the mechanisms that have supported repeated data-push innovation through the design of the data/uses fit system following a platform architecture. Based on this analysis, the paper proposes several contributions. First, the case of O.I.E. sheds light on a few original characteristics that contribute to enriching our views on digital platforms. Second, more broadly contributing to research on data-based innovation, the notion of “data/uses fit system” offers fresh insights to better conceptualise and

potentially frame various forms of data-based innovation strategies beyond data-push innovation.

1) Unveiling specific mechanisms of platform expansion: contributions to research on digital platforms

a) Favouring the design of peripheral components laying the ground for enriching the generic core

Similarly to the global developers of open ERP systems aiming to “stay away from directly designing for particular local needs” (Gizaw et al., 2017), the main objective of O.I.E. lies in the enrichment of the generic core, avoiding building components that are “too much oriented towards a specific domain”, as highlighted by an interviewed O.I.E. member. In the same vein, (Gizaw et al., 2017) further highlight that “although important, the ultimate goal of open generification is not to make a software work in a particular context; it is rather to take the working solution further to multiple other contexts”. In this perspective, O.I.E. goes beyond considering peripheral components as a way of complementing the generic core with additional functions to better serve the specificities of local needs, but rather considers *the peripheral components as necessary building blocks setting the ground for future expansions of the generic core*. Indeed, at some point, O.I.E. can temporarily accept to take charge of designing some use-specific components, provided that it contains the possibility of further enriching the generic core. For example, the case of ISWT gives the opportunity to explore new components (e.g. digital surface model) that have the potential to serve multiple other contexts (e.g. grid operators). However, to the difference with the cases described by (Gizaw et al., 2017), O.I.E. cannot initially rely on a community of local developers that can directly be involved in designing the use-specific components adapted to local needs, due to the initial limited capacities of third-party actors in leveraging data (e.g. Magalhaes and Roseira, 2020; Jetzek et al., 2019; Janssen et al., 2012). To deal with this issue, it appears that O.I.E. has dedicated thorough efforts to foster the co-expansion of the platform architecture and the capacities of the overall ecosystem. The development of these capacities have also been highlighted as a crucial point for the generification of ERP systems (Gizaw et al., 2017; Silsand and Ellingsen, 2014), however it appears that O.I.E. has implemented a richer pool of actions that are worth being closely examined.

b) Enhancing the capacities of the overall ecosystem: boundary resources complemented by focused actions of stimulation

In order to enhance the capacities of the overall ecosystem, similarly to open data platforms described by (Bonina and Eaton, 2020), specific efforts are indeed made by O.I.E. to provide actors with a range of boundary resources that concern both the demand side of the platform (e.g. help desk, solar training, JupyterNotebooks, licenses) and the supply side of the platform (e.g. web application used as a demonstration tool of the usefulness of standards for in-situ measurements). However, it is noticeable that only a few boundary resources concern the supply side, which can be explained by the downstream position of O.I.E. compared to these actors and their limited ability to trigger transformations on this side. Beyond the demand and supply sides of the platform, efforts are also made to enhance the capacities of other players of the ecosystem, especially by fostering the use of shared standards and sharing good practices with actors that are also involved in bridging EO data and users. Interestingly, this can potentially involve supporting competing actors, as underlined by O.I.E. previous director:

“A competitor of O.I.E./Transvalor started with Heliosat, but made it evolve – it’s a kind of combination between Heliosat-2 and Heliosat-4 – they are smart people.”

“A lot of methods currently built by our competitors are based on Heliosat or derivative versions. [...] And I initially educated many of those people that created competing databases.”

Moreover, the classical boundary resources referring to general supportive tools and rules are not sufficient to capture the range of actions carried out by O.I.E. to support the diverse actors of the ecosystem. Indeed, in addition of these tools, O.I.E. has also punctually implemented *focused actions of stimulation* when O.I.E. is able to identify certain bottlenecks of the ecosystem and can thus play a *prescribing role to supply and/or demand sides* based on its expertise and legitimacy gained over the years. Indeed, when interacting with data users (demand side), O.I.E. can a certain range of data uses based on their good understanding of the measuring instruments, the methods underlying the transformations of data and their validity conditions and inherent limitations. Symmetrically, when interacting with data producers (supply side), O.I.E. can prescribe relevant ways of producing data, based on O.I.E. knowledge and experience on use contexts. In this regard, it appears that the generic core plays a crucial role in *laying the foundation for imagining concepts of future development*

paths on the demand and supply sides, and stimulating the ecosystem with these concepts. This aspect is particularly apparent for the case of ISWT, but has also been mentioned for earlier periods in the development of Heliosat methods:

“Before working with ISWT, I had been working on solar cadasters for PACA region at 200m of resolution. And I gave a talk at a conference where I said: if we want to go from 200m to 1m, we need 3D models. [...] Nicolas [one of the founder of ISWT] wanted to create a start-up to support the development of photovoltaics at urban scale. He called me and [...] and I told him that I had talked about the possibility of assessing solar radiation at urban scale at this conference, and that I had identified 3D data as the main issue. So I told him it would be interesting to talk with IGN, and that I could put him in contact with the research director of IGN that I knew. [...] ISWT was then hosted by IGN, providing ISWT with their data for the digital surface model, which IGN initially did not know what to do about.”

“So with the same conceptual framework underlying the Heliosat method [for solar radiation assessment], we made a system for the detection of forest fires. [...] It’s the Heliosat method that led me to think of these kinds of applications and what we can build on it.”

It is important to note that these focused actions of stimulation occur thanks to *recurrent forms of interactions with the different actors of the ecosystem*. Some of them are supported by the boundary resources that have already been formalised, such as Solar Training sessions, similarly to the social forms of boundary resources described in other open data platforms such as hackathons or other specific events (Bonina and Eaton, 2020). However, some of them also occur through less formalised devices and more diffused forms of interactions, e.g. based on regular e-mail exchanges or meetings. It remains nonetheless important to acknowledge the crucial role of these interactions in supporting the growth of the ecosystem and their interplay with the design of boundary resources. Interestingly, O.I.E. is currently involved in the H2020 project ‘e-shape’ funded by the European Commission, where specific efforts are made to develop a dedicated “co-design framework” supporting the interactions of O.I.E. and other developers of EO-based services with different actors of the ecosystem (Barbier et al., 2022, 2021). This co-design framework could thus be seen as a boundary resource in the making, that will later support the interactions of O.I.E. with the different actors of the ecosystem in a more formalised way.

Finally, it is interesting to notice that the *resourcing* function usually described for boundary resources (Ghazawneh and Henfridsson, 2013) often unfolds in a double direction: *resourcing*

the actors of the ecosystem, but also resourcing the platform owner itself. Indeed, the nature of the resources to be provided might not be known in advance by O.I.E. itself. In this regard, the interactions with the actors of the ecosystem are also opportunities for O.I.E. to enrich its own understanding of the ecosystem and identify what forms of boundary resources would be worth being developed and what paths for future platform developments appear as most promising. This double-way resourcing function for example appears for the help desk that allows users to express specific requests but also allows O.I.E. and Transvalor to identify most promising development paths for future services based on the overall requests.

c) Non-dominant platform leadership favouring generative power over controlling power

Underlying the development of these boundary resources, it also appears that O.I.E. has developed an intriguing form of *platform leadership*, differing from historical cases of technological platforms (Gawer and Cusumano, 2002), or well-known success stories of digital platforms such as Apple's iOS operating system (Eaton et al., 2015; Ghazawneh and Henfridsson, 2013). The form of platform leadership developed by O.I.E. could be characterised as a *non-dominant leadership that focuses more on gaining generative power rather than controlling power*. Both generativity and control have been extensively described as a fundamental characteristic of digital platforms (Yoo et al., 2010). For a platform owner, gaining controlling power basically consists in strengthening its capacity to orchestrate the overall ecosystem around the platform, whereas gaining generative power rather involves *strengthening its capacity to open up new innovation spaces for others*. In the case of O.I.E., in addition to the focused actions of stimulation described above, three additional aspects reflect particularly well this non-dominant logic: the nature of boundary resources, their specific use of standards, and the distribution of captured value.

Regarding boundary resources, they are generally considered as the key resources to manage the tension between generativity and control, allowing the platform owner to stimulate third-party actors while also defining what is allowed and what is not (Eaton et al., 2015; Ghazawneh and Henfridsson, 2013). In the case of O.I.E., although controlling aspects are present (e.g. through licenses defining what is allowed and what is not), the resources directed towards generativity largely prevail, especially for the demand side and other players of the ecosystem

as detailed above. In a sense, it seems consistent with the necessity of enhancing the capacities of third-party actors, that is predominant in the investigated case of data-push innovation.

Regarding standards, IS literature has already shown how firms could establish an exclusive and powerful position in the ecosystem by influencing or imposing some forms of standards (Lyytinen and King, 2006; Yoo et al., 2005). In the case of O.I.E., the use of standards unfolds in a different logic. These standards are promoted by third-party bodies, such as the Open Geospatial Consortium (OGC) for standards related to Webservices, the intergovernmental Group on Earth Observation (GEO) promoting data sharing principles for EO data, or the European Commission promoting the 'FAIR' framework. These standards aim to ensure the interoperability of various systems and thus further stimulate innovation across organisations. O.I.E. clearly acknowledges the importance of these standards in strengthening their position in the ecosystem:

“When we joined the Group on Earth Observation, we became aware of the powerful role of standards. Even if you merely comply with them and do not necessarily develop them, they have a multiplier effect on your capacity for action in the community.”

“Standards have enabled small players like us to be part of big initiatives. They have played a crucial enabling role in creating new partnerships.”

However, O.I.E. does not aim to gain dominating control over the ecosystem based on these standards, but rather to foster the diffusion of these standards among the different actors of the ecosystem to further enhance generativity. For example, in this perspective, e.g. through the “Data Management Plan self-assessment tool” recently developed by O.I.E. to provide actors with a framework to assess their current status and trajectory regarding data sharing principles towards full compliance with standards promoted by GEO and the European Commission. Interestingly, fostering the use of standards rather consists in *a progressive process that still needs to ensure a certain compatibility with non-standard formats*. This aspect is for example noticeable in the web application developed by O.I.E. to aggregate in-situ measurements from worldwide networks, as detailed in (Blanc et al. 2022) and expressed during an interview as follows:

“We cannot and do not want to change the practices of experts that have been using CSV files for 30 years. And I understand – if you have developed well-

working routines based on these files, and you are already recognised for this expertise, you don't want to change anything. So our web application needs to integrate the standard approaches that we want to develop, but also provide an 'export to CSV' feature among other additional features. So we can say: 'look you still have the possibility to use your CSV files, but on top of that you also have additional features that might be interesting for you and for the broader community.'

As a third aspect reflecting this non-dominant form of platform leadership, O.I.E. does not aim to appropriate all the value generated by the development of the platform. Indeed, O.I.E. rather *shares this value with a network of partners* taking charge of maintaining some building blocks of the data/uses fit system (e.g. Transvalor in the case of O.I.E.). This echoes the observation made by other scholars (Zeng and Glaister, 2018), arguing that “by proactively investing in seeding an ecosystem through developing and cultivating new business partners while not trying to appropriate all the value allows a firm to have sustainable access to a greater variety of capabilities and resources.”

2) The notion of “data/uses fit system”: contributions to research on data-based innovation

The notion of “data/uses fit system” has been introduced to more clearly specify the rationale underlying the class of platforms targeting repeated data-push innovation, accounting for the insights brought by another stream of works describing the peculiarities of data as digital artefacts. However, the relevance of this “data/uses fit system” notion could also be discussed for other forms of data-based innovation beyond repeated data-push innovation. We indeed argue that this data/uses fit system needs to be designed every time that data are to be integrated in a given use context. The class of platforms investigated in the paper corresponds to situations of high “distance” between the targeted use context and the initial context of production, referring to the observation made by (Aaltonen et al., 2021; Monteiro and Parmiggiani, 2019). Through the lens of the data/uses fit system, *the distance of a given use context can be associated with the number of components to be designed in order to make data fit into this given use context*. A range of distances can thus be considered and are represented for illustrative purposes in Figure 7. In situations of high distance, as investigated in the paper, designing the data/uses fit system entails substantial efforts especially to build up new technical components (e.g. a pool of relevant algorithms and processing chains), but also extensively new and intricate cognitive components (gaining knowledge on the potential

value of data for sectors that are initially hardly known by the data producers or platform developers), and organisational components (creating relationships with actors of these sectors from scratch). But the data/uses fit system can also exist in situations of lower distances, although being less sophisticated thus less evident to distinctively identify. Such situations could be associated with the case of a company making an internal use of the data that it produces itself, corresponding to an “inbound” data-based innovation strategy described by (Trabucchi et al., 2018). These internal uses for example include marketing (Erevelles et al., 2016; Fan et al., 2015; Sorescu, 2017), new product or service development (Johnson et al., 2017; Tan and Zhan, 2017; Urbinati et al., 2019), supply chain management (Hazen et al., 2014; Wang et al., 2016), strategy making (Constantiou and Kallinikos, 2015; Woerner and Wixom, 2015). In this situation, designing the data/uses fit system involves building up technical components (e.g. new tools and methods to collect, process and store data), as well as organisational and cognitive elements that are limited to a use context that is already largely known (the internal sphere of the firm) thus less complex to be built. As an example of a slightly increased distance compared to the previous example, the case of Uber is quite illustrative (Trabucchi and Buganza, 2020). Indeed, when Uber sells data in an aggregated form to urban planning departments, the use context is not limited to the internal sphere of Uber, thus requiring a more complex design process of the data/uses fit system. This at least includes learning on the current practices of urban planning departments (cognitive components), designing new algorithms and processing chains to aggregate data in a valuable form for urban planning departments (technical components), and building specific contracts (organisational components). Therefore, similarly to the cases of digital platforms, in these different situations with varying distances between data and use contexts, eliciting the data/uses fit system as a dedicated object of design can help clarify the specificities of the operations required to organise the fit between given data and given use contexts, set apart from other types of operations related to the transformations of data or use contexts.



Low distance (a)

e.g. data produced and used by the same organization (for supply chain management, marketing etc.)



Moderate distance (b)

e.g. data produced by an organization and sold to another one ready to pay for it (Uber)



High distance (c)

e.g. open data situations where the potential users are difficult to identify and are unfamiliar with data

Figure 7: Representation of the data/uses fit system with varying distances between data and a given use context. The more this distance increases ($a < b < c$), the more sophisticated the composition of the data/uses fit system becomes, and the more likely it becomes to develop a generic core in order to address several distant use contexts while limiting the residual design efforts for each new use context.

Finally, the notion of the data/uses fit system is especially useful to better conceptualise the “genericity” of data, basically understood as the capacity of data to fit into multiple use contexts. Indeed, it invites us to define genericity not as an intrinsic property of data, but rather as a property resulting from the design of the data/uses fit system. In this perspective, data are considered *all the more generic as the residual design effort to fit data into a new use context is low, or in other words as the data/uses fit system comprises a large number of components that are common to different use contexts* (e.g. Heliosat methods estimating solar radiation at ground level at a certain spatial and temporal resolution). By contrast, data are considered as *all the more specific as the data/uses fit system comprises a large number of components that are specific to a limited range of use contexts* (e.g. highly customised app for a specific type of user), thus requiring significant design efforts at each new use context. In this regard, the strategy followed by O.I.E. could be labelled “*data genericity building*”, as it has consisted in progressively enriching the generic core of the data/uses fit system. This is consistent with other well-developed research works on generic or general-purpose technologies, characterised by their “potential for pervasive use in a wide range of sectors and by their technological dynamism” (Bresnahan and Trajtenberg, 1995). Scholars in innovation management have indeed shown that designing these generic technologies involves “intentionally designing common features that bridge the gap between a priori heterogeneous applications and technologies”, rather than only relying on a trial-and-error approach where common features are randomly discovered (Hooge et al., 2016c). This does not imply that serendipity cannot occur, however it is all the more successful as it is actually steered and potentially triggered by a dedicated genericity-building strategy (Hooge et al., 2016c; Kokshagina et al., 2016). Figure 8 represents the data/uses fit system with varying levels of genericity.

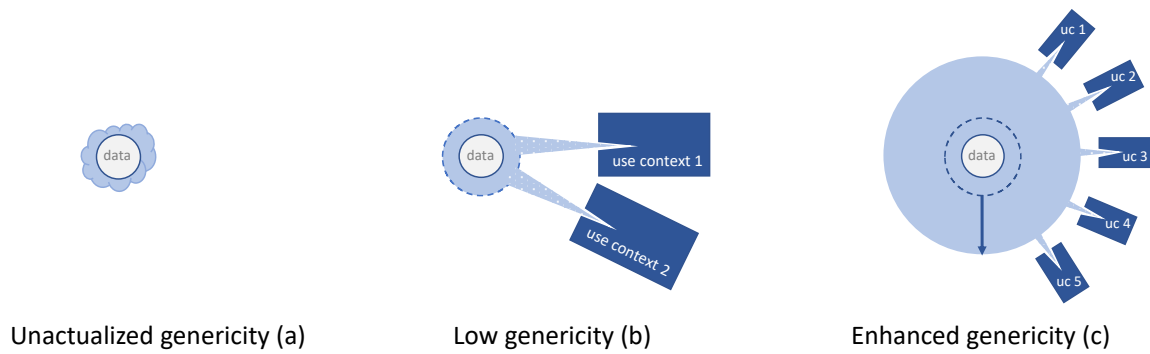


Figure 8: Representation of the data/uses fit system with varying levels of genericity. Situation (a) represents data tokens when data are only potentially generic. Situation (b) represents data with a data/uses fit system comprising highly-use-specific elements (large spikes) thus resulting in low genericity. Situation (c) represents data with enhanced genericity, i.e. with a data/uses fit system comprising a larger generic core (extended blue circle) that enables only limited use-specific developments (little spikes) and thus to address a broader range of use contexts.

3) Limits and further perspectives

Our paper has delved into a single case study. Although a longitudinal view provides interesting insights on the aspects related to long-term dynamics and underlying mechanisms, this also results in several limitations. The case of O.I.E. unveils an interesting strategy to support repeated data-push innovation, however it does not reflect on other possible strategies that could also lead to successfully steer data-push innovation beyond serendipity. Moreover, O.I.E. has a specific profile, being a research center accompanied by a valorisation company, that might influence some of the aspects described above. Consequently, at least two aspects would deserve further investigations: (1) *are there other forms of ‘data genericity building’ strategies, relying on different mechanisms or organisational logics?* (2) *are there other ways of successfully steering repeated data-push innovation, differing from a ‘data genericity building’ strategy?* Indeed, literature on open data has unveiled the existence of a range of business models and actors involved in bridging the gap between data and use contexts (Magalhaes and Roseira, 2020; Janssen and Zuiderwijk, 2014). In this regard, recent projects in Europe aiming at stimulating the use of EO data in multiple sectors suggest that diverse forms of actors might be concerned by similar strategies (Thierry Ranchin et al., 2021), including private companies, public authorities, and also meteorological institutes that already have a long history in developing EO-based weather forecasts and their applications (Lenfle and Söderlund, 2022). It will be thus interesting to compare the different strategies, mechanisms and organisational logics that might exist depending on the profiles of these actors.

Moreover, further investigation are also needed to *better understand the conditions of emergence and viability of these actors*. O.I.E. has benefitted from the high complementarity of expertise in their team, gathering people from different backgrounds and sometimes atypical trajectories. It will be thus interesting to further investigate *how to support the development of such a range of competencies*. In the case of O.I.E., it also appears that public investments have played an important role in implementing and strengthening their data genericity building strategy over time. Indeed, several boundary resources and strategic core components of the platform have been progressively built through a sequence of projects funded by the European Commission. Therefore, *the role of public funding, as well as specific forms of partnerships between public and private actors*, will deserve closer attention, in line with the observations made on the development of open data ecosystems (e.g. Magalhaes and Roseira, 2020; Gupta et al., 2020; Zuiderwijk et al., 2016), and the development of new forms of policies to tackle grand socio-environmental challenges (Robinson and Mazzucato, 2019; Kuhlmann, 2018).

Finally, O.I.E corresponds to an extreme case where the constraints on data and use contexts are particularly stringent, thus offering a particularly interesting situation to study the mechanisms that are specifically related to the design of the data/uses fit system, set apart from other mechanisms that would rather aim to disrupt the ways data are produced or used. It will be also interesting to further examine *how the mechanisms related to the design of the data/uses fit system can be coupled with other forms of platform-based mechanisms*, e.g. in the contexts of IoT platforms combining data production and data-push innovation (de Prieëlle et al., 2022; Mosterd et al., 2021), or Uber combining data-push innovation and transformation of use contexts (Trabucchi and Buganza, 2020). In particular, while designing the data/uses fit system primarily involves adjusting to existing constraints on data and use contexts, it also seems that it eventually results in making these constraints evolve in a progressive way (e.g. through focused actions of stimulation described above). In this respect, it is interesting to wonder *how these progressive evolutions could also eventually result in deeply transforming data and use contexts, and what complementary mechanisms would be potentially needed*.

VI. Conclusion

This paper has investigated a specific form of data-based innovation, coined “repeated data-push innovation”, that focuses on stimulating the use of existing data by a large variety of actors spanning heterogeneous organisations and sectors. In particular, the paper has proposed to more closely examine how to steer repeated data-push innovation beyond serendipity, based on an innovation platform strategy, when the capacities of third-party actors in leveraging data are initially limited. Based on the longitudinal analysis of an actor that has specialized on steering data-push innovation in the field of Earth observation for more than 40 years, the paper contributes to this question in several ways.

First contributing to research on digital platforms, the paper unveils specific forms of platform expansion dynamics, that are associated with the nature of repeated data-push innovation, and that enrich the current landscape of digital platforms as they differ from other prevailing forms. The platform expansion dynamics observed in the case of O.I.E. are especially characterised by the three following aspects: (a) favouring the design of peripheral components laying the ground for further enrichments of the generic core, (b) enhancing the capacities of the actors of the ecosystem based on specific forms of boundary resources and focused actions of stimulation, (c) favouring generative power over controlling power through a specific form of “non-dominant” platform leadership. Second, more largely contributing to research on data-based innovation, the paper has introduced the notion of “data/uses fit system” that appears to be relevant to conceptualise and frame data-based innovation strategies beyond data-push innovation. In this regard, designing the data/uses fit system actually concerns all situations that involve fitting data into a given use context, with varying distances between data and this use context (from low distances when data are used internally by the organisation that has produced them, to large distances for data-push innovation situations). Based on this analytical lens, the genericity of data (i.e. its ability to fit into a large range of use contexts) can also be defined not as an intrinsic property of data but as a resulting property of how the data/uses fit system is designed. In this respect, the strategy of O.I.E. has consisted in progressively building up the genericity of solar radiation data based on a strategic design of the data/uses fit system.

These academic contributions also pave the way towards more practical contributions, especially for actors willing to define and conduct their own data-based innovation strategies. The paper indeed suggests that designing the fit between data and use contexts requires a specific managerial logic, that might thus be considered distinctively from other data-based innovation patterns targeting the production of new data or the deep transformation of use contexts. Further research will be needed to continue exploring these questions. In particular, as the paper is based on the analysis of a single case study, it will be highly beneficial to confront these results with other empirical cases in the Earth observation field or other fields facing similar issues.

Acknowledgements

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 820852. The authors also warmly thank the whole team of O.I.E. and Transvalor for their involvement and our fruitful interactions, in particular P. Blanc, L. Ménard, T. Ranchin, L. Wald that have brought stimulating insights contributing to this work.

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Co-design for novelty anchoring into multiple socio-technical systems in transitions: the case of Earth observation data

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Status: accepted in IEEE Transactions on Engineering Management

Abstract

Tackling grand challenges requires new forms of collaborative innovation to support intricate design processes involving heterogeneous actors. This paper specifically investigates how co-design supports the anchoring of promising novelties into multiple socio-technical systems to accelerate their respective sustainable transitions. A co-design framework adapted to this multi-system context is derived from transition research and design and innovation management research. The framework is validated empirically based on twenty-seven case studies where the novelty to be anchored corresponds to Earth observation data. Contributing to transition research, the paper shows how this multi-system co-design framework provides novelty developers with a diagnostic tool to clarify their anchoring strategy, by framing the relevant actions to conduct at different time horizons. Several enrichments of the anchoring concept are also proposed, highlighting some complementarities between different forms of anchoring and the endless property of the process. Contributing to design and innovation management research, the paper sheds light on co-design in an original perspective by considering a context crossing the usual boundaries of socio-technical systems and focusing on a diagnostic dimension preceding the organisation of collective design sessions. The co-design framework also highlights a so-called 'resource-based' form of collaborative innovation aiming to build novelty-based resources for heterogeneous actors facing grand challenges. This approach complements more common 'challenge-based' approaches aiming to directly address a targeted challenge.

Keywords: co-design, collaborative innovation, grand challenges, sustainable transitions, anchoring, multi-level perspective, strategic niche management, Earth observation data, digital innovation

I. Introduction

Addressing grand societal challenges appears today as a major priority, requiring deep transformations of societies. Different streams of management research underline the specific issues associated with these grand challenges, calling for new forms of technical and social innovations [1], [2], institutions and policies supporting them [3], [4], and practices within organisations [5]. Eisenhardt *et al.* [6] define them as “complex problems with significant implications, unknown solutions, and intertwined and evolving technical and social interactions”, that might include among others climate change, water scarcity, poverty, or food security. Recent works particularly underline that addressing such challenges requires new forms of collective action [7]–[10], especially to stimulate intricate innovation processes beyond organisational boundaries [11]–[14], that need to be considered in a long-run and evolutionary perspective [2], [3], [11], [12], [15] to efficiently ensure deep and viable socio-technical transformations [4].

The *multi-level perspective* (MLP) framework offers an interesting analytical tool to better understand the long-term socio-technical transformations involved in addressing these grand challenges through so-called *sustainability transitions* [16]–[22]. MLP draws upon the notion of *socio-technical system*, referring to the actors, institutions and artefacts interacting to fulfil societal functions (e.g. transport, communication, nutrition) [23]–[26]. Transitions are conceptualised as non-linear processes resulting from the interactions between three analytical levels of the socio-technical system: *niches*, defined as protective spaces for the development of radical novelties; *regime* referring to the rules and practices framing the action of the different social groups involved in transitions (e.g. engineers, users, policy makers) and accounting for the stability of the existing system; and *landscape* corresponding to the exogenous context affecting socio-technical developments (e.g. global societal trends putting pressure on the existing regime). A transition occurs when there is a shift from one regime to another following a specific interplay between these three levels. As described in early MLP works, the internal tensions of regimes or an intensified landscape pressure can generate a “window of opportunity” for niche innovations (i.e. novelties maturing in niches) to progressively agglomerate into a new socio-technical configuration, competing with the incumbent regime, and eventually establishing itself as a new regime [23].

Scholars have progressively refined the analysis of these transition dynamics by unveiling different transition pathways [24], [27]–[29], and have recently called for further research on how these transition dynamics could be accelerated [30], [31]. They especially suggest that present transition dynamics might occur through more complex and subtle interactions between niches and regimes compared to past transitions [20]. In this perspective, scholars have more precisely shed light on certain forms of mechanisms, coined “anchoring”, aiming at newly or more firmly connecting a novelty to a niche or regime within a socio-technical system [32], [33]. They also underline the importance of considering the interactions between multiple socio-technical systems [29], [34]–[36], that can be especially fruitful in enhancing niche resilience, as illustrated by the case of biogas anchoring in both agriculture and energy systems [34].

Our paper aims at unveiling certain forms of managerial practices that would support novelty anchoring into multiple socio-technical systems. We especially propose to focus on so-called ‘co-design’ practices, supporting the implementation of an interactive design approach involving intricate learning processes [17], [37]. This analytical lens is indeed particularly relevant for our investigation as it combines two crucial aspects of grand challenges and sustainability transitions: a *design* aspect accounting for the high degree of unknown entailed in building new forms of actions to address grand challenges, a *collective* aspect accounting for the variety of actors to be involved beyond usual disciplinary and sectorial boundaries [1], [2], [6]. Our paper thus proposes to investigate the following question: *how can a multi-system co-design framework help the developers of a certain novelty steer an anchoring strategy into multiple socio-technical systems?*

A theoretical co-design framework adapted to the investigated context is first derived from transition research complemented by research in design and innovation management, leading us to distinguish between four main types of co-design depending on the nature of the learning processes in which novelty developers engage. The relevance of these co-design types is validated and discussed empirically based on twenty-seven case studies rooted in the Earth observation field, where specific actors are encouraged to use co-design to further anchor Earth observation data into various socio-technical systems that would benefit from these data to accelerate their respective sustainability transitions.

This paper offers several contributions advancing research on collaborative innovation for sustainability transitions. Contributing to transition research, our work takes a specific look

at managerial practices that can support multi-system anchoring. Our study shows that the co-design framework provides novelty developers with a helpful *diagnostic tool* to clarify their anchoring strategy by distributing their design efforts over time, thus allowing them to handle significant learning processes with broad design ambitions in a long-term perspective. Several enrichments of the anchoring concept are also derived from these outcomes.

Contributing to design and innovation management research, our work sheds light on co-design in an original perspective. Indeed, this paper does not focus on the aspects of co-design related to the organisation of specific collective design sessions or workshops, but focuses on a *diagnostic dimension* preceding the actual collective design sessions. This diagnostic dimension is especially crucial in the *multi-system context of co-design* considered in the paper, requiring specific efforts to identify the relevant actors among a complex and evolving range of heterogeneous actors. Second, in the perspective of tackling grand challenges, our co-design framework sheds light on two complementary logics of collaborative innovation, coined *resource-based* and *challenge-based*. This paper eventually proposes several perspectives for practitioners, involved in novelty development activities or in policy making institutions.

II. Theoretical background

This section examines the relevance of taking a co-design perspective to support novelty developers in building an anchoring strategy into multiple socio-technical systems, and elicits a theoretical co-design framework based on transition studies and research in design and innovation management.

1) Anchoring novelties into niches or regimes to accelerate the sustainability transitions of multiple socio-technical systems: the relevance of considering a co-design perspective

The development of novelties and their wider uptake appear as important aspects in sustainability transitions of socio-technical systems. The MLP framework especially emphasises the importance of niches as the “seeds for systemic change” [22], playing the role of protective spaces where radical novelties are developed and sheltered from possible tensions with the existing regime [23]–[26]. A dedicated branch of transition research, called *strategic niche management* (SNM), has more specifically underlined the importance of

creating social networks endorsing intricate *learning processes* that concern multiple dimensions - including technical aspects and design specifications, market and user preferences, cultural and symbolic meaning, infrastructure and maintenance networks, industry and production networks, regulations and government policy, societal and environmental [38]–[41].

Drawing upon MLP and SNM insights, Elzen *et al.* [32] have introduced “anchoring” as an analytical concept to expand the organisation of these learning processes beyond the initial development of novelties towards their wider uptake in socio-technical systems. Anchoring is defined as “the process in which a novelty [i.e. a new technology, a new technical concept or a new socio-technical practice] becomes newly connected, connected in a new way, or connected more firmly to a niche or a regime”. The authors precise that anchoring does not refer to the permanent uptake of the novelty in a new environment (niche or regime), but rather consists in a “continuous process of probing new connections” until their transformations into more durable links. Three forms of anchoring are distinguished: *technological anchoring* when the technical characteristics of a novelty are more specifically defined and adapted to the actors’ operations and practices; *network anchoring* “when changes occur in the network of actors that ‘carry’ the novelty, e.g. by producing it, using it or developing it further”, and *institutional anchoring* when changes occur in the beliefs, visions, or problem views of actors (*cognitive or interpretative institutions*), formal and informal rules about what is desirable or not (*normative institutions*), and rules and arrangements (e.g. contracts, business networks) that govern market or economic activities (*economic institutions*).

This anchoring concept has been further expanded to account for the interactions between multiple regimes, e.g. novelties for renewable energy production that have successfully developed by anchoring in both agriculture and electricity regimes [34]. This multi-system perspective seems especially important for different types of novelties mentioned in literature, especially so-called generic or general purpose technologies having the potential to be used in many different application domains, such as materials science, 3D printing, biological and genetic engineering, computing [30], or other digital innovations [42]. Sutherland *et al.* [34] highlight that these multi-regime anchoring processes can be supported by the emergence of a new regime, coined “fiat regime” - “fiat” meaning formal authorisation, proposition or a decree - characterised by new sets of rules and regulations facilitating the

cooperation between parent regimes while preserving their own structure and dynamics (e.g. targets set by the European Commission and implemented nationally to support renewable electricity production). A complementary focus on the underlying managerial practices could provide additional insights on how to support these multi-system anchoring processes, in line with scholars' recommendations on considering the agency involved in sustainability transitions, i.e. the actors and their micro-level actions supporting transition dynamics [16], [22], [28], [43]. Several studies already offer interesting perspectives to examine these managerial practices. Although not in a multi-system perspective, some works highlight the potential of participatory design approaches in handling the intricate multi-actor design processes supporting the sustainability transitions of the agricultural system [33], [44], [45] or the energy system [46]. For example, Beguin *et al.* [45] emphasise the role of collective and innovative 'co-design' approaches in "fostering cross learning processes amongst designers and users in order to achieve the joint building of a technology, of a desirable future, and of the activity or the collective action in which the technology will be used". Studying the animal production system, Elzen and Bos [33] have more specifically shown the fruitful combination of the anchoring concept with an interactive design approach to design a new integrally sustainable system, by especially targeting the uptake of novelties from the beginning of the design phase.

Our paper proposes to advance these works by jointly considering these two streams of recent research on anchoring, building complementarities between their respective results and remaining blind spots, i.e. on the one side investigating *multi-system* interactions with a specific attention on micro-level managerial practices, and on the other side considering the fruitful *combination of anchoring with collective and innovative design approaches* so far described within the boundaries of a single socio-technical system. We will use the term "co-design" to refer to these design approaches, as it is explicitly mentioned by Grin *et al.* [17] as one of the shared concepts of transition research, underlining that "knowledge is developed in a complex, interactive design process with a range of stakeholders involved through a process of social learning". This especially leads us to formulate the following question: *how can a multi-system co-design framework help the developers of a certain novelty steer an anchoring strategy into multiple socio-technical systems?*

Transition literature does not explicitly propose a co-design framework in the context of anchoring novelties into multiple socio-technical systems. To examine this question, we

have thus been confronted with the issue of building an adapted co-design framework. Next paragraphs show how such a framework can be theoretically derived from existing literature, leveraging transition studies to conceptualise the overall co-design setting, and additional insights from design and innovation management literature to distinguish between different types of co-design depending on the nature of learning processes.

2) Co-design framework through the lens of transition research

Transition literature provides us with several insights to conceptualise the overall setting of a multi-system co-design framework by clarifying the following elements: the considered multi-system configuration and related agency, the expected outcomes of co-design and the associated learning processes.

In the context of novelty anchoring in multiple socio-technical systems, the developers and the users of the novelties might belong to different socio-technical systems, resulting in an increasing variety of possible actors to be involved and a large heterogeneity of knowledge between these actors. We especially distinguish between the so-called *novelty-emergence socio-technical system* into which the novelty has initially developed (e.g. biogas primarily embedded into the agriculture regime to address waste management problems) and *novelty-use socio-technical systems* that might benefit from the use of the novelty to accelerate their respective sustainability transitions by better tackling the grand challenges they are facing (e.g. further anchoring of biogas into the energy regime). Looking at underlying agency, scholars have highlighted the benefits of taking an “insider” perspective, describing the strategies deployed by the advocates of niches that mobilise and create protective spaces over time through multi-actor relationships [43]. Following a similar line, our paper focuses on the view of *novelty developers* supporting the development of a certain novelty by anchoring it into various socio-technical systems.

Regarding the expected outcomes of co-design, the definition provided by Beguin *et al.* [45] suggests considering, “the joint building of a technology, of a desirable future, and of the activity or the collective action in which the technology will be used”. Considering the investigated context of anchoring to accelerate the transitions of multiple socio-technical systems, these outcomes can be further specified following two dimensions. First, focusing on the anchoring dimension, the expected outcomes can be characterised following the *three types of anchoring* detailed above: *technological anchoring* (in line with the “joint technology

building” aspect), *network anchoring* (in line with the “collective action” aspect), and *institutional anchoring* (in line with the “desirable future” aspect). Scholars also argue that successful anchoring seems to require an interplay of these three forms of actions [32], [33]. For example, the limited development of biogas in some countries can be associated with a lack of network anchoring or a lack of cognitive institutional anchoring resulting in altering the normative institutional support (dedicated rules and regulations) brought to renewable energy production [34]. For this reason, it seems relevant to consider co-design as potentially associated with all three types of anchoring. Second, as anchoring is investigated in the perspective of accelerating the sustainability transitions of multiple socio-technical systems, the expected outcomes of co-design can also be specified according to a second dimension related to *its interaction with transition dynamics of both the novelty-emergence and the novelty-use socio-technical systems*.

Finally, taking a micro-level perspective on co-design involves considering an additional analytical layer closer to the novelty developers’ contexts of actions. The co-design definitions provided by Beguin *et al.* [45] and Grin *et al.* [17] both suggest considering the *learning processes* underlying the co-design approach. In this perspective, SNM scholars emphasise the importance of learning processes that do not merely focus on accumulating facts and data (coined as first-order learning), but also expanding cognitive frames and assumptions (coined as second-order learning) [38]–[41]. Empirical case studies have especially highlighted that niche development might be significantly hampered when learning processes are limited to first-order learning, e.g. by restrictively perceiving users as consumers with already articulated needs [41], [47]. However, second-order learning processes appear to be particularly difficult to reach in practice and might depend on specific drivers and contexts [48], [49]. These elements suggest that *co-design might be associated with different forms of learning processes depending on the context of action*. Our investigation especially needs to consider the forms of learning processes that will address the large degree of unknown and high heterogeneity of knowledge prevailing in the context of multi-system sustainability transitions.

3) Co-design framework through the lens of design & innovation management research

Research in design and innovation management provides complementary insights to further characterise these forms of learning processes that can be specified by considering the design space of novelty developers, involving different levels of unknown related to co-evolving problem and solution spaces.

a) Expanding the design space of actors through the intertwined expansion of problem and solution spaces

Design research has shed light on a so-called ‘co-evolutionary’ paradigm in which creative design involves the exploration of two distinct spaces - *the problem space and the solution space* – that continuously evolve through mutual interaction [50]–[52]. Dorst and Cross [53] further explored the empirical validity of this model and elaborated on the notion of *pairing*: “creative design involves a period of exploration in which problem and solution spaces are evolving and are unstable until (temporarily) fixed by an emergent bridge which identifies a problem-solution pairing.”

Similar considerations can be found in innovation management research. In particular, von Hippel and von Krogh [54] propose an original problem-solving approach, conceptualised as the discovery of viable “need-solution” pairs, linking a certain point of the need landscape (defined as the pool of need-related information) and a certain point of the solution landscape (defined as the pool of solution-related information). Indeed, the authors notice that individuals sometimes “[recognise] a problem worth solving only after encountering a potential solution worth implementing”, thus contrasting with classical problem solving starting with problem formulation. For the sake of clarity, we will only keep the terms introduced in design literature, i.e. “problem-solution pairs” and “problem and solution spaces”.

The context of sustainability transitions has not been explicitly investigated by these different works, that have indeed mainly considered problem-solving cases encountered by individuals in their everyday life [54], or in laboratory settings with clearly defined and delimited design tasks [55], [53]. However, the problem-solution pairing approach appears to be well adapted when problem spaces are complex and various problem-solution pairs are potentially viable, avoiding costly efforts in formulating a problem or searching an exhaustive

problem or solution space [54]. Grand challenges and sustainability transitions clearly meet these conditions, given the large amount of unknown associated with both problems and solutions [2], [6].

Moreover, although mainly based on the perspective of an individual designer that would be able to discover problem-solution pairs on its own, von Hippel and von Krogh [54] also mention situations involving multiple actors (e.g. in crowdsourcing or open source initiatives). They suggest that the approach is more likely to be successful when solver individuals or teams have expertise in aspects related to both problems and solutions. In the context of multi-system anchoring, it can be reasonably assumed that such expertise is not shared by the same actors. Basically, novelty developers might have a limited expertise on problem aspects (i.e. for what purposes the novelty could be used), and the actors that could potentially benefit from this novelty might also have a limited expertise on solution aspects (i.e. how the novelty could be transformed into a promising solution). In such situations, the discovery of problem-solution pairs appears to be hardly achievable by the actors taken individually, thus requiring a dedicated collective design setting. This confirms further the interest of investigating the potential role played by co-design for actors involved in multi-system anchoring. Taking the view of novelty developers, the expected outcomes of co-design can be more precisely described according to the *expansion of the design space of novelty developers, made of two co-evolving sub-spaces (problem and solution spaces) resulting in the discovery of viable problem-solution pairs*.

b) Design space associated with various degrees of unknown related to problem and solution spaces

Recent advances in design theory are helpful to go one step further in characterising this design space. Hatchuel *et al.*[37] especially recalls that the strength of design lies in its 'generativity', i.e. "the ability to conceptualize and create non-existent alternatives". It has thus been argued and demonstrated that design reasoning logic goes beyond "bounded rationality" [56], but rather involved an "expandable rationality" [57]. In this perspective, both problem and solution spaces are associated with a certain degree of unknown and can be progressively expanded through an intertwined exploration of unknown and known objects [58], [59]. Unlike usual decision-making and problem-solving paradigms, the unknown is not limited to the uncertainty on the value of well-known design parameters, but can potentially

include the exploration of unknown design parameters. Hatchuel *et al.*[37] also stress that the level of unknown (or generativity) involved in a design process determines the paradigm and social spaces in which the design process should take place: situations with a low level of unknown can be dealt with usual forms of problem-solving and social spaces, whereas situations with a higher level of unknown tend to require more generative models of design theory and the creation of original forms of social organisations. These considerations lead us to theoretically distinguish between *four types of co-design corresponding to different contexts defined by the level of unknown associated with the problem and solution spaces of novelty developers, leading to different forms of learning processes*, as defined in Table 1.

		Level of unknown - <i>Problem space</i>	
		Low	High
Level of unknown <i>Solution space</i>	Low	<p><i>Co-design type 1</i></p> <p>Problem-related unknown: identified problems that might need further specification Solution-related unknown: limited development efforts leveraging existing building blocks Learning processes to build problem-solution pairs: slight co-expansion of problem and solution spaces</p>	<p><i>Co-design type 2</i></p> <p>Problem-related unknown: unknown or little-known problems to be identified Solution-related unknown: limited development efforts leveraging existing building blocks Learning processes to build problem-solution pairs: large on problem space, limited on solution space</p>
	High	<p><i>Co-design type 3</i></p> <p>Problem-related unknown: identified problems that might need further specification Solution-related unknown: extensive development efforts Learning processes to build problem-solution pairs: large on solution space, limited on problem space</p>	<p><i>Co-design type 4</i></p> <p>Problem-related unknown: unknown or little-known problems to be identified Solution-related unknown: extensive development efforts Learning processes to build problem-solution pairs: large co-expansion of problem and solution spaces</p>

Table 1: *Four types of co-design theoretically deduced from the level of unknown associated with problem and solution spaces of novelty developers*

To summarise this section, recent works in transition studies have led us to raise the following research question: *how can a multi-system co-design framework help the developers of a certain novelty steer an anchoring strategy into multiple socio-technical systems?* Two main streams of literature have then been used to build a theoretical co-design framework adapted to the context of multi-system anchoring entailing intricate learning processes. The respective insights brought by these two broad streams of literature are synthesised in Figure 1, more largely outlining the overall argument developed in the paper.

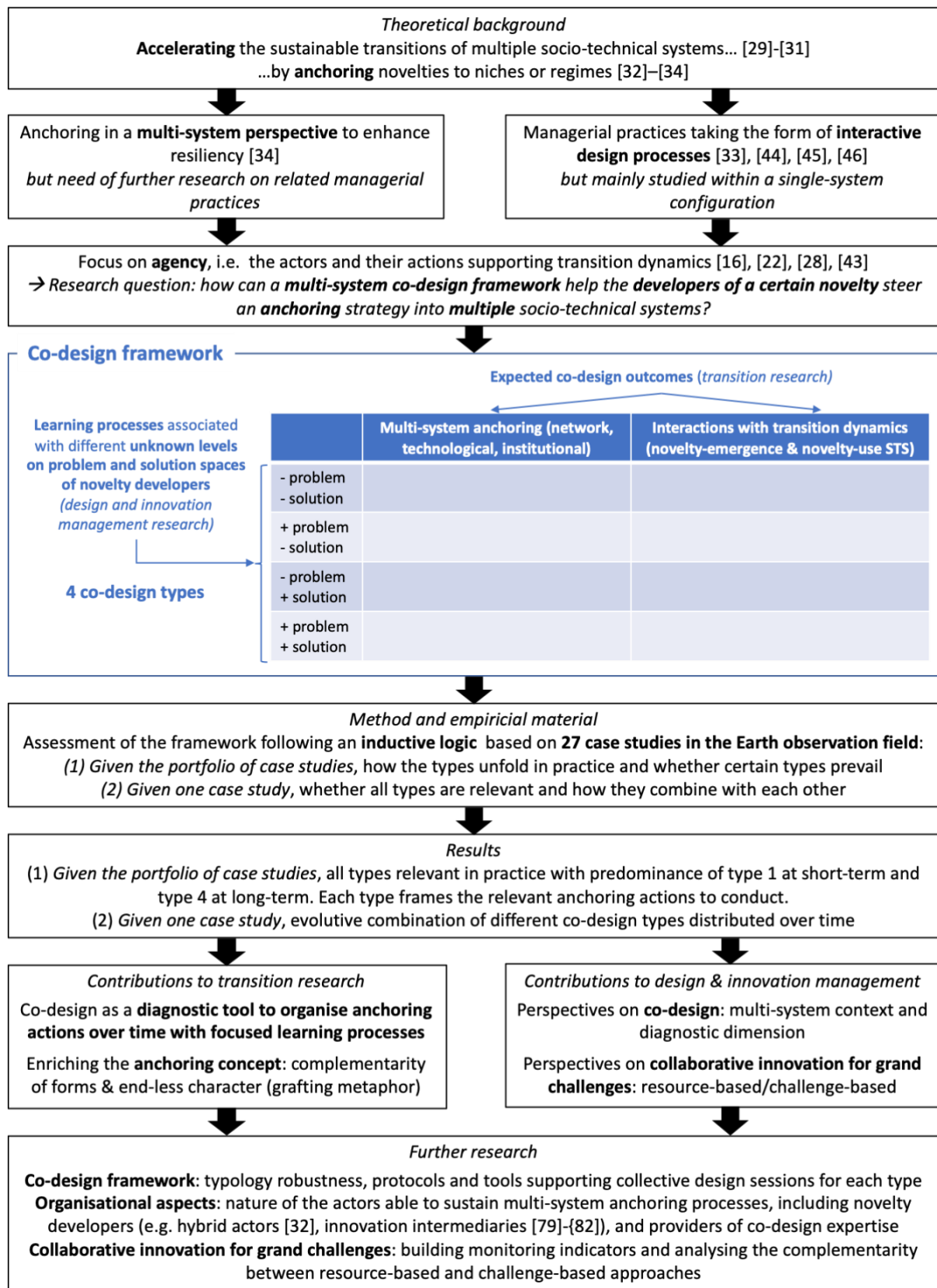


Figure 1: Synthesis of the overall argumentation developed in the paper, summarising theoretical background (precising how the co-design framework is built), method and empirical material, main results, research contributions and further perspectives (STS used for “socio-technical system”)

III. Method and empirical material

Aligned with the guidelines proposed by Eisenhardt *et al.* [6] for research related to grand challenges, this research question is addressed through an empirical investigation following an inductive logic, aiming at taking advantage of rich empirical data to validate and potentially enrich the theoretical co-design framework derived from literature, drawing on multiple case studies [60] in the context of Earth observation. Assessing the relevance of the framework will especially include the two following aspects: (1) *given the portfolio of case studies*, investigating whether all four types of co-design appear to be relevant and to what extent certain types are predominant over the others, (2) *given one case study*, investigating whether the actors are concerned by one or several co-design types and how these types combine with each other.

1) Relevance of the Earth observation field as an empirical context

Earth observation (EO) data are produced by a large range of instruments (e.g. satellites, in-situ sensors such as meteorological land stations, but also more recently IoT or smartphone data), to monitor, understand, or predict the evolution of our man-made or natural environment. These data are thus a good example of a novelty that might support multiple actors in tackling grand challenges [42], e.g. building a more sustainable agriculture, building resilience to natural disasters, supporting the development of renewable energies.

The distinction between the *EO-emergence socio-technical system* and the *EO-use socio-technical systems*, into which EO data might be used to address certain grand challenges, can be justified by considering the three types of rules - regulative, normative and cognitive - defining a socio-technical regime [26]. On the regulative aspect, the EO socio-technical system is governed by laws and standards (e.g. related to satellite developments, processing and sharing of data), differing from laws and regulations followed by the potential user communities (e.g. the Common Agriculture Policy in agriculture, or the Stockholm Convention for surveillance of persistent organic pollutants). On the normative aspect, as the actors belong to very distinct profession bodies (e.g. data analyst on the one side and farmer on the other side), they hardly share the same norms or performance logics. Finally, on the cognitive aspect, there is a large gap between the considered timelines (e.g. very long cycles to develop

new instruments differing from short timelines of actions to be taken based on data uses), and the competencies (e.g. specific technical expertise related to data processing differing from specific domain expertise related to data uses).

In recent years, significant efforts have been undertaken to anchor EO data into various socio-technical systems, especially in the perspective of helping actors progress towards sustainable development goals. Considering the European context, these scientific data have been increasingly considered as a common good and made freely accessible to all potential users in an ‘open-data’ approach [61], [62]. However, the success of these ‘open-data’ policies is still limited in practice, as the different stakeholders are hardly familiar with EO data and seem to have difficulty in leveraging them on their own. In this context, significant efforts are currently carried out by the actors of the EO-emergence socio-technical system to go beyond ‘open-data’ policies and implement specific forms of collaborative innovation, referred as *co-design* (or similarly co-production or co-development [63], [64]), involving multiple stakeholders of the EO-emergence and EO-use socio-technical systems. This empirical context seems thus particularly adapted to investigate how co-design can support novelty developers in further anchoring the novelty in multiple socio-technical systems.

2) Empirical setting

Our empirical material is derived from our involvement in a large research project, which received a 4-year grant (2019-2023) from the European Commission under the Horizon 2020 programme. This project, called *e-shape* initially gathered a team of 54 experienced partners from academia, industry, institutional entities to develop 27 pilot applications based on EO data, organised in seven showcases (agriculture, health, renewable energy, biodiversity, water resources, disaster resilience and climate) [65]. Each pilot is in charge of developing a certain set of EO-based solutions within a specific showcase. It involves one or several organisations participating to the project, and is coordinated by one of these organisations designated as the “pilot leader”. As an initial condition for project participation, each pilot interacts with at least one user organisation. These user organisations do not receive direct funding from the project and are thus considered as external actors to the project. An overview of the 27 initial pilots is given in the appendix of the paper, describing for each: the overall pilot’s rationale,

the types of organisations involved in the pilot's development, and the different user groups targeted by the pilot.

All four authors of the paper are involved in e-shape, leading a work package dedicated to co-design aiming to provide the pilots with a co-design framework and guiding tools that are progressively designed and tested in interaction with the pilots. This setting is thus particularly favourable to conduct multiple case studies [60], corresponding to the different pilot cases, in the unified empirical context offered by the project.

3) Data collection and analysis

Our participation to the project enables us to have direct interactions with all the organisations involved in the project and their network of partners. On this basis, rich empirical data could be exploited from heterogeneous sources, necessary for a sound inductive approach [6]: questionnaires, interviews, observation notes taken during project meetings, and secondary sources of data on the different actors (application forms filled up by each pilot to participate to the project, websites and scientific publications of the different partners). The data used for this paper were collected between September 2018 and July 2021 with no noticeable impact due to Covid-19 situation as our main interactions were already organised on virtual platforms due to the international composition of the project. Within this timeframe, our work package activities included the validation of a co-design theoretical framework but also first experimentations of specific workshop protocols for each identified type. The present paper only focuses on the first aspect, assessing to what extent the four types of co-design provide useful support to the pilots in steering their anchoring strategy.

The validation process was designed in a collaborative research setting, involving both researchers and practitioners (here *e-shape* project members) [66]. This setting especially aims to “reduce the likelihood of drawing false conclusions from the data collected, with the intent of both proving performance of the system [of action] and adding to the broader body of knowledge in the field of management” [67]. Following guidelines for collaborative research [67], [68], the validation process consisted in *progressively building a shared interpretation of empirical data and findings between researchers and practitioners*. This involved the rigorous formalisation of a shared understanding of each pilot's context and the associated assessment of relevant co-design types for each pilot, through a sequence of steps detailed below. As the pilots were not familiar with the ‘anchoring’ concept, our approach consisted in first assessing

the relevance of co-design types based on their definitions related to the nature of unknown and learning processes, and deriving the associated anchoring strategy from the complementary points of analysis discussed with the pilots and detailed below in step 3.

Step 1 (September 2018 - May 2019) – Preliminary data analysis: building an overall understanding of the empirical context and the research tools supporting the validation process

This first step corresponds to a preliminary strategy for data analysis allowing us to become more familiar with the empirical context. Following case study guidelines [60], this involved the manipulation of empirical data supported by the creation of dedicated visual displays and templates, facilitating the triangulation of data by organising heterogeneous materials, in a more synoptic and comparable form [69]. We indeed built a specific template to synthetically represent each pilot as a chain linking data sources, the information derived from these data, their expected uses and associated actors. This template was first tested, discussed and validated in a dedicated one-day meeting organised with one pilot in April 2019. The outcomes were formalised in a deliverable report, reviewed and validated by the participants and by two external reviewers, and made publicly available on the project website [70]. The template was considered as a useful tool to create a shared understanding between researchers and practitioners, and was thus consequently used to support the validation process undertaken for each pilot by systematically (1) drafting a first version of the pilot template based on secondary sources of data and observation notes taken during the project kick-off meeting; (2) sharing this pre-filled template with the pilot through the online management platform of the project and updating it based on the pilot's feedback.

Step 2 (November 2019) – Shared validation of the co-design framework with project coordinators

The theoretical framework involving four types of co-design was first discussed with the project members having an official coordinating role, i.e. the project management team, showcase coordinators and work package leaders. A dedicated meeting was organised by our team in November 2019, where the co-design framework was presented, using the definition of the four types of co-design related to the nature of the associated learning processes. These different forms of learning processes were illustrated on concrete examples of pilots based on

the preliminary empirical data gathered in step 1. The relevance of the framework was discussed and approved by all participants of the meeting.

Step 3 (November 2019 - July 2021) – Assessment of the co-design framework for each pilot

To assess the relevance of the co-design framework for the 27 pilot cases, an interview of one hour and a half was conducted remotely with each pilot (video calls based on zoom application). The participants to this interview included at least two members of our research team and the pilot leader, and also in some cases the showcase leader and additional members of the pilot when judged relevant by the pilot leader. The profiles of the interviewees for each pilot are detailed in the appendix of the paper. Prior to the interview, a preliminary report was written by our team and shared with the pilot through the online management platform, formalising the current status of understanding on the pilot's context based on the information gathered in the previous steps. This report was structured in different points of analysis listed below, related to the anchoring activities of the pilot and transition dynamics of both EO-emergence and EO-use socio-technical systems, and associated with different parts of the template built in step 1 (see Figure 2):

- *Pilot's understanding of the transition dynamics of targeted EO-use socio-technical systems (a)*, i.e. overall regime organisation (specific rules and regulations, regime actors), the actors that would potentially benefit from EO data and their position within the socio-technical system;

- *Status of EO data anchoring into the targeted EO-use socio-technical systems:*

- Network anchoring by specifying *the actors identified as potential users by the pilot (b)*
- Technological anchoring by specifying *the expected EO-based solution to be built (c)*: problems expected to be taken by would-be users based on EO data, lists of requirements when identified;
- Cognitive and normative institutional anchoring by specifying the *current capacity of niche/regime actors to handle EO data on their own (d)*, i.e. identifying their familiarity with EO data, and their design and development capacities, and the potential rules and standards that could potentially encourage the use of EO by these actors;
- Economic institutional anchoring by specifying the *nature of the relationships built with these actors so far (e)*, i.e. the history of the relationship, the forms and intensity of the interactions, whether these interactions have been contractually formalised;

- Integration of the pilot in the transition dynamics of EO-emergence socio-technical system:

- *Overview of the pilot members' history and expertise (f)*: main research fields and expertise of pilot members, involvement in previous projects, role of e-shape in their overall trajectory;
- *Ability of the pilot to build a solution addressing a certain problem once specified (g)* for a first prototype and its further operationalisation: identifying potential development challenges, and the relationships to be created or reinforced to overcome these challenges.

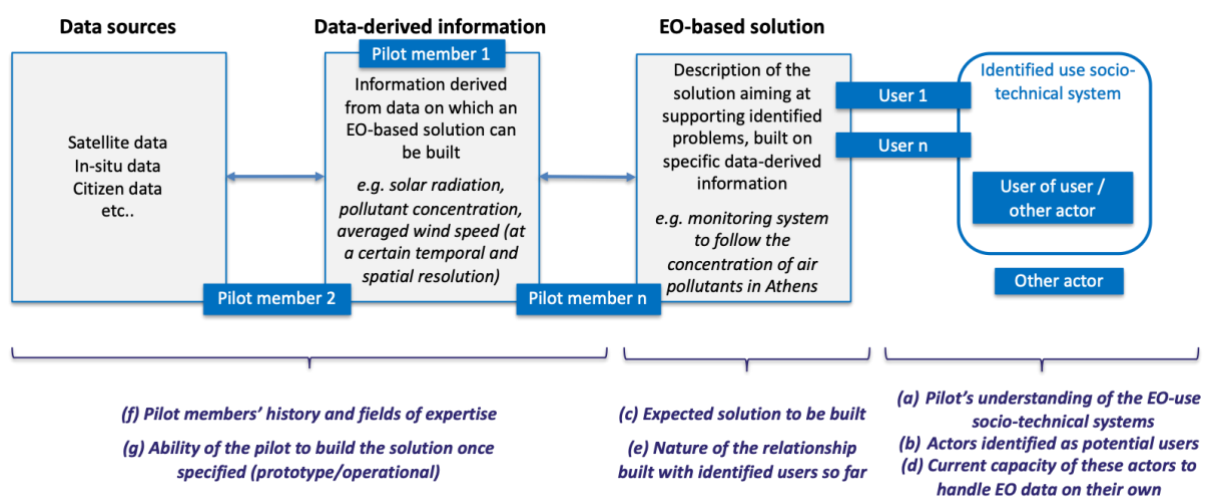


Figure 2: Template built for preliminary data analysis and link with the points of analysis guiding the interviews

Each interview was then organised following a semi-guided process. In a first phase, one member of our team made a brief reminder of our research goals, presented the synthetic template of the pilot and the associated preliminary analysis on the five main points mentioned above. A second phase was dedicated to a thorough discussion with the pilot to further understand its context following the points of analysis defined above. A final phase consisted in confirming the relevant types of co-design for the pilot context. To take into account the dynamics of socio-technical systems, two time horizons were considered: short-term for co-design types assessed as currently relevant for the pilot, and long-term for co-design types that the pilot expected to be relevant in the future.

After each interview our team updated the report written prior to the meeting, completing the description of the pilot's context and formalising the conclusion on the relevant co-design types at short-term and longer-term time horizons, occasionally resorting

to the recordings of the interviews in cases where it was harder to understand the participants (e.g. due to technical or language issues). This report was systematically shared through the online project management platform and validated by all participants of the meeting.

	Data collection	Data analysis
Step 1 (Sept 2018-May 2019) <i>Building an overall understanding of the empirical context</i>	Secondary sources (pilots' application forms to the project, academic publications, websites) Field notes (kick-off meeting, informal interactions with project members)	Construction of a template for heterogeneous data compilation, tested and validated by researchers and practitioners (one-day meeting with a pilot and formalisation in a reviewed and shared deliverable report)
Step 2 (Nov 2019) <i>Shared validation of the co-design framework with project coordinators</i>	2h meeting with the seven showcase coordinators, the project management team and the work -package leaders	Validation of the framework of four co-design types by all participants of the meeting, and agreement on undertaking further assessment on all case studies
Step 3 (Nov 2019-July 2021) <i>Assessment of the co-design framework for each pilot (in total 27 case studies)</i>	1h30 semi-guided interview with each pilot (see table in <i>Appendix</i> for the details on the participants)	Assessment of each pilot's context and identification of relevant co-design types validated by all researchers and practitioners: - Report written by researchers before each interview , including specific points of analysis and filled-up template - Report updated by researchers, shared and validated after each interview by all participants , updating the description of the pilot's context and the conclusion on relevant co-design types at two time horizons

Table 2: Overview of the process followed for data collection and analysis

IV. Results

This section presents the findings that emerged through the analysis of the twenty-seven case studies. The outcomes consist in assessing the relevance of the co-design framework by (1) considering the portfolio of case studies to examine the respective relevance of all types; (2) considering case studies separately to analyse how the different co-design types combine with each other within a single case study.

1) Specifying the relevance of the four co-design types considering the portfolio of case studies

The outcomes of the co-design diagnosis for each pilot are shown in Table 3, confirming that all four types of co-design are relevant in the context of supporting EO data anchoring in heterogeneous socio-technical systems. The respective contributions of each type to multi-system anchoring and transition dynamics are detailed in the following paragraphs, synthesised in Table 4 and represented graphically in Figure 3.

Pilot	Short-term	Long-term	Pilot	Short-term	Long-term
#1	Type 1	Type 3	#15	Type 1 & 3	Type 4
#2	Type 1 with user 1 Type 2 for new user group	Type 1 with users 2 & 3 Type 3 with partner	#16	Type 2	Type 1
#3	Type 3	Type 4	#17	Type 1	Type 4
#4	Type 1 & 2	Type 4	#18	Type 1	Type 2
#5	Type 1	Type 4	#19	Type 1 or 2	Type 3 & 4
#6	Type 1	Type 3 & 4	#20	Type 1 & 3	Type 4
#7	Type 1 for user group 1	Type 2 for user group 2	#21	Type 1	Type 3 & 4
#8	Type 1 & 3 & 4	Type 4	#22	Type 1 & 4	Type 4
#9	Type 3 & 4 for user group 1 Type 1 & 3 for user group 2	Type 4	#23	Type 1	Type 3 & 4
#10	Type 2	Type 3	#24	Type 3	Type 4
#11	Type 1	Type 4	#25	Type 1	Type 3 & 4
#12	Type 3	Type 4	#26	Type 1	Type 4
#13	Type 3	Type 4	#27	Type 1	Type 4
#14	Type 1 & 4	Type 4			

Table 3: Validated assessment of co-design types for the twenty-seven case studies (pilots)

a) Co-design type 1

It is theoretically defined as a situation where the level of unknown associated with problem and solution spaces is considered as relatively low by the pilot. This situation applies when the pilot has already identified potential uses of EO by specific actors that are willing to interact further. A slight expansion of problem and solution spaces is thus needed to build problem-solution pairs.

In this perspective, co-design type 1 aims at supporting a certain form of *technological anchoring*, consisting in further detailing the specifications of potential EO-based solutions addressing problems that have been identified on a first basis. This entails enhancing some forms of *network anchoring*, by establishing a robust relationship between the identified users and the relevant members of the pilot. On the pilot's side, it appears that all members of the pilot are not necessarily involved: some of them might indeed focus on the development of a certain building block as defined by the actors interacting with users. On the users' side, the identified users proved to be either niche actors (e.g. a start-up willing to integrate EO data to estimate solar energy potential on building roofs), or regime actors (e.g. a national health agency having the project of building a data observatory for health-related issues). This co-design type also involves some forms of institutional anchoring. Creating robust interactions between actors might indeed require the enrichment of the actors' respective perceptions and visions (*cognitive institutional anchoring*). The EO developers might for example need to push the users towards considering different ways of using EO data, such as for monitoring purposes (e.g. to assess the concentration of air pollutants), decision-support purposes (e.g. triggering existing pollution mitigation actions when a threshold is exceeded), or design-

support purposes (e.g. designing new pollution mitigation actions by using EO data to build and assess various scenarios). This can also involve *economic institutional anchoring* by reshaping the existing forms of contracts or value chains (e.g. a public agency contracting with unusual types of actors), and *normative institutional anchoring* if the integrate EO-based solutions in users' existing workflows and procedures requires the introduction of specific rules.

In terms of socio-technical systems' dynamics, co-design type 1 can be described as *supporting the identified dynamics of a given EO-use socio-technical system* by anchoring EO data to a niche or regime actor of this system (e.g. supporting the development of a niche related to solar resource self-consumption in urban areas aiming to accelerate the sustainability transition of the energy system).

b) Co-design type 2

It is theoretically defined as a situation where the level of unknown is considered high for the problem space and low for the solution space. This can especially occur when the pilot does not have sufficient knowledge on the EO-use socio-technical system to identify the potential of EO data for specific actors and/or the relationships with these actors seem difficult to establish (e.g. if actors are not willing to devote time to the interactions, or if previous interactions have been limited to one-shot exchanges). A significant exploration and expansion of the problem space is thus needed until problem-solution pairing can be initiated.

In this perspective, co-design type 2 implies a form of *technological anchoring* consisting in building and sharing the legitimacy of potential EO-based solutions. This might involve extensive efforts to identify the added-value of this new source of information compared to existing sources (e.g. correcting specific errors of existing instruments or capturing new physical phenomena), to ensure its technical validation (i.e. taking into account the limits of the measuring instrument, indicating a trustworthiness index associated with the provided information, precisifying if specific corrections have already been made), and to establish its legitimacy within a given community (e.g. by facilitating the comparison of this new source of information compared to commonly used ones). This involves a certain form of *network anchoring* consisting in building relationships between relevant pilot members and actors of the EO-use socio-technical system, targeting a better understanding of this socio-

technical system. It seems especially important to consider both regime and niche actors that provide complementary insights and collaboration opportunities. For example, in the offshore wind industry, regime actors such as utility companies developing and operating wind farms prove to be reluctant to use EO data but can share precious knowledge on the existing socio-technical system's rules and dynamics; whereas certain niche actors, such as specialised consultants, appear to be interested in using EO data to improve their wind-resource analysis workflows but struggle to make such data broadly accepted by the industry. This co-design type also entails some forms of *institutional anchoring: cognitive* as it consists in making emerge robust and reliable promises that might be associated with EO data, *economic* by creating specific forms of contracts (e.g. partnership to undertake a specific exploratory study), *normative* by encouraging the introduction of rules or standards to be shared in the EO-use socio-technical system (e.g. making EO data accepted as a legitimate source of information by banks assessing the expected performance of wind offshore projects).

In terms of socio-technical systems' dynamics, co-design type 2 consists in *identifying and linking up with the ongoing dynamics of an EO-use socio-technical system that are partly unknown* by assessing and creating the promising anchoring points.

c) Co-design type 3

It is theoretically defined as a situation where the level of unknown is considered low for the problem space and high for the solution space. This especially occurs when the pilot does not have sufficient knowledge on the EO-use socio-technical system to be able to target a specific problem that EO data could address, but faces a number of issues related to the operationalisation or long-term maintenance of an EO-based solution addressing this identified problem. A large expansion of the solution space is thus needed until a point where the viability of problem-solution can be ensured by EO-based solution developers.

In this perspective, co-design type 3 aims at establishing a certain form of *technological anchoring*, consisting in building the engineering required for operationalising EO-based solutions addressing identified problems. This involves *network anchoring* consisting in building specific relationships between relevant representatives of solution developers with other actors of the EO-emergence socio-technical system (e.g. providers of technical infrastructures, other data providers, organisations taking charge of commercialisation

aspects). As noted for co-design type 1, all pilot members might not be concerned by this action but only the ones that need to reshape their partner network to sustain the required efforts towards long-term operationalisation of the solution. This co-design type also entails some forms of *institutional anchoring: cognitive* as it consists in elucidating new visions related to the engineering infrastructure required to sustain the EO-based solutions, *economic* by creating or reshaping specific forms of contracts (e.g. between a research lab and a spin-off supporting engineering and commercialisation aspects), *normative* by establishing certain forms of standards to be shared in the EO-emergence socio-technical system (e.g. standards related to the release of in-situ measurements).

In terms of socio-technical systems' dynamics, co-design type 3 consists in *leveraging ongoing dynamics of the EO-emergence socio-technical system* (in case ongoing dynamics bring new resources for supporting the operationalisation efforts, such as the emergence of cloud computing infrastructures), *and potentially influencing these dynamics* (for example by reshaping the existing network of actors through the creation of new forms of partnerships).

d) Co-design type 4

It is theoretically defined as a situation where the level of unknown is considered high for both problem and solution spaces. This situation might appear as particularly challenging as it involves the most substantial learning processes. Our empirical investigation reveals that this type of co-design appears as relevant only when the pilot already has significant knowledge on the EO-use socio-technical system through previous developments of EO-based solutions. A large exploration of both problem and solution spaces can thus be reasonably handled by the pilot with the objective of building new problem-solution pairs.

Co-design type 4 thus aims at enhancing a certain form of *technological anchoring* that consists in exploring the specifications of future EO-based solutions, by taking advantage of the existing ones. This involves *network anchoring*, between relevant pilot members belonging to the EO-emergence socio-technical system and niche or regime actors of the EO-use socio-technical system, willing to take part in such a joint exploration effort. This can be illustrated by the pilot involved in building EO-based solutions to better predict the influx of sargassum algae on Caribbean beaches having negative environmental and economic impacts for local actors. The pilot already provides local actors with a 6-month ahead prediction

bulletin of algae influxes, and aims to sustain and expand this solution, potentially by exploring several ways of stimulating the emerging actors involved in tackling the negative impacts of algae influxes. This co-design type also entails some forms of *institutional anchoring: cognitive* as it consists in elucidating new visions and promises associated with the future uses of EO data (e.g. exploring how sargassum forecasts could be provided following the model of weather forecasts), *economic* by creating or reshaping specific forms of contracts (e.g. extending the scope of partnership with existing users or creating new partnerships with others), *normative* by introducing certain forms of standards on future uses of EO data or on the related production and maintenance infrastructure.

In terms of socio-technical systems' dynamics, co-design type 4 can thus be described as a way of *identifying and stimulating future promising dynamics of both EO-emergence and EO-use socio-technical systems* (e.g. further mobilising actors involved in collecting or transforming algae).

e) Occurrences of the different types

Table 3 shows that several types appear more frequently than others, especially type 1 in the short term and type 4 in the long term. The predominance of type 1 over the other types in the short term can be largely explained by the initial configuration of the project as the pilots were expected to have identified at least one potential user organisation to join the project. But interestingly, the existence of other types show that the pilots face heterogeneous issues beyond further specification of EO-based solutions for identified actors. This especially suggests that the identification of relevant users might be actually more complex than expected (type 2), or that the pilots are also concerned with other issues related to the long-term sustainability of developed EO-based solutions (type 3) and their further expansion (type 4). The predominance of type 4 in the long term seems consistent as this type requires stringent conditions that can only be met after primary problem-solution pair developments and associated learning on the EO-use socio-technical systems.

3) Analysing the combination of the four co-design types relevant for one case study

Another order of outcomes consists in analysing how the different types of co-design might combine within the context of one single pilot. First considering *a given time horizon* (short-term or long-term), it appears that several co-design types are relevant for one single pilot, hence underlining that *co-design types are not exclusive*. This seems pretty much consistent as each co-design type corresponds to complementary anchoring objectives concerning different actors. For example, at the same time, the pilot might be willing to strengthen a collaboration with identified actors (type 1), while also willing to explore other use cases of EO data in different EO-use socio-technical systems (type 2). Second, the results show that *the relevant co-design types are distributed over time*, confirming the usefulness of considering different time horizons. According to the definition of these types, a certain temporal trajectory could be expected: (1) *co-design type 2* to learn on partly unknown EO-use socio-technical systems and find relevant actors that would ensure linking up with the system's dynamics; (2) *co-design type 1* to build the adapted relationships with the relevant actors identified in type 2; (3) *co-design type 3* to build the engineering and infrastructure of the EO solution, in order to meet the lists of requirements identified in type 1; (4) *co-design type 4* to explore future uses and associated solutions based on the first uses built through previous co-design types.

However, the analysis of the pilots shows that this temporal trajectory cannot be systematically followed. Indeed, the pilot appears to regularly face unexpected changes within the EO-emergence or EO-use socio-technical systems, leading to a switch between different types of co-design. Several pilot cases give telling examples of this phenomenon. Indeed, some pilots had to transform the initially planned co-design type 1 or type 4 into a type 2, because the actors initially identified as relevant users had changed their priorities, declining their initial interest for collaboration (due to Covid-19 crisis in one case, due to the internal restructuration of the company in another case). Moreover, in some cases, a type 3 can be launched without being preceded by a thorough type 1. Indeed, the identified problem (required as a starting point of type 3) is not necessarily derived from specific user requirements, but might also result from the dynamics of the EO-emergence socio-technical system (e.g. to adapt to the identified competitors going towards a certain direction).

These results highlight that *the combination of relevant co-design types for a given case study might evolve over time*, especially to adapt to the continuous evolution of the different socio-technical systems.

Type	Design space	Multi-system anchoring	Link with STS dynamics
1	<p>Problem-related unknown: identified problems that might need further specification</p> <p>Solution-related unknown: solutions requiring limited development efforts leveraging existing building blocks</p> <p>Learning processes to build problem-solution pairs: slight co-expansion of problem and solution spaces</p>	<p>Technological: enhancing the specifications of novelty-based solutions addressing identified problems</p> <p>Network: relevant novelty developers and identified users (niche/regime actors of novelty-use STS)</p> <p>Institutional: new articulation of technical and user-related aspects (<i>cognitive</i>), reshaping existing forms of contracts (<i>economic</i>), introducing rules limited to the identified users (<i>normative</i>)</p>	<p>Supporting identified novelty-use STS dynamics by anchoring the novelty into relevant niche/regime actors of this STS</p>
2	<p>Problem-related unknown: problems unclearly identified</p> <p>Solution-related unknown: solutions requiring limited development efforts leveraging existing building blocks</p> <p>Learning processes to build problem-solution pairs: large on problem space, limited on solution space</p>	<p>Technological: building and sharing the legitimacy of novelty-based solutions</p> <p>Network: relevant novelty developers & niche/regime actors of newly targeted novelty-use STS</p> <p>Institutional: building new visions and promises associated with the novelty uses (<i>cognitive</i>), building new forms of contracts (<i>economic</i>), introducing shared standards on the novelty uses (<i>normative</i>)</p>	<p>Identifying and linking up with ongoing novelty-use STS dynamics by assessing and creating the favourable entry points for anchoring</p>
3	<p>Problem-related unknown: identified problems that might need further specification</p> <p>Solution-related unknown: solutions requiring extensive development research efforts</p> <p>Learning processes to build problem-solution pairs: large on solution space, limited on problem space</p>	<p>Technological: building the engineering required for operationalising novelty-based solutions addressing identified problems</p> <p>Network: relevant novelty developers & niche/regime actors of initial novelty-emergence STS</p> <p>Institutional: building new visions for the novelty production and maintenance infrastructure (<i>cognitive</i>), building new forms of contracts (<i>economic</i>), introducing shared standards on the novelty production and maintenance infrastructure (<i>normative</i>)</p>	<p>Leveraging or influencing initial novelty-emergence STS dynamics to strengthen the anchoring viability based on strong engineering and operationalisation efforts</p>
4	<p>Problem-related unknown: problems unclearly identified</p> <p>Solution-related unknown: solutions requiring extensive development or research efforts</p> <p>Learning processes to build problem-solution pairs: large co-expansion of problem and solution spaces</p>	<p>Technological: exploring the specifications of future novelty-based solutions based on existing ones</p> <p>Network: relevant novelty developers & niche/regime actors of novelty-emergence and novelty-use STS</p> <p>Institutional: expanding visions and promises associated with the novelty based on existing uses (<i>cognitive</i>), reshaping/building contracts (<i>economic</i>), introducing shared standards on future novelty uses or production and maintenance infrastructure (<i>normative</i>)</p>	<p>Identifying and stimulating future promising dynamics of both initial novelty-emergence and novelty-use STS</p>

Table 4: Synthesis of the relevance of each type of co-design according to the characteristics of the design space, the effects from a niche development perspective, and the contribution to the dynamics of EO and usage STS (STS used for "socio-technical system")

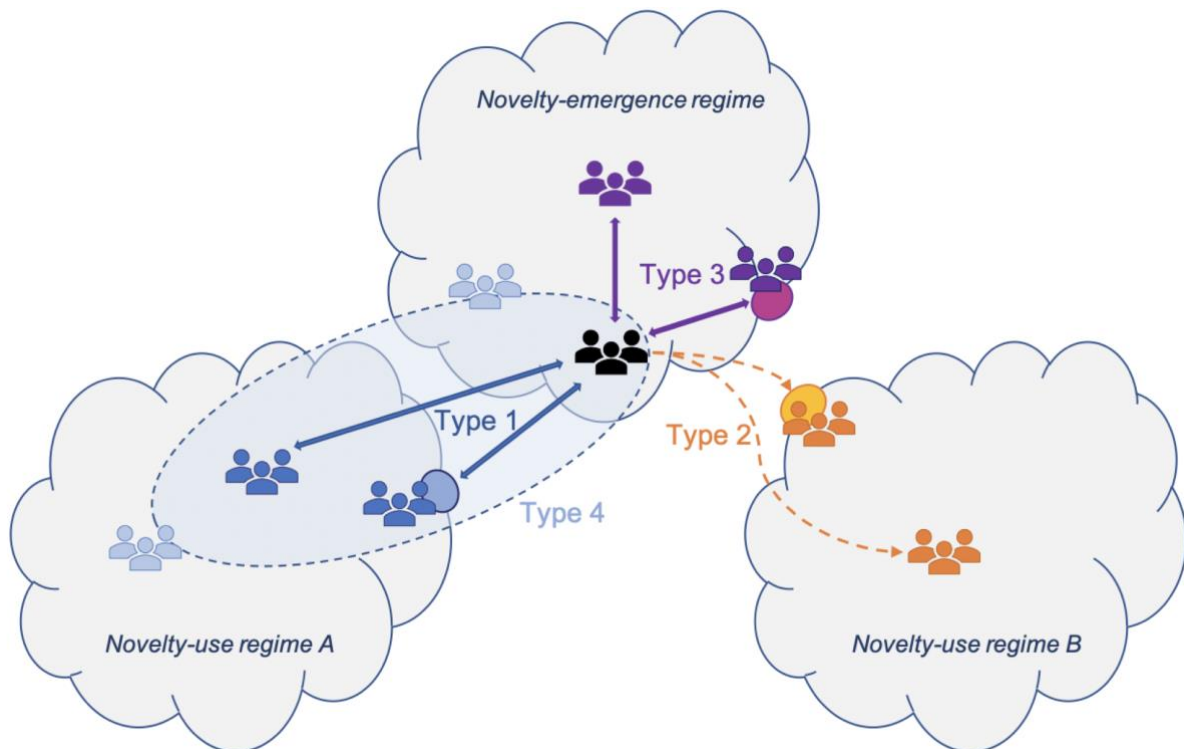


Figure 3: Graphical representation of the different co-design types based on the associated forms of network anchoring, inspired by the simplified representation of socio-technical systems (STS) proposed in Elzen et al. [32]. Regimes are represented by irregular forms to underline their constant transformations. Niches are located at the edges of regimes with a partial overlapping zone (e.g. accounting for shared technical components, actors operating both in the regime and the niche). Novelty developers are represented in black. **Type 1** consists in enhancing network anchoring with identified relevant niche/regime actors of a novelty-use STS (in dark blue). **Type 2** consists in identifying niche/regime actors that might be promising anchoring points in a newly targeted novelty-use STS (in orange). **Type 3** consists in reshaping novelty anchoring with niche/regime actors of the novelty-emergence STS to sustain the engineering of identified novelty-based solutions (in purple). **Type 4** consists in expanding existing anchoring with existing or new niche/regime actors to explore future novelty-based solutions based on existing ones (in lighter blue).

V. Discussion

In this section, we discuss key contributions of the paper, for both transition research and design and innovation management research, especially advancing research on collaborative innovation for grand challenges and sustainability transitions.

1) A multi-system co-design framework used as a diagnostic tool to identify relevant anchoring actions at different time horizons

Considering transition research, our empirical investigation of twenty-seven case studies suggests that the framework of four co-design types plays an important role in helping novelty developers clarify their anchoring strategy. This multi-system co-design framework indeed *provides novelty developers with a diagnostic tool to identify and sequence their anchoring efforts by focusing on certain aspects at once (as delimited in each co-design type)*. Each co-design type indeed frames the relevant forms of anchoring actions to conduct. The

distribution of different types over time especially allows novelty developers to undertake ambitious and intricate learning processes by progressively addressing a reasonable amount of unknown at each step. An initial situation with a high level of unknown on both problem and solution spaces could be addressed by first focusing efforts on problem expansion while limiting solution expansion (type 2), or the other way round (type 3), then followed by other types until viable problem-solution pairs can be reached. To be noted that the assessment of relevant types for each pilot only mirrors the 'ex-ante' vision of the pilot on the relevant forms of anchoring actions, it thus does not account for how these actions will be effectively implemented in reality. It especially appears that the pilot might actually change its strategy compared to what was initially planned, in reaction to potential unexpected developments (see for the example the switch from type 1 to type 2 due to a decreased interest of previously identified users). However, these changes do not undermine the guiding effect provided by the framework: having an explicit framework indeed enhances the ability of actors to more easily react to unexpected developments by switching from one frame of anchoring actions to another one, as defined in the different co-design types.

Our investigation also leads us to propose several enrichments of the anchoring concept as defined by Elzen *et al.* [32]. First, the co-design framework enriches our understanding on the possible interplay between the three forms of technological, network and institutional anchoring activities, that seems to play a critical role in ensuring a successful anchoring process [32], [33]. In each co-design type, the three forms of anchoring appear to be highly complementary. More specifically, it is worth noting that technological anchoring is considered as the driver of the anchoring strategy reflected on by the pilots, defining their main objectives according to the targeted developments of the technology. Interestingly, this technological anchoring takes broader forms than making the technology more specific to given user needs as previously described in literature similarly to type 1 [32]–[34]: it can also involve building and sharing the legitimacy of the novelty at the larger scale of the socio-technical system (type 2), building the engineering required for operationalising novelty-based solutions addressing identified problems (type 3), or building the specifications of future novelty-based solutions by taking advantage of the existing ones (type 4). Although being the initial driver of the pilots' considerations, each co-design type also underlines how technological anchoring needs to be supplemented by specific forms of network anchoring and institutional anchoring.

A second enrichment of the anchoring concept concerns the nature of anchoring mechanisms. Elzen *et al.* [32] highlight the continuous and long-term efforts involved in newly or more firmly connecting a certain novelty to its environment, but consider that anchoring ends up when durable links are created. Our study tends to suggest that such links cannot be actually considered as durable once and for all, as the environment into which the novelty anchors might evolve itself, potentially following unexpected new dynamics. To account for this evolutionary character of the environment into which the novelty anchors, we thus propose that anchoring should not be considered as a temporary process followed by durable links, but rather as an *ever-running process*, in which a novelty becomes newly connected, connected in a new way, or connected more firmly to a certain environment (regime or niche actor of a socio-technical system), *specifically considering that this environment is constantly evolving either stimulated by the connected novelty or due to other external factors*. Anchoring could thus be compared to a *grafting* process, underscoring the ‘living’ feature of the process drawing parallels with the biological world of plant grafting where a tissue of plant (the novelty) is added to growing plants (niche or regime of a socio-technical system considered as a living body) to make the plants further grow (transition dynamics) by taking advantage of the characteristics of the grafted tissue. In this perspective, anchoring does not only concern the newly targeted novelty-use socio-technical systems, but rather *jointly concerns the novelty-use socio-technical systems and the novelty-emergence socio-technical system*, as the latter also undergoes continuous transformations, thus requiring repeated efforts to reshape the connections of the novelty with its initial emergence environment.

By taking a closer look at managerial practices, our research also offers complementary insights on how to sustain fruitful interactions between different socio-technical systems through this process of anchoring. Sutherland *et al.* [34] especially unveil the benefits of creating a so-called ‘fiat’ regime supporting the interactions of two pre-existing regimes while preserving their respective structures and dynamics, but also underscore the inherent difficulty in ensuring its long-term sustainability. In the EO context, the investments of the European Commission in projects supporting the development of specific managerial practices such as co-design could be interpreted as the creation of such a ‘fiat’ regime between the EO-emergence regime and various EO-use regimes. However, differing from the cases reported by Sutherland *et al.* [34], this ‘fiat’ regime does not only consist in setting new rules and regulations guiding transition dynamics, but rather aims at developing the capacities

of relevant actors of establishing robust and sustainable interactions between socio-technical systems. This gives another perspective to the creation of such a ‘fiat’ regime, that could be rather considered as a temporary support to experiment, implement and embed good practices that could be later sustained by the actors themselves.

Regarding the issue of accelerating sustainability transitions, the impact of an anchoring strategy supported by co-design on transition dynamics is hard to directly assess. However, this paper proposes an improved understanding of how speeding-up transitions could be operationally supported by specific managerial practices, “shying away from merely describing the temporal dynamics transitions” as encouraged by Sovacool and Geels [31]. The co-design framework indeed proves to be helpful in *developing the ability of actors to further interact with transition dynamics*, by continuously identifying, adapting to, enhancing and provoking dynamics at regime and niche levels of the different socio-technical systems. Recent works have also highlighted the role of novelty users that might have different profiles and contributions in shaping sustainability transitions [42]–[44]. Our research has taken the view of novelty developers but also suggests that the nature of considered users plays an important role in the anchoring process. It seems especially crucial to identify the type of users that will be adapted to a given design objective (e.g. considering a large variety of users with various competencies in co-design type 2, but a tendency to focus on relevant actors with sufficient novelty-related competencies for co-design type 1, or with broad exploration competencies for co-design type 4).

2) Enriching the forms of collaborative innovation for sustainability transitions: diagnostic dimension and multi-system perspective of co-design and resource-based vs. challenge-based collaborative innovation

Taking the perspective of design and innovation management literature, this research also contributes to deepen our understanding of the possible forms of collaborative innovation, especially in the context of addressing grand challenges.

First, our study sheds an original light on co-design. Literature largely reports on co-design by considering the protocols and range of possible toolkits to organise collective design sessions involving multiple actors such as probes, demonstration tools, or visual displays [45], [46], [71]–[73]. In these approaches, the nature of the involved actors is identified by the team implementing co-design and is considered as an initial input of the process. Our paper shows

that co-design does not only consist in the actual organisation of collective design sessions but might also include a *diagnostic dimension* to identify what are the relevant actors to be involved and for what purposes (as defined by the different co-design types of the framework developed in the paper). This diagnostic dimension intervenes as a preliminary phase prior to the actual implementation of design sessions, but it should also be regularly reassessed to take into account possible evolution of the socio-technical systems. The elicitation of such a diagnostic dimension is actually connected with the general context in which co-design takes place. Indeed, the co-design theoretical framework elaborated in this paper corresponds to a situation where co-design does not occur within one single socio-technical system - e.g. focusing on the transitions of the agricultural system [45], or the energy system [46] – but in a *multi-system* perspective involving interactions between multiple and evolving socio-technical systems. The heterogeneity between these socio-technical systems complexifies the range of potential actors to be involved in the design process, thus requiring supplementary efforts to identify and frame the relevant setting for subsequent collective design sessions. This multi-system perspective on co-design also echoes recent advances in other streams of works in innovation management, especially calling for further research on open innovation processes expanding the concept of openness (initially related to knowledge exchange across organisational boundaries) towards openness at an industry or larger societal scale [12], [14], [74], in which digital technologies play a specific role in crossing existing boundaries [75], [76].

Second, our research also leads us to better distinguish between different forms of collaborative innovation supporting sustainability transitions. The co-design approach described in this paper could be indeed categorised as a so-called '*resource-based*' form of collaborative innovation, differing from a so-called '*challenge-based*' form that literature more largely focuses on. The difference between '*resource-based*' and '*challenge-based*' lies in the nature of the trigger and driver of the collaborative process. In the '*resource-based*' case, the collaborative process starts from a specific novelty (in the sense given by Elzen *et al.* [32], i.e. a new technology, a new technical concept or a new socio-technical practice) that has been initially developed by an initial pool of actors (e.g. EO data) and attempts at transforming it into an actionable resource for a larger number of actors facing grand challenges. Taking a problem-solving perspective, the actors steering this form of collaborative innovation should not be reduced to mere problem solvers: they rather act as resource providers to support others in their own problem-solving processes. It is worth

highlighting that this novelty is not directly a resource for grand challenges: such a resource is actually built through the collaborative innovation process. The objective of *resource-based* collaborative innovation could thus be summarised as *creating the infrastructure and the conditions into which multiple actors might better tackle their own challenge-related problems*. By contrast, a *challenge-based* collaborative innovation process is triggered by challenge-related objectives and aims at *organising a joint exploration of solution paths responding to or progressing towards these challenge-related objectives*. Considering a problem-solving perspective, this would consist in formulating problems (although not clearly defined) and searching for solutions given this problem. This last perspective seems to prevail in the last management studies on collaborative innovation for grand challenges, e.g. depicting the involvement of advocacy groups in search consortia for joint search of solutions in EU-funded projects [9], NGOs transforming the social interactions of local groups to tackle social inequality [7], the creation of local ventures in response to the 2010 Haiti earthquake [10], or the implementation of dedicated open innovation approaches to enhance sustainability in the food and beverage industry [13], or to respond to the recent Covid-19 crisis [12]. In transition research, the anchoring mechanisms described so far also correspond to a ‘challenge-based’ approach, as the novelty is anchored to address a certain identified challenge, such as designing an integrally sustainable animal production system [33], or the development of biogas to address waste management issues and renewable energy production [34]. It is worth noting that ‘challenge-based’ does not necessarily mean that the problem is considered as fixed and clearly defined once and for all. Ferraro *et al.* [2] indeed underline that the objective of collaboration should be “repeated participation, inscription, and experimentation, continuously generating novelty and sustaining engagement”, rather than “reaching some final conclusion”.

3) Limits and perspectives for further research

Several limitations and perspectives for further research can be highlighted. First, it will be worth further testing and enriching our co-design framework based on additional empirical contexts (either in EO or in other fields). To be noted that we do not claim for exhaustivity with the typology of co-design. Indeed, it might be relevant in some contexts to refine the four co-design types in other sub-types to better address specific aspects of the design process

under consideration. Nevertheless, although our results are derived from an investigation in the particular EO context, we can reasonably assume that they might also be insightful for other empirical contexts facing similar issues, especially considering how other forms of novelties (such as generic technologies with a large range of potential applications, but also potentially new kinds of practices) could also be transformed into resources for various actors facing grand challenges.

Moreover, the co-design framework focuses on aspects of co-design preceding the implementation of dedicated collective design sessions. Further research is thus needed to explore the protocols and tools that could support the implementation of such collective design sessions in the context defined by each co-design type. This will involve examining existing co-design tools and practices more closely [46], [71], [73], [77], and potentially extend them or build new ones to handle the specificities and complexities of the design processes at stake. Beyond co-design literature, several works related to collaborative innovation for grand challenges already indicate that these protocols should take care of several important dimensions. This includes creating a certain form of “participatory architecture”, providing the necessary structure and rules of engagement to ensure long-term involvement of the actors, as proposed by Ferraro *et al.* [2] and as recently advocated for the organisation of hackathon sessions in the context of Covid-19 crisis [12]. These protocols should also involve creating specific drivers and guidelines to go beyond the mere accumulation of facts (e.g. by merely collecting expressed user needs) and rather encourage second-order learning involving the expansion of cognitive frames, as encouraged by transition scholars [40].

Furthermore, the successful implementation of the co-design framework relies on specific conditions that would deserve further investigation. It indeed first relies on specific kinds of actors (corresponding to the “relevant pilot members” mentioned above) that are able to sustain anchoring processes in a multi-system perspective by circulating among the different socio-technical systems and articulating the variety of actors involved in building EO-based solutions and the actors identified as potential users of the solutions. Elzen *et al.* [32] have already identified specific forms of “hybrid actors” having a crucial role in bringing about anchoring processes through their ability to circulate between niche and regime. Hence, it will be worth wondering whether these crucial actors identified in the paper could be compared to such hybrid actors in a multi-regime perspective, or if they could be comparable to other figures of actors described in innovation management literature, such as innovation

intermediaries [78]–[81], or “cross-application managers” involved in the development of generic technologies [82]. Second, it is also worth reflecting on the role we had as researchers in making the co-design framework operational for novelty developers. Indeed, the pilots found extremely useful to have a third-party actor providing them with an external look at their activities, thus encouraging them to clarify their anchoring strategy beyond what they would spontaneously do on their own. This element calls for further research on how this co-design framework could be integrated in novelty developers’ workflows on an operational basis beyond the project timeline and through which organisational forms.

Finally, more largely considering the issue of tackling grand challenges, how to monitor the progress of collaborative innovation towards this objective remains eminently challenging, be it in a ‘challenge-based’ or ‘resource-based’ perspective. In a ‘challenge-based’ approach, Ferraro *et al.* [2] especially highlight the difficulty in accounting for the complex and heterogeneous visions of worth that could be potentially relevant to measure the progress towards an evolving target. In a ‘resource-based’ perspective, the exact effect of the collaborative innovation process cannot be easily expressed in terms of quantified challenge-related targets (e.g. reducing emissions of n %). Our co-design framework, however, suggests that a resource-based approach could be monitored in terms of quality of the anchoring processes, by monitoring how technological specifications have been enriched, the new forms of partnerships that have been initiated, and the institutional rules that have been further entrenched (e.g. expansion of cognitive frames thanks to learning processes, introduction of new standards or economic relationships). Nevertheless, significant efforts are still needed to build operational indicators based on these considerations. In addition to exploring such indicators, it could also be interesting to further investigate how ‘challenge-based’ and ‘resource-based’ collaborative innovation might complement each other in tackling grand challenges.

VI. Conclusion

This paper has proposed to investigate how a multi-system co-design framework could help the developers of a certain novelty steer an anchoring strategy into multiple socio-technical systems. A framework of four co-design types has been derived from transition research and design and innovation management research. Each type corresponds to specific

learning processes entailing various levels of unknowns, and can be described according to the form of technological, network and institutional anchoring it aims to enhance, and the related interactions with the transition dynamics of the novelty-emergence and novelty-use socio-technical systems. The framework has been tested and enriched empirically in an inductive approach, drawing on 27 case studies undertaking co-design efforts to anchor Earth observation data into multiple socio-technical systems.

Contributing to transition research, we have argued that this co-design framework provides novelty developers with a *diagnostic tool supporting them in clarifying their anchoring strategy by considering an evolving combination of different co-design types distributed over time*. This especially allows them to better handle the complexity of learning processes involved in sustainability transitions by sequencing their design efforts. We have also proposed several enrichments of the anchoring concept, shedding light on specific complementarities between the three forms of technological, network and institutional anchoring, and underscoring the continuous and endless character of anchoring, illustrated by the 'grafting' biological metaphor accounting for the constant evolution of socio-technical systems to which a novelty might come to be connected.

Contributing to design and innovation management research, our paper endeavours to enrich the current understanding of possible forms of collaborative innovation. Compared to existing literature on co-design, the co-design framework elaborated in this paper especially includes two original aspects: (1) it does not occur within the boundaries of a single socio-technical system but occurs across *multiple socio-technical systems*, echoing recent works in open innovation calling for further considerations on innovation processes at a large societal scale; (2) it does not focus on the actual organisation of collective design sessions but sheds light on a preliminary *diagnostic dimension*, that appears to be crucial in a multi-system perspective to identify the relevant actors to be involved in subsequent design sessions and for what purposes. Furthermore, concerning collaborative innovation for grand challenges, the paper introduces a distinction between *challenge-based* collaborative innovation organising collective action directed towards a targeted challenge, and *resource-based* collaborative innovation organising collective action to create the infrastructure and the conditions into which multiple actors might benefit from a certain resource (e.g. Earth observation data) to better address their respective challenge-related problems on their own.

These considerations open up interesting perspectives for practitioners. For policy-makers, our research especially encourages them to consider specific forms of innovation policies supporting the anchoring of promising novelties into multiple socio-technical systems. These policies could go beyond usual funding or regulation instruments, limited in terms of ensuring anchoring sustainability, *by focusing on enhancing the ability of actors to identify and interact with transition dynamics of these socio-technical systems on their own*. That might include encouraging these actors to build a certain expertise in co-design as suggested in our paper, but also certainly other forms of competencies that could be further assessed. This echoes recent scholar discussions, suggesting that innovation policies for grand challenges should consist neither in mere demand-orientation nor in supply-push instruments but rather in policies that would be less interventionist but rather directed towards creating conditions for others to self-organise and experiment around grand challenges [4]. Finally, our results offer insights for practitioners considering how Earth observation data, or other kinds of novelties with significant use potential, could contribute to tackling grand challenges. In this respect, our research suggests that building interactions between the novelty-emergence and novelty-use socio-technical systems might be beneficial but also require intensive efforts that should not be overlooked. In this regard, navigating across heterogeneous socio-technical systems appears as a crucial capacity that might need to be strengthened and assumed by specific actors. Further research in different empirical contexts could confirm the relevance of such approaches, possibly enrich them, and develop adapted guiding tools.

Appendix

SC	Pilot's rationale	Pilot's members (pilot leader in bold)	Targeted user groups	Interviewees for framework validation
Agriculture	Supporting global agricultural monitoring	Independent research institute (Belgium) Public research institute (Netherlands) Independent research institute (Austria) National meteorological institute (Germany) Non-profit public-private network (Greece) Public research institute (Israel)	National, regional and global agricultural organizations and administrations	- Team leader of the Agricultural Applications group (<i>pilot leader organization</i>) - Researcher in the Agricultural Applications group (<i>pilot leader organization</i>)
	Supporting farmers for CAP (Common Agricultural Policy) compliance and farm performance	Public research institute (Greece) Private ICT company (Greece) Independent research & technological organization (Belgium) Public research institute (Netherlands) Independent research institute (Austria) National meteorological institute (Germany) Non-profit public-private network (Greece)	Paying agencies Agriculture cooperatives Agro-consultants Insurance companies	Researcher in the institute of astronomy, astrophysics, space applications and remote sensing (<i>pilot leader organization</i>)
	Supporting farmers with crop insurance services	Public research institute (Netherlands) Independent research institute (Austria) Public research institute (Ethiopia)	Digital finance & payment services' provider Insurance Companies Micro-Finance Institutions, Various key-government agencies	- Lead of the Spatial Agriculture and Food Security research theme (<i>pilot leader organization</i>) - Senior researcher in the department of natural resources (<i>pilot leader organization</i>)
	Supporting agriculture activities at farm level	Independent research institute (Belgium) Independent research institute (Austria) National meteorological institute (Germany) Non-profit public-private network (Greece) Public research institute (Israel)	Agro-consultants Policy Makers Agricultural cooperatives Agro-industries Farmers	- Team leader of the Agricultural Applications group (<i>pilot leader organization</i>) - Researcher in the Agricultural Applications group (<i>pilot leader organization</i>)
	Surveilling mercury pollution	Public research institute (Italy) Public research institute (Germany) Public research institute (Italy)	Health communities Conference of Parties (UN Minamata Convention) Local and regional authorities	- Research director of the institute (<i>pilot leader organization</i>) - 3 senior researchers in atmospheric pollution & remote sensing (<i>pilot leader organization</i>)
Health surveillance	Surveilling persistent organic pollutants	Public research institute (Czech Republic) Public research institute (Italy)	Policy makers Regional organisation groups and Conference of Parties (UN Stockholm Convention)	- Director of the Centre of toxic compounds & of the Stockholm Convention Regional Centre (<i>pilot leader organization</i>) - Head of the Data services core facility (<i>pilot leader organization</i>)

	Improved monitoring of air quality and related health issues, to support public health assessment and urban planning.	Public research institute (Greece) Private ICT company (Greece) National space agency (Germany) National meteorological institute (Finland) Public research institute (Italy) Independent research institute (Austria)	International organizations (UN, WHO) National authorities Cities and municipalities Private sector (insurance, real estate, industrial companies)	- Research director of the department for environmental research & sustainable development (<i>pilot leader organization</i>) - Researcher in the same department (<i>pilot leader organization</i>)
Renewable energy	Nowcasting and short-term forecasting of solar energy	Public research institute (Greece) Public research institute (Switzerland) Public research institute (France) Private company (France) International inter-governmental organization (Egypt)	Ministries of Electricity and Renewable Energy Power generation operators Power distribution and transmission operators	- Researcher in the department for environmental research & sustainable development (<i>pilot leader organization</i>) - Senior researcher in remote sensing & energy (<i>Swiss pilot member</i>)
	Encouraging high photovoltaics penetration in urban areas	Public research institute (France) Private company (France) National Space Agency (Germany)	Energy providers Citizens Collectivities & urban planners	- Director of the research institute (<i>pilot leader organization</i>) - Senior researcher in remote sensing & energy sector (<i>pilot leader organization</i>) - Research engineer expert in databases and web services (<i>pilot leader organization</i>) - 2 senior researchers in remote sensing & solar energy (<i>German space agency</i>)
	Providing wind resource assessment tools for the offshore wind industry	Public research institute (Denmark)	Offshore wind farm developers Offshore wind farm operators Consultants Research, academia, educators	- 2 senior researchers in remote sensing & wind energy (<i>pilot leader organization</i>) - Technical lead of wind resource assessment applications (<i>pilot leader organization</i>)
Biodiversity	Monitoring & modelling the states of ecological ecosystems by integrating remote sensing & in-situ data	Public research institute (Italy) Public research institute (Spain) Independent non-profit research organization (Netherlands) Independent non-profit research organization (Greece) Public research institute (Germany)	Technical staff and managers of European Protected Areas (PAs)	- Director of the department of geosciences and Earth resources (<i>pilot leader organization</i>) - 4 senior researchers in remote sensing & ecological ecosystems (<i>pilot leader organization & representatives of the other pilot's organizations</i>)
	Building a common registry of observation & experimentation facilities of ecological ecosystems	Public agency (Austria) Public research institute (Germany) Public research institute (Serbia)	Research communities Technical and scientific staff of project groups European and national conservation agencies	- Head of department for ecosystem research and environmental information management (<i>pilot leader organization</i>) - Data engineer in the same department (<i>pilot leader organization</i>) - Researcher in remote sensing & ecological ecosystems (<i>German organization</i>)

				- Manager of the product development center (Serbian organization)
	Providing harmonized sets of variables for biodiversity observation and conservation	Public research institute (Germany) Public research institute & agency (Finland) Public research institute (Netherlands)	Research communities Monitoring agencies that inform ministries	4 senior researchers in remote sensing & ecological ecosystems (<i>pilot leader organization & representatives of each other pilot's organization</i>)
Water resources	Providing historical and near-real time information for a number of hydrological variables	National meteorological & hydrological institute (Sweden) Public research institute (Luxembourg)	Geological institutes Water and marine authorities	Senior researcher in hydrology, leading research in forecasting of water variables (<i>pilot leader organization</i>)
	Estimating flood hazard at a large-scale	Public research institute (Luxembourg) National meteorological & hydrological institute (Sweden)	Members of the Global Flood partnerships: Research and meteorological institutes R&D Companies Governmental authorities	Senior researcher, leading the group on remote sensing & natural resources modelling (<i>pilot leader organization</i>)
	Providing a near-real time visibility score for specific diving locations	Independent research institute (UK)	Diving centers, commercial divers	- Senior researcher in remote sensing (<i>pilot leader organization</i>) - Linux data analyst & support engineer (<i>pilot leader organization</i>) - Data and web services engineer (<i>pilot leader organization</i>)
	Predicting the landing areas and severity of the sargassum algae season	Private company (France)	Local authorities Research community Private sector (insurance companies, tourism, algae valorization)	Project manager in the environmental applications department (<i>pilot leader organization</i>)
	Improving monitoring and regulation of fishing activities in the Northeast Atlantic	Public agency (Portugal) Private company (Portugal)	Fishermen associations NGOs International organizations scientific communities Regional and national authorities	- 2 senior researchers in marine science (<i>pilot leader organization</i>) - 2 project engineers (<i>private company</i>)
	Disaster resilience	Improving monitoring of volcanic eruptions	Public research institute (Italy) Public research institute (Greece) Public research institute (Italy) Public research institute (France) National meteorological institute (Finland) National meteorological institute (Iceland)	Special units in meteorological institutes Air traffic managers Civil protection authorities Local authorities Policy makers
Developing a tool for fire and risk assessment and supervision scenarios		Public research institute (Italy) European body – SatCen Public research institute (Greece)	National and regional civil protection authorities Hydro-Meteorological Agencies	Research director - expert in atmospheric modelling and statistical analysis of extreme events (<i>pilot leader organization</i>)

	Assessing geohazard vulnerability of cities and critical infrastructures	Public agency – geological survey (Spain) European body – SatCen Private company (Italy)	Urban managers and civil protection authorities Energy and infrastructure companies Policy makers	Researcher in remote sensing & geosciences (<i>pilot leader organization</i>)
	Assessing geohazard vulnerability of agriculture	Public research institute (Greece) Private ICT company (Greece) Independent research institute (Austria)	Insurance company Farming cooperatives	- Senior researcher in remote sensing for hydrology, floods, natural disasters (<i>pilot leader organization</i>) - Researcher in remote sensing and atmospheric modelling (<i>pilot leader organization</i>)
Climate	Providing territorial and ocean carbon and greenhouse gas fluxes information to support the Global Carbon Project	Research Infrastructure (headquarters in Finland) Public research institute (Germany) Public research institute (Norway) Public research institute (UK) Public research institute (UK) National meteorological institute (Finland) Public research institute (Finland) Non-profit research institute (Italy)	Global Carbon Project Research and international organizations related to GHG and ocean carbon emissions	Researcher with specific focus on data analysis for ecology (<i>pilot leader organization</i>)
	Providing information to municipalities on heat waves, heavy precipitations and extreme weather events	National meteorological institute (Germany) National meteorological institute (Finland) National meteorological institute (Austria)	Cities and municipalities Consultancy company for urban climatology and wind research	- Researcher in the department of climate and environment consultancy (<i>pilot leader organization</i>) - 2 senior researchers in seasonal and climate applications (<i>Finnish meteorological institute</i>) - Head of the data center for climate change (<i>Austrian meteorological institute</i>)
	Providing seasonal forecasting of forest harvest conditions to support forest industry	National meteorological institute (Finland) Public research institute (Finland)	Private companies in forest management support R&D company	Senior researcher in seasonal and climate applications (<i>pilot leader organization</i>)
	Supporting hydropower companies by better predicting hydrological conditions	National meteorological institute (Finland)	Hydropower or energy companies	Senior researcher in remote sensing and geoscience (<i>pilot leader organization</i>)
	Helping transportation and tourism sectors to better prepare for seasonal changes	National meteorological institute (Finland) Public research institute (Greece)	Tyres companies Tourism stakeholders	- 2 senior researchers in seasonal and climate applications (<i>pilot leader organization</i>) - 2 researchers (senior & research assistant) in remote sensing & atmospheric modelling (<i>Greek organization</i>)

Acknowledgement

This research work has been carried out within the *e-shape* project, funded by the European Union's Horizon 2020 research and innovation programme under grant agreement No 820852. The authors warmly thank all *e-shape* partners for their contributions, and especially Thierry Ranchin, scientific coordinator of the project.

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RÉSUMÉ

Nos modèles de société sont aujourd'hui remis en question par de grands défis sociaux et environnementaux. Ces difficultés poussent notamment à explorer de nouvelles formes d'action collective, qui dépassent les frontières habituelles entre organisations et secteurs. C'est dans ce contexte que le « co-design » (ou co-conception) connaît aujourd'hui un fort engouement, répondant notamment au besoin d'organiser des processus collectifs de conception impliquant de multiples acteurs. L'organisation de tels processus s'avère néanmoins particulièrement complexe. Il s'agit en effet de relier des acteurs qui évoluent dans des sphères différentes, qui n'ont que peu d'intérêts communs, et qui peuvent même ignorer leur existence respective. Autrement dit, ces acteurs semblent être séparés par une forme de « grande distance », apparaissant ainsi comme largement inconnus les uns des autres. Dans de telles conditions, une quelconque action collective semble loin d'être assurée, voire même envisageable.

Cette thèse contribue à éclairer dans quelles conditions et sous quelles formes le co-design peut aider à organiser de l'action collective dans des situations de grande distance. En particulier, la thèse propose un modèle de co-design à « haute résilience ». Ce modèle a été construit et expérimenté dans le domaine de l'observation de la Terre, où la problématique de grande distance se pose de manière particulièrement aiguë, notamment entre des fournisseurs de données et de potentiels utilisateurs qui restent très largement étrangers les uns des autres.

Les résultats de cette recherche ont été formalisés dans trois articles académiques, chacun correspondant à un niveau d'analyse spécifique (micro, méso, macro). Ces résultats ont permis de caractériser le modèle de co-design à « haute résilience » selon quatre dimensions : ses méthodes et outils (« substrat technique »), son objectif cible (« philosophie gestionnaire »), les rôles et caractéristiques des acteurs impliqués (« relations organisationnelles »), et les mécanismes de conception à l'œuvre (« raisonnement de conception »).

La thèse confirme ainsi que le co-design peut organiser de l'action collective même dans des situations de grande distance extrême où cela paraît *a priori* hautement improbable, à condition que le modèle de co-design prenne bien en compte cette problématique de grande distance. Le modèle de co-design à haute résilience a déjà de fortes retombées pratiques dans le domaine de l'observation de la Terre. Ce modèle ouvre également de nombreuses perspectives quant à l'organisation de nouvelles formes d'action collective, notamment dans l'optique de relier transitions digitales et écologiques.

MOTS CLÉS

Co-conception, action collective, transitions écologiques, innovation digitale, Observation de la Terre

ABSTRACT

In the face of contemporary socio-environmental challenges, our current models of society are increasingly faced with their own limits. Consequently, organisations and individuals are led to explore new forms of collective action spanning current organisational and sectorial boundaries. In this context, the use of "co-design" has been flourishing in the last years to respond to the need of organising intricate innovative and collective processes requiring the involvement of multiple actors. However, these efforts prove to be eminently challenging. Indeed, it involves bridging people who usually evolve in highly different spheres, who have very little in common, and who might not be even aware of the existence of one another. In other words, the actors seem separated by a form of "grand distance", making them appear as largely unknown to each other. In such conditions, collective action seems nowhere near guaranteed, if even possible.

The thesis contributes to eliciting under which conditions and which forms co-design can help organise collective action in these situations of grand distance. In particular, the thesis proposes a model of co-design named "resilient-fit", that has been built and experimented in the field of Earth Observation (EO), where the issue of grand distance unfolds in a particularly extreme way, specifically between EO data providers and potential users that remain mostly unknown to each other.

The results of this research are analysed at three different levels (micro, meso, macro), each being the focus on one academic paper. Drawing on these results, the resilient-fit co-design model is characterised according to four dimensions: the methods and tools supporting the co-design process ('technical substratum'); the overall purpose which co-design is aimed at ('management philosophy'); the characteristics and roles of the actors involved ('organisational relations'); and the underlying design mechanisms ('reasoning logic').

By eliciting the resilient-fit co-design model, the thesis shows that co-design can indeed help organise collective action even in extreme situations of grand distance where collective action seems highly improbable, provided that co-design adequately takes into account the issue of grand distance. Although further efforts are still needed, the resilient-fit co-design model has already been largely praised by practitioners of the EO field. More broadly, it also offers multi-fold perspectives for management researchers and practitioners, suggesting new forms of collective action in times of digital and sustainability transitions.

KEYWORDS

Co-design, collective action, sustainability transitions, digital innovation, Earth Observation