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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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## **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 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 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, sustainability 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 the 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.

### A. 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.

## B. 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.

### C. 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.

- 1) 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*.

## 2) 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 recall 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><b>Problem-related unknown:</b> identified problems that might need further specification</p> <p><b>Solution-related unknown:</b> limited development efforts leveraging existing building blocks</p> <p><b>Learning processes to build problem-solution pairs:</b> slight co-expansion of problem and solution spaces</p>	<p><i>Co-design type 2</i></p> <p><b>Problem-related unknown:</b> unknown or little-known problems to be identified</p> <p><b>Solution-related unknown:</b> limited development efforts leveraging existing building blocks</p> <p><b>Learning processes to build problem-solution pairs:</b> large on problem space, limited on solution space</p>
	High	<p><i>Co-design type 3</i></p> <p><b>Problem-related unknown:</b> identified problems that might need further specification</p> <p><b>Solution-related unknown:</b> extensive development efforts</p> <p><b>Learning processes to build problem-solution pairs:</b> large on solution space, limited on problem space</p>	<p><i>Co-design type 4</i></p> <p><b>Problem-related unknown:</b> unknown or little-known problems to be identified</p> <p><b>Solution-related unknown:</b> extensive development efforts</p> <p><b>Learning processes to build problem-solution pairs:</b> 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.

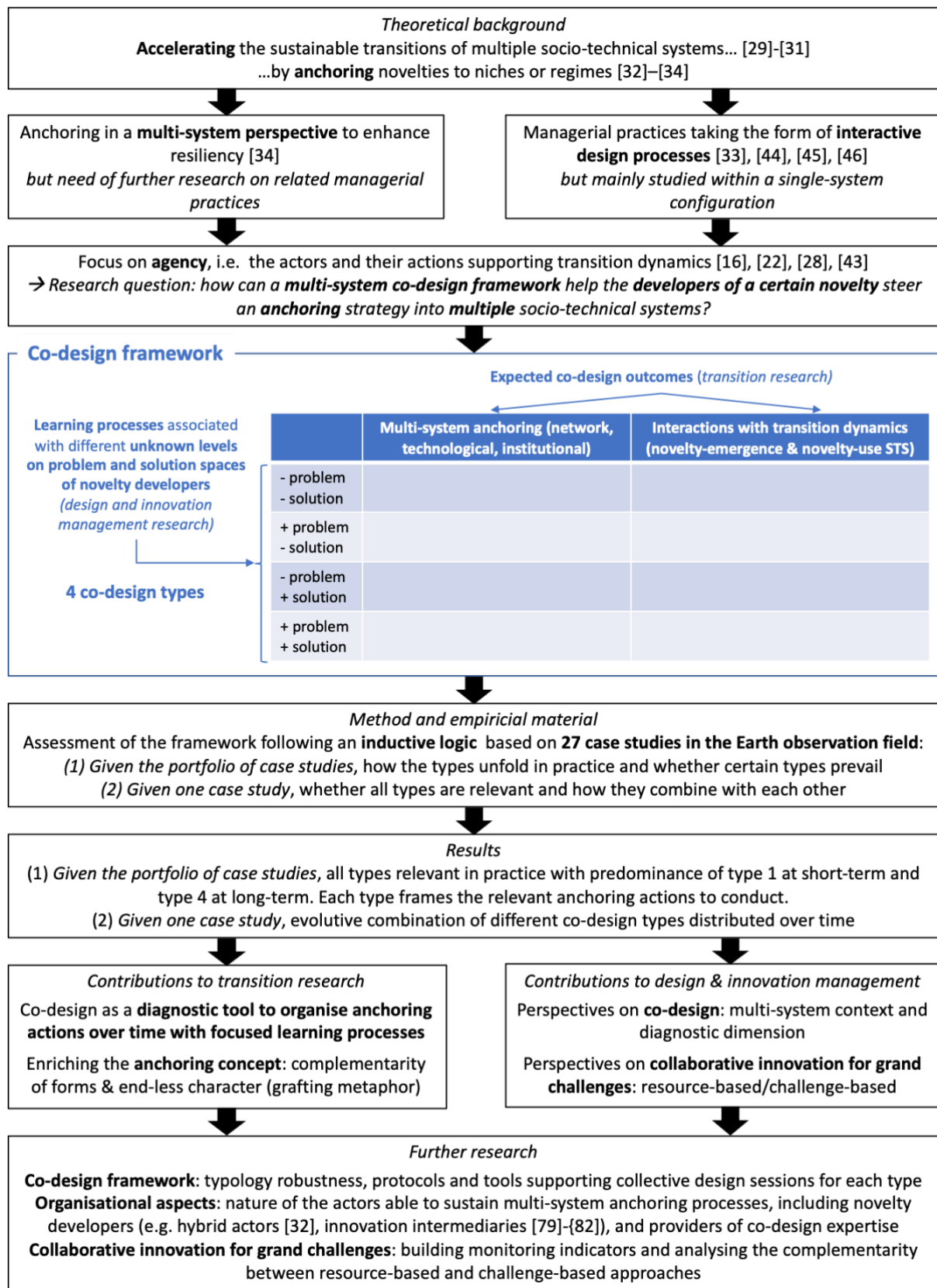


Figure 1: Synthesis of the overall argumentation developed in the paper, summarising theoretical background (precising how the co-design framework is built), method and empirical material, main results, research contributions and further perspectives (STS used for “socio-technical system”)

### 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.

#### A. 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.

## B. 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 must interact 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.

### C. 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 the pilots with useful support to steer 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 and synthesised in Table 2. 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.

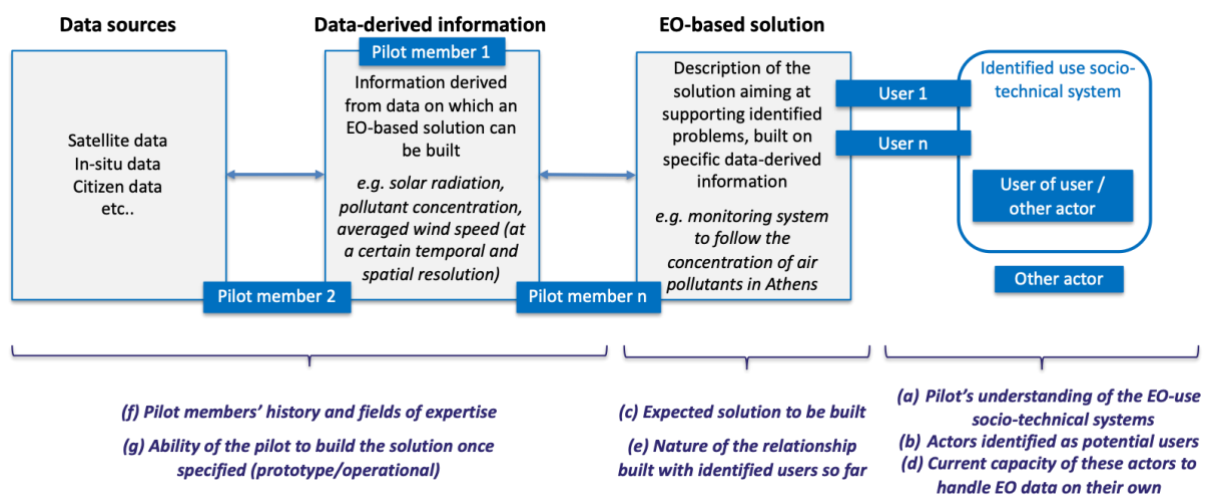


Figure 2: Template built for preliminary data analysis and link with the points of analysis guiding the interviews

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.

	<b>Data collection</b>	<b>Data analysis</b>
<b>Step 1 (Sept 2018-May 2019)</b> <i>Building an overall understanding of the empirical context</i>	<b>Secondary sources</b> (pilots’ application forms to the project, academic publications, websites) <b>Field notes</b> (kick-off meeting, informal interactions with project members)	<b>Construction of a template</b> for heterogeneous data compilation, <b>tested and validated by researchers and practitioners</b> (one-day meeting with a pilot and formalisation in a reviewed and shared deliverable report)
<b>Step 2 (Nov 2019)</b> <i>Shared validation of the co-design framework with project coordinators</i>	<b>2h meeting</b> with the seven showcase coordinators, the project management team and the work -package leaders	<b>Validation of the framework of four co-design types</b> by all participants of the meeting, and agreement on undertaking further assessment on all case studies
<b>Step 3 (Nov 2019-July 2021)</b> <i>Assessment of the co-design framework for each pilot (in total 27 case studies)</i>	<b>1h30 semi-guided interview with each pilot</b> (see table in <i>Appendix</i> for the details on the participants)	<b>Assessment of each pilot’s context and identification of relevant co-design types validated by all researchers and practitioners:</b> - <b>Report written by researchers before each interview</b> , including specific points of analysis and filled-up template - <b>Report updated by researchers, shared and validated after each interview by all participants</b> , 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.

### A. 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)

#### 1) 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 integrating 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).

## 2) 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.

### 3) 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 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 pairs 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).

#### 4) 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).

#### 5) 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 shows 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.

#### B. 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 pilots appear 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	<b>Problem-related unknown:</b> identified problems that might need further specification	<b>Technological:</b> enhancing the specifications of novelty-based solutions addressing identified problems <b>Network:</b> relevant novelty developers and identified users (niche/regime actors of novelty-use STS)	<b>Supporting identified novelty-use STS dynamics</b> by anchoring the novelty into relevant niche/regime actors of this STS

	<p><b>Solution-related unknown:</b> solutions requiring limited development efforts leveraging existing building blocks</p> <p><b>Learning processes to build problem-solution pairs:</b> slight co-expansion of problem and solution spaces</p>	<p><b>Institutional:</b> 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>	
2	<p><b>Problem-related unknown:</b> problems unclearly identified</p> <p><b>Solution-related unknown:</b> solutions requiring limited development efforts leveraging existing building blocks</p> <p><b>Learning processes to build problem-solution pairs:</b> large on problem space, limited on solution space</p>	<p><b>Technological:</b> building and sharing the legitimacy of novelty-based solutions</p> <p><b>Network:</b> relevant novelty developers &amp; niche/regime actors of newly targeted novelty-use STS</p> <p><b>Institutional:</b> 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><b>Identifying and linking up with ongoing novelty-use STS dynamics</b> by assessing and creating the favourable entry points for anchoring</p>
3	<p><b>Problem-related unknown:</b> identified problems that might need further specification</p> <p><b>Solution-related unknown:</b> solutions requiring extensive development research efforts</p> <p><b>Learning processes to build problem-solution pairs:</b> large on solution space, limited on problem space</p>	<p><b>Technological:</b> building the engineering required for operationalising novelty-based solutions addressing identified problems</p> <p><b>Network:</b> relevant novelty developers &amp; niche/regime actors of initial novelty-emergence STS</p> <p><b>Institutional:</b> 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><b>Leveraging or influencing initial novelty-emergence STS dynamics</b> to strengthen the anchoring viability based on strong engineering and operationalisation efforts</p>
4	<p><b>Problem-related unknown:</b> problems unclearly identified</p> <p><b>Solution-related unknown:</b> solutions requiring extensive development or research efforts</p> <p><b>Learning processes to build problem-solution pairs:</b> large co-expansion of problem and solution spaces</p>	<p><b>Technological:</b> exploring the specifications of future novelty-based solutions based on existing ones</p> <p><b>Network:</b> relevant novelty developers &amp; niche/regime actors of novelty-emergence and novelty-use STS</p> <p><b>Institutional:</b> 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><b>Identifying and stimulating future promising dynamics</b> 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")

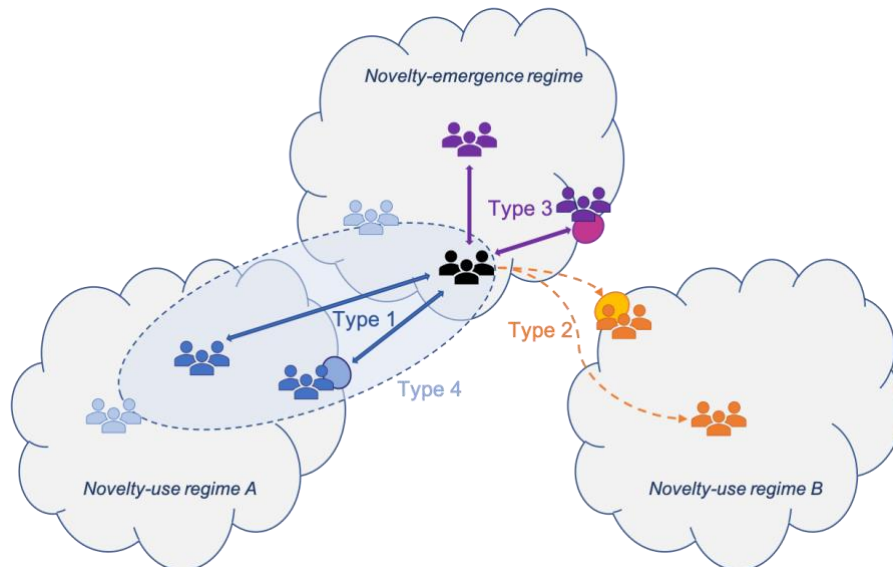


Figure 3: Graphical representation of the different co-design types based on the associated forms of network anchoring, inspired by the simplified representation of socio-technical systems (STS) proposed in Elzen et al. [32]. Regimes are represented by irregular forms to underline their constant transformations. 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.

### A. 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 mainly 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).

#### B. 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 deepening 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”.

### C. 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 target 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 article investigates 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 unknown, 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 not consist neither in mere demand-oriented or supply-push instruments but rather in policies that would move away from orchestration 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 requires 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 supported 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	<b>Independent research institute (Belgium)</b> 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	<b>Public research institute (Greece)</b> 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	<b>Public research institute (Netherlands)</b> 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	<b>Independent research institute (Belgium)</b> 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> )
Health surveillance	Surveilling mercury pollution	<b>Public research institute (Italy)</b> 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> )
	Surveilling persistent organic pollutants	<b>Public research institute (Czech Republic)</b> 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.	<b>Public research institute (Greece)</b> 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	<b>Public research institute (Greece)</b> 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	<b>Public research institute (France)</b> 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	<b>Public research institute (Denmark)</b>	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	<b>Public research institute (Italy)</b> 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 &amp; representatives of the other pilot's organizations</i> )
	Building a common registry of observation & experimentation facilities of ecological ecosystems	<b>Public agency (Austria)</b> 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	<b>Public research institute (Germany)</b> 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 &amp; representatives of each other pilot's organization</i> )
<b>Water resources</b>	Providing historical and near-real time information for a number of hydrological variables	<b>National meteorological &amp; hydrological institute (Sweden)</b> 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	<b>Public research institute (Luxembourg)</b> 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	<b>Independent research institute (UK)</b>	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	<b>Private company (France)</b>	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	<b>Public agency (Portugal)</b> 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> )
	<b>Disaster resilience</b>	Improving monitoring of volcanic eruptions	<b>Public research institute (Italy)</b> 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		<b>Public research institute (Italy)</b> 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	<b>Public agency – geological survey (Spain)</b> 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	<b>Public research institute (Greece)</b> 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	<b>Research Infrastructure (headquarters in Finland)</b> 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	<b>National meteorological institute (Germany)</b> 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	<b>National meteorological institute (Finland)</b> 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	<b>National meteorological institute (Finland)</b>	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	<b>National meteorological institute (Finland)</b> 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> )

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