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Participatory downscaling of global SSP–RCP scenarios to local fisheries social–ecological systems

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Abstract

Policymakers and managers need projections of the trajectories of change in human societies and natural ecosystems to plan actions to address the potential consequences of global change. There are many projections at the global scale, but these need to be downscaled to local marine social–ecological systems to plan targeted interventions. We aimed to provide policy-relevant projections of the consequences of climate change and socio-economic orientations for the fisheries of the French North Sea and the Mediterranean. Our approach consisted of a downscaling of global scenarios of IPCC Shared Socioeconomic Pathways (SSPs) and Representative Concentration Pathways (RCPs) for the 2100 horizon. We engaged with fisheries managers, policymakers, scientific experts, and NGOs, and co-constructed four contrasting scenarios through interdisciplinary participatory workshops. Our approach ensured strong anchoring in regional, national, and local contexts and provided references to fisheries scenarios. We then conducted a novel comparative analysis of SSP–RCP scenario narratives from different local marine social–ecological systems in the same country. Across all scenarios, 83% of the themes highlighted by the stakeholders were common between the two social–ecological systems. However, within the themes, at a more detailed level, only 30% of the narrative elements were mentioned in both systems, reflecting the specificity and richness of these downscaled scenarios and their relevance to local management. We also integrated disruptive changes and emotional aspects by conducting a novel standardized emotion analysis using an artificial intelligence language model. Overall, these downscaled scenarios identified pathways to be avoided, as well as potential actions for transformative change, mitigation, and adaptation to global change at the local scale. Our protocol allowed us to address some criticisms of SSP–RCP scenarios by helping to bridge science–policy gaps and to focus more on human–nature relationships.

Keywords Global change · Scenario downscaling · Fisheries · Interdisciplinary research · Participatory research · Stakeholder engagement

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Introduction

Marine social–ecological systems (SES) are facing a series of increasing and unprecedented anthropogenic impacts since the 1970s (Díaz et al. 2019; Garcia-Soto et al. 2021; O'Hara et al. 2021; Williams et al. 2022). These impacts affect the climate system, biogeochemical cycles, and ecosystem functioning, erode biodiversity, and jeopardize human livelihoods and well-being.

Policymakers and managers around the world have acknowledged the current magnitude of global change, its future trends, and the urgency to mitigate it and adapt to its impacts. However, despite increased pledges and targets to tackle global change, current policies adopted thus far are insufficient to achieve the objectives set by the international community such as the 2030 targets of the Convention on Biological Diversity, the Sustainable Development Goals (SDGs), and those of the Paris Climate Agreement (Buchanan et al. 2020; Meinshausen et al. 2022; Sachs et al. 2023). Achieving these goals requires transformative changes and solutions (Sachs et al. 2019; IPCC 2022).

To engage in transformative pathways, policymakers and managers need to anticipate future global changes and the future impacts of their actions. In that sense, scenarios and models function synergistically, wherein scenarios delineate potential trajectories for drivers influencing change or policy interventions, while models extrapolate the implications of these scenarios on the environment and the associated benefits to human well-being (IPBES 2016). However, despite the increasing integration of interdisciplinary research in models and scenarios of SES, achieving future projections of SES is challenging due to the uncertainty and complexity of socio-economic and biophysical interactions (Rounsevell et al. 2021). To generate a set of alternative futures, the scientific community has often used different scenario categories, namely exploratory (“What can happen?”), predictive (“What will happen?”), and normative scenarios (“How can a specific target be reached?”) (Börjeson et al. 2006). Scenarios are thus generated to explore the spectrum of possible, probable, or preferable trajectories of the human–Earth system under different assumptions and a wide range of focuses such as trends in climate change, demography, biodiversity, ecosystem services, and geo-resource supply and demand (e.g., Moss et al. 2010; Pereira et al. 2010; Jones and O'Neill 2016; Kubiszewski et al. 2020; Watari et al. 2020). In this article, we will focus on scenario narratives, also referred to as scenario storylines, which, as defined by IPBES (2023), are “qualitative descriptions of plausible future world evolutions, describing the characteristics, general logic and developments underlying a particular quantitative set of scenarios”.

Shared Socio-economic Pathways (SSPs) and Representative Concentration Pathways (RCPs) of the Intergovernmental Panel on Climate Change (IPCC) have been the most widely used scenarios globally over the last decade (O'Neill et al. 2020; Burgess et al. 2023). Combined in pairs of SSP–RCP scenarios to span the range of plausible futures, these scenarios are projections of global socio-economic trajectories (SSPs), linked to greenhouse gas concentration trajectories (RCPs) and, therefore, to different levels of climate change mitigation and adaptation challenges. SSP–RCP scenarios serve as benchmarks for comparing possible futures of human societies and biodiversity under climate change (O'Neill et al. 2020; van Ruijven et al. 2022).

Currently, two of the most common limitations of the research on these global scenarios to inform decision-making and inspire action are: (1) their lack of downscaling to regional and local scales, across a broad spectrum of environmental and socioeconomic conditions (Frame et al. 2018), and (2) poor legitimacy by not considering the plurality of visions, values, and knowledge existing across regions and local SES (Kok et al. 2016; Duncan et al. 2018). The latter includes a recognition of biodiversity and the diversity of human–nature relationships, to better align with the Nature Future Framework developed by the Intergovernmental Science–Policy Platform on Biodiversity and Ecosystem Services (IPBES) and the 2050 vision adopted by the Convention on Biological Diversity (CBD) (Alexander et al. 2023). These challenges can be overcome by adopting a transdisciplinary approach (Lang et al. 2012; Norström et al. 2020), relying on a scientific interdisciplinarity and including a diversity of stakeholders in the process of co-creating local scenarios (Mauser et al. 2013; Pereira et al. 2020). Note that the most widely used and inclusive definition of stakeholders refers to those individuals or representatives of a group who have an interest in a given decision, i.e., all who can influence that decision and all who are affected by it (Chevalier and Buckles 2019).

Over the UN Decade of Ocean Science for Sustainable Development (2021–2030), attention is paid to the co-development of inter- and transdisciplinary scenarios to inform decision-makers and mobilize citizens and industries for sustainable transformations of marine and coastal SES (Nash et al. 2021; Gaill et al. 2022; Melbourne-Thomas et al. 2023). The initiatives of co-construction of such scenarios are encouraging, but still preliminary. Indeed, they are mainly developed on a large scale, based on scientific experts, so greater efforts are still needed to ensure a plurality of local visions, values, and knowledge, notably by involving decision-makers, citizens, and industrial sectors (e.g., Maury et al. 2017; Zandersen et al. 2019; Pinnegar et al. 2021).

Capture fishing is one of the main sectors of activity at sea (FAO 2022). It contributes to food security with a

stabilized global production since the late 1990s, in parallel with an upward trend in fishing effort and overexploitation of fish stocks (van Anrooy et al. 2021; FAO 2022). Fishing has been the main driver of marine biodiversity loss over the last 50 years (IPBES 2019, Appendix 4), and climate change combined with overfishing is having major negative impacts on fisheries resources and marine ecosystems (Bindoff et al. 2019; Cheung et al. 2021; Tittensor et al. 2021). However, such risks of loss vary considerably at regional and local scales (Free et al. 2019; Payne et al. 2021; FAO 2022), and fisheries around the world need to anticipate and adapt based on local-scale projections.

Little research has focused on downscaling SSP–RCP scenarios to local marine SES, and even less has been applied to fisheries (van Ruijven et al. 2022). However, there may be significant differences between the evolution of marine SES at global and local scales, just as there may be large contrasts in the projections of the same scenarios in different localities. Comparisons of local scenarios are rarely addressed in scientific literature, and we hypothesized that the same global SSP–RCP scenario downscaled to different local SES could result in major differences and specificities between SES due to the diversity of environmental, social, economic, governance and technological conditions. This work aimed

at downscaling and comparing contrasted SSP–RCP scenario narratives for the fisheries of two French SES, in the Gulf of Lion (Mediterranean Sea) and the North Sea (North-east Atlantic Ocean) (Fig. 1). For this purpose, we implemented an interdisciplinary and transdisciplinary approach engaging fisheries stakeholders from the national to the local level. In collaboration with managers, scientists, and NGOs, we addressed the environmental and human characteristics of these two SES in order to co-construct relevant scenarios for long-term fisheries management. We then compared these narratives between the two SES for a given SSP–RCP scenario, which to our knowledge is a first for local marine SES in the same country. Finally, emotional integration is still extremely rare in future scenario research (Richter et al. 2023). However, this approach has the potential to overcome both psychological barriers to stakeholder engagement and cognitive biases that prevent their immersion in future scenarios, the implementation of adaptation and mitigation strategies, and the initiation of transformative change (Richter et al. 2023). Indeed, a promising avenue emerges from recent work in psychology, which suggests that imagining plausible futures has moderate to strong effects on individual affect (Schubert et al. 2020), and that adaptation to global change and societal transformation are strongly linked to

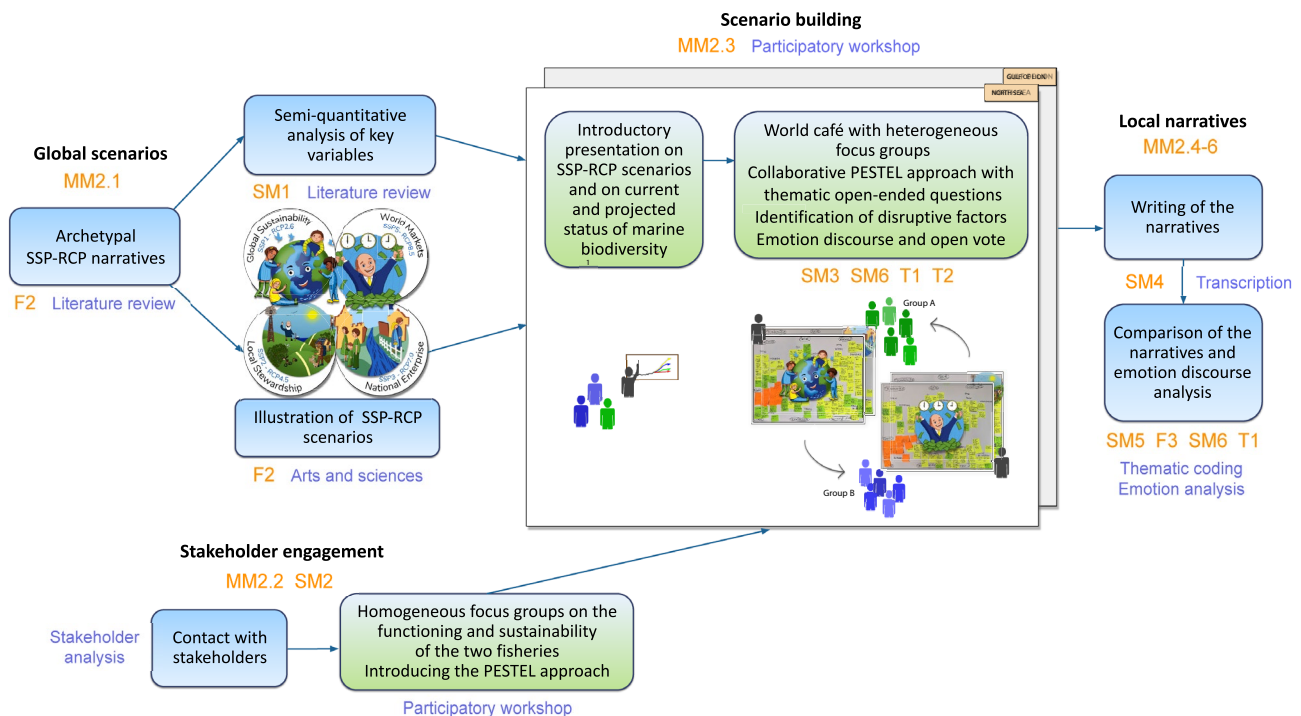


Fig. 1 Protocol for the participatory downscaling of SSP–RCP scenarios at the local scale. Preparatory and analytical steps are shown in blue, while participatory steps are shown in green. Orange text indicates methodological sections, figures, tables, and supplementary material related to these different steps: *MM* material and methods, *F*

figure, *T* table, *SM* Supplementary Material. Purple text indicates the type of action taken to complete each step of the protocol. Glossary: *SSP* shared socio-economic pathways, *RCP* representative concentration pathways, *PESTEL* political, economic, social, technological, environmental and legal analysis

stakeholders' perceptions, particularly positive and negative affect regarding the collective and individual changes at stake (van Valkengoed and Steg 2019; Schneider et al. 2021). In this context, we assessed stakeholders' feelings towards each of the co-constructed scenarios, as well as their perceived plausibility and preferences regarding the possibility of their realization.

Material and methods

The successive activities implemented for the co-construction and the comparison of local narratives for the French fisheries in the Gulf of Lion SES and the North Sea SES for the time horizon of 2100 are summarized in Fig. 1. Overall, we provided a detailed methodology of the participatory process and subsequent analyses, as researchers and practitioners have in recent years expressed a critical need for clear and explicit strategies for conducting transdisciplinary

research (Thompson et al. 2017; Djenontin and Meadow 2018).

Formulating global scenarios

We used the narratives of the four socio-political scenarios developed by the CERES European project (2016) as global narratives for four reference SSP–RCP scenarios of the latest IPCC report (2022) (Fig. 2): “World Markets” (SSP5–RCP8.5), “Global Sustainability” (SSP1–RCP2.6), “National Enterprise” (SSP3–RCP6.0), and “Local Stewardship” (SSP2–RCP4.5). To communicate these global change scenarios to the local stakeholders participating in the workshops, we worked with professional illustrators to depict these archetypal scenarios with cartoons symbolizing the key characteristics of each scenario and presented them to the stakeholders along with the CERES global narratives (Fig. 3). To allow stakeholders to quickly compare the impacts of global change across the four scenarios, we have added a common set of semi-quantitative key variables

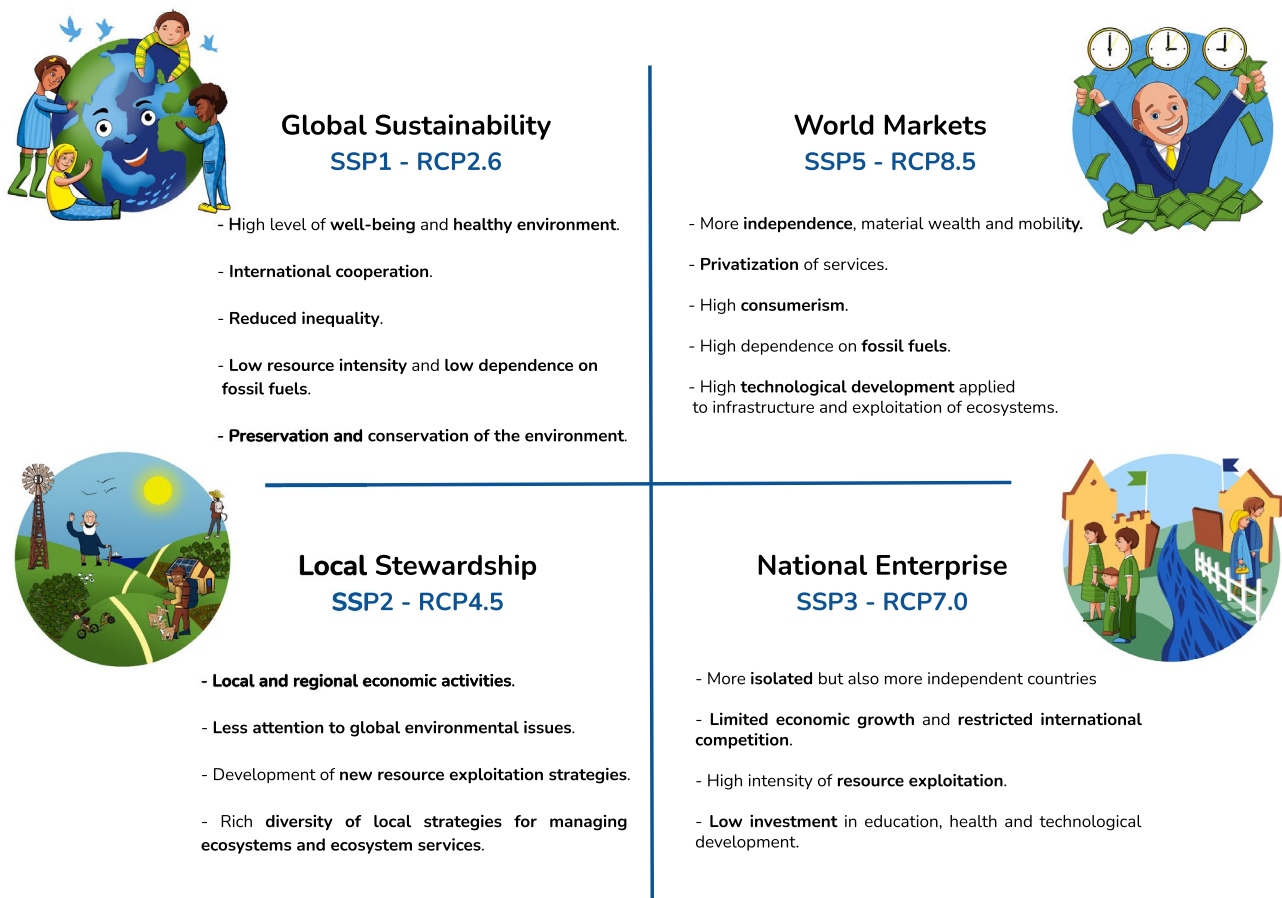


Fig. 2 Four contrasted narratives of the global SSP–RCP scenarios. Narratives were adapted from the EU CERES project (2016). Illustration: © CERES (2016) for the “Global Sustainability”, “World

Markets”, and “National Enterprise” scenarios and Raphaël Seguin (2022) for the “Local Stewardship” scenario

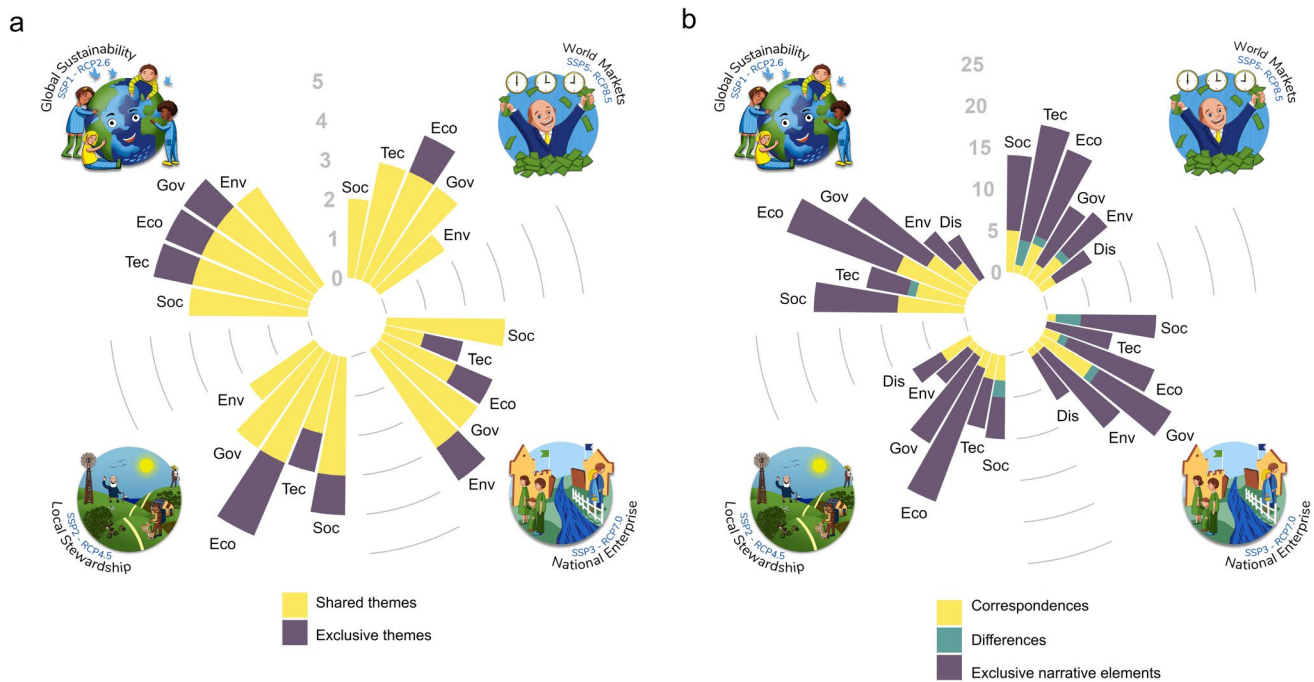


Fig. 3 Comparative discourse analysis of the co-constructed narratives between the Gulf of Lion and North Sea scenarios. **a** Shared and exclusive themes for each of the different dimensions explored: *Soc* social, *Tec* technology, *Eco* economy, *Gov* governance, *Env* environment. **b** All themes combined, number of correspondences and differences in narrative elements within themes in terms of patterns of

meaning between the two social–ecological systems, and exclusive narrative elements for each of the dimensions examined when no correspondence or difference was observed between the social–ecological systems. *Dis* disruptive factors, for all potential disruptive factors in the different scenarios

(i.e., human and environmental factors with a range of possible values to quickly characterize the state of an SES) for high-income countries extracted from the Organization for Economic Co-operation and Development (OECD) (Supplementary Material, Appendix 1). We determined the future values of these variables by 2100 from reference publications listed in the Appendix, along with quantitative projections of the SSP–RCP scenarios using Integrated Assessment Models (IAM) (reviewed by Riahi et al. 2017, version 2.0 of December 2018, <https://tntcat.iiasa.ac.at/SspDb/dsd?Action=htmlpage&page=10>).

Engaging stakeholders

We used a two-component (interests, influence) stakeholder analysis (Reed et al. 2009; Chevalier and Buckles 2019) to identify which stakeholders to engage in the scenario co-construction, focusing on their potential to be affected by the consequences of global and transformative changes in the fisheries sector and their influence in making and implementing decisions about these changes. After an initial phone call to explain the goals of the project and how participatory workshops operate, stakeholders who verbally agreed to participate were sent an explanatory e-mail requesting an appointment within their own organizations.

Stakeholders participated in two series of participatory workshops and gave free and fully informed written consent prior to each workshop. The first series aimed to foster stakeholder engagement and was focused on the functioning of the French fisheries in the Gulf of Lion and the North Sea and on the identification of key factors of the sustainability of the fisheries. We set up the first set of workshops as a series of 13 homogeneous focus group discussions from January to February 2022. In total, we interviewed 35 participants from the following organizations: five fish producer organizations, two local fisheries committees, the national fisheries committee, the State Department of Maritime Affairs, Fisheries and Aquaculture (DGAMPA), two NGOs working locally on fisheries sustainability, and two groups of local scientific experts. The second series of workshops focused on the co-construction of local contrasted SSP–RCP scenarios for the year 2100.

Co-constructing local scenarios

For both SES, we gathered heterogeneous stakeholder groups in May 2022: 12 participants from the Gulf of Lion SES at the Ifremer station in Sète and 13 participants from the North Sea SES at the Ifremer station in Boulogne-Sur-Mer. Participants came from the same organizations that

attended the first series of workshops, with the addition of two NGOs, and without the participation of the DGAMPA and one of the producer organizations of the Gulf of Lion (further details on the participating organizations in Appendix 2). Before starting the process of downscaling the SSP–RCP narrative scenarios, we gave an introductory presentation on the current and projected status of marine biodiversity, on the global SSP–RCP scenario framework and on the need to downscale these scenarios through a co-construction process. During the co-construction process, the global narratives, their cartoons, and the associated semi-quantitative indicators described in “[Formulating global scenarios](#)” were presented for each scenario and remained on display at all times on posters (A0 ISO 216 format). A two-group World Café workshop (Löhr et al. 2020) was designed to facilitate dialogue among a wide diversity of stakeholders and co-construct the four SSP–RCP scenarios over a 3-h period (Fig. 2). The two groups worked simultaneously on different scenarios, then by rotation, came to discuss and complete the work done by the other group. After a joint break, the two groups repeated this process for the two remaining scenarios. Trained in group facilitation techniques (Flick 2014; Russel 2017), three of the authors moderated the workshop while five scribes transcribed and displayed all of the dialogue in real time. To allow participants to project the impacts of global change scenarios on local fisheries, we conducted a PESTEL analysis (standing for Political, Economic, Social, Technological, Environmental, and Legal), which was conceptualized by Aguilar (1967) for analyzing the macro-environmental factors that impact an organization or an industry. It has been widely used by researchers and industries in scenario building (e.g., Quiceno et al. 2019; Pinnegar et al. 2021). In line with other researchers, we decided to combine the political and legal dimensions into a single “governance” dimension, because of their strong interrelatedness (e.g., Hill et al. 2014). To help participants engross themselves into each scenario in a relatively short time period and to collect specific information, we asked them thematic open-ended questions for each of the PESTEL dimensions (Appendix 3). In a second step, we asked participants to determine disruptive factors that could jeopardize the stability and the sustainability of the scenario. Finally, in a third step, we suggested that participants individually express their feelings about the co-constructed scenario in a written form. To ensure that as many thematic questions as possible were covered, the time taken to answer them collectively was timed so that each dimension was covered evenly. Once the four scenarios were co-constructed, a brief synthesis was made by the workshop facilitator and participants were invited to vote individually through an open voting process for the scenarios that seemed “most likely”, “most desirable” and “most undesirable”. To do this, each participant was provided with two stickers per

voting category, which they could stick on a single scenario or on two scenarios if they considered them to be a tie.

Writing narratives

Each statement made by a participant and transcribed by one of the scribes was hereafter referred to as a ‘narrative element’, and all narrative elements for a given scenario together constituted a scenario narrative. For each SSP–RCP scenario narrative, all narrative elements were organized into sections corresponding to the PESTEL dimensions that the participants had to address, plus a final section on the disruptive factors listed by the participants for each scenario (Appendices 4a–d). To enhance the readability of the scenario narratives, all narrative elements were inserted into sentences, taking care not to alter the voice and meaning of the participants. The narratives were then sent to the participants to confirm accuracy.

Comparing narratives

To compare each SSP–RCP narrative between the two SES, we applied the thematic coding procedure developed by Flick (2014) to the list of narrative elements organized by section (Appendices 5a–d). The first step consisted of a reflexive thematic analysis of each scenario narrative for the Gulf of Lion SES to determine the themes covered (Braun and Clarke 2006). In order to identify themes, it was first necessary to become familiar with the transcribed data set and then to systematically assign labels (or codes) of a few key words or short phrases to the narrative elements, which allowed the researchers to explain their meaning (see Terry et al. 2017 for a practical methodological guide). The compiled list of these labels was then used to identify themes, i.e., recurring patterns of meaning into which all narrative elements can be classified. The second step was to determine whether these themes from the Gulf of Lion scenario analysis also encompassed elements of the same scenario sections for the North Sea SES. If not, we considered whether the themes could be adapted to be integrative for both SES, and if not, we identified additional themes that incorporated the remaining narrative elements. This was an iterative process of modifying and identifying new themes until all narrative elements were grouped into themes. In the end, we obtained themes that were shared between the two SES and themes that were exclusive to one of the two SES. The iterative process resulted in a thematic structure, which is an organized set of sections, themes, and narrative elements for each scenario. Finally, at a more detailed level within shared themes, we were able to identify correspondences and differences in terms of patterns of meaning between narrative elements of the two SES. For example, for the Global

Sustainability scenario, within the Technology section and the “Motorization with clean energies” theme, there is a correspondence between the two SES that project the use of hydrogen in fisheries, but a difference in the other energies used for motorization, namely ammonia motorization for the Gulf of Lion and electric motorization powered by solar, wind, and wave energy for the North Sea (Appendix 5b). In this way, we were also able to identify the “exclusive narrative elements” that dealt with topics that were mentioned exclusively in one of the two SES, i.e., when no correspondence or difference was observed between the SES.

Analyzing emotions

We compiled all the emotion-related text passages that participants in the two workshops had written individually to express their feelings about each of the different co-constructed scenarios (Appendix 6). The strong overlap between the emotions perceived in the two SES and the small number of text passages on emotions overall led us to analyze them together for each scenario. Using the AI language model ChatGPT-3.5 Turbo (Brown et al. 2020, February 2024 stable release), for each scenario, we identified the main emotion expressed by the stakeholders for each emotion-related text passage, following a strict protocol (Appendix 6). To classify the emotions described in each of the text passages, the AI identified a mix of primary emotions according to the basic theory of emotions (Ekman 1992; Gu et al. 2019): fear, anger, joy, sadness, surprise, and disgust. From this mix of primary emotions, the AI used Russell’s Circumplex Model of Emotions (1980) to determine the main emotion corresponding to each text passage. Russell’s model reflects individuals’ subjective evaluations of their emotional experiences and classifies emotions along two independent dimensions: the valence which refers to the pleasantness or unpleasantness dimension of an emotion, and the neuropsychological concept of ‘arousal’ which refers to the physiological and psychological state associated with an emotion in which the sensory organs are aroused or stimulated to the point of perception, ranging from calm to excited or anxious states. Whereas in psychological research valence and arousal are often determined by direct physiological measurement or self-report, AI language models are trained to infer them indirectly from textual data by analyzing linguistic patterns and context. To account for the probabilistic nature of the Chat GPT language model (Radford et al. 2018) and, therefore, the variability of its responses, we repeated our protocol 10 times for each emotion-related text passage. The Chat GPT model generates a probability distribution over all the words in the query that is addressed to it, and

the final answer is determined by a stochastic sampling of this distribution.

Results

Implementing our methodology was successful in co-constructing four narratives of IPCC reference SSP–RCP scenarios for each local SES for the horizon 2100 (Appendices 4a–d). Workshop participants developed narrative elements for each of the PESTEL dimensions—social, technology, economy, governance, environment—as well as potential disruptive factors (e.g., Online Fig. 4). For each scenario, by answering to our thematic open-ended questions (Appendix 3), they provided detailed information on fishing gear types, technological development, working conditions, the social and cultural identity of the fishers, the dynamics of market prices and supply and demand, the economic strategies implemented, the governance model and some of the main management measures adopted, the main environmental impacts observed, the health status of the marine ecosystem and of the fishery resources, their monitoring and assessment, and the disruptive factors that could jeopardize the stability and the sustainability of each scenario.

Quantitative comparison of the narratives between social–ecological systems

Overall, considering the two heterogeneous focus group workshops, one held for the Gulf of Lion SES and the other for the North Sea SES, 64 themes were developed within the four narratives by the stakeholders for the two SES (Online Fig. 5), of which 17% were mentioned exclusively in one of the SES. Within the themes, 298 narrative elements were specified, of which 70% were exclusive to one of the two SES, while the remaining 30% of narrative elements consisted of 26% correspondences and 4% differences between SES in terms of meaning patterns.

For the economic dimension, workshop participants co-constructed more themes and narrative elements exclusive to one of the two SES. In terms of mean and standard deviation, 1.3 ± 0.4 exclusive themes and 13.3 ± 2.5 exclusive narrative elements per scenario were co-constructed by all participants together for the economic dimension, compared to 0.6 ± 0.4 exclusive themes and 8.7 ± 2.2 exclusive narrative elements for all other dimensions addressed. Narrative elements relating to disruptive factors were less numerous than for the PESTEL dimensions (1.8 ± 1.5 correspondences, no differences and 5.3 ± 0.8 exclusive narrative elements, compared to 3.2 ± 2.2 correspondences, 0.5 ± 0.7 differences, and 8.7 ± 2.2 exclusive elements on average for all dimensions addressed). Apart from the economic dimension

and disruptive factors, the number of themes and narrative elements varied little from one dimension to the next.

There was little variation in the total number of themes among scenarios (16 ± 1.6 themes). A larger total number of narrative elements was generated for the *Global Sustainability* scenario compared to the average (84 and 74.5 ± 6.8 narrative elements, respectively), while the *Local Stewardship* scenario was associated with the lowest number of narrative elements (65).

For each scenario, by comparing the narratives co-constructed for each of the two SES (Appendices 5a–d) we found that, on average, the North Sea participants contributed more exclusive themes and exclusive narrative elements (56% and 59%, respectively) than the Gulf of Lion participants (44% and 41%, respectively).

Qualitative comparison of the narratives between social–ecological systems

The *Global Sustainability* scenario (SSP1-RCP2.6) provided a wealth of narrative elements for each of the two SES, distributed within common themes around social progress, the transformation of the fishing fleets towards reduced environmental impacts and powered by a renewable energy mix, and the promotion of sustainable fishing that would be socially and economically valued, driven by a change in consumer habits and accompanied by a mutation of the processing and sales sectors. The socio-economic system would be supported by strong international cooperation for sustainable fisheries management, promoting good practices and discouraging those with the greatest environmental impacts via a system of incentives and taxation enforced by greater control. The governance model would also aim to integrate regional and local features through close collaboration with local stakeholders and would enjoy a high degree of social acceptability. Impacts on the two marine ecosystems would be reduced through integrated spatial planning of all maritime uses and a strong scientific monitoring of the health of the marine ecosystems and their exploited resources. Beyond these common narratives for both SES, North Sea participants emphasized the need for an ecosystem-based, adaptive fisheries management to strengthen the social–ecological resilience of the fisheries. They also envisioned a dynamic spatialized management of fishing zones and marine protected areas to account for climatic and environmental variability. They projected that sea-use changes, such as the implementation of marine protected areas and wind farms, would have a significant impact on offshore fishing, but not on small-scale coastal fishing. Participants from the Gulf of Lion planned an extension of the network of marine protected areas, combined with an enhanced level of protection. They also insisted on the future development of renewable marine energies such as offshore wind turbines, which

could serve as additional refuges and nursery areas for some marine species. North Sea participants added that industrial and grow-out aquaculture would be drastically reduced in favor of small-scale local aquaculture. There were no major differences between the two SES in terms of narrative elements, except for the technological dimension, for which the Gulf of Lion participants projected ammonia engines for ships, combined with the development of green hydrogen, while the North Sea participants projected an electric fleet powered by hydrogen and solar, wind and wave energy. Regarding the potential disruptive factors threatening the stability and the sustainability of this scenario, the Gulf of Lion participants mentioned the “emergence of socio-economic conflicts due to numerous regulatory constraints, the absence of tangible positive results in the short term, and efforts and costs too high to be endured in the medium to long term by the populations”. The North Sea participants projected that these threats would be manifold: the demographic growth could lead to an increase in seafood demand; the industrial fishing sector could refuse to commit to this transformation process, and engage in strong opposition lobbying; the technical complexity of the challenges mentioned in this scenario; the risk that the technological development would not be sufficiently focused and effective to ensure environmental protection and improved socio-economic conditions; and the weakening of the fishing industry, since the transition choices mentioned would correspond to a niche market and not to the majority of the seafood demand.

The common themes developed in the *World Markets* scenario (SSP5-RCP8.5) in terms of social, economic, and technological dimensions, revolved around the deterioration of socio-economic conditions leading to professional reconversion, rising oil prices and their strong impact on fishing, innovation and segmentation of the fishing fleets, various associated economic strategies supported by significant investment in research and development, and a booming aquaculture industry. To cope with rising fuel prices, the Gulf of Lion industry would shift to biofuels, while the North Sea industry would invest in the electrification of its fleets. In both scenarios, the governance model would tend towards self-regulation and systematically prioritize profit over environmental conservation. In the Gulf of Lion, European and state governance would persist, with managers eliminating regulatory barriers and taxes, notably on fuel, and multiplying public aid for fleet renewal and compensating for the low economic profitability of fishing companies. The most prosperous companies would accumulate these subsidies and access rights to fishery resources. In the North Sea, public governance would disappear, letting major industrial groups enter into multilateral agreements and set up a private system of Individual Transferable Quotas (ITQs). To maximize fish landings, different economic strategies would be implemented, in addition to fishing down the food web.

In the Gulf of Lion, for example, industrial fishers would focus on diversifying the small pelagic species exploited, with reduced selectivity, while in the North Sea, they would rely on highly selective, monospecific fisheries. In addition, in the Gulf of Lion, shrimp would increasingly be targeted in submarine canyons, while in the North Sea, new species such as zooplankton and myctophids would be targeted. The Gulf of Lion participants added that the anticipated mutation of the fishing sector, with an industrial fleet consisting of a few large, high-tech vessels capable of catching large volumes, and an abundant small-scale coastal fishing fleet for very limited fish resources, would lead to major profit inequalities and intensified competition. For both SES, this intensive exploitation would lead to a deterioration in marine ecosystems, amplified by the strong development of other maritime activities. Climate change would cause numerous species migrations, which could be either beneficial or detrimental to fishing. The Gulf of Lion participants emphasized the migration of species that could be seen as opportunities, such as the northward migration of the pink shrimp *Parapenaeus longirostris*, exploited in marine canyons, the increase in cephalopod and sea cucumber populations near the coast, and the exploitation of some invasive exotic species such as the blue crab and the rabbit fish *Siganus spp.* Participants from the North Sea also perceived the climate-induced migrations of many species as opportunities in this scenario (e.g., tuna, gilthead bream, John Dory, octopus, and red king crab). On the other hand, they emphasized the negative effects of some invasive species on local resources, mentioning in particular the predation of octopus on scallops, a highly valued species. According to participants in both SES, the stability and the sustainability of this scenario could be threatened by the weakening role of political institutions in regulating access to the commons, managing fishing stocks and preventing overexploitation. This would lead to systemic instability: job losses, inequality, extreme competition, as well as a sharp deterioration in working conditions, social ties, and the notion of community which could provoke strong social protests. The Gulf of Lion participants also stressed the threats posed by research and development that would serve commercial interests only, thus disrupting the balance of the marine ecosystem, while the North Sea participants emphasized the tragedy of the commons, where strong individualism would lead to resource depletion, lower profitability of the fishing industry due to resource depletion, and the shortage of non-renewable energies.

In the case of the *Local Stewardship* scenario (SSP2-RCP4.5), common themes included a greater appreciation of the profession and a revival of fishing culture. This was accompanied by various changes, such as improved working conditions, more diversified, versatile, and adaptive fishing practices, and the use of vessels and gears adapted to these practices. Stakeholders in the Gulf of Lion pointed out that

the fisheries would adapt particularly well to the arrival of new exotic species. In the North Sea, stakeholders envisaged that exploitation would be optimal for species that can be managed locally, in particular benthic species such as scallops, coastal mussels, cockles, and bittersweet clams. In the Gulf of Lion, working conditions on board would improve thanks to local innovations, while cumulative working hours would increase. In the North Sea, working conditions on board would be similar to current levels, but with shorter fishing trips and a reduction in cumulative working hours, as fishers would be less concerned with maximizing profits. On the technological front, Gulf of Lion participants added that, in this scenario, the local territories would be committed to achieving energy self-sufficiency, by optimizing the use of local resources and through strong development of photovoltaic and wind energy on land and at sea. On the economic front, the two SES envisioned strong local demand for seafood products, the development of short food supply chains and a densification of the distribution network. For both SES, the governance of French administrative regions and territories would be strengthened, and an area-based management would be implemented, with, in the case of the Gulf of Lion, an adaptive co-management system with fallow of trawling grounds and rotation of marine protected areas for the regeneration of habitats and fish stocks, and in the case of the North Sea, management plans implemented by area rather than by species, and the cessation of the exploitation of remote and jointly managed ICES Fishing Areas 4A and 4B. Gulf of Lion stakeholders emphasized that this context of strengthened territorial governance, spatialized resource management on a territorial scale, and territorial commitment to energy self-sufficiency, would lead to greater inequalities between and within territories. These inequalities could lead to social conflicts, particularly among “prud’homies”, the territorial communities of French fishers in the Mediterranean, whose elected representatives exert a variety of historical powers at the local level (regulatory, disciplinary, police and judicial), under the control of the maritime administration. On the environmental front, the two SES are projecting an overall improvement of the state of the marine ecosystem and resources, although their monitoring and evaluation beyond the local level would be largely insufficient and could contribute to the emergence of environmental problems. For both SES, the threats to the stability and the sustainability of this scenario lied in the difficulties in consulting and making joint decisions within a decentralized management system, the lack of vision beyond the local scale, and the lack of capacity to manage common stocks according to their distribution area. Stakeholders in the Gulf of Lion mentioned several additional threats such as the lack of monitoring and assessment of stocks on a larger regional scale, the difficulty in adaptively managing the exploitation of species with complex life cycles such as

sea bream and bass, growing social and user conflicts, and the fact that energy autonomy would be severely limited by the availability of resources in each territory. Those from the North Sea added, in terms of regulation, that it would be difficult to apply local measures to vessels from other territories within a given territory, and that a decentralized management model would be highly unstable.

For the *National Enterprise* scenario (SSP3-RCP7.0), the common social and technological themes focused on trends in employment and working conditions, a deterioration in the social and cultural environment, and a renewal of the fishing fleet (motorization, automation, on-board processing). The number of jobs was a noteworthy difference between the two SES. It would decrease in the North Sea, due to the lack of motivated French fishers and the refusal to employ foreign labor, whereas it would remain stable in the Gulf of Lion despite difficult working conditions. The profession's attractiveness would decline in the North Sea even though fishers would obtain civil servant status, with higher and more stable wages. Stakeholders added that half of all vessels would be destroyed in the North Sea, with the disappearance of some métiers with the end of fishing outside territorial waters. Persistent fishing trades would diversify and adapt to the arrival of new species, gillnetters would turn to traps, and bottom trawlers to seiners and scallop fishing. On the economic front, both SES would experience an increase in domestic demand, a market transformation centered on national production, and a corresponding adaptation for national processing, distribution, and sales. The economic strategies of the SES would differ, with most products in the Gulf of Lion being less valued than today, while local species in the North Sea would be revalued. Stakeholders in the North Sea projected a crisis in the processing sector, even if part of it would shift to filleting local species. In both SES, stakeholders envisioned a centralized governance model organized around a national quota allocation system and public subsidies to finance fleet renewal and increased vessel productivity. A major difference was that the fishing sector would be nationalized in the North Sea scenario, while large fishing companies would dominate the sector and capture most subsidies in the Gulf of Lion scenario. In both cases, territorial waters would be heavily guarded to prevent illegal foreign fishing, while the government would disengage from environmental regulation and conservative stock management. This management approach would lead to overexploitation and numerous additional impacts that would spread throughout the marine ecosystem. These impacts would be coupled with pollution and dumping of contaminants at sea due to the heavy exploitation of terrestrial ecosystems. Investment in research and ecosystem monitoring would be reduced. Moreover, in the North Sea and the English Channel, the high concentration of vessels in territorial waters would hinder cohabitation. Potential obstacles

to the stability and the sustainability of the *National Enterprise* scenario would be, first and foremost, international conflicts over the exploitation of common fish stocks. Other types of conflicts could also arise: according to stakeholders in the Gulf of Lion, wars involving other countries, such as the current conflict between Russia and Ukraine and its repercussions on fuel prices; and according to stakeholders in the North Sea, cohabitation conflicts between French fishers confined to territorial waters, and conflicts between fishers and other marine ecosystem users (aggregate extraction, CO₂ storage, harbor development, etc.). The Gulf of Lion stakeholders also mentioned strong competition with the intensive aquaculture sector, land-based contamination of the marine ecosystem, and difficulties in establishing a functioning quota system on a national scale, with a centralized management model that would not consider territorial specificities.

Emotion discourse analysis and open vote

For both SES combined, our emotion discourse analysis supported by ChatGPT AI identified the main emotions conveyed in stakeholders' expressions of their feelings about each scenario, with a 96% success rate for the 23 emotion-related text passages and an average occurrence per main emotion of $68 \pm 23\%$ over the 10 repetitions of the query submitted to the AI (Table 1). For each main emotion and the corresponding valence and arousal determined by the AI, we found no inconsistencies with the framework of Russell's Circumplex Model of Emotions (1980). On average, the elicited emotions were associated with high arousal (0.60 ± 0.13) regardless of the main emotion identified, and with little variation across scenarios (standard deviation of means per scenario of 0.02). The *Global Sustainability* and *Local Stewardship* scenarios provoked an alternation of positive and negative valence emotions, with mean values tending towards 0 (-0.06 ± 0.65 and 0.12 ± 0.66 on average, respectively), oscillating mainly between joy and fear. Joy was associated with well-being, social ties among individuals, people's attachment to the territories where they live or have lived, responsiveness to the specific needs and challenges of local communities, citizen empowerment and collective mobilization ability. Fear was associated with criticism and doubts about the applicability of the *Global Sustainability* scenario to the local scale and the preservation of individual freedoms and cultural heritage. For the *Local Stewardship* scenario, fear was associated with high levels of uncertainty and risk, particularly that of widening inequalities, low predictive capacity, and the need for more research. The *World Markets* and *National Enterprise* scenarios elicited negative valence emotions exclusively (-0.50 ± 0.16 and -0.67 ± 0.06 on average, respectively), oscillating mainly between sadness and anger. Sadness was

Table 1 Emotion discourse analysis

Scenario	Emotion-related text passage	Main emotion	Occurrence (%)	Mean valence	Mean arousal
Global Sustainability SSP1-RCP2.6	Attractive, feeling of well-being, inspiring	Joy	100	0.73	0.60
	Difficult to achieve, potentially unattainable, utopian	Frustration ^b	50	-0.60	0.65
	Concern about its applicability at the local level	Fear	100	-0.53	0.55
	Does not prevent a strong mobilization to achieve it	Joy	40	0.75	0.69
	Loss of individual freedoms and traditions	Fear	50	-0.65	0.70
World Markets SSP5-RCP8.5	Rejection, malaise, discouragement	Sadness	90	-0.64	0.50
	Withdrawal into themselves	Sadness	90	-0.56	0.28
	Artificial, it resembles the current context in many ways	Surprise	40	-0.56 ^a	0.75
	Will to rebel, need to escape this system	Anger	80	-0.22	0.75
Local Stewardship SSP2-RCP4.5	Interesting, attractive	Joy	60	0.71	0.65
	Closer to local realities	Joy	80	0.72	0.44
	Pride in belonging to the territory	Joy	50	0.65	0.50
	Citizen empowerment	Joy	80	0.75	0.63
	Satisfaction of the need for stronger social ties	Joy	80	0.72	0.59
	Ambitious, risky	Fear	30	-0.50	0.67
	Uncertain, limited ability to project into this scenario	Fear	80	-0.59	0.59
	Many points still need to be explored	Fear	30	-0.75	0.75
	Inadequate, too many disparities between territories	Fear	40	-0.63	0.56
National Enterprise SSP3-RCP7.0	Worrying, frightening, widely rejected	Fear	100	-0.75	0.75
	Loneliness, withdrawal, shame, feeling of being exploited manipulated, loss of freedom	Sadness	80	-0.69	0.47
	Vulnerability and instability of the French fishing sector	Sadness	60	-0.58	0.38
	Dangerous, exacerbates conflicts, unsustainable	Anger	60	-0.71	0.75
	Strong incentive to oppose it	Anger	100	-0.64	0.69

Emotion-related text passages are displayed in light green for a main primary emotion with positive valence and low arousal (<0.5), dark green for positive valence and high arousal (≥ 0.5), light blue for negative valence and low arousal, and dark blue for negative valence and high arousal

^aFor this text element, “surprise” was qualified by Chat GPT with a positive valence. According to Russel’s circumplex model of affect (1980), the term “surprise”, depending on the context, can be related to “alarmed”, which has a low negative valence, or to “astonished”, which has a low positive valence. Here, in line with the results of the open vote (Table 6), we concluded that the valence of “surprise” was negative for the *World Markets* scenario and therefore multiplied its valence value by -1

^bOnly in this case, ChatGPT was unable to provide a dominant emotion based on the query formulated (Appendix 4) and returned a non-basic emotion. Based on the other occurrences for this text element, we interpreted “frustration” as a mixture of disgust (2 occurrences) and sadness (also 2 occurrences)

associated with malaise, devaluation, loss of individual freedom, withdrawal and isolation, and a context of vulnerability and instability of the French fishing sector in the face of numerous external pressures. Anger was associated with the will to resist, rebel or escape, and was also linked to the occurrence of intensified conflicts.

The open vote of stakeholders to determine the most likely, most desirable, and most undesirable scenario

revealed similarities and differences between the two SES (Table 2). For each social-ecological system, the most desirable, the most undesirable and the most likely scenario were highlighted. For both SES, *World Markets* was voted as the most likely scenario. North Sea stakeholders elected *Global Sustainability* as the most desirable scenario, whereas *Local Stewardship* was the most desirable one for Gulf of Lion stakeholders. The most undesirable scenario was *National*

Table 2 Stakeholder open vote on the most desirable, most undesirable, and most likely scenario

Scenario	Global sustainability SSP1–RCP2.6		World markets SSP5–RCP8.5		Local stewardship SSP2–RCP4.5		National enterprise SSP3–RCP7.0	
Social–ecological system	Gulf of Lion	North Sea	Gulf of Lion	North Sea	Gulf of Lion	North Sea	Gulf of Lion	North Sea
The most desirable	45%	<u>74%</u>	0%	0%	<u>55%</u>	26%	0%	0%
The most undesirable	5%	0%	<u>59%</u>	42%	0%	0%	36%	<u>58%</u>
The most likely	27%	23%	<u>36%</u>	<u>50%</u>	9%	14%	27%	14%

Enterprise for North Sea stakeholders and *World Markets* for Gulf of Lion stakeholders.

Discussion

Through participatory stakeholder workshops, we were able to downscale and co-construct the narratives of four global SSP–RCP scenarios to the local scale of the French fisheries of the Gulf of Lion and the North Sea SES. Our comparative analysis of local SSP–RCP scenario narratives between different SES in the same country is a novel approach to account for the diversity of knowledge, visions and values shared by stakeholders. Our projection work was also enriched by the identification of potential disruptive factors for each scenario and took into account the emotions and perceptions expressed by stakeholders that are potential drivers for action and transformative change.

Co-constructing local SSP–RCP scenarios

Although there is currently no consensus on a pool of common methodologies for downscaling global SSP–RCPs (O'Neill et al. 2020), recommendations on how to proceed include: (1) the use of a common set of global scenarios such as the SSP–RCP reference scenarios presented in the 6th IPCC assessment report; (2) the development of a set of spatially and sectorally consistent regional scenarios, such as those developed for the European fisheries and aquaculture sectors by Pinnegar et al. (2021), Hamon et al. (2021) and Kreiss et al. (2020); (3) the use of standardized and reproducible participatory approaches to integrate the best available scientific, indigenous and local knowledge into regional and local scenarios (O'Neill et al. 2020; van Ruijven et al. 2022).

Our designed protocol and its implementation for the two French SES can be considered successful in view of (1) the generated co-production of four local scenario narratives, resulting in 64 themes and 298 narrative elements; (2) the balanced distribution of this co-production, both in terms of the small variation in the total number of themes per scenario, and in the number of themes and narrative elements between the PESTEL dimensions developed for each scenario; and (3) the high level of detail provided by the participants for each of these dimensions. The active participation of the stakeholders can be partly attributed to the design implemented in the two participatory workshops. Our introductory presentation enabled us to share the latest theoretical and practical knowledge on future scenarios with the stakeholders. This knowledge was directly mobilized via the interdisciplinary PESTEL approach, which has proven its effectiveness in scenario co-construction. (e.g., Quiceno et al. 2019; Pinnegar et al. 2021). We optimized

the duration and balanced distribution of these workshops by organizing World Café workshops, which engaged two groups of stakeholders simultaneously, and allowed them to discuss and complement each other's work, by timing each PESTEL dimension and using thematic open-ended questions. These questions also enabled participants to immerse themselves collectively in the scenarios and to obtain specific information that could be compared between SES. The mobilization of a large team of facilitators should not be overlooked. This meticulous organization was made possible by the involvement of a team of eight scientific collaborators for each workshop.

Our approach can be compared to similar approaches for downscaling SSP–RCP scenario narratives to European marine SES: Hamon et al. (2021) downscaled SSP–RCP scenarios to create narratives for European fisheries using the CERES scenario framework (CERES 2016). The aim of that study was to provide projections of change through year 2050 of the values of input variables used in five quantitative ecosystem and bioeconomic models and one semi-quantitative model. As a case study, the authors then implemented the four SSP–RCP scenarios within one bioeconomic model downscaled to the North Sea flatfish fishery. Unlike our study, which is based entirely on stakeholder workshops, they used diverse sources of information to produce these projections: gray literature, legislation texts and legal experts, stakeholder workshops, and unpublished model results. Similar to our study, they developed narratives incorporating all PESTEL dimensions. The number of themes (e.g., two to three themes per dimension apart from the governance that had 10 legal and political themes) was in the same order of magnitude as our study. The number of narrative elements developed within each theme was generally much smaller. This difference can mainly be explained by the limited number of input variables considered in their models and by the fact that the stakeholder workshops in which they participated were not directly organized to meet the objectives of their studies. Another notable difference was that Hamon et al. (2021) addressed the same themes for all their scenarios, whereas our thematic open-ended questions were the same for each scenario, but our methodology allowed workshop participants to develop themes specific to the context of each scenario. Apart from these elements of comparison, their approach was quite different as it consisted of downscaling the narratives of the SSP–RCP scenarios to the European scale and then to a local SES using a quantitative bioeconomic model and existing data. We could also mention the current co-construction of narratives in the FutureMARES project (Peck et al. 2023), which focuses on a different topic, but with strong methodological similarities to our approach. Focused on nature-based solutions applied to habitat-forming species in European and Latin American marine SES, the project aims to downscale three of the

four SSP–RCP narratives developed by the CERES project. To this end, it also relies on thematic open-ended questions addressed to a broad panel of stakeholders and applied across all PESTEL dimensions. One of the main methodological differences is that these questions were asked through a questionnaire while we conducted participatory workshops allowing extensive interaction among participants.

In our approach, the representativeness and the engagement of stakeholders from the fisheries and conservation sectors ensured a strong anchoring in regional, national, and local contexts, accounting for current and past trends. These are necessary to build plausible and policy-relevant downscaled scenarios and pathways, as demonstrated by numerous other works addressing the future consequences of climate change (e.g., Shaw et al. 2009; Craddock-Henry et al. 2018).

As an example of anchoring the downscaled scenarios in the regional context, the post-Brexit context appears to have strongly influenced North Sea stakeholders to downscale the *National Enterprise* scenario. Between 2020 and 2022, hundreds of French boats were denied their fishing licenses to operate in UK territorial waters, a problem which had escalated into intense social, economic, and political conflicts between the two countries (van Balsfoort et al. 2022; Drake 2023; Elvestad and Bjørndal 2023). The UK's exit from the European Union is still having many socio-economic impacts on the livelihoods of French fishers and on the seafood market. The fishing industry has faced national plans to withdraw some fishers and vessels, the risk of overcrowding of French fishing grounds, the increase of administrative complexity, and impacts on common fish stock management, import–export, and more generally on the sales and processing sectors. The *National Enterprise* scenario, with its closure of foreign territorial waters, thus found a particular echo in this anxiety-provoking context. In this scenario, which is the most undesirable for North Sea stakeholders, they envisioned the destruction of approximately half of the vessels, a reduction in the number of jobs, and a spatial redistribution of the remaining fleet in French territorial waters. This would lead to conflicts among fishers concentrated in reduced fishing zones, conflicts between neighboring states over the exploitation of resources, and a crisis in the local processing sector due to the collapse of traditional activities.

As an example of embedding the *National Enterprise* scenario in the national context, stakeholders in the Gulf of Lion pointed to a specific national feature: the predominant share of nuclear power in the energy mix. Nuclear power has accounted for around 75% of the country's primary energy production over the last two decades (SDES 2021). Stakeholders have relied on this important source of energy and on the electrification of consumption to reduce the high dependence on fossil fuels in this archetypal SSP3-RCP7.0 scenario (Appendix 1). This national projection requires

timely decisions on the future electricity mix and acceleration of investments, as France is currently faced with an aging nuclear fleet (IEA 2021) and a predominant and growing energy consumption by the residential and tertiary sectors (SDES 2021).

Finally, as an example of anchoring the scenarios in the local context, in the *Local Stewardship* scenario, stakeholders in the Gulf of Lion highlighted the role of the “prud’homies”, territorial communities of French fishermen specific to the Mediterranean, whose origins date back to the thirteenth century (Pehau 2008). Their elected representatives still exercise a range of historic powers at the local level (including regulatory, disciplinary, policing, and judicial powers) under the control of the maritime administration, with significant variations from place to place. Their role is reinforced in this scenario. Stirred up by the strong territorial inequalities, the stakeholders envisioned potential conflicts between the prud’homies, while some of them would try to forge alliances.

Lessons from comparing narratives between social–ecological systems

For a given scenario, we identified many common themes and narrative elements between the Gulf of Lion and the North Sea SES. These similarities may be due to the fact that: both fisheries are managed under the same European governance regime, which includes the Common Fisheries Policy (CFP; European Commission 2013) and the Marine Strategy Framework Directive (MSFD; European Commission 2008). They are also experiencing the same economic consequences of global change and geopolitical tensions, with inflation triggered by the COVID-19 pandemic, the war between Ukraine and Russia, and the subsequent global energy crisis of 2021–2023 (e.g., Massetti and Exadaktylos 2022; Liadze et al. 2023). They face common national trends in the fisheries sector, with a decline in the number of fishers and vessels and an increase in the median age of vessels (Gorodetska et al. 2022). Finally, based on the seminal work of Hofstede (1983), we could also assume that some form of national culture partly explains the similarities observed between the narratives of the two French SES. However, we have not directly investigated the cultural factors that would predict such a result.

Our study also revealed striking differences between the two SES for a given scenario. These differences concerned the exploitation (*World Markets*) and commercialization (*National Enterprise*) strategies implemented, the technological innovation of the fishing fleets (*Global Sustainability*), the public or private governance of the sector, and the changes in the number of jobs and working conditions (*National Enterprise* and *Local Stewardship*). Some of these contrasting projections appear to be deeply rooted in the

current and historical characteristics of these fisheries. For instance, under the *World Markets* scenario, stakeholders from the North Sea envisioned a mostly monospecific and highly selective fishery along with a decrease in the diversity of species consumed, whereas stakeholders from the Gulf of Lion envisioned a diversification of exploited species and a reduction in selectivity. To meet the objective of increasing local seafood landings in the World Market scenario, these projections seem consistent if we consider existing fisheries: most of the fleet from the North Sea and Eastern Channel fisheries come from a multi-species demersal fishery targeting a small number of gadoid species. Faced with several overexploited and collapsed fish stocks (Vermard and Ulrich 2024), and to minimize some of the short-term economic impacts of the CFP's landing obligation policy (European Commission 2013), the demersal fishery has tended to increase its selectivity (e.g., Vogel et al. 2017). Regarding the Gulf of Lion, small-scale fisheries make up the majority of the local fleet. As throughout the Mediterranean, they are known for their great diversity and seasonal variation in the fishing techniques used and the species landed (e.g., Leleu et al. 2014; Sternberg and Faget 2014). In a scenario where consumers are diversifying their demands, there could be an incentive for these fisheries to further diversify their catches.

In addition to these differences, we observed a high degree of specificity among all downscaled scenarios with 17% of the themes and 70% of narrative elements mentioned exclusively in one of the two SES. These additional themes and elements reflect the local anchoring and richness of the downscaled scenarios and their relevance to local management. Here is a series of examples: in the North Sea, the *Global Sustainability* and *Local Stewardship* scenarios projected an improvement in well-being through crew rotation and a reduction in working hours on board. Such solutions would not be appropriate in the Gulf of Lion, where fishing trips last less than 24 h and work on board is intensive. For the *World Markets* and *Global Sustainability* scenario, North Sea stakeholders projected the establishment of a system of Individual Transferable Quotas (ITQs), probably inspired by practices implemented in other countries bordering the North Sea (Hoshino et al. 2020). While the main commercial species are managed under quota in the North Sea, very few species are managed under quota in the Gulf of Lion, which explains why stakeholders in this SES are concerned about the inadequacy of a national system of ITQs, which they envisage in the *National Enterprise* scenario. They argued that such a system would not take into account the specific characteristics of the region, in particular the wide variety of local fishing métiers. Moreover, given the large number of fishers' organizations spread across the Gulf, the allocation of these quotas could lead to conflicts. The intensification of these potential conflicts between local organizations, aggravated by socioeconomic inequalities, is also perceived as

one of the main disruptive changes in the *Local Stewardship* scenario. However, not all the themes and elements mentioned for only one of the two SES are necessarily specific to that SES. Some of them could have been addressed in both SES. We can assume that they were less important to the stakeholders or that the limited time of the scenario co-construction workshop did not allow them to be addressed. Identifying such elements can also be useful for management strategies at supra-local scales. An example envisaged by stakeholders in the North Sea is the spatial competition caused by the intensive development of offshore activities such as wind farms and marine protected areas in the *Global Sustainability* scenario. Fisheries in the Gulf of Lion are also exposed to this risk as several projects of offshore floating wind farms are currently underway, and their implementation seems to follow the strong growth trend in the European market, accompanied by the political will to decarbonize energy production (Díaz and Soares 2020; Henry et al. 2022). An extension and strengthening of the current network of marine protected areas in the Gulf of Lion has also been announced, in line with the National Biodiversity Strategy 2030 (SNB 2023), which reflects France's commitment to the Convention on Biological Diversity.

Innovating and looking to the future of SSP–RCP scenario research

Within our methodology for downscaling SSP–RCP scenarios, we implemented two key innovations.

The first innovation was asking stakeholders to identify potential disruptive changes for each scenario. Although these discontinuous shifts are a key feature of SES, studies of global SES scenarios, including integrated scenarios such as the SSP–RCP, generally assume structural continuity or neglect these discontinuities (Rothman et al. 2023). In a global change context, neglecting these potential discontinuities can quickly render such scenarios inoperable, distorting decision support and undermining confidence in scientific production. To address this important issue, Rothman et al. (2023) recommend strengthening participatory co-construction processes and enriching the scenario narratives, which reinforces our methodological choices. These disruptive risks threaten the paths adopted by the SES in the downscaled scenarios and pose social, economic, scientific, technological, governance, environmental and energy challenges. Most of these challenges need to be anticipated and addressed by stakeholders in the fishing industry, but some also relate to broader societal issues, such as reducing marine pollution (*National Enterprise* scenario) or securing energy supply, which implies considering potential shortages of non-renewable energy (*World Markets*) and developing a plan for energy self-sufficiency at national and local levels (*Local Stewardship*).

A second innovation was to bridge a research gap by measuring the emotional impacts of imagining plausible futures on individuals using a scenario co-construction framework (Richter et al. 2023). The study results contribute to providing clues for overcoming psychological barriers to stakeholder engagement and cognitive biases that prevent stakeholders from being immersed in future scenarios, a future avenue for implementing adaptation and mitigation strategies and initiating transformative change. Methodologically, in our scenario co-construction workshops, participants expressed their feelings about each scenario individually, and we analyzed the perceived emotions. To our knowledge, this is the first time that a standardized emotion analysis has been conducted for SSP–RCP scenarios. Moreover, we strengthened this standardization by using artificial intelligence (AI), at the beginning of what promises to be a scientific revolution in many fields, including the psychology of emotions (e.g., Assunção et al. 2022; Gual-Montolio et al. 2022). It is important to note that, even with the support of a trained AI, this analysis is based on a subjective evaluation and should be interpreted with caution. In any case, it provides an innovative framework for identifying and understanding the emotions expressed by stakeholders in their discourse. Although it is still under development and not optimized for scientific use, the ChatGPT AI language model was very successful in identifying the main emotions expressed in text passages. Furthermore, in line with the recommendations of Richter et al. (2023), our methodology, which includes cartoon illustrations of global scenarios, and the co-construction of detailed scenario narratives anchored in local contexts, is suitable for the systematic integration of emotional aspects.

Looking forward, work is underway to use the scenario narratives to contribute to Integrated Ecosystem Assessments (IEAs) by providing quantitative and spatio-temporal projections of the long-term responses of ecosystems and fisheries in the Gulf of Lion and North Sea. Promising approaches are being tested with the development of qualitative intermediate models, such as fuzzy cognitive maps and ecological discrete event networks (Gaucherel and Pommereau 2019; Olsen et al. 2023). These models, by incorporating social, economic, and governance dimensions and their interactions with marine ecosystem components, could inform and contribute to the parameterization of marine ecosystem models (MEMs). It should be noted that our downscaled scenarios will be used by several ongoing national modeling projects (ADAPT, GEMMBE, MEDIATION). Based on the scenario narratives and reference literature, Erauskin-Extramiana et al. (2024) modeled changes in biomass, catch, and profit for four major commercial species and three Gulf of Lion fleets through 2050 for the four downscaled scenarios. On a global scale, the EU FutureMARES project used the *Global Sustainability*,

World Markets, and *National Enterprise* scenarios as part of a climate risk assessment to evaluate the effectiveness of nature-based marine solutions (Bueno-Pardo et al. 2024). They will also be used in the European ACTNOW project to better compare projected ecosystem-level impacts of fisheries and other stressors across different European regional seas and SES.

Conclusions

Overall, our participatory downscaling protocol addresses several criticisms of the SSP–RCP scenarios (van Ruijven et al. 2022; Alexander et al. 2023). First, we attempted to bridge the science–policy gap between information on climate risks, their societal impacts, and potential adaptation measures useful to local stakeholders. Second, we focused on biodiversity and human–nature relationships within the SSP–RCP scenarios, to better align with the Nature Future Framework developed by IPBES and the CBD 2050 vision. Third, we considered disruptive factors for each scenario in order to identify specific processes that would enable or hinder transformative change, to halt and reverse the decline of biodiversity and its contributions to people by 2050. Finally, we assessed and analyzed emotional aspects in the scenarios, which can help overcome psychological barriers to stakeholder engagement and cognitive biases that prevent their immersion in future scenarios.

For policy and decision-makers, here are the three policy-relevant findings of our study, in line with the literature:

1. The comparative analysis of the downscaling of global SSP–RCP scenarios applied to two French fisheries SES suggested that numerous major themes emerging from stakeholders' future narratives are common to French and potentially European fisheries. If confirmed by extending this exercise to other fisheries SES, these themes should be incorporated into decision-makers' roadmaps. The European Commission is currently engaged in a reflection process to evaluate and improve the performance of the implementation of the CFP Regulation within the European marine SES in the long term (European Commission 2023, 2025). In the context of its ongoing consultation process, the key themes highlighted by the French stakeholders who participated in the workshops should be addressed to the European Commission to illustrate the progress still to be made and the pitfalls to be avoided. The lack of stakeholder inclusion in long-term fisheries management has been a long-standing criticism of the EU CFP (Long 2017; Clayton 2021). Our study also shows that stakeholders have addressed these common themes in future narratives across fisheries SES by integrating a variety of

local specificities. In line with the long-term objectives of regionalization of European fisheries management (European Commission 2022), these local specificities need to be identified and taken into account in future scenarios.

2. Disruptive changes are a key feature of SES, as illustrated by the recent COVID-19 pandemic, the Russian invasion of Ukraine, or the abrupt collapse of fish stocks of high socio-economic importance (e.g., GFCM 2019), or any of the disruptions projected by fisheries stakeholders in our scenario-building workshops. With potentially high socio-economic and environmental impacts on fisheries, the risk of disruptive changes needs to be taken into account by stakeholders and society at large, strengthening the capacity to adapt to these changes and mitigate their negative impacts. As projected by stakeholders for the *Global Sustainability* and *Local Stewardship* scenarios, this will require the implementation of more adaptive governance systems across stakeholders, sectors and scales (Schultz et al. 2015; Sharma-Wallace et al. 2018). Participatory approaches, such as our scenario-building workshops, should be multiplied as they can help strengthen collaboration and engagement to anticipate and manage disruptive changes and link knowledge to decision-making through transdisciplinary data collection.
3. Our innovative analysis of the emotions felt by stakeholders, along with their perceptions of the likelihood and desirability of the scenarios, informed us that the SSP5–RCP8.5 *World Markets* scenario was perceived as the most likely scenario and was associated exclusively with negative valence emotions. This perspective on the future should be taken into account by policymakers, especially in light of recent empirical research in climate change psychology suggesting that negative affect would promote the intention to engage in adaptive behaviors to mitigate a harmful state of mind (van Valkengoed and Steg 2019). Interestingly, the RCP8.5 scenario is considered very unlikely by climate and energy experts both in terms of fossil fuel burning and greenhouse gas concentrations (Hausfather and Peters 2020). They also emphasize the need for optimistic narratives to make the international climate goals set by the Paris Agreement seem feasible.

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Declarations

Conflict of interest All authors certify that they have no affiliation or involvement with any organization or entity that has a financial or non-financial interest in the subject matter or materials discussed in this manuscript. This research, which involved human participants who provided oral and written data, was conducted in strict compliance with EU Regulation 2016/679 (General Data Protection Regulation—GDPR) and French national legislation. For the two series of participatory workshops, we obtained free and fully informed written consent from all participants by providing them with informed consent forms, detailed information sheets, and an introductory oral presentation at the beginning of each workshop. The informed consent forms included information about the collection, storage, and use of written and audio data and the rights of participants in this regard. Data collection, storage, and use were conducted in a manner that respected the anonymity, confidentiality, and dignity of the subjects, and no data was analyzed at the individual or organizational level. The personal data of all workshop participants were protected in accordance with the GDPR, stored using a pseudonymization process in an encrypted European cloud storage and on a password-protected hard drive for a period of 5 years following data collection. No vulnerable groups were involved in any of the participatory workshops. The authors report no declarations of interest.

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