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The social science of offshore aquaculture: uncertainties, challenges and solution-oriented governance needs

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Aquaculture technology is on the move, enabling production in more open and exposed ocean environments around the world. These new systems offer solutions to environmental challenges facing conventional aquaculture, yet new technologies also create new social challenges while potentially exacerbating, or at minimum recreating, others. Offshore aquaculture research and governance are still in early stages, as is our understanding of the social repercussions and challenges associated with development. This paper provides an evaluation and reflection on offshore aquaculture from a social science perspective and is based on findings from a modified World Café group discussion method including the thoughts and experiences of social science experts. Key challenges and uncertainties including a lack of an appropriate regulatory framework, societal perceptions of offshore aquaculture, and offshore aquaculture's contribution to society were identified. The governance implications of these challenges are discussed as well as the need for social sciences to address these challenges through transformative and transdisciplinary approaches that bridge science and society.

KEYWORDS

governance, inter- and transdisciplinarity, systems perspective, social dimensions, offshore aquaculture

Introduction

In recent years, "offshore" aquaculture has gained increased attention as a major avenue for the expansion of aquaculture, especially for commercially important finfish species such as Atlantic salmon (Morro et al., 2022), but also for various species of shellfish (Barillé et al., 2020; Heasman et al., 2020). We hereby follow the definition given

in Buck et al., 2024, in which it is suggest that the definition of "offshore" versus "nearshore" and "exposed" versus "sheltered" be defined exclusively according to the distance from shore based on visibility and the wave and current conditions respectively, creating discrete categories for each term. By and large, the discourses on offshore aquaculture have been driven mainly by biological and technological considerations. In contrast, social science perspectives are, as of yet, rather under-researched areas that require more attention (Krause et al., 2015), a trend that is present throughout ocean sustainability research (Partelow et al., 2023). Indeed, while there has been a recent proliferation of social science research on aquaculture (Budhathoki et al., 2024), most has been focused on near-shore coastal aquaculture contexts; thus, nuanced understandings of societal concerns about offshore aquaculture is greatly lacking in the aquaculture literature. This is however urgently needed, as climate change, biodiversity loss and food security are central challenges humanity is facing (Krause et al., 2022; FAO, 2021). These challenges call for novel research approaches that lead to interventions, actions and change to encourage more sustainable pathways. For instance, to limit compromising the integrity of the planet, a shift is needed toward marine food production with low environmental impacts and low carbon footprint (Krause et al., 2022). Hence, while knowledge-oriented basic research is required for the development of long-term innovations, research should also adopt a more immediate and solution-oriented focus directed at the most vulnerable and support associated regulatory and policy needs (Drakvik et al., 2020).

The management of aquaculture has previously been described as a "wicked problem" due to uncertainty around its impacts on the environment and society and the rapidly changing nature of the industry (Osmundsen et al., 2017). Wicked problems are characterized by being difficult to solve due to their complexity and interdependencies including linkages between social, economic, and policy issues and outcomes (Weber and Khademian, 2008). Understanding these issues and outcomes as well as their implications for policy and regulation have been approached through the social sciences, their subfields, and associated methodologies including economics (e.g. Anderson et al., 2019; Asche et al., 2022), geography (e.g. Belton and Bush, 2014; Vandergeest and Unno, 2012), sociology (e.g. Safford et al., 2019), and political science (e.g. Young et al., 2019; Martin et al., 2021; Wiber et al., 2021). Many of these approaches highlight the need for a place-based and spatial understanding of the impacts and outcomes of aquaculture, and the interactions between them. Therefore, the wicked problem of aquaculture management, policy, and governance can be expected to be replicated, accentuated, and changed as aquaculture moves offshore, creating new linkages between social and ecological systems while changing the nature of others. Managing these emerging challenges will necessitate new and evolving policies and regulations. Social science research approaches, like those already employed toward understanding the current and previous state of aquaculture systems, need to be expanded. In addition, the integration of these approaches and emerging transdisciplinary research will be needed to understand changing aquaculture social-ecological systems and inform policy and regulation as infrastructure moves offshore.

In this pursuit, we argue that there is a risk that offshore aquaculture is treated as a "one-type-only" type of aquaculture, disregarding the different modes of offshore aquaculture operations that entail discriminating uncertainties and challenges. Next to the type of species cultivated, the interplay between water depth, distance from dock, people time, vessel efficiency and sea conditions all play an important role to the commercial viability of an offshore aquaculture farm (Buck et al., 2024). Furthermore, governance issues range from fish welfare, security of workforce, liability of technical structures as well as ownership issues pertaining the offshore aquaculture structure as such, as well as on the fish production therein. From a social science stance, these result in different types of societal concerns and related governance needs, where governance includes the policies, processes, and practices that are used to manage coastal and ocean resources in ways that reflect societal expectations (Jolly et al., 2023). Accordingly, an informed differentiation between different types of offshore aquaculture is crucial (see Froehlich et al., 2017; Buck et al., 2024). In recognition of the need to clarify definitions related to the term "offshore" (Watson et al., 2022), which are also described through terms such as "exposed", and "open ocean" aquaculture (Buck et al., 2024), this paper deals primarily with definitions distinguished by distance, since most of the social implications and considerations resonate around the challenges and uncertainties of moving operations further from shore. Accordingly, the discussions around the challenges and considerations will focus on offshore aquaculture, as this term better represents the farm's geographical distance from the shore.

Based on summarizing key insights of experts, the objective of this paper is to reflect on the state of current knowledge in understanding anticipated social repercussions and challenges of entering a new aquaculture landscape. Thus, this paper offers a critical social science examination of the current state of offshore aquaculture research. In addition, it discusses the opportunities for social science to increase solution-oriented governance that addresses in an adequate manner the pivotal role that societal concerns play in the decision for, and development of, sustainable offshore aquaculture systems. Therefore, this reflection on the state of knowledge regarding the social implications of offshore aquaculture and opportunities for social science also serves as a call to natural scientists and policymakers to more strongly engage social scientists and social science methodologies in addressing the challenges that lie ahead.

Methodological approach

To endorse the topic of offshore aquaculture from a social science perspective, this paper presents reflections that emerged through discussions by social science experts. These discussions follow from evidence that the sustainability outcomes of offshore aquaculture differ across social dimensions and scale, and are dependent on farm scale and location (Krause et al., 2020). To this end, and working under the assumption that offshore

aquaculture and its social dimensions are highly site-specific, we collated the findings of a modified World Café session during the annual European Aquaculture Society (EAS) meeting in Rimini, Italy in September 2022. Generally, the World Café is a large group method, which contains a sequence of discussions at tables with 4 to 7 people seated at each table (Brown and Isaacs, 2005). Such sessions can last from a couple of hours up to one to two days. In our case, an adapted version of the World Café method took place during one full-day at the EAS conference that focused on "Socio-economic challenges for sustainable aquaculture in a changing environment". Participants included 14 expert presenters from European and North American institutions who provided in-depth research talks, as well as an audience of approximately 50 conference attendees with a diverse background, ranging from natural to social sciences. Since most of the experts and participants were from countries from the Global North, the focus of the deliberations were biased toward high-tech offshore salmon aquaculture systems. That said, the following sections recognize this potential bias by carving out the very central issues of social science engagements in this research field in a more generic manner. To foster social science perspectives on the challenges and opportunities for offshore aquaculture, experts were asked to provide their thoughts and experiences on the following research questions:

(1) What emerging trajectories and related uncertainties can be observed that need to be considered from a social science perspective to foster innovative solutions of sustainable offshore aquaculture?

(2) What challenges or constraints can be identified that relate to the broader context of this development?

(3) What other thematic areas can be identified that need to be addressed to foster solution-oriented governance outcomes?

Given the venue and conference format constraints prevented a typical World Café with multiple tables, we organized the conference session into different thematic sub-sections. These were (a) emerging trajectories, (b) approaches and tools, and (c) governance. Under each of these thematic headings, presenters provided an overview of their cutting-edge research and provided their thoughts on the three questions listed above. During the three subsequent World Café breakout sessions (~25 min each) the thoughts and personal experiences of experts and audience on the three questions were discussed in plenary. One central focus of this exercise concerned the main uncertainties, challenges and the identification of under-researched topics that relate specifically to offshore aquaculture from a social science epistemology.

In the following sections, we present central themes and findings that emerged in the discussions. These results reflect themes emerging from experts present at the World Café session, and further reflections and references to the social science literature. The first section describes the key challenges and uncertainties identified by experts. The next section provides a reflection on the governance implications of these challenges. In the final section, these are synthesized to identify opportunities for social science research to contribute knowledge and inform governance of offshore aquaculture. Given this approach and the diversity of expertise, theoretical foundations, and methodological approaches of experts who participated in the World Café, this discussion focuses on broad thematic points of discussion. Although this approach may neglect some of the nuance of the discussion that took place among experts, we hope that this broader perspective provides a practical overview for natural scientists and policymakers, and that it may inspire social scientists to address the challenges of offshore aquaculture from specific theoretical perspectives and methodologies.

Challenges and uncertainties to offshore aquaculture governance

New production systems such as offshore aquaculture have their own challenges and uncertainties that warrant attention e.g., infrastructure, financial needs and risks, fish welfare, and societal/consumer perceptions, among others. The following section describes participants' insights into key social challenges and uncertainties related to offshore aquaculture, and the repercussions they might have on society and governance. Many of the identified challenges and uncertainties coincide with long-standing challenges of conventional aquaculture. This section describes the additional challenges, highlighting that often those existing challenges are exacerbated due to distance and/or exposure.

Unfolding regulatory frameworks

As of today, ongoing processes for developing technology for offshore aquaculture are in motion (Moe Føre et al., 2022). Yet, participants regularly discussed that a major obstacle in establishing offshore aquaculture has been the difficulty of navigating present regulatory frameworks (Watson et al., 2022). There is a lack of streamlined, consistent and predictable policy frameworks that support permitting processes for offshore aquaculture (Morro et al., 2022). In recent years, few jurisdictions have begun to explore and implement offshore aquaculture policies, including the United States of America (NOAA, 2016; Upton, 2019), New Zealand (The New Zealand Government, 2019), Panama[1] and Norway[2]. Beyond these notable exceptions, many aquaculture jurisdictions lack dedicated regulatory frameworks for offshore aquaculture (Davies et al., 2019), often taking a largely "one size fits all" approach to culture practices. For instance, although there is an Aquaculture Act regulating all aquaculture activities in Norway (Norwegian Ministry of Fisheries and Coastal Affairs, 2005), there is a need for additions and adjustments to adequately address aspects

1 https://thefishsite.com/articles/offshore-farmer-reveals-global-seafood-ambitions-forever-oceans-bill-bien-

2 https://www.intrafish.com/aquaculture/norway-updates-rules-for-offshore-aquaculture-but-plenty-of-work-still-lies-ahead/2-1-1347935

of offshore aquaculture. For example, tax regulations are only valid in certain (nearshore) areas, creating a need for more specific tax regulations for offshore aquaculture. Public authorities may have jurisdiction only within specific distances from the coast, prompting decisions to be made for new jurisdictional areas, or the substitution of other regulatory bodies to oversee aquaculture production. While jurisdictions are working to accommodate offshore aquaculture, the frameworks are not expedient and are complicated by existing fragmented and complex regulatory frameworks that are often composed of regulations across various agencies and spatial scales (Osmundsen et al., 2022). Based on these insights, the participants of the World Café discussed how the complexity of existing frameworks and uncertainty of creating effective governance structures designed to meet the unique challenges of offshore aquaculture are not only challenging for government, but may also hinder the willingness of investors to develop offshore aquaculture in jurisdictions that lack clear regulatory regimes (Knapp and Rubino, 2016).

Offshore aquaculture production systems are driven by a plethora of diverging considerations and decision-making aspects that have implications for effective planning, licensing and management decisions. From our discussions, participants reflected on shared experiences that current governance mechanisms, management approaches and monitoring requirements in many areas are designed to account for environmental and production features of the nearshore environment. However, offshore systems have variable considerations that can range from decisions on infrastructure in relation to the type of product produced, the variable welfare and disease aspects, and potentially drastically different environmental conditions, all of which experts felt would have repercussions on the respective probable governance regime. Additionally, decisions on technology are also interlinked with site specifications and the needs for operational safety, manpower/presence of staff, emergency preparedness, energy needs, equipment liability needs, etc. For example, environmental conditions in more exposed, offshore areas means workers are likely more susceptible to high wind and waves, having important considerations for worker health and safety (Holmen, 2022; Neis et al., 2023). As a result, these needs require tailoring the respective technological designs for specific sites and conditions to a larger extent than is common for conventional aquaculture technologies in nearshore sheltered areas. Therefore, participants reflected that siting and planning considerations and criteria would likely be variable, given the variable underlying biophysical and social considerations of more offshore and exposed aquaculture. In sum, contextual differences between offshore and nearshore aquaculture, as well as the site-specific context of offshore developments will affect strategic decisions related to licensing, site and technology use, and tactical planning and operational decisions that consider type of system and key decision makers.

Understanding societal perceptions

Underlying much of the discussion in breakout sessions were the influence and repercussions of societal perceptions, and how the introduction of an emerging technology may influence the space of public trust and legitimacy. Experts reflected on how in many areas, public perceptions of aquaculture and its regulations are a factor driving regulatory change, and have been recognized as a barrier to effective governance and growth of aquaculture worldwide (Young et al., 2019). Societal concerns are affected by the relationship between nature and humans, and specific contextual societal values, perceptions and priorities evolve and can rapidly change, all of which can affect the social license to operate offshore aquaculture (Mather and Fanning, 2019; Krause et al., 2020). Participants felt that these considerations are particularly relevant in new production systems as technologies and practices are still evolving, which could trigger unexpected sustainability challenges. More often than not, societal interests and values concerning offshore aquaculture are anticipated to be linked with prior experience with, and expectations toward conventional nearshore aquaculture, even if new production methods arise. As an emerging sector in aquaculture, offshore aquaculture may also have unique characteristics that mediate public opinion and acceptance of the technologies.

Participants also discussed how existing conflicts related to aquaculture and societal expectations may become emphasized as industry production enters new areas further away from coastal communities and uncertainties concerning potential conflicts with societal actors/communities increase. That said, the utilization of novel offshore areas for aquaculture hosts the creation of new conflicts, e.g. related to other industries, diverging power-relations and interests, demanding authorities to handle potential conflicts and trade-offs previously unknown. For example, offshore aquaculture may occur in areas of interest for offshore wind development, which may create new conflicts, or conversely identify new opportunities for synergies (Billing et al., 2022).

Furthermore, the current trajectories toward offshore aquaculture face the challenge that social equity outcomes are not yet well understood. Next to the unresolved issue of the ocean as a common to all, this also relates to legitimacy beyond the aquaculture sector as conflicts and concerns about aquaculture span multiple time and space scales. Experiences from sectors beyond aquaculture that have recent technological shifts, such as offshore wind and renewable energy, illustrate that society can exhibit a renewed sense of uncertainty and caution toward new technology sectors (Kermagoret et al., 2016; Batel, 2020). The public may be, to greater degrees, uncertain about accepting a new technology, regardless of site or design specific considerations. However, exploring how the public may respond to emerging offshore technologies has yet to be realized (Guthrie et al., 2024).

Offshore aquaculture's contribution to society

Recent experience has been gained in understanding how offshore aquaculture relates to the larger themes of sustainable development. The United Nations Sustainable Development Goals (SDGs) were adopted in 2016, but to date there is little sector-specific work done to link offshore aquaculture to the broad social, political and ecological expectations of the SDGs. However, marine

aquaculture is clearly linked to SDGs: In a pilot project financed by the Research Council of Norway in 2021[3], the Norwegian organization representing over 40 small- and medium-sized salmon farms, Salmon Group AS (https://salmongroup.no/), worked with interdisciplinary social scientists at the University of Bergen to assess which of the 169 targets of the UN SDGs were relevant to salmon aquaculture in Norway. The result was that 103 targets over all of the 17 Sustainable Development Goals were deemed either directly or indirectly relevant for salmon production in Norway. These surprising results revealed the power of understanding the underlying value chains of marine aquaculture, and that the sourcing of ingredients for salmon feed, for example, have direct links to labor rights, gender equality, data access, political representation and ecological preservation that reflect the complexities of the social-ecological system. These value chain components and linkages to SDGs can also be expected for offshore aquaculture; therefore, the role of social science in sustainable development of offshore aquaculture is crystal clear, considering the direct social and political links of offshore aquaculture to the global normative guidance toward sustainability.

All of these potential contributions need to be assessed to determine whether emerging offshore aquaculture systems can provide sustainable production by advancing the analysis of the social effects of different types of resource management regimes, supply chains and logistics. Furthermore, the uncertainties of new production systems are exacerbated by the anticipated potential mitigation of environmental impacts, which is one of the most prominent aspects driving public opinion in traditional nearshore aquaculture (Olsen et al., 2023). This is strongly linked to trade-offs of sustainability outcomes that can be further differentiated between long- and short term effects (Krause et al., under review)[4].

In addition, new technologies often require substantial capital investment and incur financial uncertainty and risks to producers. The cost factor in offshore aquaculture is an essential uncertainty in this regard. Most operational costs will increase (related to investments, operations, transports etc.), the structures are expected to be replaced more often than traditional farms, and license costs are still highly uncertain since there are to date few examples of governments with established license regimes for offshore aquaculture (Morro et al., 2022). Furthermore, higher costs and uncertainties regarding production will also affect the possible economic gains for society at large and thus the distribution of these. Combined, the increased costs and risks to establish offshore operations create a form of barrier to entry for small-scale producers, as those establishing these technologies are likely well-funded large corporations. Indeed, there is already a high degree of horizontal integration and increasing firm size in salmon aquaculture (Asche et al., 2013) and the potential dominance of the offshore sector by large multinational corporations could have distributive justice implications and considerations for equitable distribution of benefits to hosting areas and jurisdictions.

It may be tempting to address these challenges and uncertainties on a case-by-case basis, with new research and development, new assessments and public campaigns and the like. However, we believe these are short-term and temporary fixes. Instead, we argue that taking a systematic social science perspective on offshore aquaculture is needed to understand these challenges and uncertainties in their societal context and identify long-lasting sustainable pathways to societal change.

A social science reflection on offshore aquaculture governance

Reflecting on the challenges and uncertainties that accompany offshore aquaculture systems and technologies reinforces critical opportunities for social science perspectives to advance effective governance of the emerging sector. Yet, the question of how we can integrate the social perspective in the current development toward offshore aquaculture is not an "easy fit". Indeed, it is challenging to integrate the (often not easily measurable) social perspectives, since it requires consideration of a very diverse public. In addition, there are many remaining uncertainties in the operation, maintenance, and interconnectedness of production within the respective social-ecological system at large. These challenges are exacerbated by the largely ineffective ways that social perspectives are incorporated for conventional aquaculture, thus highlighting a lack of effective frameworks from which to model (Osmundsen et al., 2020a). The following section reflects on the thematic points of World Café discussions surrounding the considerations of incorporating a social perspective to offshore aquaculture governance, and the critical discourses and issues that social sciences can help inform. These key themes set the boundaries around which a social science agenda for offshore aquaculture can be discussed.

Governing public and private interests

Any kind of governance regime needs to consider the role of access to capital, cross-sectional dialogue forms and collaboration arenas between private and public stakeholders, all of which need to be tailored to novel licensing regimes of offshore aquaculture. In conventional aquaculture, emergency preparedness based on collaboration between private and public stakeholders from multiple sectors in the coastal zone still have potential for improvement (Osmundsen et al., 2020b). This aspect of collaboration is also highly relevant for offshore sites. Regulating a multi-technology aquaculture sector requires fundamental changes in current regulatory frameworks and must avoid merely adapting and extending current regulatory designs to include new production concepts. Layered, complex and fragmented regulatory frameworks for aquaculture already exist in many aquaculture

3 https://prosjektbanken.forskningsradet.no/en/project/FORISS/323913?Kilde=FORISS&distribution=Ar&chart=bar&calcType=funding&Sprak=no&sortBy=score&sortOrder=desc&resultCount=30&offset=0&Fritekst=sdg+wizard

4 Krause, G., Filgueira, R., Ahmed, N., Alexander, K., Fanning, L., Ferse, S., et al. (under review). Regionalisation alone will not make marine aquaculture more sustainable. *Rev. Aquaculture*.

producing countries due to continuous adaptation of existing frameworks (McDaniels et al., 2005; Osmundsen et al., 2022; Sandersen and Kvalvik, 2014). New offshore production areas entail different characteristics than coastal areas where farms are already established, thus existing regulations may not be appropriate but must be made relevant for species, environment and production methods (Morro et al., 2022; Watson et al., 2022). For example, licenses for offshore production in Norway represent a new form of regulation of aquaculture, connecting site (geographical location), installation (production technology) and volume (allowable biomass) per each license. In the case of Norway, offshore aquaculture is defined by the Norwegian government beingoutside the existing geographical jurisdictional areas for existing regulations as well as beyond the sectoral authorities' responsibility in terms of control and management of the industry. Consequently, development of new licenses must be accompanied by processes and establishment of jurisdictions, collaborations, and clarifications of roles and responsibilities of the involved public authorities. Adherent to this, governments must make decisions upon which public authorities are relevant and what possible new roles and laws are needed in securing good governance of offshore aquaculture production.

The Norwegian example demonstrates a central mainstay of research needs for offshore aquaculture: How to tackle current licensing schemes under adaptive and cross-sectional governance regimes. To date, licensing procedures are commonly customized for conventional aquaculture, not for new production systems such as offshore aquaculture (Davies et al., 2019), but even sector-specific approaches may disregard the many attitudes toward the legitimacy of offshore aquaculture that are beyond the aquaculture sector and revolve around broader environmental, social, and governance issues. As such, governance structures need to involve many actors, who are all responsible for "different pieces of the same pie" and range from local, regional, national as well as international institutions.

Acknowledging the complexity of production and political interests

The complexities of aquaculture production and political interests and values that range from nation specific interests to the current global economic and political environment all shape the potential governance of emerging technologies on a site-specific scale. This is extremely challenging, as there are yet manifold knowledge gaps and uncertainties related to causal effects in offshore aquaculture operations. However, it is clear that policy design will have different impacts on industry development as well as repercussions for society at large. From this stance, the World Café highlighted the need to include assessments of societal impact, e.g. changes in value creation, economic benefits and distribution, and if/how these are sought and accounted for in governance measures during the process of developing new regulatory frameworks for offshore aquaculture. This would be an important factor which should be included in the debate about licenses and their costs, representing a possible trade-off in balancing necessary risk relief for industry on one hand and important revenues for society/communities on the other hand.

First research results show that geographical conditions, to a limited extent, determine the importance of various social impacts and involvement of different stakeholders. Operations further offshore imply that the production has relevance for multiple adjacent communities, stakeholders, and interests. Perceived benefits and impacts are beyond direct visual impacts as stakeholders are equally concerned about indirect impacts including equity, collective choice rights, and the distribution of impacts (Suryanata and Umemoto, 2005). In this sense, a shift in focus to community wellbeing is necessary to realize the potential social benefits of marine aquaculture expansion (Campbell et al., 2021). The classification of various types of offshore aquaculture can shed some light on the differences in social acceptance. However, as pointed out in the discussion among the participants of the World Café, this should not be used in a deterministic manner as some social impacts, and concerns, transcend the boundaries of geographical distance. Ultimately, the question remains however, who should make the choice?

Social supply-chain perspective

Offshore aquaculture can be viewed as new production systems that offer solutions for more sustainable development of the industry. However, new production systems also have their own challenges in terms of infrastructure needs, risks, and fish welfare and societal/consumer perceptions (Wever et al., 2015, Morro et al., 2022). New farming technologies for offshore aquaculture necessitate larger and more expensive structures which will rely on the labor supply and competence of supplier industries, hence different ripple effects from aquaculture can be expected. The discussants agreed that additionally, the development of new value chains for new production systems that include offshore aquaculture are in nascent stages and thus much still needs to be researched. Under this light, the whole supply chain must be considered. This includes production costs and benefits, infrastructure and competence needs, enabling environment and management, and environmental and social risks and resilience. For example, vulnerabilities and resilience to supply chain disruption that will have implications for sustainable livelihoods are untested. Life Cycle Analysis (LCA) is needed to demonstrate sustainable production, vis à vis the real-world application of spatial scale modeling will be needed to understand trade-offs across geographic scales associated with emerging value chains. Further, social acceptance and consumer receptivity in aquaculture are intertwined and engage with broader social change movements reflecting a discourse extending beyond sole aquaculture issues and its local governance.

New policies and regulations as well as existing market-driven governance schemes will need to account for new production systems for offshore aquaculture while also considering cascading impacts, vulnerabilities, and risks across the supply chain. Novel policy design and the shaping of regulatory frameworks need to

acknowledge their impact on industry development. This relates to the direct production volumes, number of jobs, but also to the rather indirect societal development that relate to the questions of where should people live, and who should live there. Furthermore social norms that revolve around the relationship between nature and humans, i.e.how do we interact with nature, and what are the limits for human actions, need to be considered.

Legitimacy and democratic decision-making

A key under-researched theme identified in the discussions of the World Café in the context of social science engagement with offshore aquaculture relate to the questions of the limits of democratic processes in decision-making, addressing societal expectations, and regulatory needs for securing social acceptance and sustainable outcomes of new production methods and areas for offshore aquaculture. By virtue, democratic decision-making infers the need for decisions that affect society to reflect those societal values, priorities, and expectations. Those decisions, and the subsequent outcomes (e.g. industry development) should ideally be viewed as fair and legitimate. Recently, the legitimacy of aquaculture has been a key factor in understanding the societal acceptance of aquaculture (Bjørkan and Eilertsen, 2020; Sønvisen and Vik, 2021; Olsen et al., 2023; Weitzman et al., 2023). These findings emphasize the need to understand societal perceptions and expectations and how aquaculture aligns with them. Despite the recent advances in this area, participants discussed the challenge of what is felt to be a substantial knowledge gap in social perceptions, attitudes, and understanding the factors that drive them. Indeed, only recently these have begun to be investigated in conventional aquaculture systems in nearshore environments. These challenges become exacerbated due to the noteworthy limit of social science research on the specific needs and considerations for governance of offshore aquaculture.

Although offshore aquaculture involves major changes in production, participants reflected on how it could be anticipated that the expectations from society may still be positive in terms of sustainability, industry contributions to society, and regulatory demands. Offshore aquaculture systems may offer solutions to current environmental challenges facing nearshore aquaculture (Fairbanks, 2016; Jansen et al., 2016; Lester et al., 2018), which are often viewed as a key element for a sustainable development of the industry and a recurring societal concern. Yet, participants also acknowledged that there may also be trade-offs in the environmental and social costs of offshore production systems, and reinforced the importance of understanding the specific societal perceptions and responses to offshore aquaculture for specific areas, species, and policy contexts.

Ensuring legitimacy for offshore aquaculture production is dependent on societal expectations being met by industry proceedings and governmental regulation. Recent evidence from nearshore aquaculture systems illustrates that public trust in government and transparency of regulatory processes as a key component in the legitimacy of aquaculture within communities (Weitzman et al., 2023). As such, governments' arguments and policies supporting offshore aquaculture as a solution for targeting sustainability goals must be deemed acceptable from societal stakeholders as well. For conventional aquaculture and industry activities in general, an important factor for acceptance is the distribution of economic benefits from industry, or distributive justice that pertain to industry contributions in local communities and for the wider public (Ertör and Ortega-Cerdà, 2015; Misund et al., 2023). With offshore aquaculture however, there is great uncertainty to how such production and adherent regulations will affect the benefits and distribution of these to society, and therefore the legitimacy of offshore aquaculture.

Adding to calamity, participants highlighted that social acceptance in aquaculture is always embedded in broader social change movements. Politics, perceptions and social expectations can change rapidly and often. Moreover, the relationships between nature and humans are fluid. Appropriately presenting and accounting for this fluidity and dynamic state of these considerations is an enduring challenge for effective coastal governance and MSP (Jones et al., 2016). This may be especially notable with the accompaniment of the rapid technological and governance changes of an emerging offshore aquaculture sector. This underlines the importance of not only continued, up to date co-produced social science knowledge generation on these aspects, but also that governance responses to the emergence of this novel sector need to be adaptive and flexible to effectively ensure legitimacy of policies and practices.

A social science agenda for offshore aquaculture governance

Capturing social dimensions of offshore aquaculture in support for solution-oriented research approaches can be viewed as "wicked problems" in that all parameters cannot be specified, there is no single optimum to be attained and "…there is no criterion system nor rule which would tell you what is correct or false" (Rittel, 1977; Osmundsen et al., 2017). Indeed, the above compilation of under-researched trajectories, challenges and solution-oriented governance needs that were identified by the participants of the World Café exercise and mirrored by literature review leads to asking two questions at once: What should social science do? And what should be done with the social science knowledge created? In other words, *how* should the scientific arena shift toward urgently needed solution-oriented research outcomes and what are the identified specific under-researched social science arenas therein? In this section, we highlight that there are significant opportunities for social science to provide co-produced knowledge and insights to better understand the social repercussions and considerations of offshore aquaculture systems. This knowledge could ultimately inform more legitimate and effective governance to promote an emerging sector sustainably.

What can social science do?

We have identified several topical areas of concern that can be addressed by social science approaches (Figure 1). These include, among others, the need to identify areas of conflict between marine users, understanding the social impacts of offshore aquaculture, and assessing the economic costs and risks thereof. Successful and sustainable governance processes and practices that lead to appropriate regulatory frameworks will only be possible via understanding of societal concerns as they intersect across the offshore aquaculture value chain. Recent social science research efforts have sought to understand, quantify, and explore social repercussions and perceptions of aquaculture. This demonstrates the value of social science methods and knowledge for the aquaculture industry and society. For example, Marine Spatial Planning (MSP) has been suggested by several authors (Ehler and Douvere, 2009; Foley et al., 2010; White et al., 2012) as a suitable tool for reducing conflicts and fostering synergies between maritime uses under a sustainability lens. Public surveys, media analysis, and ethnographic methods have been used to improve understanding of social acceptance of aquaculture (e.g. Kraly et al., 2022; Aanesen et al., 2023; Olsen et al., 2023; Weitzman et al., 2023). Critical analyses of policy, regulations, and other governance practices have been applied to better understand governance processes and outcomes, and reveal the limitations of current public and private governance (Anderson et al., 2019; Falconer et al., 2023; Osmundsen et al., 2022; Jonell et al., 2013; Rector et al., 2024). Economic modeling has been used to understand the impacts of aquaculture in rural and developing economies (Filipski and Belton, 2018; Grealis et al., 2017). Each of these social science approaches will be valuable in developing an improved social understanding of offshore aquaculture that can inform governance and associated regulatory frameworks. However, the integration of social and ecological knowledge and research that engages with industry and citizen tacit knowledge and perspectives via co-productive research methods is urgently needed. Such transdisciplinary engagements hold the promise to deliver feasible and effective pathways beneficial for societal well-being and the sustainability of offshore aquaculture production.

The case for inter- and transdisciplinarity

We have identified several areas of concern that warrant concerted inter- and transdisciplinary research approaches. Interdisciplinarity describes the integration of disciplines toward a common goal and shared research question, while transdisciplinarity describes the integration of both disciplines and non-academic participants toward shared processes that results in actionable knowledge that benefits society (Tress et al., 2005). As a general principle, most of the identified under-researched topics are related to processes and therefore require novel transdisciplinary approaches to tackle these complex questions. However, the current composition of research in offshore aquaculture is yet in nascent stages in terms of how and in what ways to combine the different knowledge realms and evidence from cross-cutting disciplines and experts in the field. By and large, the identification of "who holds a stake" in the system is the mainstay of most of social science research on offshore aquaculture, while being at the same time the principal stage in any solution-oriented governance initiative (Reed et al., 2009; Prell, 2012; Krause et al., 2015).

In the case of offshore aquaculture, it is evident that industry actors and coastal communities are stakeholders, though interests

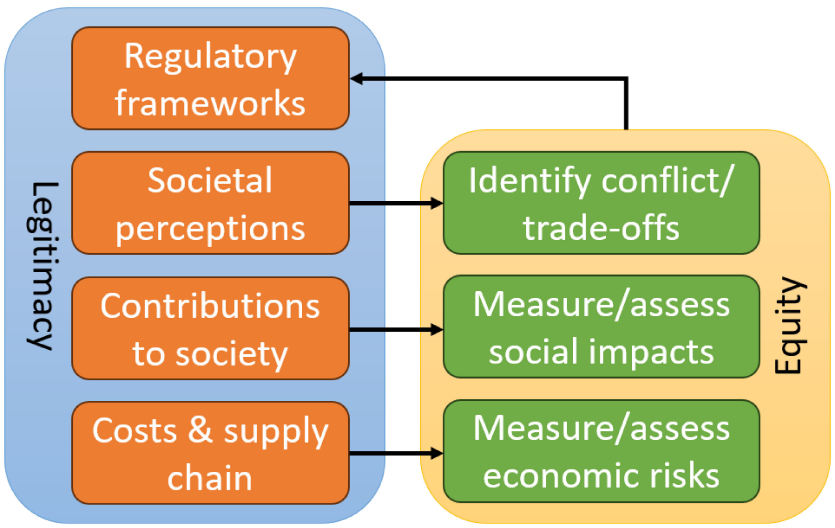

FIGURE 1
What can social science do? Orange boxes represent challenges and areas of uncertainty related to offshore aquaculture. These competing and overlapping challenges create what is known as a "wicked problem". Green boxes represent some of what social science can do to understand and address these challenges. Integration of these approaches through interdisciplinary research, and the inclusion of industry and societal knowledge and experience through transdisciplinary research is needed to address this wicked problem in ways that benefit society through the equitable distribution of benefits and the legitimacy of policy that governs offshore aquaculture.

likely extend to additional groups and institutions. Industrial actors aiming for the offshores do so because these geographical areas offer benefits not attainable in coastal waters. These relate to e.g. access to production sites that are scarce closer to shore, economies of scale since production may be largely increased, longer distance to nearby sites and greater water exchange protecting against sea lice and infection pressures, and perhaps closer distance to markets. Also, exemptions from local and regional jurisdictions and taxation regimes may, in theory, be a motivation to move further from the coast. For coastal communities, reduced geographical presence of aquaculture may allow for increased activities in other sectors, but may also very likely reduce access to direct employment benefits, ripple effects from aquaculture operations, and revenues. In contrast for societies at large, offshore aquaculture may positively contribute to global food security issues. However, it must be acknowledged that it relies on shared resources resulting in governance problems that require institutional solutions aligned with collective interests (Partelow, et al., 2022; Krause et al., under review)[4].

That said, the management of human activities is complex and broad touching on many facets of wellbeing and affecting multiple actors and institutions (Reed, 2008). Hence, from a planning perspective of offshore aquaculture, it is crucial to have a full understanding of the stakeholders and their relations and characteristics that may influence decisions through their power, or support the initiative promoting cooperation and knowledge exchange during engagement (Prell et al., 2008). This makes the decision-making process transparent and contributes to democratic and holistic decision-making process (Reed, 2008), while acknowledging social processes such as knowledge transfer, information sharing and power relations. It is essential to identify the key actors or stakeholders in a respective offshore aquaculture system arrangement and to understand their behavior, intentions, interrelations and interests, as well as their respective sustainability outcomes (Krause et al., under review)[4]. The assessment of influence and resources they bring for implementation of the process is important (Grimble and Wellard, 1997; Brugha and Varvasovszky, 2000). However, societal values, perceptions, and priorities are constantly changing and evolving. As thus politics and perceptions (and social expectations) can change rapidly and often, these uncertainties and their impact are not easy to measure or specify. As of yet, there remains a substantial knowledge gap in social perceptions, attitudes, and understanding the factors that drive them.

Methodological challenges to a holistic social perspective

In a holistic approach, the social science perspective will point out contradictions and inherent trade-offs, even though this view alone will rarely provide applicable solutions for this. Thus, the challenge remains of how to integrate societal perspectives that cover the need to recognize the tension between individual expression and longing for social recognition for particular communities (Fukuyama, 2018). Methods in transdisciplinary research are still emerging. For instance, Fuzzy Cognitive Mapping is a well-known method for mapping inherent interactions of the social-ecological system in smaller diverse groups (Tiller et al., 2016), but there is no experience of up-scaling this method to larger groups. Next, on a global scale the sustainable development of offshore aquaculture is constrained by nation specific interests, but also by the current unsettled global economic and political environments of our time. Contextual changes can lead to shifting priorities and conflictual goals, increasing the necessity of trade-offs. All of this influences the respective social license to operate offshore aquaculture. As the latter spans across multiple time and space scales, it is challenging to create effective transdisciplinary research methods that foster sustainable responses for societally acceptable aquaculture.

Despite these difficulties, there are potential solutions within reach. For example, social licenses depend on authentic dialogues among the public, industry, and authorities. Dialogues that respond to concerns of a diverse public, and which are perceived as genuine, trustworthy and transparent, may move public sentiments in a positive direction. Experiences from virtual round tables in Scotland demonstrate that the inclusion of a diverse public with industry representatives, researchers and authorities in a transdisciplinary research setting are capable of fostering such dialogue, even though such events include a fairly large number of participants (SSAC, 2023). Other approaches to investigate community concerns and possible measures for reducing conflicts and establish social license is exemplified by Condie et al. (2022). By looking into submissions to two governmental inquiries in Tasmania, they identified stakeholder groups, and co-explored prominent issues of concern by the community, such as environmental sustainability, regional economic growth, governance, communication, and the role of science. Similar approaches could be useful for other governments and science as well, and could provide important knowledge related to emerging issues concerning offshore aquaculture and its possible implications.

When it comes to governance complexities, e.g., overlapping regulations and/or regulatory gaps, the optimal approaches for social-ecological data collection remains a challenge as input and output data are limited by location and time. In addition, the systems being analyzed are dynamic, as well as time and resource dependent while being driven by system uncertainty. The development of new offshore aquaculture provides opportunities to both study social dimensions and incorporate social perspectives in the development of the industry and governance approaches. Integration experts and methods will be needed to facilitate inter- and transdisciplinary approaches, but these experts and the costs of truly integrative solutions-oriented research are not well-supported or facilitated by institutional and academic structures (Hoffmann et al., 2017, 2022). The challenge remains to work cost- and time-efficiently while also producing thorough in-depth data and analyses of social-ecological systems in order to create knowledge that can be harnessed for sustainable development pathways of further offshore aquaculture expansion.

TABLE 1 The most salient challenges, risks, and solutions for offshore aquaculture development.

Challenges	Risks	Solutions
Lack of dedicated regulatory frameworks; fragmented regulatory frameworks across multiple agencies and spatial scales	Scaffolding offshore aquaculture permitting onto existing regulatory frameworks designed for nearshore environments could lead to inefficiencies or ineffective governance; investors are unwilling to develop offshore aquaculture in jurisdictions that lack clear regulatory regimes	Develop and implement context-specific, streamlined, consistent, and predictable policy frameworks that support offshore aquaculture permitting
Understanding public perception, opinion, and acceptance of emerging offshore aquaculture technologies	Creation of new conflicts with relevant actors and communities; negative impacts on the legitimacy of offshore aquaculture	Use of participatory and transdisciplinary research approaches to identify potential societal conflicts, trade-offs, and understand acceptance of and opposition to offshore aquaculture
Potential conflict with offshore industries and other marine uses	Competition for offshore space and development of one offshore industry at the expense of others	Inclusive Marine Spatial Planning process that recognizes stake- and rightsholders
Understanding and predicting impacts of offshore aquaculture on society across the supply chain at relevant spatial scales	Creating undesirable trade-offs between social and environmental sustainability	Assess social, environmental, and economic risks and identify trade-offs at local, regional, and global scales
Increase in capital and operational costs	Barrier to entry for small-scale producers and dominance of multinational corporations result in inequitable distribution of risks and benefits of offshore aquaculture development	Equitable distribution of benefits of offshore aquaculture through mechanisms that benefit host communities

Conclusion

This paper offers a critical social science reflection on an emerging offshore aquaculture sector, based on discussions among aquaculture experts and researchers raised in a one-day World Café session. The discussion revolves around the most salient social challenges and risks that offshore aquaculture could face and the role of social science in mediating those challenges (Table 1). While many of the observations and discussions draw on experiences and research from nearshore aquaculture environments, this reflection offers a renewed perspective that can be valuable for industry and decision-makers to foster an equitable, sustainable offshore aquaculture sector. While this paper offers general reflections on the social repercussions and policy implications of offshore aquaculture, specific societal consequences, perceptions, and policy strategies warrant more contextualized research and discussions to consider the needs and implications for different areas, species, and production systems.

Based on our discussions, we observe that the technological changes in offshore aquaculture challenge conventional governance and require transformed and disrupted solutions that intersect not only science and society, but also different scientific bodies and disciplines. Indeed, many of the solutions, challenges, and social science reflections on governance for offshore aquaculture revolve around resolving aspects of legitimacy. This highlights the need to consider aspects of procedural justice, equity, and well-being in aquaculture. These dimensions reinforce the need to "humanize" aquaculture governance (Brugere et al., 2023) through an emphasized social framing of challenges (Krause et al., 2015) that embraces intersectionality and promotes cross-disciplinary knowledge systems. The development of offshore aquaculture is both a challenge and an opportunity for the application of this transformed mode of research and knowledge generation. In this regard, transdisciplinary research approaches are warranted. However, how to put such transformative change toward sustainable food production while ensuring food security into practice remains a challenge and will require transdisciplinary approaches to find societal appropriate solutions (Markus et al., 2017; Krause et al., 2020; Franke et al., 2022; Krause et al., 2022; Partelow et al., 2023). These solutions need to be implemented, and this may require profound changes, including ethical and philosophical considerations regarding the relationship and responsibility of humans to nature (Huss et al., 2022). It implies a different orientation of science and its role in governance in the 21st century. The character of this new (transformative) orientation of science is only now beginning to emerge, but will need to accommodate new opportunities for science in tandem with society. Only then can we forge a collective meaning on how to manage the complex challenges for offshore aquaculture.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material. Further inquiries can be directed to the corresponding author.

Author contributions

GK: Conceptualization, Investigation, Methodology, Writing – original draft, Writing – review & editing. JW: Investigation, Writing – original draft, Writing – review & editing. MR: Investigation, Writing – original draft, Writing – review & editing. RF: Conceptualization, Investigation, Methodology, Writing – original draft, Writing – review & editing. SB: Investigation, Writing – original draft, Writing – review &

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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