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Understanding fishers' wellbeing through participatory processes in fisheries management

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Evgenia Micha[1] & Ingrid Kelling[2] ✉

Within the social dimension of fisheries management, fisher wellbeing remains inadequately addressed due to divergent stakeholder perspectives. This study conceptualises fisher wellbeing as a dynamic system, shaped by the knowledge of the stakeholders involved. The primary objective is to quantify disparities in stakeholder perceptions and construct a comprehensive depiction of fisher wellbeing by integrating stakeholder knowledge. Leveraging a systems thinking methodology, we employ fuzzy cognitive mapping (FCM) to develop cognitive maps for individual stakeholders that show distinct pathways towards fisher wellbeing. We then integrate these into a unified map, illustrating the complexity of the system when all stakeholder voices are considered. Our findings highlight the existence of common wellbeing goals despite stakeholder differences and the challenges fisheries managers face when trying to implement co-decision making. This integrated approach provides a foundation for understanding diverse perspectives, fostering collaboration, and formulating inclusive policies that incorporate fisher wellbeing into fisheries management.

In light of rapid changes in oceanic environments and the high impact these changes have on fishing communities, an equitable and effective fishery must meet all three sustainability dimensions: economic, social and environmental[1]. Although economic and environmental aspects of sustainability are increasingly incorporated in policy procedures, social sustainability, and particularly fisher wellbeing, is often more difficult to grasp[2–4]. Frequently, the concept of sustainable fisheries is presented as a win-win framework of fish stock protection combined with increased profits[5]. In this context, sustainable fisheries are usually defined in economic growth terms, which neglects the full dimension of sustainability[6]. Instead, sustainable fisheries require a systems approach comprising economic, psychological, environmental, and social factors, which go beyond monetary growth to prioritizing the wellbeing of fishers[7].

According to the OECD[8], the social sustainability of all industries and societies relates to human wellbeing. A person's wellbeing is multidimensional, covering objective aspects such as housing, income, job quality, health, civic engagement, social connections, safety and work-life-balance, as well as being influenced by more subjective factors such as environmental, social and economic factors at the individual, family and community level, in addition to each person's unique circumstances and experiences. Fisher wellbeing is increasingly recognised as requiring multidimensional approaches to understanding and evaluating social sustainability[9] because it gives a "comprehensive frame for understanding what is important to people, communities and society"[10]. To address the multidimensionality of social sustainability, policy designers across Europe and North America have shifted towards more holistic models of fisheries governance that use fisher-knowledge integration and public participation methods[11–14] in their decision-making. Despite this, the concept of fisher wellbeing is still not fully developed, and policy efforts often adopt linear, top-down approaches, where controversial issues are addressed as they emerge, according to the perception of the stakeholders most involved. This model of policy design, in reality, sustains siloed approaches to fisher wellbeing[15] and often results in fragmented solutions that overlook the big picture.

In order to strengthen the knowledge base of decision-making around fisher wellbeing, it is necessary to design and implement more effective and democratic processes of communication between stakeholders, to enable them to access and explore each other's knowledge[16]. This will improve equity and participation, as well as sharing responsibility between impacted parties[17]. Stakeholders' conflicting interests and different understandings often hinder their participation in knowledge-sharing. As a result, the evidence base reaching final policy designers can be fragmented. The literature identifies several reasons behind difficulties in ensuring effective knowledge sharing models. These are: (i) stakeholders' divergent perceptions and goals that depend on their understanding of the current situation[18]; (ii) a lack of clarity regarding stakeholders' roles, information gaps, policy overlaps, poor

[1]University of Gloucestershire, Countryside and Community Research Institute, Francis Close Hall, Cheltenham, UK. [2]Lyell Centre, Heriot-Watt University, Edinburgh, UK. ✉e-mail: i.kelling@hw.ac.uk

data collection and inadequate monitoring[19]; and (iii) a lack of adequate roadmaps that will assist stakeholders in "translating" their knowledge to other groups (e.g., scientists vs fishers)[20]. For participatory knowledge-sharing, particularly for complex issues like fisher wellbeing, it is critically important to build adequate tools that will integrate all necessary stakeholder experiences, expertise and requirements in a tangible way[21].

This paper uses a systems-thinking conceptual framework to investigate and explore the complexity of addressing fisher wellbeing when shared stakeholder knowledge is incorporated in the decision-making mechanism[22–26], using the Scottish nephrops (Nephrops norvegicus) fishery as a case study. Systems-thinking approaches have been identified in the literature as suitable for encompassing holistic knowledge in the marine environment research [i.e., 20]. However, most of these approaches have a marine resource management focus and aim to understand the level of acceptance of marine protection policies or to investigate the impact of fishers' activities on the marine environment [for example, 21-25]. This study explores the diverse understandings of how fisher wellbeing is affected by external pressures, and incorporates the fisher point of view, which has commonly been lacking in published literature and is consequently under-investigated[27]. The purpose of this research is to explore the similarities and differences of the understanding of wellbeing by different stakeholders and to explore its complexity when all views and opinions are interlinked. To achieve this, the paper investigates differences in knowledge systems by analysing and comparing representations of group-thinking maps from stakeholders involved in decision-making around fisher welfare in Scotland. We then compare perceived key concepts for each group, identify similarities and differences and explore how this affects communal knowledge. Next, we combine all stakeholder knowledge into a communal knowledge system where all stakeholders are included equally. Finally, we evaluate the method as a tool for policy decision-making. Using participatory techniques to elicit stakeholders' views and incorporating them into mental models enables us to represent the structure of the wellbeing system as they perceive it. The structures of the stakeholders' knowledge systems are presented as cognitive maps (CM) and specifically as fuzzy cognitive maps (FCM). A CM is a qualitative model of how a system operates[28]. Practically, it is a system depiction method in which a number of identified concepts and the relations between them are shown as a graph. An FCM[29] is a modified CM where the relations between components have a numeric value between $[-1, 1]$. This allows for the quantitative description of the interactions between system components. FCMs are used in various disciplines as methods to gather expert-derived data that would otherwise be collected via more complicated processes[30]. In socio-ecological contexts their use is limited but they have been used in recent systems-thinking approaches to understand food production systems[31,32], explain the complexity of natural resource management[33–37], and explore co-decision making processes when multiple stakeholders are involved[38–41]. In the context of marine research, the method has been used to assess stakeholder perspectives on marine and coastal ecosystems management[42–45], the management of recreational fisheries[46,47], and Gray, Chan[48] used it to construct stakeholder-driven socio-ecological models for sustainable fish stock management in American fisheries.

Scotland's commercial fishing comprises a significant proportion of the United Kingdom's fishing industry with landings by Scottish vessels accounting for 61% of the value and 67% of the volume of all landings by UK vessels[49]. Aside from its contribution to GDP, fishing in Scotland plays an important role for local communities through a sense of identity, social capital and connection to local heritage[50]. The fishing industry in Scotland faces a variety of challenges, including – but not limited to – a lack of young people in the profession, increasing pressure from environmental polices[51], and competition for resources with other industries such as tourism, aquaculture and renewable energy production[52]. In order to ensure the sustainable development of the fishing sector in alignment with the global sustainability goals as set by the United Nations[53], the Scottish government created a framework that defined successful fisheries[49], moving towards a co-design framework to shape its new Fisheries Management Plans. Understanding synergic and conflicting interests among stakeholders and designing tools for effective knowledge-sharing leading to improved well-being is crucial. This paper uses the Scottish fishing industry as the contextual framework to develop and test a knowledge sharing tool to assist policy design, that can be applied in other similar contexts.

Results

The indicators that formulated the initial structure of the system are listed in Table 1. Similarly to the mapping exercises, participants were given the opportunity to add components to their map. Six new components emerged that are listed in Table 2.

Figures 1–6 present the graphical images of the knowledge maps.

The map metrics (Table 3) uncovered several similarities and differences in stakeholder knowledge systems.

The fishers' map has the fewest components (34) and links between them (107), suggesting a perception of simplicity regarding the factors influencing their wellbeing. However, the diameter of the fishers' map is 9, the longest of all maps. This implies that fishers believe up to 9 'steps' are required for certain map components to indirectly influence the system, indicating a perceived complexity in their understanding of the system. In contrast, the government map has the shortest diameter (5), signifying that, despite identifying more components, they view the system as less complex. This finding aligns with the prevailing paradigms of top-down approaches in fisheries management[54]. The density of the fishers' map is 9.5%, and it includes 3 transmitters and 4 receivers. Similarly to the government map and in comparison, to other maps, this suggests a heightened perception of cause-and-effect relationships. However, as mentioned in the literature, the increased number of receivers may also indicate fishers' enhanced ability to 'see the big picture"[40]. Commenting on this during the validation interviews, several participants agreed that fishers' usually hold a broad perspective as it is their own wellbeing that is being assessed.

The researchers' map has a relatively high density (10.9%), a higher number of connections (130), a relatively long diameter (7) and 0 components that are transmitters or receivers. These characteristics combined show that researchers perceive the system to be fully circular and highly complex. However, contrary to government representatives and fishers, the non-existence of transmitters and receivers could also mean a failure of researchers to "see the bigger picture". In general terms, this may be supported by the literature as researchers sometimes overlook types of knowledge that are outside their discipline[48]. The validating interviews confirmed that research may sometimes adopt siloed approaches.

The civil society map is the densest (14%) and has the highest number of connections (168). It has only one transmitter and no receivers. These characteristics show that fisher representatives also perceive fisher wellbeing as a circular system with multiple inter-connections, but again, the small number of transmitters and receivers may reflect failure to see the big picture. Interviewees elaborated during the validation interviews that this may be because civil society institutions often address specific issues related to one aspect of fisher wellbeing (such as housing) and are less engaged in decision-making beyond a single issue, which may frame their goal setting.

The government representatives' map includes all components (37), is the least dense (8.5%) and has 9 transmitters and 3 receivers. It has the smallest diameter of all stakeholder maps (5). These metrics suggest a more linear approach to fisher wellbeing. Using a systems-thinking approach, this could mean that government officials do not consider fisher wellbeing as a closed system, but rather as open-ended, comprised of cause-outcome links. According to graph theory[28], the large number of transmitters also signifies that they see many external forces that influence the system, but anticipate fewer outcomes. This observation may reflect an overarching mentality stemming from the fact that in policy design approaches, policies typically tend to address only a small number of goals. Government officials often face multiple pressures from various actors that need to be considered[54], a finding that was confirmed in the validation interviews by several participants.

Table 1 | Indicators that formulated the initial structure of the system

Indicator	Definition
Job satisfaction	Core Wellbeing indicator (All) The extent to which fishers are satisfied with their work.
Business success	Core Wellbeing indicator (Social) – The perceived successful outcomes of fishing.
Economic security	Core Wellbeing indicator (Economic) – Fisher perception of being economically secure and confident they can cover their financial responsibilities.
Quality of life	Core Wellbeing indicator (Human) – Perceived quality of life including the ability to live a life with qualitative elements beyond covering basic needs.
State of the marine environment	Core Wellbeing indicator (Environmental) – The condition of the natural marine ecosystem(s) fishers operate in.
Safety	Fishers safety on-board, while at sea.
Communication to shore	Ability to communicate with important contacts while at sea.
Comfort on board	Facilities on board that go beyond basic needs, such as diverse nutrition, religious facilities or entertainment options.
Sense of identity	Strength of identity as a fisher.
Mental health	Current perceived state of fishers' mental health condition and perceived ability and willingness of fishers to receive mental health support.
Access to healthcare	Access to doctor/dentist appointments when require-. Ability to access emergency services or receive healthcare on board.
Inclusive local community	Being an accepted and active member of the local community.
Fishers' representation	The extent to which extension bodies such as fishers' associations, unions and NGOs defend fishers' rights and project their views.
Influence on policies	Fishers' meaningful ability to participate in and influence policy design,
Access to labour/ Crew recruitment	Ease of local owners/skippers to recruit crew.
Freedom to make decisions	Fishers' freedom to make fishing-related decisions regarding practices and management of boat and crew.
fish where fishers' want	Fishers' freedom to choose fishing grounds.
Quantity of catch	Quantity of fish landed
Access to markets	Fishers' ability to effectively access fishing markets.
Revenue	Gross income from fishing activities.
Access to credit	Access to financial credit for fishing businesses.
Subsidies for fishers	Financial support to fishers that does not come from own activities.
Diversification	Business activities that provide non-fishing income from fishing boats.
Access to quotas	Ability and ease of acquiring quota.
Stock levels	Ensuring the continuous existence of sufficient fish in the sea.
Crew recruitment policies	Impact on fishers' ability to recruit crew – such as immigration policies.
Isolation on board	Lack of engagement in communal activities with other crew members.
Fishing operational costs	The cost of performing fishing activities.
Environmental policies	Impact on fishers' ability to perform their activity due to government policies aimed at protecting the environment.
Environmental activism	Impact on fishers' ability to perform their activity due to non-government policies aimed at protecting the environment.

Table 2 | Additional components added to the initial structure by stakeholders

Indicator	Definition
Investment	Investing on new boats, new boat equipment and on-board facilities.
Science	Collaboration between fishers and scientists to produce evidence
Evidenced policy decisions	Policy decisions based on holistic evidence (including social)
Personal relations	Fishers' relations with influential people
Quality of catch	The quality of the fish landed
Quality of crew	Indicated perception of having a skilled and easy to work with crew
Wind farms	Wind farms' installation taking up space at sea

In comparison to stakeholder maps, the community map has a large increase in the number of edges without a corresponding increase in the number of components. This shows that although stakeholder groups perceive the same components to be part of the system, they have very diverse views on how these components are interlinked. This means that different stakeholders may have a common understanding of what the problems are, but have conflicting views on how they affect each other and the system. This could mean they perceive differing management strategies as more effective.[11]. It was suggested in the validation interviews that different stakeholders may have different perceptions about how identified problems should be managed in the policy-making process. This became evident through opinions expressed during map comparisons, with some interviewees indicating that the research outcomes demonstrate conflicting opinions on policy-making needs. The community map has a density of 22.2% and only 1 transmitter and 0 receivers, which suggests that the community collectively identifies a highly circular system. This means that despite their conflicting views, collectively, stakeholders would be able to find synergies among seemingly unrelated elements, which recent literature also confirms[13]. In the case of the community map, the small number of transmitters and receivers – compared to the group maps – is because the receivers and transmitters are different for each group, demonstrating the differences in their perspectives.

Table 4 presents the top 5 components for each metric by map.

As seen in Table 4, *economic security* is a leading component for three stakeholder groups—fishers, fishers' representatives, and civil society—as well as for the community. As explained in the validating interviews, this

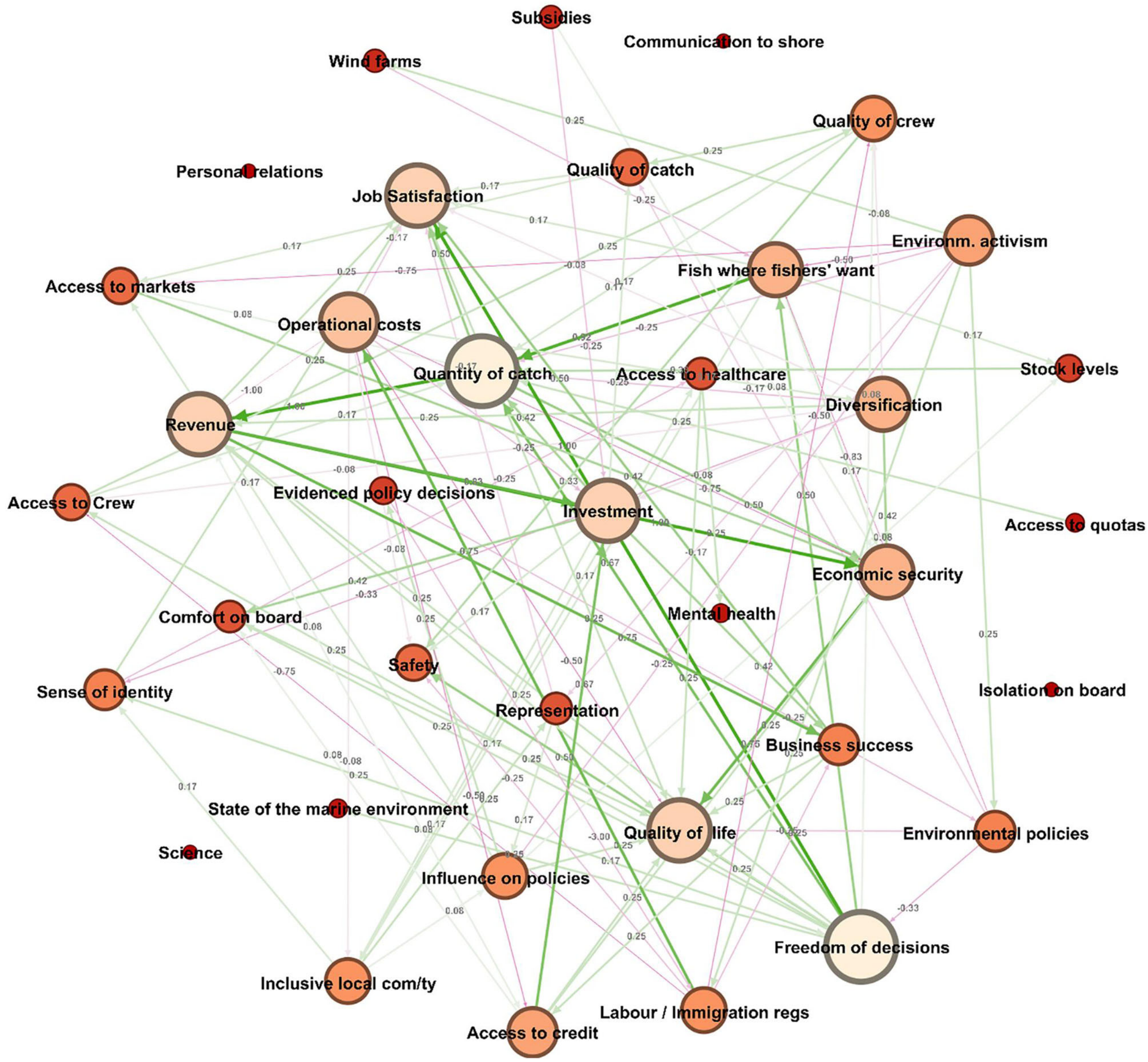

Fig. 1 | Fishers knowledge map. Circles represent the components with size and colour showing a component's degree of centrality. The lines represent the links between components. The point of the arrow shows the direction, the colour represents the nature of the link – red is negative, and green is positive – and the thickness reflects the strength.

may stem from the perception that *economic security* for fishers extends beyond alleviating financial burdens and instead has a wider impact on their wellbeing. In the literature, *economic security* is identified as a pivotal element of social sustainability, premised on the notion that individuals can sustain other aspects of social life only when they feel economically secure[55,56]. As illustrated in the community map (Fig. 6), *economic security* is primarily shaped by financial factors such as *revenue* and *access to credit*, but has an impact on *mental health*, *inclusion in the community*, and *sense of identity* as well as on *safety* and *quality of life*. This confirms the view that *economic security* is a fundamental goal for fishers, contributing to wellbeing rather than as a means to interlink other causes[57]. However, all other stakeholders (except for civil society representatives) do not perceive *economic security* as a connector. *Quality of life* is among the top leaders for researchers, fishers' representatives, civil society, and the community, but not for fishers and government officials. However, *quality of life* is identified as one of the top 5 targets (high in-degree) for all groups. Figures 1–6 reveal that *quality of life* is a target for many diverse factors, ranging from revenue to mental health. However, it is a weak driver, affecting only job satisfaction for researchers and having minimal impact for other groups. These characteristics reflect a collective acknowledgment of the significance of *quality of life* as a final goal in the system and underscores its role as a defining element of fishers' wellbeing[8].

Investment is among the top leaders for all groups and the community. Stakeholders, as revealed in validating interviews, attribute various dimensions to it. For fishers, *investment* translates into new gear or devices to enhance precision fishing and reduce physical labour. Researchers perceive *investment* as directing funds towards data collection or to enhance environmental efficiency. Fishers' representatives prioritize *investment* in safety, rapid access to healthcare, and improving comfort on board; as such, investments may attract and retain "better crew"[58]. Civil society acknowledge the importance of investing in comfort on-board, not only to enhance access to crew but also to improve living conditions and the mental wellbeing of fishers while at sea. Government officials define *investment* as upgrading gear, ensuring safety, improving environmental efficiency, and hiring/training more skilled crew. Given that the community map aggregates inputs from all

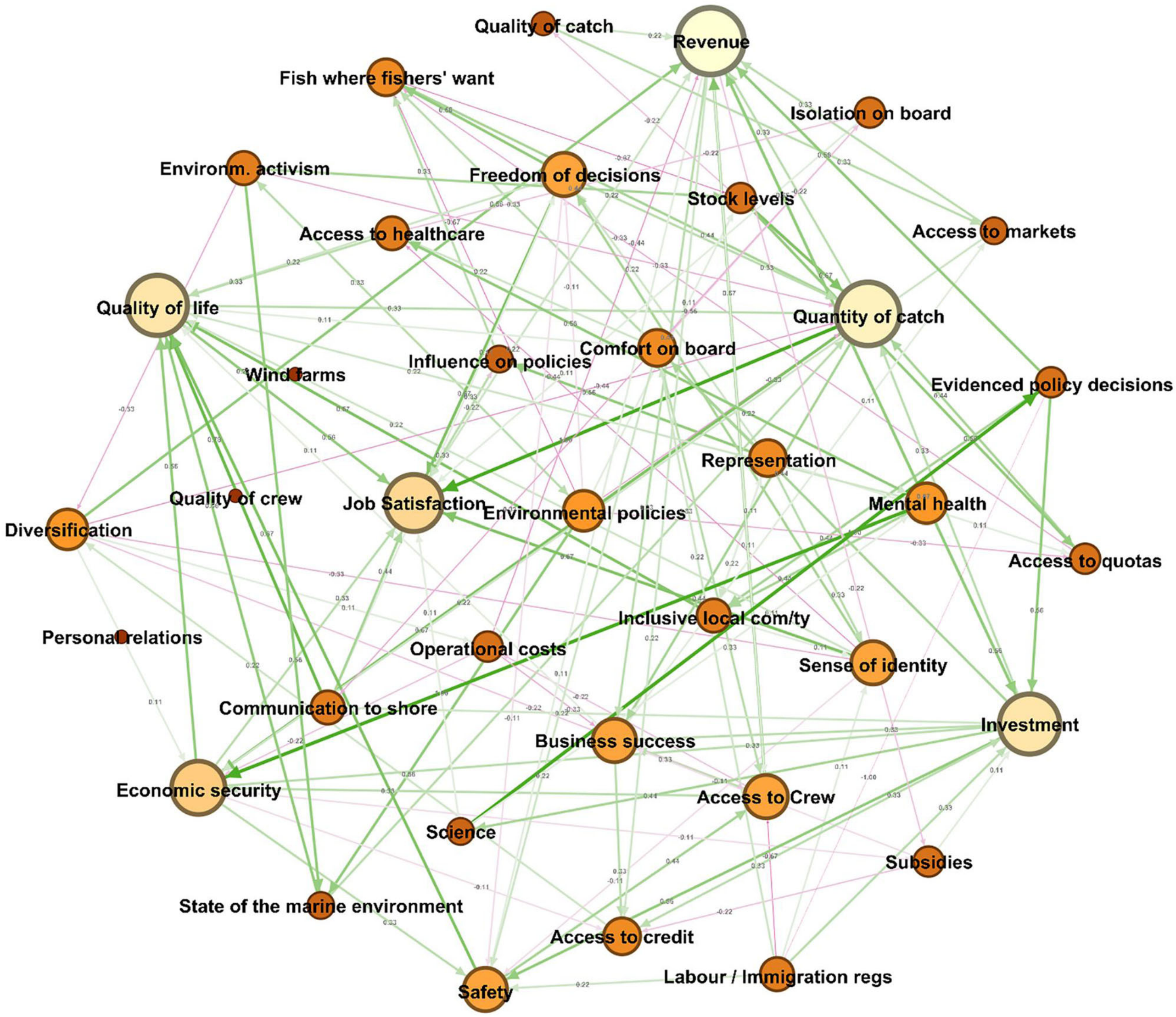

Fig. 2 | Researchers knowledge map. Circles represent the components with size and colour showing a component's degree of centrality. The lines represent the links between components. The point of the arrow shows the direction, the colour represents the nature of the link – red is negative, and green is positive – and the thickness reflects the strength.

groups, for the community, *investment* encompasses all these dimensions, and is the top priority. *Investment* is regarded as a connector by all groups and emerges as the community's foremost connector. This consensus shows that stakeholders had the most diverse connections for investment.

Job satisfaction ranks among the top leaders for the community, researchers, and fishers' representatives, although not for fishers and civil society. Fishers perceive *job satisfaction* as a significant target (Table 4), influenced by factors such as the *quantity of catch*, *revenue, business success*, *sense of identity*, and *freedom to make decisions*. However, it is a weak driver, affecting only *quality of life*, a pattern observed for civil society also. Fishers' representatives and researchers also prioritize *job satisfaction* as a target, with 14 and 12 out of 35 components respectively. In the community map, it is influenced by 21 components out of 37, impacting only three. Notably, *job satisfaction* is a connector in the researchers' group and the community map, emerging as a major goal for all groups. The literature aligns with the significance of *job satisfaction* as a key wellbeing indicator[59]. However, the complexity of its role in achieving other goals is not always evident when examined linearly.

Quantity of catch is a leader for all groups except fishers' representatives. This term refers to the amount of seafood landed, with unanimous agreement across the four groups that it is positively influenced by *investment* and hindered by *operational costs*, *access to labour* and *environmental policies*. As seen in Figs. 1–6, it has a direct impact on *revenue, access to markets*, *business success*, and *job satisfaction* for all groups. While fishers, researchers, and the community perceive the *quantity of catch* as a major driver in the system, only fishers identify it as a major target. Additionally, fishers, researchers, and civil society view *quantity of catch* as a connector, particularly between policy regulations and economic outcomes (Figs. 1, 2 and 4), although this attribute is not prominent in the community map.

Revenue is the last indicator identified as a leader by more than one group. It is among the leading components for fishers, researchers, and government, though it is not reflected in the community map. *Revenue* is a major driver for most groups (Table 4), impacting components related to *economic sustainability*, *quality of life*, and *job satisfaction*. The prominence of *revenue* as a driver can be attributed to its strong influence on *economic security* and *business success* (0.5 and 0.66 out-degrees, respectively, in the community map, Fig. 6). *Revenue* is influenced by multiple factors across all maps, including *operational costs, investment, policies* and *fishers' decision-making models*. Despite affecting fewer targets than other components, *revenue* is considered a major connector by most groups (all except civil

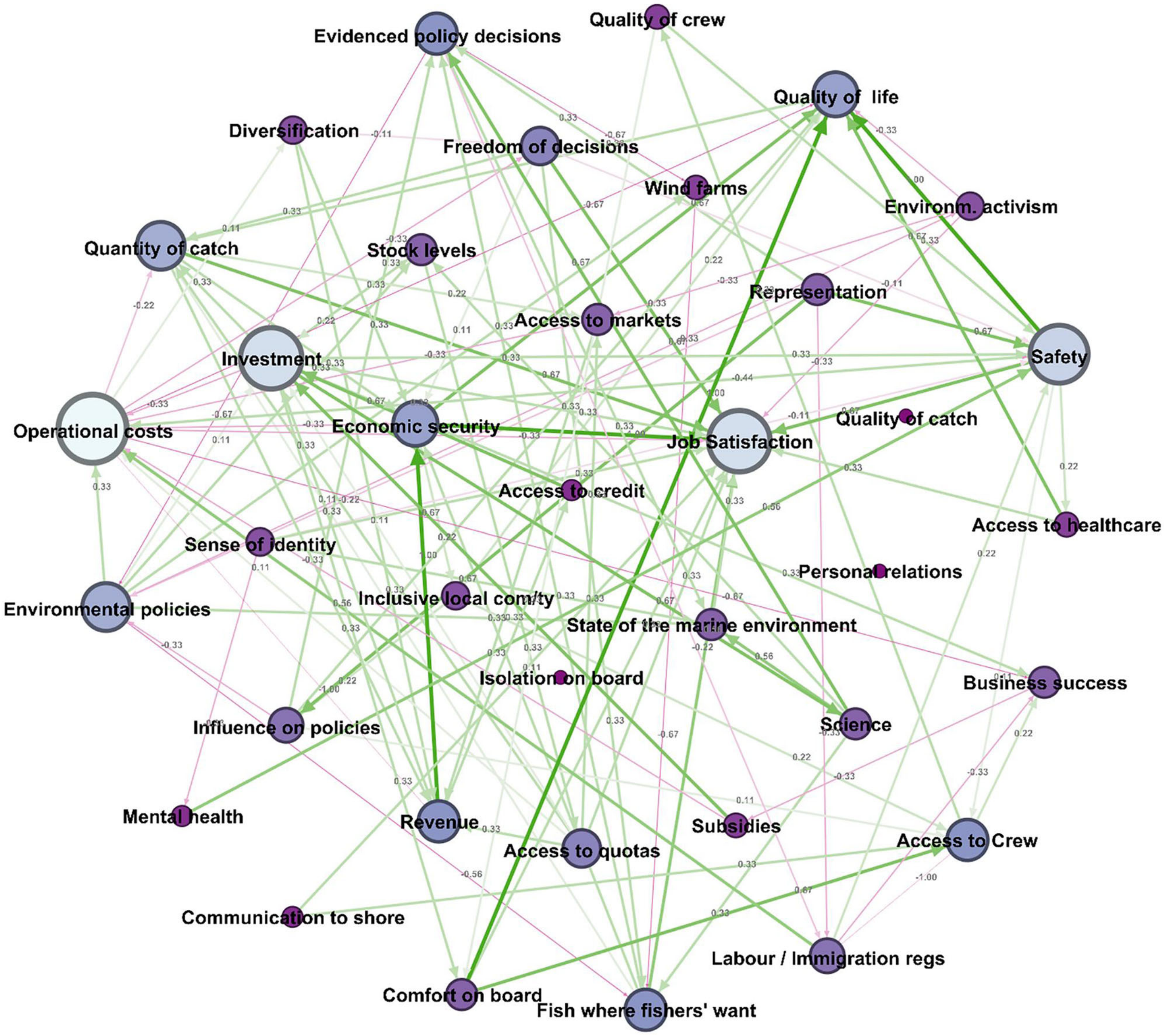

Fig. 3 | Fishers representatives knowledge map. Circles represent the components with size and colour showing a component's degree of centrality. The lines represent the links between components. The point of the arrow shows the direction, the colour represents the nature of the link – red is negative, and green is positive – and the thickness reflects the strength.

society) and by the community, affirming its effectiveness in enhancing fisher wellbeing comprehensively.

It is crucial to note that leaders, especially in the community map, are key components not only due to their direct or indirect links with other components, but also because of their strong interconnections with each other. This underscores their importance to the system and highlights the overarching circularity of the fishers' wellbeing system.

Freedom of decisions is only recognised as a leader by fishers. In their map (Fig. 1), it is strongly influenced by their *sense of identity*[7] and is a crucial driver in the system, positively impacting economic outcomes, like *quantity of catch* and *revenue*, as well as *job satisfaction* and *quality of life*[60], *safety*, *comfort on board*, and *crew recruitment*. In the fishers' map, *freedom of decisions* is hindered by the impact of *environmental policies* and *crew recruitment policy decisions*[61]. It connects to fishers' ability to *fish where they want*, a component also limited by *environmental policies* and activities. While *freedom of decisions* doesn't emerge as a top leader in other maps, it is acknowledged by other groups as a driver influencing *mental health* (civil society – Fig. 4), *job satisfaction* (researchers - Fig. 2, Government - Fig. 5, Fishers' representatives - Fig. 3), and *quality of life* (research, Government). Interestingly, contrary to fishers, other groups believe it has a negative effect on fishers' safety. This collective perspective results in a high cumulative out-degree (Table 6), positioning *freedom of decisions* as a top driver in the community map. This indicates its perceived significance in the system as an impactful force.

Safety is a leader only for fishers' representatives. In validating interviews, fishers' representatives emphasised their concern for *safety* and their investment in time and resources to improve fisher behaviour around safety. Fishers' representatives also positively link *safety* to *quality of crew* and fishers' *mental health*[62], and believe it is hindered by fishers' *sense of identity* and *freedom to make decisions*[7]. Representatives found *safety* positively influenced *job satisfaction, quality of life, access to labour/ crew recruitment policies*[52], and *access to healthcare*[60]. Despite directly affecting only four out of 35 components, it appears in the fishers' representatives' map as a major driver due to its highly weighted impact (Fig. 3). As a connector, it bridges elements of representation and legislation to issues of *mental health* and *quality of life*. Fishers' representatives explained that their safety concerns exist because fishers often feel over-confident in their knowledge of staying safe at sea. This perspective is mirrored in the fishers' map (Fig. 1), where safety is solely a receiver and is positively affected by *freedom of decisions*. Fishers also believe it is enhanced by *investment* but hindered by *operational*

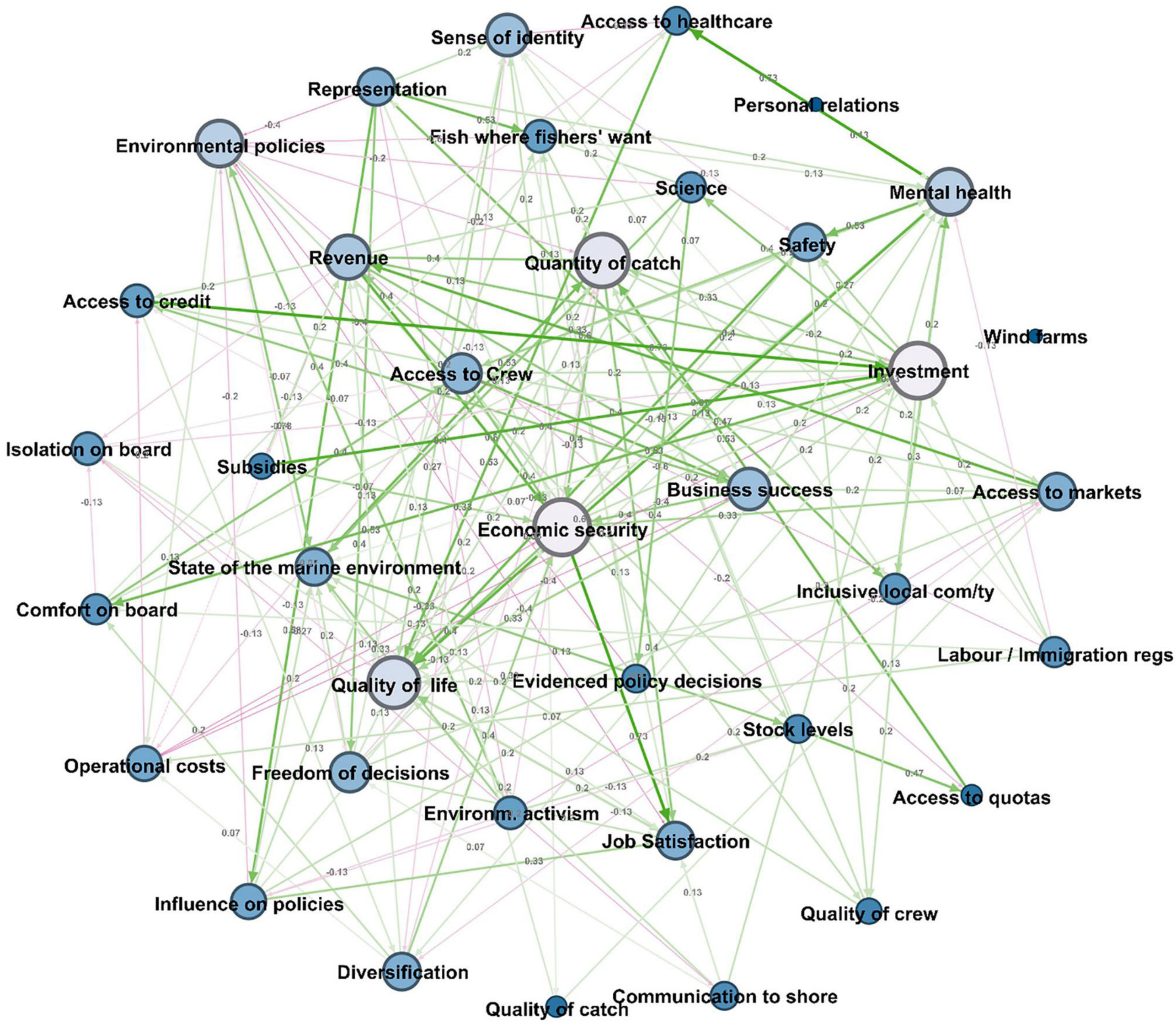

Fig. 4 | Civil society representatives knowledge map. Circles represent the components with size and colour showing a component's degree of centrality. The lines represent the links between components. The point of the arrow shows the direction, the colour represents the nature of the link – red is negative, and green is positive – and the thickness reflects the strength.

costs and *crew recruitment policies* (labour and immigration regulations), noting that strict regulations result in the recruitment of a "less skilled" crew, adversely impacting safety on board. Due to the contrasting perceptions between fishers and fishers' representatives, *safety* does not emerge as a leader in the community map despite its strong links to *quality of life* and *job satisfaction*. This is because positive and negative links from the two maps cancel each other during the aggregation process. This is a noteworthy example of the potential outcomes of knowledge sharing between stakeholders with conflicting interests: the realisation that in a co-management model, what each stakeholder may consider extreme could, in fact, be balanced.

Civil society representatives consider *mental health* a leader, a driver, and a connector (Table 4). As explained in the validating interviews, this is possibly because it aligns with their core principles e.g., several NGOs aim to provide mental and emotional support to fishers – and it has a deeply pivotal role in their fishers' wellbeing system. Figure 6 shows that *mental health* is influenced by *economic security*[61], fishers' *representation*[63], and specific management and policy options[64] (*freedom of decisions*, *fish where they want, evidenced policy decisions, access to labour/crew recruitment)*, as well as pressures of labour laws and regulations. As a driver, *mental health* positively affects fishers' *quality of life, safety*[56], and *access to healthcare*[65] and has a target/driver relation to *inclusion in the local community*[63]. For researchers, *mental health* is a top driver influencing *inclusion in the local community* and economic factors like *economic security*, *investment*, and *revenue*[66], while it is a key target for *science* and has a target/driver relationship with *access to healthcare* and *quality of life*. In contrast, fishers and government find *mental health* to have minimal significance, influenced solely by *access to healthcare*, with no impact on other aspects of their wellbeing. The multi-target attribute of *mental health* in civil society and research maps is reflected in the community map. However, it does not emerge as a strong leader or connector, because it is overshadowed by links between other components that carry greater weight due to the groups' consensus on their importance. Nevertheless, the appearance of *mental health* on the community map is another confirmation of the necessity for communication and knowledge sharing in this area.

Government officials identify *business success* and *influence on policies* as primary leaders. *Business success* is a key driver and target, but not a connector, in their map. Economic factors (*quantity of catch, access to markets, investment, subsidies*), predominantly influence *business success*, *operational costs* hinder it, and it has a target/driver link to *revenue* and

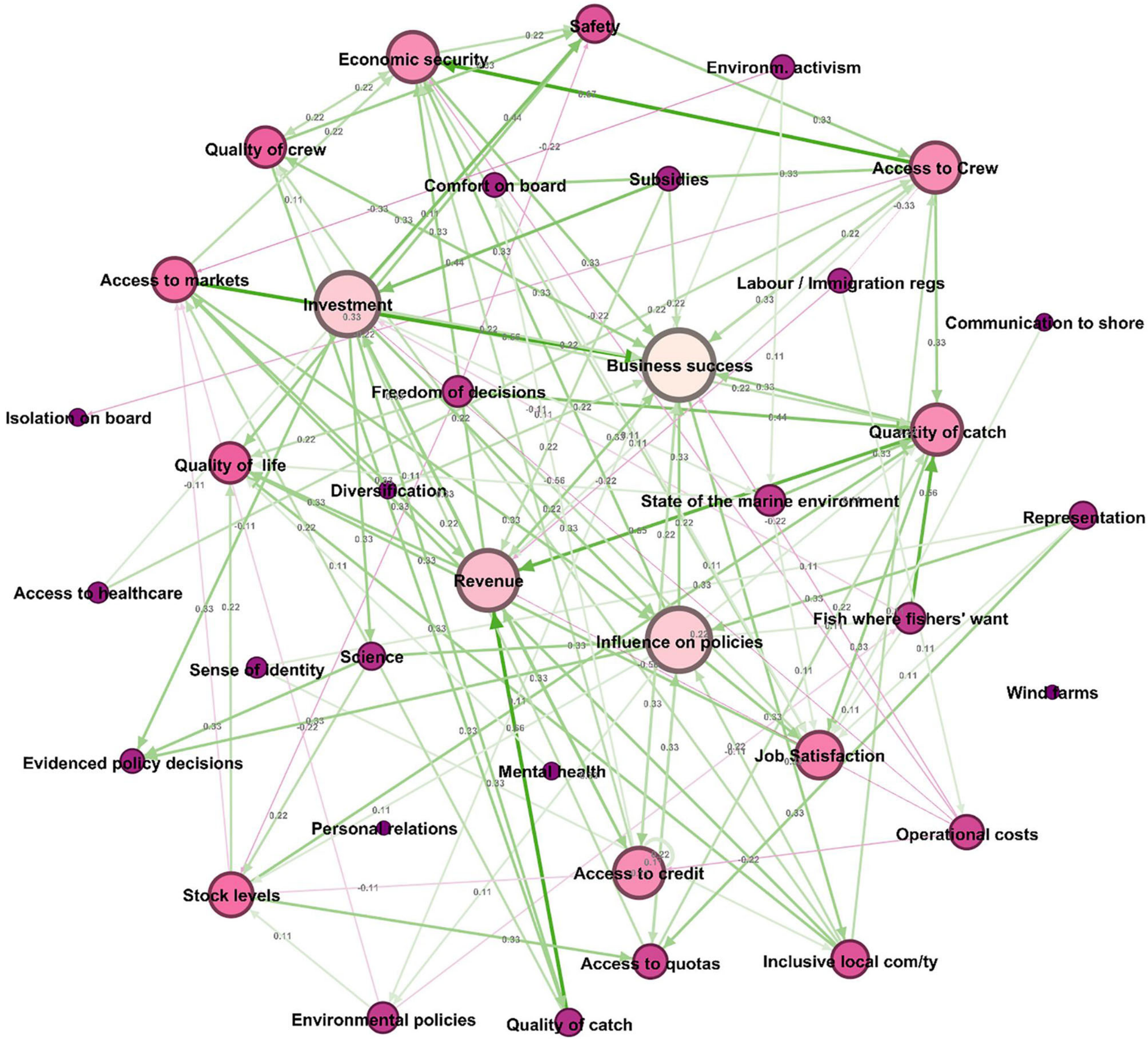

Fig. 5 | Government representatives knowledge map. Circles represent the components with size and colour showing a component's degree of centrality. The lines represent the links between components. The point of the arrow shows the direction, the colour represents the nature of the link – red is negative, and green is positive – and the thickness reflects the strength.

access to credit. In contrast to recent findings about the negative connection between business-oriented fishing and crew recruitment[67], government officials believe that "*good quality" crew* contributes to *business success*, and *business success*, in turn, helps attract good crew. Additionally, *business success* for government officials is influenced by fishers' *ability to influence policy decisions* and contributes to fishers' *inclusion in local communities*[10]. *Business success* is a key target in their system, and, as explained in validating interviews, the assumption is that addressing business issues is a prerequisite for achieving broader sustainability goals[68].

Influence on policies strongly affects *business success* and is a top leader, driver, target, and connector for government officials. The ability of fishers to influence policies is positively affected by *inclusion in local communities* and good *representation*[14], *access to quota* and *markets*, *investment*, and *science*. In turn it affects fishers' ability to *fish where they want*, leads to *evidence-based policy decision*s, shapes *environmental policies*, increases *stock levels* at sea[12], and has positive impact on various economic factors such as *quantity of catch, access to quota, business success*, and *economic security*[50]. This effectively positions it as a connector between social and scientific components and environmental and economic outcomes[69]. Other groups find policy-influence to be affected by *inclusion in local communities* (fishers, fishers' representatives), fishers' representation (fishers' representatives, civil society), and to affect the ability to *fish where they want* (research, civil society). Fishers' representatives and civil society found it to have a negative impact on *environmental policies*, while fishers and civil society representatives believe it has a positive effect on the *state of the marine environment* and it is negatively influenced by *environmental activism*. For researchers, it is negatively affected by *job satisfaction*, meaning, as explained during the validation interviews, that more satisfied fishers are less inclined to be involved in policy design[16]. It is notable that due to the high weight of its links, *influence on policies* is also a connector in the fishers' map, bridging social aspects with economic and environmental outcomes. The fact that many links are common across more than one group is reflected in the community map, where *influence on policies* emerges as a top connector linking socio-economic elements and scientific investments to economic outcomes and more efficient environmental protection actions.

Inclusive local community is the top connector in the fishers' map. For fishers, being included in their local community depends on *investment* and *diversification* and is hindered by *operational costs*, confirming that fishers

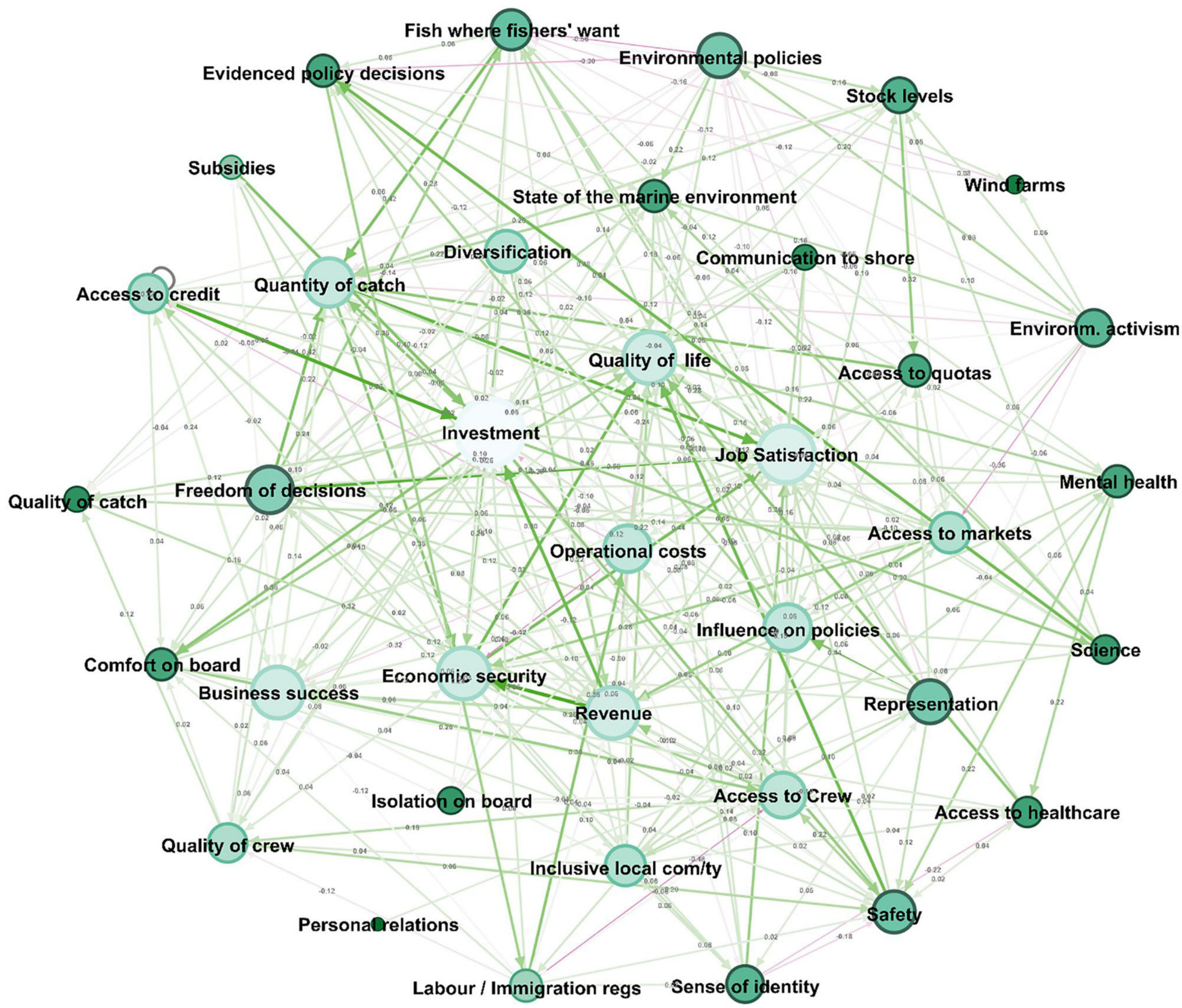

Fig. 6 | Community map combining all stakeholders knowledge maps. Circles represent the components with size and colour showing a component's degree of centrality. The lines represent the links between components. The point of the arrow shows the direction, the colour represents the nature of the link – red is negative, and green is positive – and the thickness reflects the strength.

Table 3 | Stakeholder knowledge systems

	Fishers	Research	Fishers' Representatives	Civil society	Government	All
Number of participants	5	3	3	4	3	17
Number of components	34	35	35	35	37	37
Number of edges	107	130	111	168	114	301
Network diameter	9	7	8	6	5	5
Graph density	9.5%	10.9%	9.3%	14%	8.5%	22.2%
Transmitters	3	0	3	1	9	1
Receivers	4	0	2	0	3	0

believe that inclusion in the community is linked to economic prosperity[8]. Simultaneously, an *inclusive local community* appears as a positive driver for good *representation*[63], a *sense of identity*[5], the *ability to influence policies*[6], and *access to healthcare*. So, for fishers, *inclusive local community* acts as a connector between economic and human factors. Researchers and civil society representatives believe it connects to fishers' *mental health*[58], with no identified links to economic factors. Fishers' representatives see an *inclusive local community* as a driver for *quality of life* and *access to labour*[61]. Government officials believe it is influenced by *business success* and affects access to good *quality crew*[61], *access to markets, quality of life*, and helps *influence policies*. The strong connectivity of an *inclusive local community*, as depicted by fishers and supported by other groups, transitions to the community map, where it is also a top connector, once again underscoring the importance of uniting stakeholder perspectives.

Science is a connector for researchers and civil society and a driver for fishers' representatives (Table 4). According to follow-up interviews, for all

Table 4 | The top 5 components for each metric by map

Leaders	DC	Targets	ID	Drivers	OD	Connectors	BC
Fishers							
Quantity of catch	4.51	Quantity of catch	2.43	Freedom of decisions	4.25	Inclusive local com/ty	241.92
Freedom of decisions	4.09	Job Satisfaction	2.42	Revenue	3.16	Investment	196.50
Revenue	3.74	Economic security	2.09	Quantity of catch	2.08	Revenue	137.42
Economic security	2.84	Quality of life	2.00	Investment	1.77	Quantity of catch	135.25
Investment	2.69	Investment	0.92	Fish where fishers' want	1.60	Influence on policies	132.25
Research							
Quality of life	5.56	Quality of life	5.00	Mental health	3.34	Investment	367.21
Investment	5.54	Job Satisfaction	4.44	Quantity of catch	2.55	Revenue	277.08
Job Satisfaction	4.66	Investment	3.22	Investment	2.32	Quantity of catch	210.25
Revenue	4.45	Revenue	3.01	Representation	1.77	Science	169.33
Quantity of catch	3.99	Economic security	2.11	Freedom of decisions	1.67	Job Satisfaction	168.65
Fishers' Representatives							
Job Satisfaction	5.22	Job Satisfaction	5.22	Safety	2.3	Investment	254.51
Investment	4.43	Quality of life	3.22	Investment	2.3	Operational costs	230.77
Safety	3.78	Investment	2.11	Comfort on board	2	Safety	148.66
Economic security	3.66	Economic security	1.77	Economic security	1.9	Revenue	144.60
Quality of life	3.22	Evidenced policy decisions	1.66	Science	1.9	Evidenced policy decisions	123.12
Civil society							
Economic security	4.51	Quality of life	4.12	Investment	2.20	Investment	218
Quality of life	4.32	Economic security	2.72	Mental health	2.16	Quantity of catch	186.6
Investment	4.00	Job Satisfaction	1.85	Representation	1.86	Science	134.3
Mental health	3.95	Investment	1.80	Economic security	1.79	Economic security	130.5
Quantity of catch	3.19	State of the marine environment	1.80	Revenue	1.67	Mental health	104.5
Government							
Business success	4.74	Business success	3.31	Investment	2.42	Business success	166.8
Influence on policies	3.85	Quantity of catch	2.54	Influence on policies	1.98	Investment	143.3
Quantity of catch	3.75	Quality of life	1.98	Revenue	1.65	Influence on policies	117.9
Revenue	3.29	Influence on policies	1.87	Access to markets	1.55	Revenue	103.8
Investment	3.07	Economic security	1.77	Business success	1.43	Access to Crew	100.1
Community							
Investment	3.82	Quality of life	3.12	Investment	2.28	Investment	222.90
Job Satisfaction	3.30	Job Satisfaction	3.02	Revenue	2.10	Influence on policies	121.06
Economic security	3.28	Economic security	2.06	Freedom of decisions	1.86	Job Satisfaction	98.96
Quality of life	3.28	Quantity of catch	1.80	Quantity of catch	1.32	Revenue	96.10
Quantity of catch	3.12	Investment	1.54	Economic security	1.22	Inclusive local com/ty	76.76

three, *science* is the most effective way to create a robust evidence base informing decision-making at all levels. The primary target for *science*, for all groups, is *evidenced policy decisions*, with a highly weighted connection. For civil society and fishers' representatives, it affects the *state of the marine environment* and fishers' *quality of life*, and it mitigates the impacts of *environmental policies*, while researchers believe it improves *job satisfaction* and *mental health*. As explained in the validating interviews, this is because - in their view - being trusted by scientists is rewarding for fishers, which positively affects their *mental health* in the long term. All these groups also mark the influence of *investment in science*[10], and note that it is a connector between economic inputs and environmental policy outputs. Fishers' representatives and government officials note it increases *stock levels* and connects with *evidenced policy decisions*. However, these connections are weaker. *Science* does not appear at all in the fishers' maps. As a result, *science's* role as a connector is weakened in the community map, but its impact on *evidenced policy decisions* and the *state of the marine environment*, coupled with its reliance on *investment*, remains substantial (Fig. 6).

Discussion

Several benefits were identified in the use of the method as a tool for policy design. In brief, this method illustrates fisher wellbeing as a system where all stakeholders have an equal say[32]. This enables the bridging of knowledge gaps and setting of common goals. For example, conflicting interests between fishers and fishers' representatives regarding *safety* are balanced-out in the community map, indicating the "real" position of *safety* in the system. It also permits the incorporation of different perspectives into a comprehensive structure, including elements that a single stakeholder's perspective may have disregarded[70]. For instance, civil society highlighted *mental health* as a leading component with many interactions that are positioned in the community map, but which may have been otherwise overlooked. The method also enables stakeholders to frame their knowledge and depict cause-effect relations between important issues that may have appeared as seemingly unrelated. An example of this is the identified impact of science on mental health or the relationships between labour regulations on access to "good quality" crew. FCM also helps explain the structural form of complex systems by unifying diverse viewpoints and understandings[71]. In this paper, this is reflected by the number of connections in the community map, which is multiple times more than the connections in stakeholder maps, indicating that stakeholders identify the same issues but perceive them to be linked in different ways. It also provides a uniform methodology for all stakeholders, diminishing the dominance of certain groups over others, or the dominance of individuals within groups due to personality or hierarchy differences. In so doing, it allows stakeholders to express and exchange knowledge without direct interaction between them, avoiding potential confrontations due to conflicting interests, differences in vocabulary or cognitive ability[35]. In particular, fishers reported that taking a "sneak peek" at others' views and adjusting the structure of their own system was helpful as it enabled a reframing of priorities without appearing as if they had "changed their mind", which appealed to their sense of pride and identity.

Certain limitations do exist to using this method as a co-decision-making tool. For example, there is limited qualitative description of the components and links, especially for similar concepts appearing in different maps. For example, *investment* means different things for each stakeholder, but they did not necessarily explain this while constructing their maps. It is essential to remember this during the deployment of the method and ensure that facilitation of the interviews includes acquiring this information. The method also requires participants to comply with the methodological framework. This proved challenging at times, particularly with stakeholders who are unfamiliar with diverse research methodologies. However, this can be overcome by showcasing the usefulness of the method and by being adaptive to stakeholder language and terminology. Specific software is required for the creation and visualisation of the maps and this needs to be counted for in the initial stages, both in term of investment and skills. However, once the framework is established it is easy to use.

Based on the results as presented above, the following key recommendations can be extracted, which aim to address identified challenges and promote a more collaborative approach to fisheries management. First, it is critical to foster inclusive and systems-thinking decision-making processes. This study showed that bringing together diverse knowledge widens the "big picture". The systems-thinking approach revealed pathways that were not evident and showed the dynamics of a multi-stakeholder-designed system where all stakeholders have an equal say. It is important to create clear and uniform methodologies to frame knowledge-sharing where all stakeholders participate. These should balance different perspectives, emphasising the interconnectedness of wellbeing factors and leading to the creation of common goals. Second, it is necessary to position economic sustainability as a cross-cutting goal. Aspects of economic security and revenue were considered by multiple groups and by the community to be top leaders and drivers. This shows that in a complex wellbeing system, these two aspects hold a key role. Policies and initiatives must recognise the role economic security (in particular) has for fisher wellbeing, impacting not only business success but also mental health, inclusion in the community, and overall quality of life. Third, comprehensive investment strategies need to be encouraged and implemented, in ways that ensure diverse interpretations of investment are incorporated. While each group has unique perspectives on investment, there is a common understanding that it plays a crucial role in enhancing various aspects of fisher wellbeing, including economic security, safety, environmental efficiency and mental health. Policies are needed that facilitate targeted investments where fishers and stakeholders require them, either through investment initiatives or new fishing technologies and scientific advancement, or by allocating tailored funds towards emerging needs and awareness campaigns that promote fisher wellbeing. Fourth, ensure science drives decision-making. Science is a connector in the system, playing a huge role in terms of environmental protection. The study reveals that science is perceived as able to reduce environmental pressures by making policies more targeted.

This research shows it is important to: (i) allocate investment to research initiatives and technologies; (ii) build trust among fisheries researchers and policymakers; (iii) establish channels to inform policies via the latest scientific evidence on environmental protection, asd well asmental health and quality of life, and (iv) develop targeted mental health initiatives for fishers. The study puts mental health on the community map though Civil society and researchers who recognise it as a multi-connector between various aspects of wellbeing. Advancing targeted mental health support mechanists informed by insights from Civil society and researchers, is suggested. These should address the specific factors influencing mental health, including economic security, inclusion in the community, access to healthcare and comfort on board but also less strict regulations and allow fishers more freedom to make own decisions about their businesses. Finally, support inclusive local communities. Fishers identified inclusion in their communities and a multi- attribute factor strongly linking their economic growth with their social and human prosperity and sense of identity. It is crucial to design policies that foster inclusive local communities, considering these factors and connections. This could include encouraging community-building initiatives and cultural exchange programs, or fund actions that enhance fishers' active participation in the decision making.

In terms of method evaluation, FCM proved useful for capturing community knowledge while avoiding stakeholder communication challenges. Incorporating everyone's knowledge into a common system showed how all interests can be addressed and reveals what is important for the community aas a whole, identifying common goals. However, despite the benefits the method offers, its limitations need to be considered. For effective use, feedback loops ensure continuous evaluation and improvement of the method, and to flexibly adopt the method based on identified needs. Notably, the fuzzy cognitive maps can be further analysed to develop future "what if" scenarios of fisher wellbeing improvement through the stakeholder-driven modification of key factors, which can form the theoretical background for future research.

Overall, the study confirms the complexity of addressing fisher wellbeing. The findings highlight the importance of promoting interdisciplinary collaboration and the need to establish frameworks for regular stakeholder communication, knowledge sharing, and joint decision-making to bridge evidence gaps and promote holistic approaches to fisheries management.

Methods

Fuzzy cognitive mapping (FCM) FCM involves structured interviews where participants are asked to list all the factors in a system and use them to draw a map showing the causal connections between factors. Each link is assigned a score to show the causal strength of the connection. The main elements of an FCM are a) the components, which represent the components of the system, b) the edges, which represent the link between components c) the edge weights, which show the direction (negative or positive) and the strength of the relationships (Fig. 7).

FCMs are analysed via comparative content analysis[72] of the concepts in the system and aims to quantitatively characterise the structure of the system.

Data collection

Data collection began by interviewing five fisheries experts identified through the authors' networks; one each from the fishing community, policy-makers and researchers. The basic structure of the wellbeing system was initially identified by these experts to ensure equal and fair participation of all stakeholders in the same knowledge framework[73] and based on the relevant literature[7,10,60,74] in which five fundamental identifiable and measurable indicators were defined. In addition to these, the experts identified several key factors associated with the concept of wellbeing in the context of fisheries.

Research took place in the northeast of Scotland where the Scottish nephrops fishery is primarily based. The participants were asked to create individual fuzzy cognitive maps during facilitated interviews. The interviews were highly structured. At the beginning of each interview, respondents were provided with an A3 sheet of paper or a Miro-board© (online interviews) containing the predefined indicators in random positions. Participants reviewed the indicators and added or removed components as they saw necessary. They then linked components via cause/effect relationships, indicating the nature of the relationship (negative or positive), and the strength of the relationship on a scale from 1 to 3 (1 being the weakest and 3 the strongest) (Fig. 7). The cognitive maps were digitally visualised using Gephi and the elements and links between them were transformed into components and edges. Maps were additively aggregated as seen in Fig. 8 to produce one combined cognitive map[28] for each stakeholder group and one cognitive mega-map of all the maps, representing the collective knowledge of the community. In this process equal weighting was given to all groups.

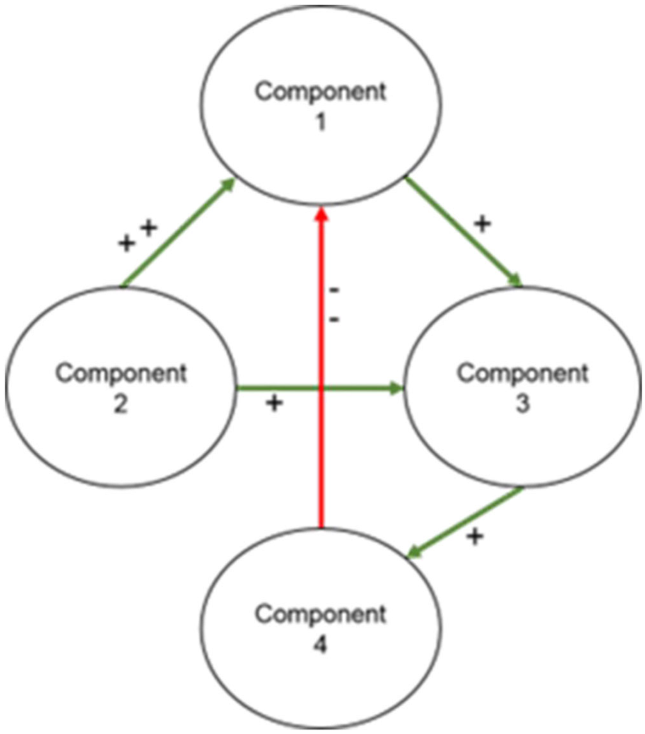

Fig. 7 | A fuzzy cognitive map with 4 components (components) and 5 edges with their directions and weights depicted by symbols (image from[30]).

Analytical framework

FCMs were analysed using exploratory network analysis. This method is based on the graph theory and involves transforming FCMs into adjacent matrices where the components are listed on both axes and connections between them are coded as numbers. Results are then quantified based on statistical outcomes from the adjacent matrix[28,73]. The metrics used to compare components for the structural analysis and comparison of FCMs are presented in Tables 5, 6.

The comparison of the FCMs occurs in two stages. First, system maps are compared according to their structural analytics to explore their dynamics. The maps are then compared in terms of their component metrics. This is primarily a function of the Degree of centrality (or the extent to which a component is a leader) and the Betweenness centrality (the extent to which a component is a connector) but we comment on in and out degrees where this seems important.

Finally, and to validate the outcomes qualitative validation interviews were held with the initial 5 experts as well as with an additional representative from each stakeholder group. Interviewees were presented with the maps and were asked to comment on the aspects the wanted and give opinions about the outcomes. The interviews were used to support the discussion and conclusions in combination with the existing literature.

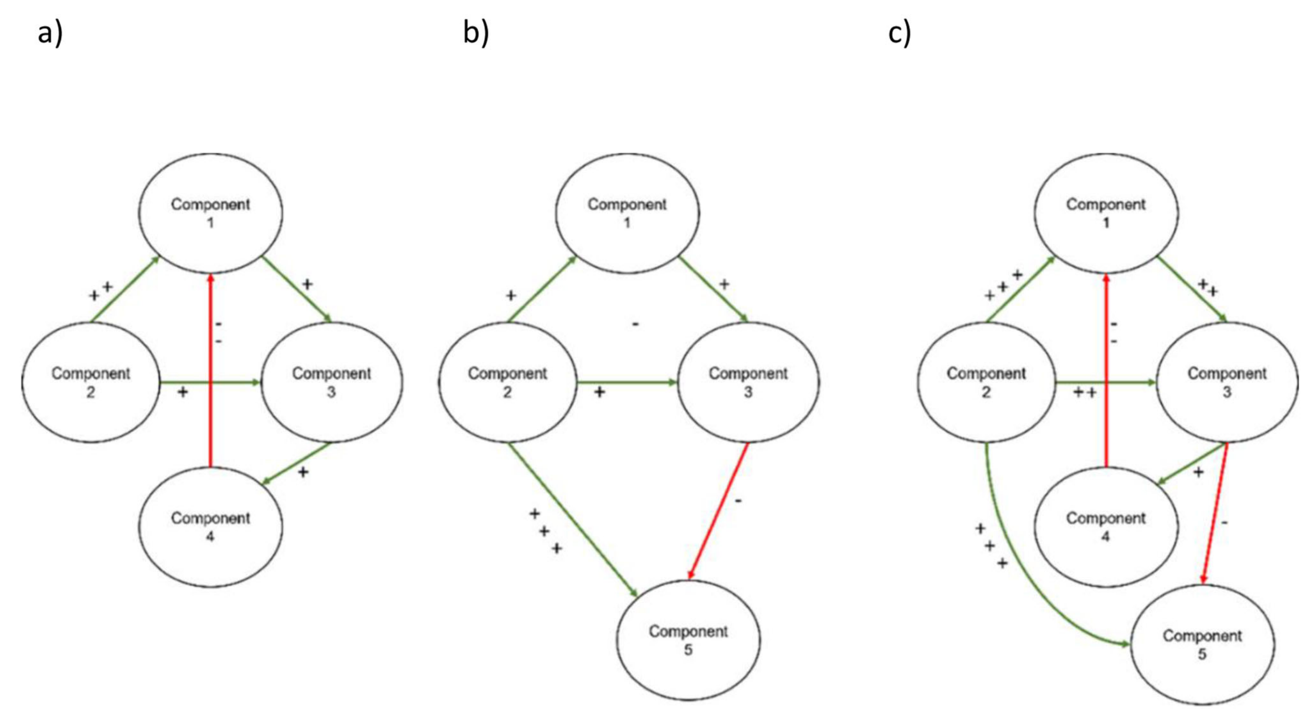

Fig. 8 | Process of aggregating individual Fuzzy Cognitive maps. Individual maps (**a**, **b**) are combined into one map (**c**). Circles represent the components of each map, the point of the arrow shows the direction, the colour represents the nature of the link - red is negative, and green is positive - and the plus and minus signs represent the nature and strength of the relationship.

Table 5 | Metrics used for structural analysis and comparison of FCMs

Metrics	Numerical Expression	Definition
Number of components	N	The number of components in the map
Number of edges	E	The total number of linkages between components
Diameter		The longest distance between two components (steps that need to be taken to achieve influence = complexity)
Density	Dn	Indicates how densely components are connected.
No of transmitters	T	Components that only have edges coming out
No of receivers	R	Components that only have edges coming in

Table 6 | Metric used for comparison of the components of each FCM, where j is the total number of components and i is the component under investigation

Measurement (weighted)	Numerical expression	Definition	Type
In-degree (ID)	$ID_i = \sum_{\kappa=1}^{N} \left\|\beta_{ij}\right\| * \sum W_{e_{ij}}$	The cumulative strength of connections with which a component is influenced by other components	Target
Out-degree (OD)	$OD_i = \sum_{\kappa=1}^{N} \left\|\alpha_{ij}\right\| * \sum W_{e_{ij}}$	The cumulative strength of connections with which a component influences other components.	Driver
Degree of centrality (DC)	$DC_{iw} = OD_{iw} + ID_{iw}$	The cumulative strength of all connections a component has (in & out). A leader is a central component that influences and is influenced by many other components	Leader
Betweenness centrality (BC)	$Bc\,(i) = \sum_{s \neq i \neq t} \frac{\sigma_{st}(i)}{\sigma_{st}}$	The ability of a node to influence the path flow of the map. A connector is a component that “stands” on many connection paths between other components.	Connector

ID_i (indegree) equals the sum of the number of edges of component i multiplied by the sum of their weights. OD_i (outdegree) equals the sum of the number of edges into component I multiplied by the sum of their weights. DC_{iw} (degree of centrality) of component i and equals is the sum of its ID and OD. BC (i) is the betweenness centrality of component i, where σ_{st} is the total number of the shortest paths from component s to component t and σ_{st} (i) is the number of those paths that pass-through component i.

Data Availability

The data that support the findings of this study are available on request from the authors.

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Author contributions
E.M. and I.K. conceptualised the study and formulated the research framework. I.K. organised the stakeholder engagement. E.M. conducted the field work. E.M. developed the analytical framework and performed the data analysis and interpretation. E.M. and I.K. wrote the text. E.M. added the Figures and Tables. I.K. edited and refined the text.

Competing interests
The authors declare no competing interests.

Additional information
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Correspondence and requests for materials should be addressed to Ingrid Kelling.