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The Complex Pathway towards Farm-Level Sustainable Intensification: An Exploratory Network Analysis of Stakeholders' Knowledge and Perception

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Abstract: Farm-level sustainable intensification of agriculture (SIA) has become an important concept to ensuring food security while minimising negative externalities. However, progress towards its achievement is often constrained by the different perceptions and goals of various stakeholders that affect farm management decisions. This study examines farm-level SIA as a dynamic system with interactive components that are determined by the interests of the stakeholders involved. A systems thinking approach was used to identify and describe the pathways towards farm-level SIA across the three main pillars of sustainability. An explanatory network analysis of fuzzy cognitive maps (FCMs) that were collectively created by representative groups of farmers, farm advisors and policy makers was performed. The study shows that SIA is a complex dynamic system, affected by cognitive beliefs and particular knowledge within stakeholder groups. The study concludes that, although farm-level SIA is a complex process, common goals can be identified in collective decision making.

Keywords: sustainable intensification; stakeholder views; fuzzy cognitive mapping; mental models; network analysis

1. Introduction

The predicted increase in world population and shifts in human dietary trends are likely to cause a greater demand for food [1]. This places increased pressure on agriculture to intensify food production against a backdrop of increasing scarcity of additional land for agriculture [2] and major threats to the global environment from commercial farming [3–5]. In the face of these global challenges, the concept of sustainable intensification of agriculture (SIA) has come to the fore in recent years [6]. SIA represents an increase in agricultural production through sustainable development, which is widely accepted by international policy and research as a concept consisting of three main pillars: economic, social an environmental [7,8].

The European Union (EU) is the largest agricultural importer in the world [9]. As such, it is associated with environmental damage in exporting countries [10] and is food-dependent on regions where food security issues may arise in the future [11]. This makes SIA in Europe a necessity. However, global versus European perspectives differ in terms of SIA, e.g., European agriculture is already very intensive and problems such as rural-urban migration and widespread land abandonment are much greater than land scarcity and food security [12]. Therefore, for SIA in Europe, the critical issues are the negative environmental impact of agriculture and the failure of the agricultural production growth model to cover the socio-economic needs of rural populations [13].

Although there are established policy agendas at national and EU levels for sustainable agricultural management, the success of SIA requires techniques that are spatially and socially site-specific [14]. SIA can be implemented at different scales, but it is acknowledged by research and policy that effective SIA depends on the sustainable management of individual farms [15]. Every farm has its own unique physical and structural characteristics, and is usually the legal and economic unit at which most EU policies are directed [16]. Additionally, farming practices are key elements in this process, and these depend on farmers who are unique individual decision-making units [17]. Assessing the success of SIA at farm-level allows for the achievement of the highest spatial accuracy, under the assumption that farms are "micro-systems" that together form landscapes and wider agricultural systems.

Recent research shows that the assessment of farm-level SIA can be achieved by quantifying the economic, social and environmental outcomes of a range of farm management practices [14,18–21]. However, this type of research tends to focus on the results rather than the reasoning behind the methods used to measure SIA and is limited when explaining the way SIA is applied in practice [22]. In reality, farm management decisions are largely affected by external factors that are beyond the control of farmers and interfere with their personal decision-making processes.

To address this, research has focused on farmers' decision-making behaviour using quantitative [23–26] or qualitative methods [27,28], which investigate how farm management decision-making processes are influenced by various factors, perceptions and attitudes. These studies consider farm management decisions related to specific interventions that address only some aspects of SIA.

Recent research approaches point out that farm-level SIA is a result of integrated farm management [29], where multiple actors must co-ordinate their actions for effective results. In this light, SIA is viewed as an aspiration, rather than a specific aim, and its achievement is an evolving process, involving various stakeholders whose perceptions of the usefulness of strategies and paths towards it may vary significantly [30]. Therefore, achieving farm-level SIA becomes a dynamic process that requires co-ordinated effort [31], and during this process the farm becomes a complex system with many components, which not only have a direct impact on farm performance, but also interact with each other [32]. These may include policies and regulations or existing beliefs and perceived effectiveness, which vary according to the knowledge and experiences of each stakeholder [33]. Understanding how these elements translate into farm management decisions requires an investigation of the links and interdependencies between them, which the current literature and policy-making practices lack.

In this paper, mental models presented as fuzzy cognitive maps (FCMs) were adapted to present and understand the views of several stakeholder groups associated with SIA. This then enabled an assessment of the current process of SIA at farm-level, considering the influence and interests of the different stakeholders. Mental models presented as FCMs describe a system as a visual network of interdependent components and indicate causal relationships between them. FCMs have been used to support the analysis of stakeholder views on different specific agricultural and environmental issues [34], or environmental decision making and management [35]. FCMs were first developed by Kosko [36] and are structured modelling techniques that can be used to describe complex knowledge systems [37]. These maps are structural versions of mental models that indicate direct and indirect causality between the components of dynamic systems, and are able to represent group beliefs [38]. Such studies [32,39–41] enable a better understanding of the behaviour of complex systems and provide pairwise associations between elements that can be easily quantified with the cumulative strength of the connection. Using FCM for group thinking allows these collective beliefs to be presented and supports the development of social learning [42].

Systems thinking has been used to explore farm-level SIA in a number of contexts [32,43,44] and also to explore various aspects of sustainable developments across the spectrum of sustainability, such as water management [34,45] or environmental policies [46]. This paper aims at contributing to the existing debate pertaining to farm-level SIA, by exploring the outcomes of the aggregation of stakeholders' views. The potential outcome of this study is the creation of a tool that could identify blockages in the communication of stakeholders and assist in the identification of common goals.

The paper is outlined as follows: initially, the methodology is outlined in detail, including the data collection, materials, and the visualisation and analysis techniques. Then the results are presented in the form of tables and maps, followed by a discussion of the main findings. Finally, some policy implications are raised, before presentation of some concluding remarks.

2. Materials and Methods

2.1. FCM Participatory Process

To understand the structural and functional aspects of how different stakeholders conceptualise the implementation of SIA on European farms, FCMs were constructed from groups of stakeholders (farmers, advisors and policy implementers) that influence the farm management decision-making process. The FCMs produced for each group were compared using semi-quantitative analysis (outlined below) and aggregated to produce a final SIA map. Combining the FCMs produced a collective FCM that mapped system components (henceforth termed nodes), which linked to a number of selected sustainability indicators.

The main elements of an FCM are: *nodes*, which represent concepts (or components); *edges*, which represent the links between nodes (indicated by arrows); and *edge weights*, which indicate the influence (positive or negative) and strength of the relationship between nodes (Figure 1). FCMs can then be analysed and explained using exploratory network analysis methods, which allow for the quantification of the map links and the in-depth explanation of their structure.

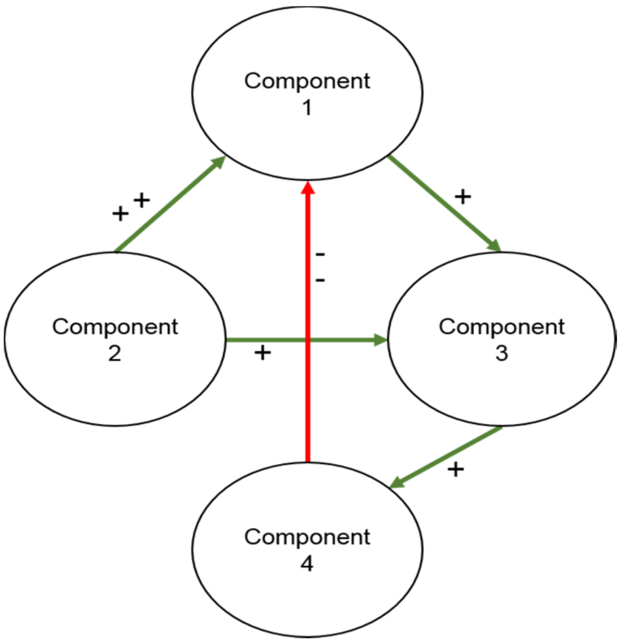

Figure 1. A simple FCM with four nodes (components) and five directed relations (edges) with their degree of influence (edge weight).

2.2. Group Mapping Exercise

The FCMs from these stakeholder groups, representing farmers, agricultural advisors and agricultural/environmental policy makers were constructed in a participatory exercise, hosted in Ireland during a workshop organized within the Marie Curie INSPIRATION Innovative Training Network (project 675120). The workshop invited stakeholders' representatives to participate for a fee. In total, 48 people participated in the workshop, including farmers, advisors, social and agri-environmental scientists, and policy implementers from a number of European countries including Ireland, the UK, Belgium, Germany, Greece and France. Please note no personal and demographic data were recorded during the workshop, partly due to confidentiality issues, but mainly to avoid potentially biased behaviour between individuals in each group. Three stakeholder groups were formed: a group including farmers, a group including agricultural advisors and applied researchers and a group including policy makers. Because of the participation of researchers in the workshop, all groups included a number of researchers: the farmers' group included two, the advisory group four and the policy making group three. These were equal participants in the groups, and the trained facilitators were entrusted with ensuring the avoidance of bias. Representatives from applied research and academic institutions, with knowledge of the SIA concept, facilitated each group discussion. The main roles of the facilitators were to guide the discussion, to provide for the participation of all members of the group, and to ensure the avoidance of bias between group participants. To make sure that facilitators were able to help the group engage in productive conversation in a neutral and accepted way, two preparatory meetings, including the creation of "mock" FCMs, were held, where potential issues of bias were raised and discussed. The exercise was based on the method suggested by Gray [37], whereby nine SIA indicators (Table 1) were presented to each group to guide construction of the FCMs. At the beginning of the exercise, each group was given a 150 cm^2 blank sheet of paper containing nine pre-defined farm-level SIA indicators (Table 1), in random order (on sticky notes). Based on personal perception and experience, the groups were asked to link them using directed arrows (Figure 1), indicating their perceived degree of influence: negative high (—), medium (–) and low (-), and positive low (+), medium (++) and high (+++). Then, workshop participants were asked to engage in a brainstorming discussion, assisted by the facilitators, to identify other components that they considered to influence the indicators and structurally connect them to each other and to the indicators, as they perceived it to be realistic.

2.3. Selection of Farm-Level SIA Indicators

The indicators which groups were asked to build their maps around were selected from papers in the literature analysing SIA assessment at farm level [47–49], based on the following criteria:

a. They were measurable at farm-/farm household-level;
b. They were relevant to European agricultural production;
c. They represent intensive and/or intensifying farms. The term intensifying refers to farms that may not be as intensive, but have a likelihood to intensify in order to contribute to food security, for example livestock or arable farms as opposed to wine-making or flower producing farms;
d. They are identified in the literature as consistent and measurable across time;
e. They equally represent the three main sustainability pillars (environmental, economic and social).

The farm-level indicators of the SIA selected are presented in Table 1.

Table 1. Selected farm-level sustainable intensification indicators.

Pillar	Indicator	Metrics	Description
Economic	Yield	Kg/ha	Farm crops and/or animal products.
	Farm income	€ or €/ha	Farm household income coming from farm activities.
	Market orientation	%	The percentage of farm income that is coming from the market.
Social	Resilience	Nominal	Probability of a farm household being resilient
	Succession	Nominal	Probability of a farmer having identified a successor
	Social capital	Nominal	Probability of a farmer's social well being
Environmental	Nitrogen load	Kg/ha	Nitrogen inputs—N outputs
	Phosphorus load	Kg/ha	Phosphorus inputs—Phosphorus outputs
	Biodiversity	%	The percentage of habitat/total farm area

2.4. Exploratory Network Analysis

Gephi© software was used for the visualization and analysis of the FCMs. The FCMs were analysed using the exploratory network analysis method based on graph theory, according to which cognitive maps are transformed into adjacency matrices where the nodes are listed on the vertical and the horizontal axes. When a connection exists between two nodes its weight is coded in the matrix as a number [50,51]. According to graph theory, the results of the FCM can be quantified based on a number of statistical outcomes from the adjacent matrix. The metrics used to compare components and for structural analysis of FCMs are presented in Tables 2 and 3 were used to explore the content of the FCMs and compare the nodes that appear in each map.

Table 2. Metrics used to compare the components of each FCM.

Components' Comparison	Numerical Expression	Definition	Characteristic of Component
Out-degree (OD)	$OD_i = \sum_{\kappa=1} \lvert\alpha_{ij}\rvert$	The cumulative strength of connections with which a component influences other components	Driver
Weighted out-degree (WOD)	$OD_{iw} = \sum_{\kappa=1} \lvert\alpha_{ij}\rvert * \sum W_{a_{ij}}$	The out-degree of a node pondered by the total weight of its outward edges	Influential/influencer
In-degree (ID)	$ID_i = \sum_{\kappa=1} \lvert a_{ji}\rvert$	The cumulative strength of connections with which a component is influenced by other components	Receiver
Weighted in-degree (WID)	$OD_{iw} = \sum_{\kappa=1} \lvert a_{ji}\rvert * \sum W_{a_{ji}}$	The in-degree of a node pondered by the total weight of its inwards edges	Affected
Degree of centrality (D)	$DoC_i = OD_i + ID_i$	The cumulative strength of connections a component has (in and out).	Central
Weighted degree of centrality (WD)	$DoC_{iw} = OD_{iw} + ID_{iw}$	The degree of centrality of a node pondered by the total weight of all its edges	Dominant

Table 3. Metrics used for structural analysis and comparison of FCMs.

Metrics	Numerical Expression	Definition
Number of nodes	N	The number of components in the map
Number of edges	E	The total number of linkages between components
Density	Dn = E/N (N − 1)	Indicates how densely nodes are connected.

Here, a represents each edge, i is the transmitter node of edge a, j is the receiving node of edge a and W is the weight of edge a.

Central nodes (high D) are the largest circles on a map (Figures 2–6), representing the most important components to the particular group, which have the most edges entering and exiting. Dominant nodes (high WD) are also signified by the high weights ('+++' or '—') of the arrows entering or exiting. They may or may not be central, but they also highly influence the system. A node is a receiver, where many arrows enter it (high ID). A node is defined as affected (high WID) when the overall weight of the arrows entering it is high. A node is a driver (high OD) when a large number of arrows exit it. A node is influential (high WOD) where the weight of the arrows exiting it is high. From the individual stakeholder types, "unique nodes" were also identified, representing factors that were only identified and considered by that particular stakeholder group. The comparison of the FCMs involves calculating values for the components of each system and indicating the similarities and differences between them.

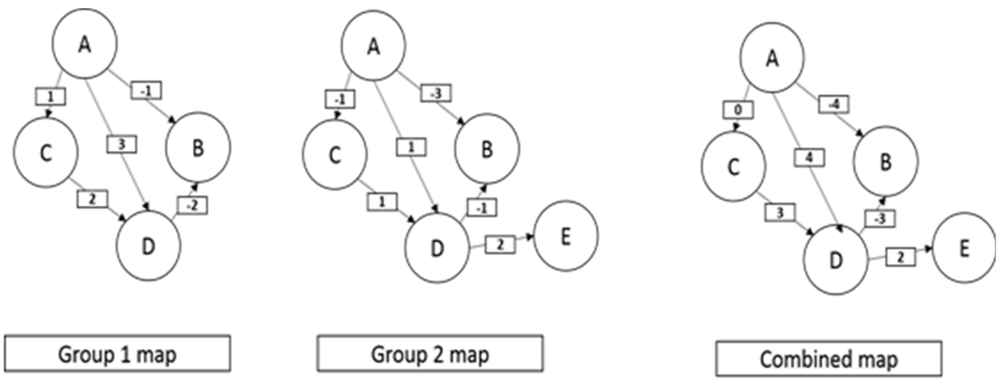

Figure 2. Example of combining stakeholder maps (based on [37]).

2.5. Map Aggregation

After an initial comparison, individual FCMs were aggregated into a final FCM with a new adjacent matrix and a "reinforced" weight for the edges that appeared in more than one FCM. The aggregation was conducted qualitatively [52]. Here, the reinforced edge weights are the result of adding the edge weight of the individual FCMs (example shown in Figure 2).

Once the aggregated map was constructed, common components were identified which occurred across all maps. Finally, for the discussion and interpretation of the results, further face-to-face interviews and consultations with the facilitators (two per group) and some of the participants enabled verification and explanation of the results. These interviews were performed for the clarification of the meanings of the nodes and edges, as they emerged in the discussion during the creation of the FCMs. The outcomes of the interviews were, therefore, used as guidelines for the discussion of the results of our FCM analysis, along with the relevant literature.

The methodological flow combines this process of building group-designed cognitive maps with the quantitative exploratory analysis, all of which is verified by in-depth interviews. This combination of methods allows for a deeper investigation of farm-level SIA from different perspectives, therefore providing more robust results. It also allows for a thorough understanding of the combined stakeholder knowledge on farm-level SIA, not only for the researchers but also for the stakeholders themselves, thereby facilitating loop learning.

3. Results

Table 4 shows the results of comparing the FCMs. Table 5 presents the results of the analysis for the comparison of nodes within and between maps, and is a summary of important nodes for each group FCM and the aggregate FCM.

Table 4. Comparison between FCMs, number of nodes and edges, density and modularity.

Metric	**Group**			
	Farmers	Advisors	Policy	Aggregate map
Number of nodes (N)	30	35	39	53
Number of edges *E*	84	96	85	233
Density	0.097	0.077	0.056	0.080

Table 5. Comparison between FCM components: in-degree, out-degree and degree of centrality.

	Farmers' Group						**Advisors' Group**						**Policy Group**						**Aggregate Map**					
Components	ID	WID	OD	WOD	D	WD	ID	WID	OD	WOD	D	WD	ID	WID	OD	WOD	D	WD	ID	WID	OD	WOD	D	WD
Yield	13	26	2	1	15	27	9	7	1	3	10	10	15	23	2	−2	17	21	28	56	3	2	31	58
Income	16	16	0	0	16	16	3	7	3	4	6	11	8	1	3	4	11	5	22	24	6	8	28	32
Market orientation	5	10	1	3	6	13	8	0	0	0	8	0	5	5	1	1	6	6	14	15	2	4	16	19
Resilience	7	3	1	2	8	5	6	5	2	4	8	9	10	10	1	3	11	13	19	18	3	9	22	27
Succession	8	8	4	4	12	12	5	5	4	6	9	11	3	8	0	0	3	8	13	22	6	12	19	34
Social capital	7	9	2	6	9	15	7	4	0	0	7	4	2	2	5	7	7	9	17	14	8	11	25	25
N balance	6	−1	2	0	8	−1	3	7	1	−3	4	4	4	−10	2	0	6	−10	11	−4	4	−3	15	−7
P balance	7	−10	3	6	10	−4	2	4	1	−3	3	1	4	−10	3	1	7	−9	11	−16	6	4	17	−12
Biodiversity	8	3	2	7	10	10	10	−4	0	0	10	−4	6	−4	1	2	7	−2	20	−5	3	9	23	4
Farmers' identity							2	2	1	1	3	3							2	2	1	1	3	3
Less favoured area	0	0	1	−3	1	−3	2	4	8	−6	10	−2	0	0	4	−3	4	−3	2	4	11	−12	13	−8
Subsidies							4	7	5	3	9	10	0	0	1	3	1	3	4	7	5	6	9	13
Technology/Infrastructure	0	0	6	22	6	22	0	0	4	4	4	4	1	2	1	2	2	4	1	2	8	28	9	30
Age							0	0	5	−5	5	−5							0	0	5	−5	5	−5
Education							2	0	3	7	5	7							2	0	3	7	5	7
Health							1	−3	1	1	2	−2	0	0	2	2	2	2	1	−3	3	3	4	0
Income support							1	3	3	5	4	8							1	3	3	5	4	8
Land management	0	0	2	0	2	0	2	2	2	−2	4	0	0	0	1	1	1	1	2	2	4	−1	6	1
Market prices	0	0	3	−3	3	−3	1	−1	3	−1	4	−2									6	−4	7	−5
Crop diversification							1	1	4	4	5	5	3	1	4	−2	7	−1	4	2	5	2	9	4
Weather extremes	0	0	4	−12	4	−12	1	−3	7	−5	8	−8	2	−2	2	−2	4	−4	3	−5	10	−19	13	−24
P losses							4	3	2	−4	6	−1	0	0	1	−3	1	−3	4	3	3	−7	7	−4
N losses							4	−2	1	−3	5	−5	0	0	1	−3	1	−3	4	−2	2	−6	6	−8
Water quality							6	−16	3	−3	9	−19							6	−16	3	−3	9	−19
Labour units							3	−1	2	2	5	1							3	−1	2	2	5	1
Stocking rate							1	−1	1	3	2	2	1	1	3	4	4	5	2	0	3	7	5	7
Farm size							1	−1	2	2	3	1							1	−1	2	2	3	1
Fertilizer applied							5	−5	3	7	8	2	1	1	3	0	4	1	6	−4	5	7	11	3
Soil testing/NMP							1	1	5	−3	6	−2	1	1	2	−2	3	−1	2	2	7	−5	9	−3
Knowledge transfer	0	0	8	17	8	17	0	0	7	7	7	7	2	4	1	1	3	5	2	4	13	25	15	29
Slurry							1	−1	4	−2	5	−3	2	4	4	7	6	11	3	3	8	5	11	8
Organic matter							0	0	3	5	3	5	3	5	1	1	4	6	3	5	3	6	6	11
Fertilizer price	0	0	4	−1	4	−1	0	0	1	−3	1	−3	0	0	1	1	1	1	0	0	6	−3	6	−3
Farm innovation	0	0	5	11	5	11	0	0	1	−1	1	−1	0	0	1	1	1	1	0	0	6	11	6	11
Energy													1	1	2	2	3	3	1	1	2	2	3	3
Drainage	0	0	4	−4	4	−4							0	0	5	−1	5	−1	0	0	7	−5	7	−5
Non-farm activities on farm													1	1	1	2	2	3	1	1	1	2	2	3
Policy design													0	0	2	−2	2	−2	0	0	2	−2	2	−2
Market access	0	0	2	0	2	0							0	0	1	3	1	3	0	0	2	3	2	3
Future planning													4	6	2	6	6	12	4	6	2	6	6	12
Research													0	0	5	10	5	10	0	0	5	10	5	10
Regulations	0	0	5	−5	5	−5							1	3	5	−2	6	1	1	3	10	−7	11	−4
Soil chemistry	0	0	1	2	1	2	1	1	2	3	3	4	1	1	2	6	3	7	2	2	4	11	6	13

Table 5. *Cont.*

	Farmers' Group						Advisors' Group						Policy Group						Aggregate Map					
Plant health	0	0	3	9	3	9							1	1	2	2	3	3	1	1	4	11	5	12
Farmer attitude	1	2	1	3	2	5													1	2	1	3	2	5
Soil fertility													2	3	3	3	5	6	2	3	3	3	5	6
Land availability	1	−3	3	6	4	3							1	2	1	1	2	3	3	−1	4	7	7	6
Urban migration	1	−3	3	−4	4	−7													1	−3	3	−4	4	−7
Labour market	1	2	2	0	3	2													1	2	2	0	3	2
Farm fragmentation	0	0	2	−5	2	−5													0	0	2	−5	2	−5
Land price	0	0	2	−5	2	−5													0	0	2	−5	2	−5
Technical knowledge	2	6	1	2	3	8							1	1	3	5	4	6	3	7	4	7	7	14
Agri-environmental schemes	1	1	5	10	6	11													1	1	5	10	6	11

3.1. Farmers' Group FCM

A visual representation of the farmers' group FCM is presented in Figure 3.

The farmers' FCM (Figure 3) has 30 nodes (including the 9 pre-defined indicators) connected with 84 *edges*, and a map density of 0.097 (Table 4). As seen in Table 5, the most central nodes are *income*, *yield*, *succession*, *P balance* and *biodiversity*. *Yield* and *technology/infrastructure* are the most dominant nodes, followed by *knowledge transfer*, *income*, *social capital succession*, *farm innovation*, *agri-environmental schemes*, *biodiversity* and *weather extremes*. The highest receivers are *income* and *yield*. *Yield*, *income* and *market orientation* were strongly positively affected, and *P balance* is the most negatively affected node (P balance appears as the most negative node because, although it is not the one where the highest number of edges come in, their cumulative weight is the highest in the map. This is based on farmers' understanding of the strong relations between P balance at farm level and the factors that affect it) No highly important drivers were identified. *Knowledge transfer* was highly positively influential (Table 2), together with *technology/infrastructure*, *farm innovation* and *agri-environmental schemes*. *Weather extremes* negatively influence the system. Six nodes are unique to the group: *farmers' attitude, urban migration, labour market, farm fragmentation, land prices and agri-environmental schemes*.

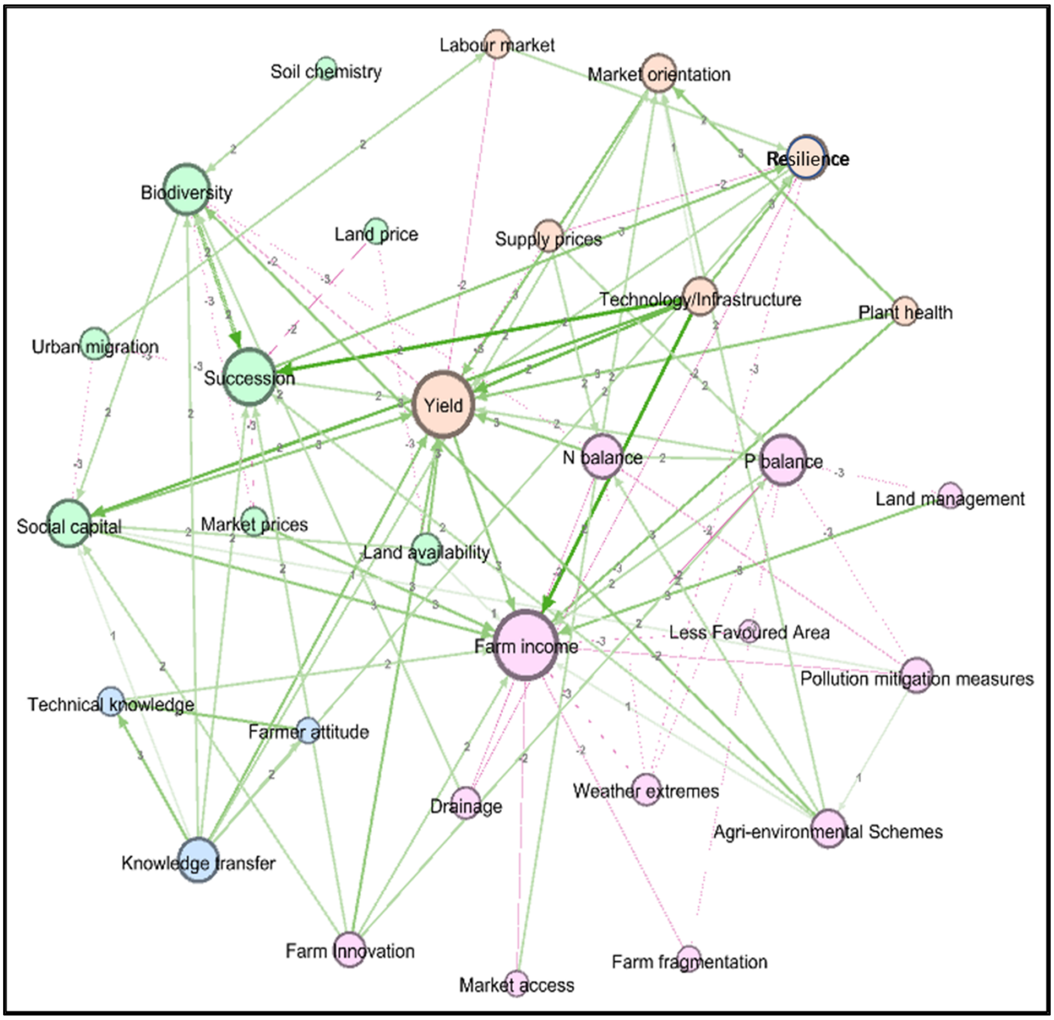

Figure 3. Fuzzy cognitive map of group 1—the farmers' group.

3.2. Advisors' Group FCM

A visual representation of the advisors' group FCM is presented in Figure 4.

The advisors' FCM (Figure 4) has 35 nodes (including the indicators), 96 edges, and a density of 0.077 (Table 4). According to Table 5, *yield* and *less favoured area* are the most central nodes, followed by *succession, subsidies* and *water quality*. The most dominant nodes are *water quality*, *income*, *succession*, *yield* and *subsidies*. The highest receivers are *biodiversity* and *yield*. *Yield* and *income* are positively influenced, whereas *water quality* is negatively influenced. There are no big influencers, but many nodes have equal smaller WIDs (except *water quality* with *WD* = −*19*). Eight nodes are unique to this group: *farmers' identity, age, education, income support*, *water quality, labour units*, and *farm size*.

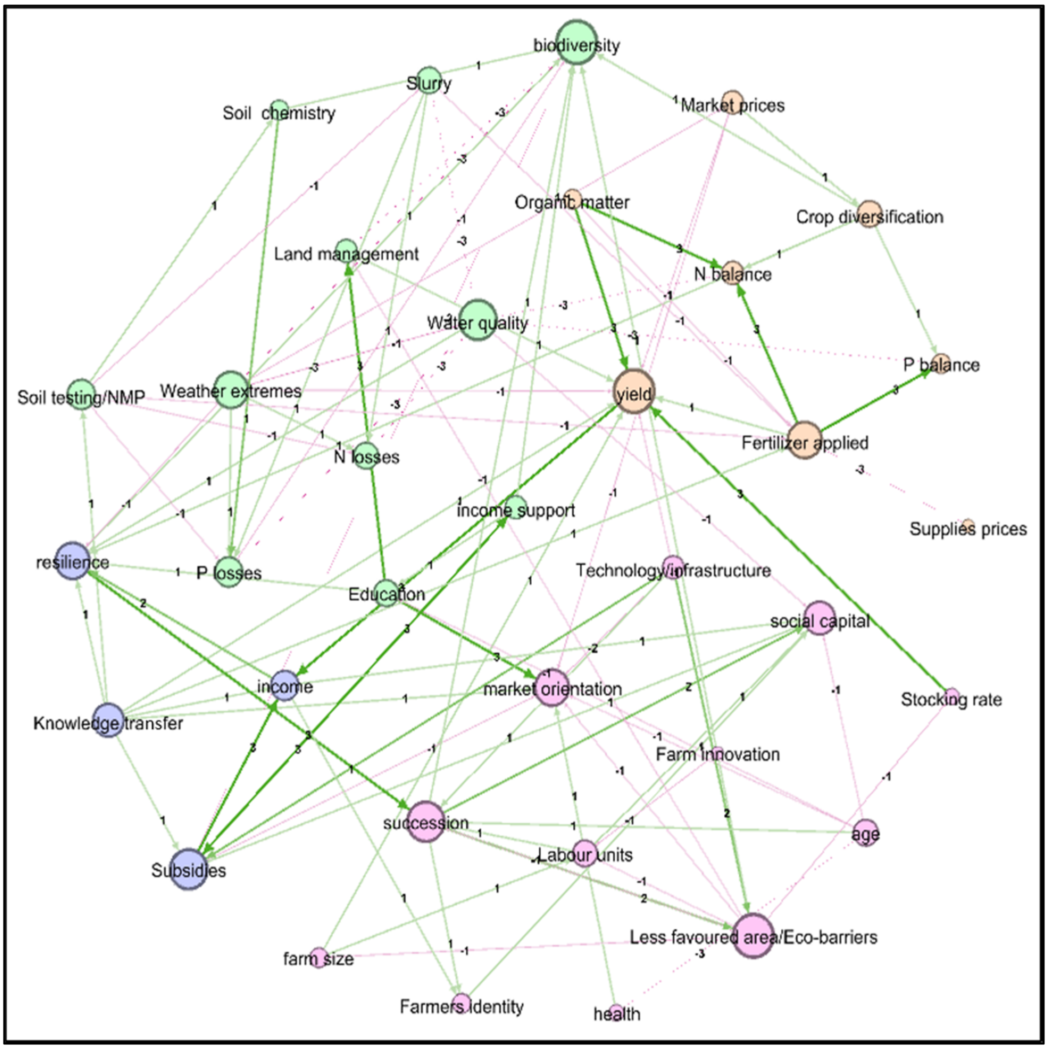

Figure 4. Fuzzy cognitive map of group 2—advisors group.

3.3. Policy Makers' Group FCM

The policy group map has 39 nodes (including the indicators) and 85 edges. The density of the system is 0.056 (Table 4). Yield, income and resilience are the most central components of the map (Table 5, Figure 4).

Yield and *resilience* are also among the most dominant components, followed by *future planning*, *slurry*, *research* and *nitrogen balance*. Both *yield* and *resilience* are the highest receivers of the map and the most positively affected nodes, while *N* and *P balances* are the most negatively affected nodes. No node was identified as a major driver, whereas *research* is a positive influencer (WOD = 10, Table 5). No strong negative influencers were identified. Seven nodes were unique to the group: energy, non-farm activities on farm, policy design, future planning, research, insecticides and soil fertility.

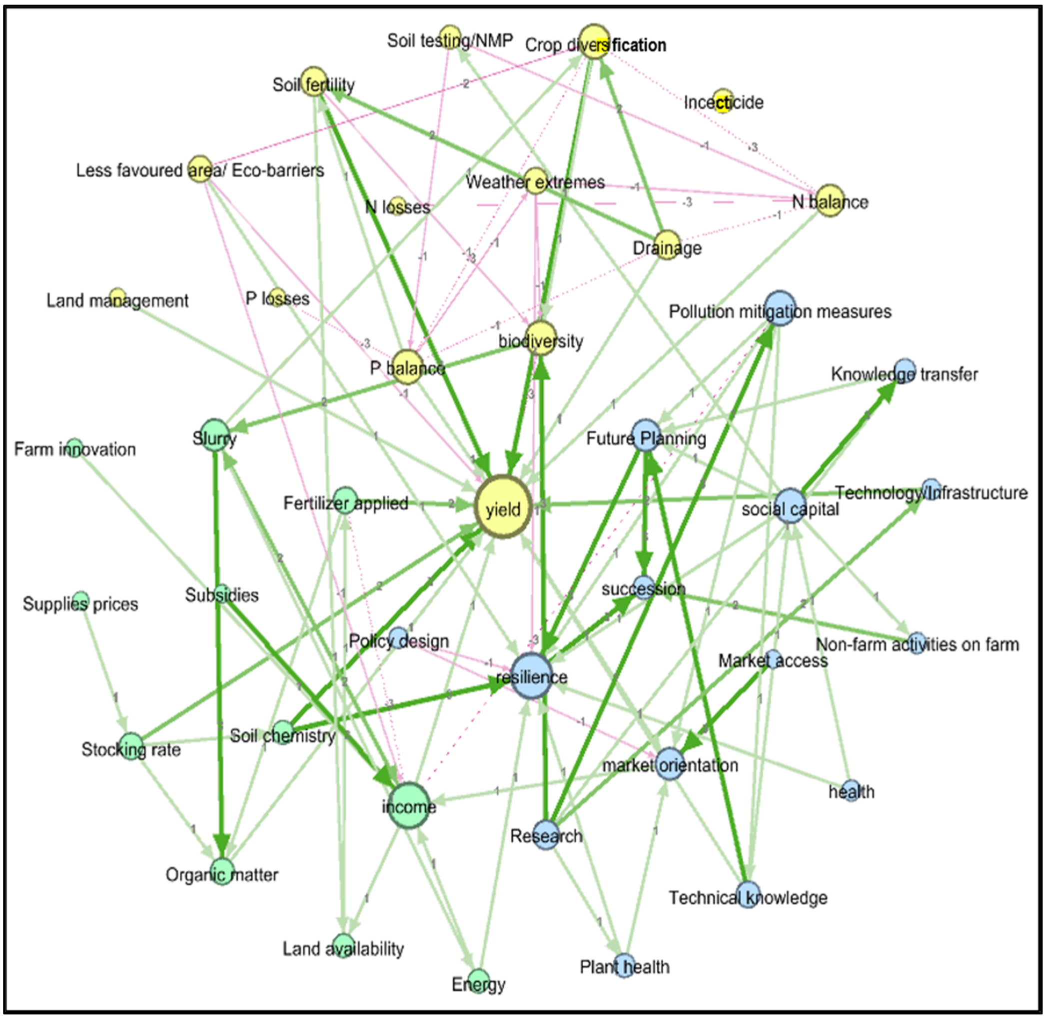

Figure 5. Fuzzy cognitive map of group 3—policy group.

3.4. Aggregate FCM

This FCM represents the complete farm SIA system (Figure 6) as viewed by all stakeholders involved in this study.

It allows the boundaries of the realisation of SIA at farm-level to be defined, and depicts the path towards SIA in a holistic manner. The aggregate FCM has 53 nodes, 233 edges and a density of 0.08 (Table 2, Table 4 and Figure 5). The most central nodes are *yield*, *income*, *social capital*, *biodiversity* and *resilience.* Due to the high number of nodes, degree values above 20 are considered high unless the absolute value of the highest degree is less than 20. This decision was made as part of the analysis. In the design of the workshop, it was possible to predict neither the number of nodes, nor their centrality, and therefore such a decision is not possible to make until the results are visible. *Yield* is the most dominant component, followed by *succession*, *income*, *technology/infrastructure*, *knowledge transfer*, *resilience*, *social capital* and *weather extremes*, with a negative WD (Table 5). The highest receivers on the map are *yield*, *income*, and *biodiversity*. From the positively affected nodes, *yield* stands out with an ID of 56 (Table 5), and *income* and *succession* follow. The most negatively affected nodes are *water quality* and *P balance*. The aggregated system does not appear to have any high drivers (the highest OD is 13 for *knowledge transfer*, Table 5). *Technology/infrastructure* and *knowledge transfer* are positively influential and *weather extremes* is a major negative influencer.

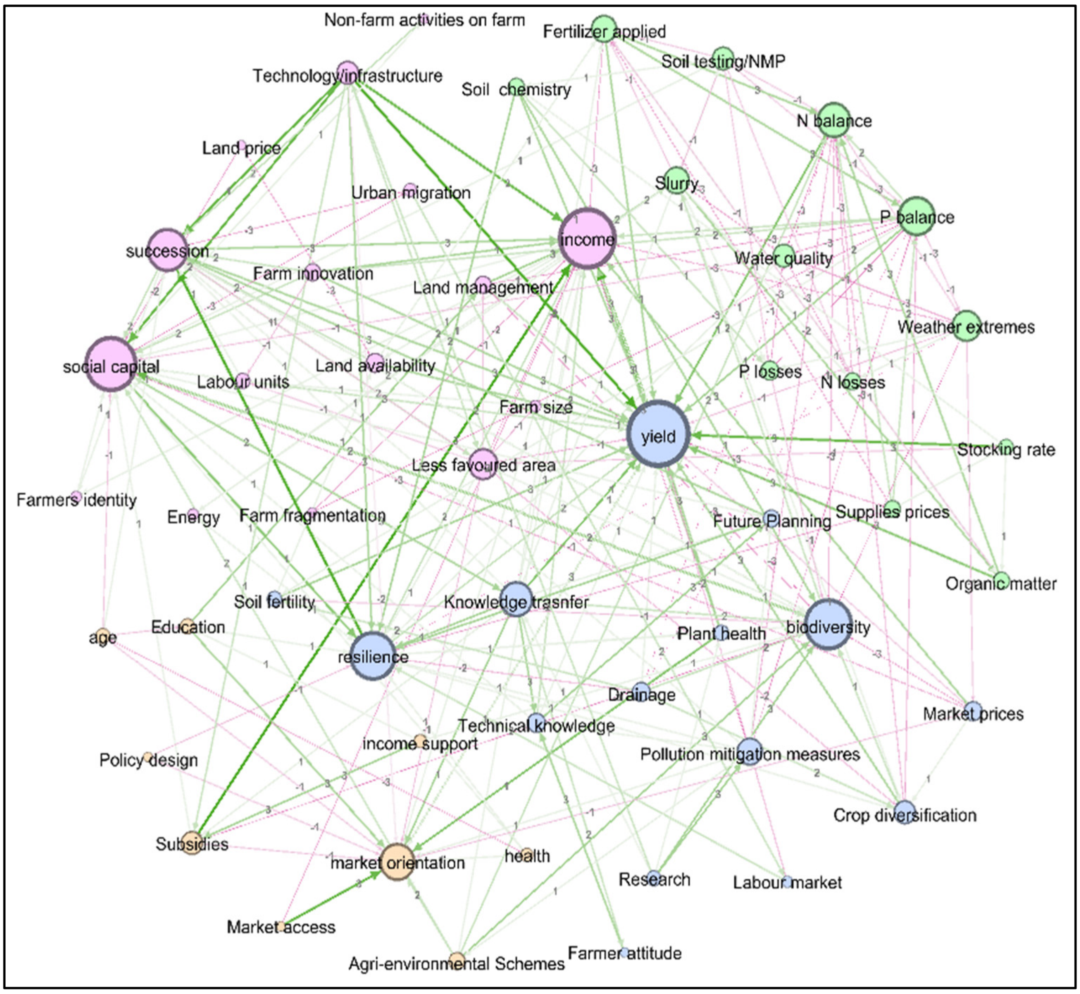

Figure 6. Aggregate FCM.

4. Discussion

4.1. Nodes of Group and Aggregate FCMs

Herein some of the most important nodes of the aggregate map are discussed. The discussion focuses on central and influential components identified by the stakeholders' groups that were not among the predefined indicators. The only exception is *yield*, because of its great centrality in the aggregate map.

- "Yield" is the only predefined indicator that solely represents agricultural intensification. Increased yield generally results from intensification, with its primary purpose to increase farm output and farm income. Therefore, yield is considered more an outcome affected by management decisions rather than a contributor to the sustainable development of a farm system [53]. The FCMs produced during this study support this theory; in all FCMs, yield was a significant receiver and by far the most influenced component, but itself was a weak driver, affecting only the other two economic indicators (Figures 3–6). This suggests that yield "stands above" the whole farm system, and can be considered a goal in its own right [54]. At the same time the high centrality of *yield* across all stakeholder groups indicates how important they all consider it for the farm (and SIA therein) and how it is interrelated to all components and elements in the SIA system.
- "Knowledge transfer" (KT) is a component common to all three stakeholder groups and one of the strongest influencers in the aggregate map. In the farmers' map, KT directly affects all social indicators, two economic indicators and one environmental indicator (resilience, succession, social

capital, yield, market orientation, biodiversity), while it indirectly links to income through yield (Figure 3). This link between KT and all three sustainability pillars (Table 1) is an acknowledgement of the perceived benefits of KT services by farmers. [55]. In the advisors' map, KT is directly linked to the economic indicators and to subsidies. According to the advisors, this outcome reflects the view that advisors mainly act as administrators who deal with farm grant and subsidy applications and ensure the financial stability of farms [56]. However, with most farm subsidies promoting best-practice methods of production [57], it is not surprising that there is a strong indirect effect of KT on environmental indicators. For policy makers, KT did not feature as strongly in their FCM. The over-riding concern of policy makers is the development of policies and achieving stated objectives, thus they are not so concerned with the details of KT services and how those may influence farm management. As expected, in the aggregate map, knowledge transfer is a highly dominant component with a strong positive influence. This highlights the overall importance of KT for SIA at the farm level, which is confirmed in previous studies [33,56,58].

- "Water quality" is an ecosystem service that can be monitored and regulated at the farm level, primarily through the control of nutrient inputs [59]. Intensive agriculture is often thought to impose greater pressure on water quality [60]. However, less intensive production systems can pose a significant threat too, under certain biophysical and climate conditions [61]. Water quality is a dominant component of the advisors' FCM, and although unique to this group, the weighted degree value of water quality is high enough to make it a dominant component in the aggregate map. Agricultural advisors play a key role in the dissemination and enforcement of regulations set out by the EU Water Framework Directive and thus recognise the importance of water quality in the SI of agricultural systems. Conversely, farmers do not consider water quality such an important aspect of SI, due possibly to the lack of a direct link between water quality and farm productivity [62].
- "Weather extremes" refer to uncontrollable weather events such as storms, flooding and drought, and are a common component of all the FCMs. Weather extremes are the main negative influencer in the aggregate map. According to the FCMs, weather extremes play an important role in the farm system, by influencing the decision-making process while being outside human control. An example of this is the requirement to import feed for livestock during periods of fodder shortage caused by storms or drought, which adds significantly to the annual feed bill. All stakeholder groups identified a negative influence of *weather extremes* on farm *resilience* (Figures 3–6). The references to extreme weather in this study are likely to reflect the negative impact extreme weather events have on agricultural production [63,64]. Such extreme weather events are increasing in frequency due to climate change effects [65]. As weather extremes become more frequent [66], policies for SIA will need to include measures that increase resilience of farm systems to severe weather events, a fact that, as this study confirms, is recognized by all stakeholders.
- Improved "technology/infrastructure" has a positive influence on farm SIA according to the aggregate map and is strongly linked to all economic and social indicators. The link between technological and infrastructure development in rural areas, and the economic and social sustainability of farming enterprises is depicted in research [23,67,68]. Despite this, only the farmer group considered technology and infrastructure to be a dominant component that influences the farm system (Table 5). According to farmers, technology and infrastructure refers to various services in their locality, ranging from broadband access to health and financial services to rural life quality. The importance of technology and infrastructure perceived by farmers for farm SIA is supported by Buysse, Verspecht [69]. However, the influence of technology and infrastructure on SI appears to be underestimated by the other stakeholder groups. This contradiction was explained in further discussions with the facilitators: infrastructure is important to the farmers as individuals, but it is not always essential for a farm to survive. Therefore, although advisors

and policy makers may recognize its importance to the farmers' quality of life, they do not fully appreciate its importance for farm-level SIA.

4.2. Group Comparison

The farmers' map shows a relatively closed system (density of 0.1). The high density of the farmers' map indicates that farmers recognize that all farm management elements are interrelated and they understand the dynamic nature of the farm management process. It also expresses the belief that farm-level SIA can be achieved by balancing the existing components, without greatly increasing the complexity of the system. Based on this system description, farm-level SIA appears as a more feasible goal (compared with the other two groups) that can be achieved through strategic changes to the most dominant nodes (e.g., yield, income, water quality, weather extremes, knowledge transfer etc.). However, the higher density of the farmers' map also indicates that the farmers' goals are specific to their farm businesses and have little focus on their role in achieving SIA beyond the boundaries of their farms [62]. In addition, the components identified as important show that farmers evaluate farm efficiency based on practical conditions on their farms, and their perception of sustainable management is only relevant to reaching specific goals [70].

The advisory group map depicts a moderately closed system with no highly central or dominant nodes (except *water quality*). This means that many nodes have small but equal interactions with the system. This indicates that advisors' knowledge of farm-level SIA does not focus on specific areas within the SIA system and, like farmers, this group sees potential in balancing the existing components for achieving SIA. Conversely, the policy map showed an open system, with many components that loosely interact with each other. In addition, most nodes in the policy FCM are identified only as receivers (OD = 0) or drivers (ID-0) (Table 5) and have very low WIDs and WODs. This indicates a direct causal relationship between a few components, but a low overall interaction of components within the system. A possible explanation for this is that policy involves several elements from design to monitoring and regulation, and can include various actors (e.g., experts, consumers, etc.) who often represent conflicting interests while generally grouped under the policy design umbrella. In turn, this could explain the fact that policy design can often send multiple signals and uphold conflicting interests, which may lead to conflicting policy messages [71]. Indeed, for policy makers, farm SIA can be viewed from different perspectives depending on context, and its goals remain subjective. On the other hand, if SIA is viewed as an overall purpose, then as an open system it provides an opportunity to re-consider practices and develop new approaches [72].

The aggregate map appears to be a highly complicated system (Figure 6). The complexity of the map depicts the "real life" complexity of achieving farm-level SIA when all stakeholder opinions converge. This confirms that, presently, SIA is not a defined aim but an abstract goal, and achieving it is not a linear process but a dynamic complex approach. The complexity of the map indicates, in principle, that collective decision-making would take longer to resolve [32]. However, this map can provide invaluable knowledge on what needs to be prioritized to achieve SIA, when a farm is "co-managed" by many stakeholders. It allows for the identification of the most important parts of a co-managed system, and enables stakeholders to identify its most important elements.

By examining the unique nodes in each map, the aspects of farm-level SIA that are important to each group but neglected by the others become apparent. For farmers, these include *farmers' attitude*, and a number of nodes that show the relationship of farm sustainability to socio-economic structures that are beyond a farmer's control. Farm and farmer characteristics are mentioned by the advisors as factors influencing sustainable farm management, a view confirmed widely in the literature [33,73,74]. Finally, policy makers did not include nodes that directly relate to decision-making processes but included concepts that enhance sustainable intensification at wider levels, such as policy design, non-farm activities, farm innovation, research, soil fertility, and future planning, which, as concepts, are all within policy agendas [75]. Particularly for the latter, group participants explained that for them, farm-level sustainable intensification is a common goal and its achievement depends on strategic planning, rather than on the farm and farmer's characteristics. This point seems to have been neglected by the other two groups; however, it indicates that policy makers fail to recognise the individualistic nature of farm-level decision making.

4.3. Method Evaluation

The exploratory analysis of FCMs provided an efficient means to investigate stakeholders' views on the pathways towards SIA. For this study, it presented an opportunity to describe elements and factors that they consider important, but also to identify and define how these are interlinked. The method gives stakeholder groups an opportunity to engage. Feedback from face-to-face interviews after the workshop indicated that most participants found the mapping task easy to follow and insightful. Participants reported that the exercise gave them an opportunity to receive an understanding of how their peers viewed SIA and the exercise opened them to conflicting opinions and broadened their own perspective.

The map aggregation process proved valuable for understanding the complexity of the "real life" situation and provided a robust impression of the opportunities and caveats in achieving farm-level SIA, when stakeholders with conflicting opinions have to co-operate for a common goal. The identification and confirmation of this complexity would be difficult without such an approach.

An area for caution with respect to the method is the limited qualitative description of the specific meaning of the components and links, particularly where similar concepts appear in different maps. Furthermore, it is important to know the discussions that led to group choices to avoid data misinterpretation, and when using FCMs for exploratory analysis the lack of qualitative information can be problematic [76]. To overcome this, and to ensure an accurate representation of the thoughts and logic of each group, the role of the facilitators was extended: in addition to co-ordinating the group exercises, facilitators held interviews with group participants after the workshop to ensure the information was captured in an accurate manner and to remove potential bias.

5. Conclusions

In this study, a group-discussion approach was used to investigate how various stakeholder groups perceive the path towards farm-level SIA and to examine the complexities of achieving a common goal when all opinions are considered. The study showed that sustainable intensification is not a simple target, but a complex dynamic system that includes institutional structures, personal goals, stakeholder interests and socio-economic factors, and is affected by cognitive beliefs and particular knowledge within a stakeholder group. The results showed how experience, knowledge and beliefs affect the perception of farm-level SIA by various stakeholder groups, and how this knowledge is often fragmented and miscommunicated. Farmers consider farm-level SIA to be a closed system, with nodes that interact highly with each other and are related to farm management and resource availability. Policy makers consider it to be an open system with more direct links between nodes, and identify policy design and research-related elements as important for its balance. Advisors see farmers' attitudes and characteristics as dominant nodes for the achievement of SIA, enabling the advisors to be the communicators between policy and the farmers.

The fuzzy cognitive technique proved useful in obtaining key concepts for farm-level SIA. The exercise confirmed the hypothesis that farm-level SIA cannot be simply measured through established indicators, but has to be seen as a dynamic process in which farm performance is affected by various factors, with the complexity of the process increasing when different stakeholder interests and beliefs combine for farm management.

Some main research and policy recommendations for future approaches arise from this study:

(a) Stakeholders look at SIA only from their own perspective if there is no satisfactory interaction, resulting in a confusing system when their knowledge is combined. This calls for essential and meaningful knowledge exchange. The FCMs provide insight on which concepts and relationships are neglected in discussions, and identify what the sustainability debate should focus on to advance a common, broader and sustainable intensification goal.

(b) Stakeholders' knowledge and contributions to achieving SIA are fragmented. This creates the requirement for more integrated systems thinking approaches. Collective systems thinking would enable stakeholders to adjust their thinking to include nodes that, in principle, are not important to their group. The aggregation process allows perspective barriers to be overcome and creates common reference points. The central and important drivers and receivers are potential "starting points" for working towards bridging the gap between stakeholders' views and guiding actions towards sustainable intensification.

(c) The results of this study show the importance of involving the different stakeholders, bringing them together and creating the opportunity for open discussion and collective understanding. More importantly, the results indicate the need for in-depth incorporation of farmers' understanding of farm-level SIA in discussions. This could help in bridging the gaps between policy design and implementation, and assist in achieving consensus between groups with conflicting interests on future approaches.

From a practical perspective, the application of such a participatory tool, which is able to aggregate and quantify stakeholders' knowledge, could assist in effective decision making for the management of farm systems. The use of this tool could be very informative, but it always has to be borne in mind that it is context specific, and therefore encoding stakeholders' knowledge should be applied at the local level and include a learning process.

The fundamental practical requirement is the support and engagement of the decision makers themselves throughout the whole process. This could be challenging at times, as conflicting interests, time limitations and different understandings of the procedure can impede such a process. In addition, the success of this tool is based on the participating stakeholders' mutual understanding and willingness to compromise, which are mainly built through the creation of trust between them.

In conclusion, treating SIA as a system created an opportunity to identify key concepts that are factored into the decision-making process to achieve farm-level sustainable intensification. When stakeholders with conflicting interests come together to identify the path towards farm-level SI, a complicated process is revealed. The results of this study can provide valuable insights on what the strengths and weaknesses of co-management are, and what future debates on farm-level SIA should focus on, for agriculture to take steps forward towards more sustainable intensification.

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