2 **Title**

3 Mapping the pathways towards farm-level sustainable intensification of agriculture: an exploratory network
4 analysis of stakeholders' views

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19 **ABSTRACT**

20 Sustainable intensification of agriculture (SIA) has become an important concept to ensuring food security in the
21 context of increasing agricultural production while minimising negative externalities in contemporary agronomic
22 systems. In supporting this, there is a need to establish a decision-making and management system that involves
23 the views and opinions of different stakeholders and unifies the goals of SIA amongst them. The objective of this
24 work is to identify and describe pathways toward farm-level SIA. An explanatory network approach and fuzzy
25 cognitive maps (FCMs) support the analysis of stakeholder views across the three pillars of sustainability: social,
26 economic and environmental. Different stakeholder groups were asked to collectively map the pathways towards
27 farm level SIA in a workshop exercise. The respective groups considered a common set of pre-selected factors as
28 potential descriptors of sustainability and created unique maps by adding their own components and descriptors
29 and identifying causal links between them. While the relative weighting of factors by each group differed,
30 according to their perspectives and interpretation, yield, knowledge transfer, water quality, weather extremes and
31 technology/infrastructure were scored as priority descriptors of farm-level sustainability by all groups in an
32 aggregate analysis. Exploratory analysis of FCMs was found to provide an efficient mechanism to investigate
33 stakeholder views on pathways towards farm-level SIA, by identifying causal relationships and interactions
34 between factors and actors that affect its achievement. The study shows that sustainable intensification is a complex
35 dynamic system that includes institutional structures, personal goals, stakeholder interests and socio-economic
36 factors, and is affected by cognitive beliefs and particular knowledge within stakeholder groups. Our results show
37 how experience, knowledge and beliefs affect the perception of farm-level SIA by various stakeholder groups, and
38 how this knowledge is often fragmented and miscommunicated. The exercise confirmed the hypothesis that farm-
39 level SIA has to be seen as a dynamic process in which farm performance is affected by various factors, with the
40 complexity of the process increasing when different stakeholder interests and beliefs combine for farm
41 management.

42

43 **Keywords:** sustainable intensification; stakeholder engagement; fuzzy cognitive mapping; mental models; group
44 thinking; network analysis

45 **1. Introduction**

46 The predicted increase in world population and shifts in human dietary trends are likely to cause a greater demand
47 for food (Alexandratos and Bruinsma, 2012). This places increased pressure on agriculture to intensify food
48 production against a backdrop of increasing scarcity of additional land for agriculture (Lambin et al., 2013) and
49 major threats to the global environment from commercial farming (Chen et al., 2018; Henle et al., 2008; Steinmetz
50 et al., 2016). In the face of these global challenges the concept of sustainable intensification of agriculture (SIA)
51 has come to the fore in recent years (Royal Society of London, 2009). SIA represents as the increase of agricultural
52 production through sustainable development, which is widely accepted by international policy and research as a
53 concept consisting of three main pillars: economic, social and environmental (Rigby et al., 2001; Sala et al., 2015).
54 The European Union (EU) is the largest agricultural importer in the world (European Commission, 2017). As such
55 it is associated with environmental damage in exporting countries (Serrano et al., 2016) food dependant from
56 regions where food security issues may arise in the future (European Environmental Agency, 2017), which makes
57 European SIA a necessity. However, global versus European perspectives differ in terms of SIA, e.g. European
58 agriculture is already very intensive and problems such as rural-urban migration and widespread land abandonment
59 are much greater than land scarcity and food security. Therefore, for European SIA, the critical issues are the
60 negative environmental impact of agriculture and the failure of the agricultural production growth model to cover
61 the socio-economic needs of rural populations (Buckwell et al., 2014).

62 Although there are established policy agendas at national and at EU levels for sustainable agricultural management,
63 the success of SIA requires techniques that are spatially and socially site-specific (Areal et al., 2018). SIA can be
64 implemented at different scales, but it is acknowledged by research and policy, that effective SIA depends on the
65 sustainable management of individual farms (Dong et al., 2015). Every farm has its own unique physical and
66 structural characteristics, and is usually the legal and economic unit at which most EU policies are directed (Kelly
67 et al., 2018). Also, farming practices are key elements in this process and these depend on farmers who are unique
68 individual decision-making units (de Oliveira Silva et al., 2016). Assessing the success of SIA at farm-level allows
69 for the achievement of the highest spatial accuracy, under the assumption that farms are “micro-systems” that all
70 together form landscapes and wider agricultural systems.

71 Recent research shows that the assessment of farm-level SIA can be achieved by quantifying the economic, social
72 and environmental outcomes of a range of farm management practices (Areal et al., 2018; Barnes and Thomson,

2014; Gadanakis et al., 2015; Lynch et al., 2018; Vayssières et al., 2011). 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 (de Olde et al., 2018). In reality, farm management decisions are largely affected by external factors that are beyond farmers' control and that interfere with the farmers' personal decision-making process.

To address this, research has focused on farmers' decision making behaviour using quantitative (Areal et al., 2012; Daxini et al., 2018; Liu et al., 2018; Micha et al., 2015) or qualitative methods (Blackstock et al., 2010; Burton, 2004) 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 some of SIA. However, if SIA is viewed as an aspiration, rather than a specific aim, then its achievement is an evolving process, and the perceived usefulness of the strategies and paths for its delivery vary significantly between stakeholders (Hoffman et al., 2014). Therefore, achieving farm-level SIA becomes a dynamic process that requires co-ordinated efforts (Weltin et al., 2018), and during this process the farm becomes a complex system with many components, which not only have direct impact on farm performance, but also interact with each other (Levy et al., 2018). These may include policies and regulations or existing beliefs and perceived effectiveness, which vary according to the knowledge and experiences of each stakeholder (Micha et al., 2018). 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, we adapted the use mental models presented as fuzzy cognitive maps (FCMs) to present and understand the views of several stakeholder groups associated with SIA to assess the current process of SIA at farm-level, taking into account 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. Fuzzy cognitive maps (FCMs) have been used to support the analysis of stakeholder views on different, specific agricultural and environmental issues (Kafetzis et al., 2010), or environmental decision making and management (Papageorgiou and Kontogianni, 2012). FCMs were first developed by Kosko (1986) and are structured modelling techniques that can be used to describe complex knowledge systems (Gray et al., 2014). 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 (Fairweather, 2010). Such studies

(Kontogianni et al., 2012; Levy et al., 2018; van Winsen et al., 2013; Vanwindekens et al., 2014) 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 the collective beliefs to be presented and supports the development of social learning (Henly-Shepard et al., 2015).

2. Methodology

2.1 FCM participatory process

To understand the structural and functional aspects of how the different stakeholders conceptualise the implementation of SIA on European farms, FCMs were constructed from groups of stakeholders (farmers, advisors and policy) 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* that represent concepts (or components); *edges*, which represent the links between the nodes (indicated by arrows); *and edge weights* that indicate the influence (positive or negative) and the 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 one indicator, four nodes (components) and five directed –relations (edges) with their degree of influence (edge weight).

122 2.3 Group mapping exercise

123 The FCMs from there stakeholder groups, representing farmers, agricultural advisors and agricultural/
124 environmental policy makers were constructed in a participatory exercise, which took place in Ireland during a
125 workshop organized within the Marie Curie INSPIRATION Innovative Training Network (project 675120). In
126 total 48 people participated in the workshop, including farmers, advisors, social and agri-environmental scientists,
127 and policy makers. Three stakeholder groups were formed: a group including farmers, a group including
128 agricultural advisors and applied researchers and a group including policy makers¹. Representatives from applied
129 research and academic institutions, with knowledge on the SIA concept, facilitated each group discussion. The
130 exercise was based on the method suggested by Gray et al. (2015), whereby the nine pre-defined SIA indicators
131 (Table 1) were presented to each group to guide construction of the FCMs. At the beginning of the exercise, each
132 group was given a 150 cm² blank sheet of paper containing 9 pre-defined farm level SIA indicators (Table 1) in
133 random order. Based on personal perception and experience, the groups were asked to link them using directed
134 arrows (**Figure 1**) indicating their perceived degree of **influence**: negative high (---), medium (--), low (-) and
135 positive low (+), medium (++), high (+++). In addition, the groups were asked to identify other **components**,
136 which they considered to **influence** the indicators and connect them to each other and to the indicators, as they
137 perceive it to be realistic.

138 2.2. Selection of farm level SIA indicators

139 The stakeholder groups were presented with a number of pre-selected SIA indicators, around which they were
140 asked to build their FCMs. The indicators were selected from the literature (Latruffe et al., 2016; Lynch et al.,
141 2019; Smith et al., 2017) based on the following criteria:

- 142 a. They were measurable at farm/farm household level
- 143 b. They were relevant to European agricultural production
- 144 c. They represent intensive and/or intensifying farms
- 145 d. They are identified in the literature as consistent and measurable across time
- 146 e. They equally represent the three main sustainability pillars (environment, economic and social).

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

¹ Due to the large number of researchers participating in the workshop, all groups included a number of researchers.

Table 1: Pre-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
Env/ntal	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 in the form of the following equation:

$$A(D) = [\alpha_{ij}]$$

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 (Byung Sung and Jetter, 2016; Özesmi and Özesmi, 2004). 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 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 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	Indicates how densely nodes are connected.

Table 3: Metric used for comparison of the components of each FCM

Components' comparison	Numerical expression	Definition	Characteristic of component
Out-degree (OD)	$OD_i = \sum_{\kappa=1}^N \alpha_{i\kappa} $	The cumulative strength of connections with which a component influences other components	Driver

Weighted out-degree (WOD)	$OD_{iw} = \sum_{\kappa=1}^N \alpha_{ij} * \sum W_{e_{ij}}$	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}^N \beta_{ji} $	The cumulative strength of connections with which a components is influenced by other components	Receiver
Weighted in-degree (WID)	$OD_{iw} = \sum_{\kappa=1}^N \beta_{ij} * \sum W_{e_{ij}}$	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

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163 **Central nodes** (high D, Table 2) are the largest circles on a map (figures 3-6), representing the most important
164 components to the particular group, which have the most “edges” coming in and out. **Dominant nodes** (high WD)
165 are signified still by the high weights (‘+++’ or ‘---’) of the arrows coming **in and out**. They may or may not be
166 **central**, but they also highly influence the system. A node is a **receiver**, where many arrows “come into” it (high
167 ID). A node is defined as **affected** (high WID) when overall weight of the arrows coming is high. A node is a
168 **driver** (high OD) when a large number of arrows “come out” of it. A node is **influential** (high WOD), where the
169 weight of the arrows coming out is high. From the individual stakeholder types “**unique nodes**” were also
170 identified, representing factors that were only identified and considered by that particular stakeholder group.

171 The comparison of the FCMs involves calculating values for the components of each system and indicating the
172 similarities and differences between them.

173 2.5 Map aggregation

174 After an initial comparison individual FCMs were aggregated into a final FCM with a new adjacent matrix and a
175 “reinforced” weight for the edges that appeared in more than one FCM. The aggregation was conducted

176 qualitatively as in Gray et al. (2012). Here the reinforced edge weights are the result of adding the edge weight of
 177 the individual FCMs (example shown in Figure 2).

179 Figure 2 Example of combining stakeholder maps (based on Gray et al., 2012)

181 Once the aggregated map was constructed, common components were identified which occurred across all maps.
 182 Finally, for the discussion and interpretation of the results, further face-to-face interviews and consultations with
 183 the facilitators (2 per group) and some of the participants enabled verification and explanation of the results.

184 3. Results

185 Table 4 shows the results of comparison of the FCMs. Table 5 presents the results of the analysis for the
 186 comparison of nodes within and between maps, and Table 6 is a summary of important nodes for each group FCM
 187 and the aggregate FCM.

188 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 €	84	96	85	233
Density	0.097	0.077	0.056	0.080

190 Table 5; comparison between FCM components: in-degree, out-degree and degree of centrality

	Farmers' group						Advisors' group						Policy group						Aggregate map					
Components	ID	W ID	O D	W O D	D	W D	ID	W ID	O D	W O D	D	W D	ID	W ID	O D	W O D	D	W D	ID	W ID	O D	W O D	D	W D
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							1	-1	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
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

192 **3.1. Farmers’ group FCM**

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

194
195 Figure 3: Fuzzy cognitive map of group 1 – farmers group
196

197 The farmers’ FCM has 30 nodes (including the 9 pre-defined indicators) connected with 84 “edges” and a map
198 density of 0.097 (Table 4). As seen in Table 5, the most central nodes are *income*, *yield*, *succession*, *P balance* and
199 *biodiversity*. *Yield* and *technology/infrastructure* are the most dominant nodes, followed by *knowledge transfer*,
200 *income*, *social capital* *succession*, *farm innovation*, *agri-environmental schemes*, *biodiversity* and *weather*
201 *extremes*. The highest receivers are *income* and *yield*. *Yield*, *income* and *market orientation* were strongly
202 positively affected and *P balance* is the node most negatively affected node. No highly important drivers were
203 identified. *Knowledge transfer* is 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.

3.2 Advisors' group FCM

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

Figure 4 Fuzzy cognitive map of group 2 – advisors group

The advisors' FCM 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

216 influenced. There are no big drivers or influencers but many nodes have equal smaller WIDs (except *water quality*
 217 with $WD=-19$). Eight nodes are unique to this group: *farmers' identity*, *age*, *education*, *income support*, *water*
 218 *quality*, *labour units*, and *farm size*.

219 **3.3. Policy makers' group FCM**

220 A visual representation of the policy group map is presented in Figure 5.

221
 222 Figure 5: Fuzzy cognitive map of group 3 – policy group

223
 224 The policy group map has 39 nodes (including the indicators) and 85 *edges*. The density of the system is 0.56
 225 (Table 4). *Yield*, *income* and *resilience* are the most central components of the map (Table 5, Figure 4). *Yield* and
 226 *resilience* are also among the most dominant components, followed by *future planning*, *slurry*, *research* and
 227 *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*.

3.4 Aggregate FCM

The aggregate FCM is presented in Figure 6.

Figure 6: Aggregate FCM

This FCM represents the complete farm SIA system 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*². *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 of 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.

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 it of its great centrality in the aggregate map.

- “**Yield**”, is the only predefined indicator that solely represents agricultural intensification. Increasing 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 a contributor to the sustainable development of a farm system (Vanlauwe et al., 2014). 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 2 economic indicators (Figures 3-6). This could confirm that yield “stands above” the whole farm system, and can be considered a goal in its own right (Firbank et al., 2018). At the same time, the high centrality of *yield* across all stakeholders' groups indicates how important they all consider it for the farm (and its SIA) and how all components and elements of the system can work towards achieving it.
- “**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, two

² Due to the high number of nodes degree values above 20 are considered high unless the highest absolute value of the highest degree is less than 20.

economic and one environmental indicator (resilience, succession, social capital, yield, market orientation, biodiversity) while 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. This confirms that generally, farmers who engage with KT services tend to recognize its benefits and have a more progressive outlook towards sustainable practices (Prager and Thomson, 2014). 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 financial stability of farms (Mahon et al., 2010). However, with most farm subsidies promoting best-practice methods of production (European Commission, 2016), 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 farm level, which is confirmed in previous studies (Mahon et al., 2010; Micha et al., 2018; Toderi et al., 2007).

- **“Water quality”** is an ecosystem service that is easily monitored and regulated at farm-level, primarily through the control of nutrient inputs (Buckley et al., 2015). Intensive agriculture is often thought to impose greater pressure on water quality (White et al., 2014). However, less intensive production systems can pose a significant threat too, under certain biophysical and climate conditions (Roberts et al., 2016). 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 (Macgregor and Warren, 2006).

- “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 of the 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 a reflection of the negative impact extreme weather events have on agricultural production. (Seitz et al., 2008; Sivakumar, 2005). Such extreme weather events are increasing in frequency due to climate change conditions (Coumou and Rahmstorf, 2012). As weather extremes become more frequent (Rahmstorf and Coumou, 2011), 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 (Carillo et al., 2013; Micha et al., 2015; van Vliet et al., 2015). Despite this, only the farmer group considers technology and infrastructure a dominant component that influences the farm system (Table 5). According to farmers, technology and infrastructure refers to a range of services in their locality, ranging from broadband access to health and financial services, to rural life quality. The perceived importance of technology and infrastructure by farmers on farm SIA is supported by Buysse et al. (2011). 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, advisors and policy makers, although they may recognize the importance to the farmers’ quality of life, they do not fully appreciate its importance for farm level SIA.

318 4.2 Group comparison

319 The farmers' map shows a relatively closed system (density of 0.1). The high density of the farmers' map indicates
320 that farmers recognize that all farm management elements are interrelated and they understand the dynamic nature
321 of the farm management process. IT also expresses the belief that farm level SIA can be achieved by balancing
322 the existing components, without greatly increasing the complexity of the system. Based on this system
323 description, farm-level SIA appears as a more feasible goal (compared with the other two groups) that can be
324 achieved through strategic changes to the most **dominant** nodes (like yield, income, water quality, weather
325 extremes, knowledge transfer etc.). However, the higher **density** of the farmers' map also indicates that the
326 farmers' goals are specific to their farm businesses and have little focus on their role in achieving SIA beyond the
327 boundaries of their farms (Macgregor and Warren, 2006). In addition the components identified as important show
328 that farmers evaluate farm efficiency based on practical conditions on their farms and their perception of
329 sustainable management is only relevant to reaching specific goals (Doody et al., 2015).

330 The advisory group map depicts a moderately closed system with no highly central or dominant nodes, (except
331 *water quality*). This means that many nodes have small but equal interaction with the system. This indicates that
332 advisors' knowledge of farm-level SIA does not focus on specific areas within the SIA system, and, like farmers,
333 see potential in balancing the existing components for achieving SIA. Conversely, the policy map showed an
334 open system, with many components that loosely interact with each other. In addition, most nodes, in the policy
335 FCM, are identified only as receivers (OD=0) or drivers (ID=0) (Table 5), and have very low WIDs and WODs.
336 This indicates direct causal relationship between few components, but low overall interaction of components
337 within the system. A possible explanation for this is that policy involves several elements from design to
338 monitoring and regulation, and can include various actors (e.g. experts, consumers, etc.) who often represent
339 conflicting interests while generally grouped under the policy design umbrella. In turn, this could explain the fact
340 that often policy design can send multiple signals and uphold conflicting interests, which may lead to conflicting
341 policy messages (Bjørkhaug and Richards, 2008). Indeed, for policy makers farm SIA can be viewed from different
342 perspectives depending on context, and its goals remain subjective. On the other hand, if looked at as an overall
343 purpose, an open system it provides an opportunity to re-consider practices and develop new approaches (Petersen
344 and Snapp, 2015).

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 stakeholders’ opinions come together. This confirms that presently SIA is not a defined aim but an abstract goal, and achieving it is not a linear process by a dynamic complex approach. The complexity of the map indicates, in principal, that collective decision-making would take longer to resolve (Levy et al., 2018). 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 examination of 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 farm sustainable management, a view confirmed widely in the literature (Areal and Riesgo, 2014; Hyland et al., 2018; Micha et al., 2018). 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 the policy agendas (Zagata and Sutherland, 2015). 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 the farm and farmers 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. 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.

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

376 A caution with respect to the method is the limited qualitative description of the specific meaning of the
377 components and links s particularly where similar concepts appear in different maps. Furthermore, Tt is important
378 to know the discussions that led to a groups’ choices to avoid data misinterpretation and. when using FCMs for
379 exploratory analysis, the lack of qualitative information can be problematic (Reed et al., 2013). To overcome this
380 and to ensure an accurate representation of the thoughts and logic of each group the role of the facilitators was
381 extended: in addition to co-ordinating the group exercises, facilitators held interviews with group participants after
382 the workshop to ensure the information was captured in an accurate manner and remove bias.

383 **5. Conclusions**

384 In this study a group discussion approach was used to investigate how various stakeholder groups perceive the
385 path towards farm-level SIA and to examine the complexities of achieving a common goal when all opinions are
386 considered.

387 The study showed that sustainable intensification is not a simple target, but a complex dynamic system that
388 includes institutional structures, personal goals, stakeholder interests and socio-economic factors, and is affected
389 by cognitive beliefs and particular knowledge within a stakeholder group. Our results showed how experience,
390 knowledge and beliefs affect the perception of farm-level SIA by various stakeholder groups, and how this
391 knowledge is often fragmented and miscommunicated. Farmers consider farm-level SIA to be a closed system
392 with nodes that interact highly with each other and related to farm management and resource availability. Policy-
393 makers consider it to be an open system with more direct links between nodes, and identify policy design and
394 research related elements as important for its balance. Advisors see farmers’ attitudes and characteristics as
395 dominant nodes for the achievement of SIA, enabling the advisors to be the communicators between policy and
396 the farmers.

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

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

- 402 a) Stakeholders look at SIA only from their own perspective if there is not satisfactory interaction, resulting
403 in a confusing system when their knowledge is combined. This calls for essential and meaningful
404 knowledge exchange. The FCMs provide insight on which concepts and relationships are neglected in the
405 discussions, and identify what the sustainability debate should focus on to advance a common broader
406 sustainable intensification goal.
- 407 b) Stakeholders' knowledge and contribution to achieving SIA is fragmented. This creates the requirement
408 for more integrated system thinking approaches. Collective system thinking would enable stakeholders to
409 adjust their thinking to include nodes that in principal are not important to their group. The aggregation
410 process allows perspective barriers to be overcome and creates common reference points. The central and
411 important drives and receivers are potential "starting points" for working towards bridging the gap
412 between stakeholders' views and guiding actions towards sustainable intensification.
- 413 c) The results of this study show the importance of involving the different stakeholders, bringing them to one
414 table and creating space and time for discussion and understanding between them. More importantly, the
415 results indicate the need for in-depth incorporation of farmers' understanding of farm level SIA, in the
416 discussions. This could help in bridging the gaps between policy design and implementation and assist in
417 achieving consensus between groups with conflicting interests on future approaches. Although in the short
418 term this may appear to be a complicated process, in the long term it will enable stakeholders to simplify
419 their thinking and concentrate on the most important points towards the common goal.

420 In conclusion, treating SIA as a system gave the opportunity to identify key concepts that are factored into the
421 decision-making process to achieve farm-level sustainable intensification. When stakeholders with conflicting
422 interests come together to identify the path towards farm-level SI, a complicated process is revealed. Our results

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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