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Harvesting European knowledge on soil functions and land management using multi-criteria decision analysis

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Abstract
Soil and its ecosystem functions play a societal role in securing sustainable food production while safeguarding natural resources. A functional land management framework has been proposed to optimize the agro-environmental outputs from the land and specifically the supply and demand of soil functions such as (a) primary productivity, (b) carbon sequestration, (c) water purification and regulation, (d) biodiversity and (e) nutrient cycling, for which soil knowledge is essential. From the outset, the LANDMARK multi-actor research project integrates harvested knowledge from local, national and European stakeholders to develop such guidelines, creating a sense of ownership, trust and reciprocity of the outcomes. About 470 stakeholders from five European countries participated in 32 structured workshops covering multiple land uses in six climatic zones. The harmonized results include stakeholders' priorities and concerns, perceptions on soil quality and functions, implementation of tools, management techniques, indicators and monitoring, activities and policies, knowledge gaps and ideas. Multi-criteria decision analysis was used for data analysis. Two qualitative models were developed using Decision EXpert methodology to evaluate "knowledge" and "needs". Soil quality perceptions differed across workshops, depending on the stakeholder level and regionally established terminologies. Stakeholders had good inherent knowledge about soil functioning, but several gaps were identified. In terms of critical requirements, stakeholders defined high technical, activity and policy needs in (a) financial incentives, (b) credible information on improving more sustainable management practices, (c) locally relevant advice, (d) farmers' discussion groups, (e) training programmes, (f) funding for applied research and monitoring, and (g) strengthening soil science in education.

KEYWORDS
DEX model, farmers and multi-stakeholders, locally relevant advice, participatory research, soil quality

1 | INTRODUCTION

Society is challenged with implementing sustainable and productive agriculture that can secure sufficient food while safeguarding natural resources. This is reflected by the 17 Sustainable Development Goals (SDGs) and targets for 2030 defined by the United Nations (UN, 2015). Nine of those goals are inherently coupled with the biophysical system where soil resources and soil functions play a major role (Keesstra et al., 2016; Tóth, Hermann, da Silva, & Montanarella, 2018). However, the achievement of these SDGs will remain elusive unless there is interdisciplinary cooperation between different scientific disciplines along with the continued involvement of other stakeholders in a transdisciplinary context (Bouma, 2015). To achieve this, stakeholders should be involved from the beginning of research activities with participatory methods (Reed, 2008) to foster a sense of ownership, trust and reciprocity towards the research outcomes.

Soils are finite resources that provide essential bundles of soil processes, which underpin the delivery of ecosystem services, and are known as "soil functions": (a) primary productivity, (b) carbon sequestration, (c) water purification and regulation, (d) habitat for biodiversity and (e) nutrient cycling (EC, 2006; Schulte et al., 2014). All soils perform these five soil functions simultaneously, but at different magnitudes as a result of the interactions between soil attributes (physical, chemical and biological), environment (e.g. climate, weather, slope and geology) and land management. The role of soil management is vital in deciding which soil functions should be prioritized. Therefore, to provide tailor-made solutions for sustainable production, more attention, value and recognition should be given to the specific local knowledge of soil and land management held by stakeholders (Bouma et al., 2012; Carr & Wilkinson, 2005).

This paper describes work completed as part of a broad participatory research project "LANDMARK" that aims to quantify the current and potential supply of soil functions across European agricultural land. The objective of this study was to involve, harvest and assess stakeholders' inherent knowledge and future knowledge requirements relating to soil quality, prioritization of soil functions and land management and to enable context-specific understanding of supply and demand for soil functions.

2 | MATERIALS AND METHODS

2.1 | Workshop consultations

Participatory workshops were designed to engage stakeholders, capture their knowledge, discuss available tools and indicators and deliver guidelines for optimising the management of land and soil functions for policy decision-making. To bridge the gap between science, policy, practitioners and wider stakeholders, a "catchment challenge" method was developed by O'Sullivan, Wall, Creamer, Bampa, and Schulte (2018). In the current study, this method was applied to harvest the tacit or explicit empirical knowledge and information needs of 473 stakeholders through 32 structured workshops (Table 1).

The workshops took place in five countries (Austria, Denmark, France, Germany and Ireland), spanning six climatic zones (Atlantic North, Atlantic Central, Continental, Lusitanian, Mediterranean North and Pannonian) as defined by Metzger, Bunce, Jongman, Mücher, and Watkins (2005) (Figure 1). The workshops brought together three different categories of stakeholders: (a) local farmers, land managers and farm advisors, (b) regional/national stakeholders and (c) European Union (EU) stakeholders and policymakers (group ii and iii are referred to as "multi-stakeholders" in the paper).

The "catchment challenge" method was customized to be applicable to those three stakeholder categories and translated for local/regional conditions into two main guides that explained workshop methodology, stakeholder identification, participation techniques and content of the consultation (Sturel et al., 2018). Farmer workshops took place either on a farm or in a research or advisory office, focussing on land and soil management issues. Multi-stakeholder workshops focussed more at catchment/regional scales utilising maps to assess the multifunctionality of soils within a given landscape. In both cases, facilitators

TABLE 1 Distribution of the different types of workshops in the participating countries (pp=number of participants)

Type of workshop	Austria	Denmark	France	Germany	Ireland	European	Total
Farmers	2	1	7	4	2	–	16 (212 pp)
Regional multi-stakeholders	3	–	4	2	2	–	16 (261 pp)
National multi-stakeholders	1	1	1	1	–	–	
European policy makers	–	–	–	–	–	1	
Total	6	2	12	7	4	1	32 (473 pp)

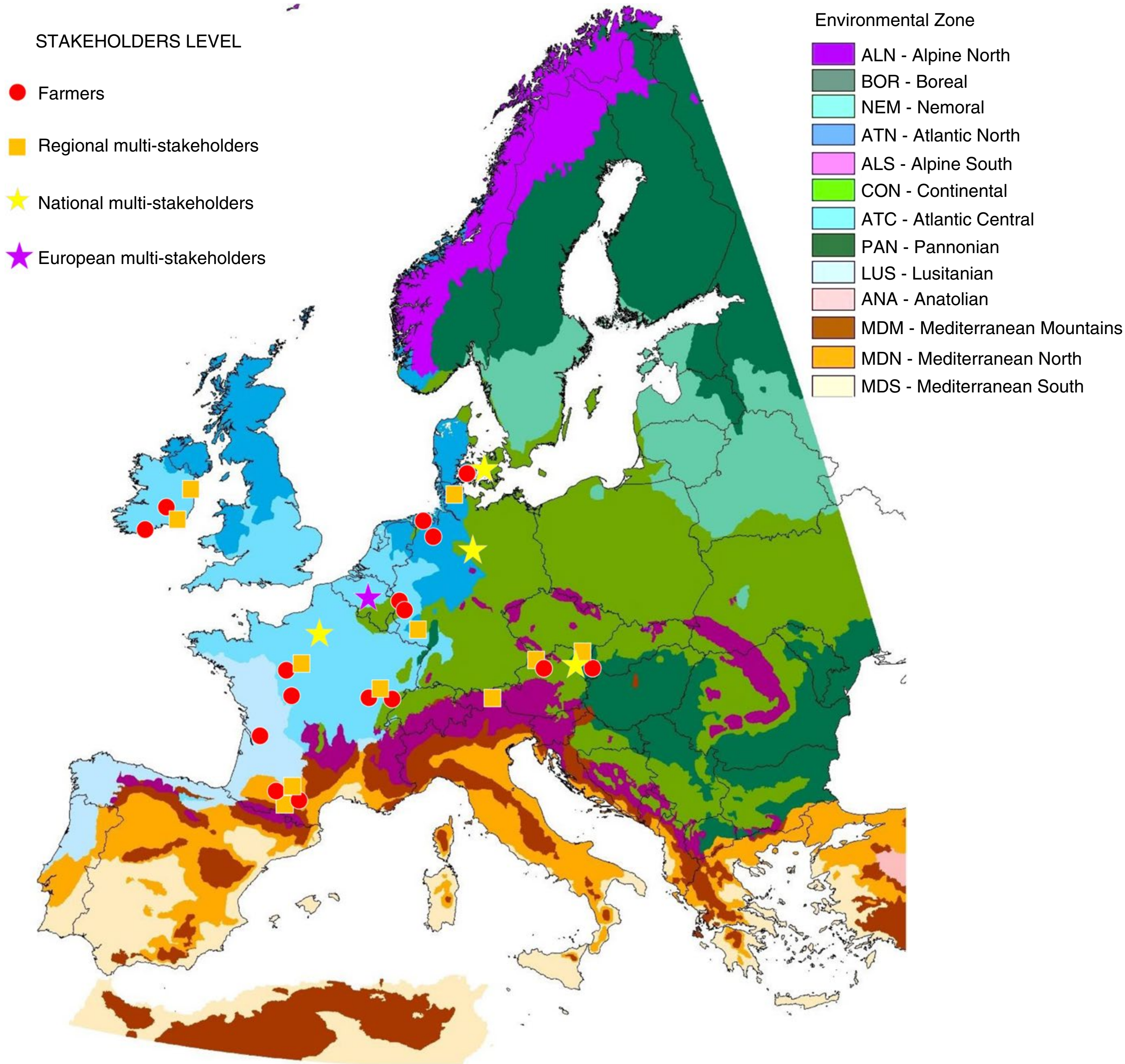

FIGURE 1 Map of the 13 main Environmental Zones of Europe (based on Metzger et al., 2005) and locations of the 32 stakeholder workshops

captured information from the discussions with and between stakeholders, recording opinions, wishes, needs and values, problems and solutions associated with soil functions. The use of the facilitator approach conforms to the transdisciplinary research of Bouma (2015) and the key questions to ask in decision-oriented research in Leeuwis and Van den Ban (2004).

Sturel et al. (2018) have summarized the facilitator reports and described all the workshops. Following the completion of the 32 workshops, it became evident that the extensive data collected needed a consistent approach for analysis and comparison between the workshop results.

2.2 | Data collection, harmonization and analysis

Several studies have used qualitative research in environmental management (Failing, Gregory, & Harstone, 2007; Li, Woltjer, van den Brink, & Li, 2016) and soil sciences (Barbero-Sierra, Ruíz Pérez, Marqués Pérez, Álvarez González, & Cruz Maceín, 2018; Bouma, Kwakernaak, Bonfante, Stoorvogel, & Dekker, 2015; Christie, Parks, & Mulvaney, 2016; Ingram, Fry, & Mathieu, 2010 and Oudwater & Martin, 2003). In this study, the workshop consultations and the reports (Sturel et al., 2018) were semi-structured to facilitate the data collection and processing required for descriptive statistics and data analysis. The results of the 32 written reports were extracted and input into two databases: (a) local farmer and farm advisor workshops (16 entries) and (b) multi-stakeholder workshops (16 entries). The workshop entries were further clustered according to the respective major land-use categories (arable cropping systems, grassland and vineyards), climatic zones, countries and stakeholder level.

Information on existing empirical soil knowledge and future soil knowledge requirements were analysed by stakeholder level and by the five soil functions. Information from the reports was harmonized with the following labels: (a) stakeholders' roles, (b) priorities (qualitative/quantitative), (c) concerns, (d) perceptions of soil quality and (e) perceptions of soil functions, (f) knowledge in terms of soil and land management techniques (qualitative/quantitative), (g) implementation of tools, indicators and monitoring systems, (h) activities and policies, and (i) knowledge gaps and ideas.

2.3 | Model definition and identification of criteria

To address the complexity of integrating and comparing such a large volume of data in a consistent way, multi-criteria decision analysis (MCDA) was used to construct two qualitative multi-attribute decision models (MADM). The main purpose of MADM is to evaluate and choose alternatives based on multiple criteria – or suite of indicators – using systematic analyses that overcome the limitations of unstructured decision problems. Several methodologies have been developed to construct MADM to integrate diverse information and to rank alternatives regarding different types of information. In this study, the DEX (Decision EXpert) integrative methodology (Bohanec & Rajkovic, 1988; Bohanec, Žnidaržič, Rajkovič, Bratko, & Zupan, 2013) was applied to construct MADM. The DEX methodology enables transparent and comprehensive models while providing mechanisms for presenting aggregation rules in a user-friendly way. In this study, the DEX models allowed us to integrate stakeholders' answers to particular questions in a hierarchical way, where the general problem (i.e. existing soil knowledge or future soil knowledge needs) was broken down into sub-problems (e.g. priority, role and concerns).

3 | RESULTS AND DISCUSSION

Following the feedback from participants, it was clear that the 32 workshops were successful in terms of highlighting the role of soil functions in agricultural management.

The DEX methodology was utilized to generate two multi-criteria decision models that structured the results on existing soil knowledge and future soil knowledge needs for farmers/advisors and multi-stakeholders. The outputs of the models were designed to answer two main questions: (1) "What is the existing level of soil knowledge by stakeholders?" and (2) "What future soil knowledge is required?". Each decision model is divided into intermediate levels of sub-attributes, including basic attributes constituting the leaf nodes of the decision tree (Supporting Information Table S1).

3.1 | What is the existing level of soil knowledge by stakeholders?

The response to this general question is structured in Figure 2. Results for the assessment are based upon a ranking of very good, good, moderate or poor knowledge. Ranking depended on the level of frequency (%)/number of citations of the answer to each basic sub-attribute collected during the stakeholder workshops and presented in the reports.

Although the second level of the model tree is merely a mechanistic clustering of the sub-attribute quality and priority, the third level of sub-attributes (Figure 2) is more informative. The DEX model has the capacity to explore the general results further and to explain where groups lack or excel in knowledge. This allowed an evaluation of the importance of soils for stakeholders in terms of (a) their role in relation to soil and land; (b) their concerns; (c) their perception of soil quality; and (d) the level of implementation of their knowledge.

3.2 | How relevant is the role of the stakeholders to understanding the importance of soil?

Across the workshops, different categories of roles were defined: soil and land managers (e.g. farmers and advisors), land planners, stakeholders focused on soil threats or soil functions, stakeholders involved in soil monitoring, policymakers and general researchers (Figure 3). At regional/national multi-stakeholder levels, the model results demonstrated that the group participants were quite varied (e.g. for three multi-stakeholders workshops in Figure 3). In relation to their role, farmers reflected a very good understanding of soil functioning, as shown in Figure 4 as an example of one farmer workshop, based on farmers demonstrating an inherent knowledge about the quality of the soil in their farms, the change over time and the reasons behind those changes.

3.3 | Are stakeholders concerned about soil?

The farmer/advisor workshops highlighted a high degree of concern for soil and land (Figure 4). In general, farmers were concerned about adverse climatic conditions, more binding policies or declining income. Farmers showed varying levels of proactive behaviour and willingness to change – some

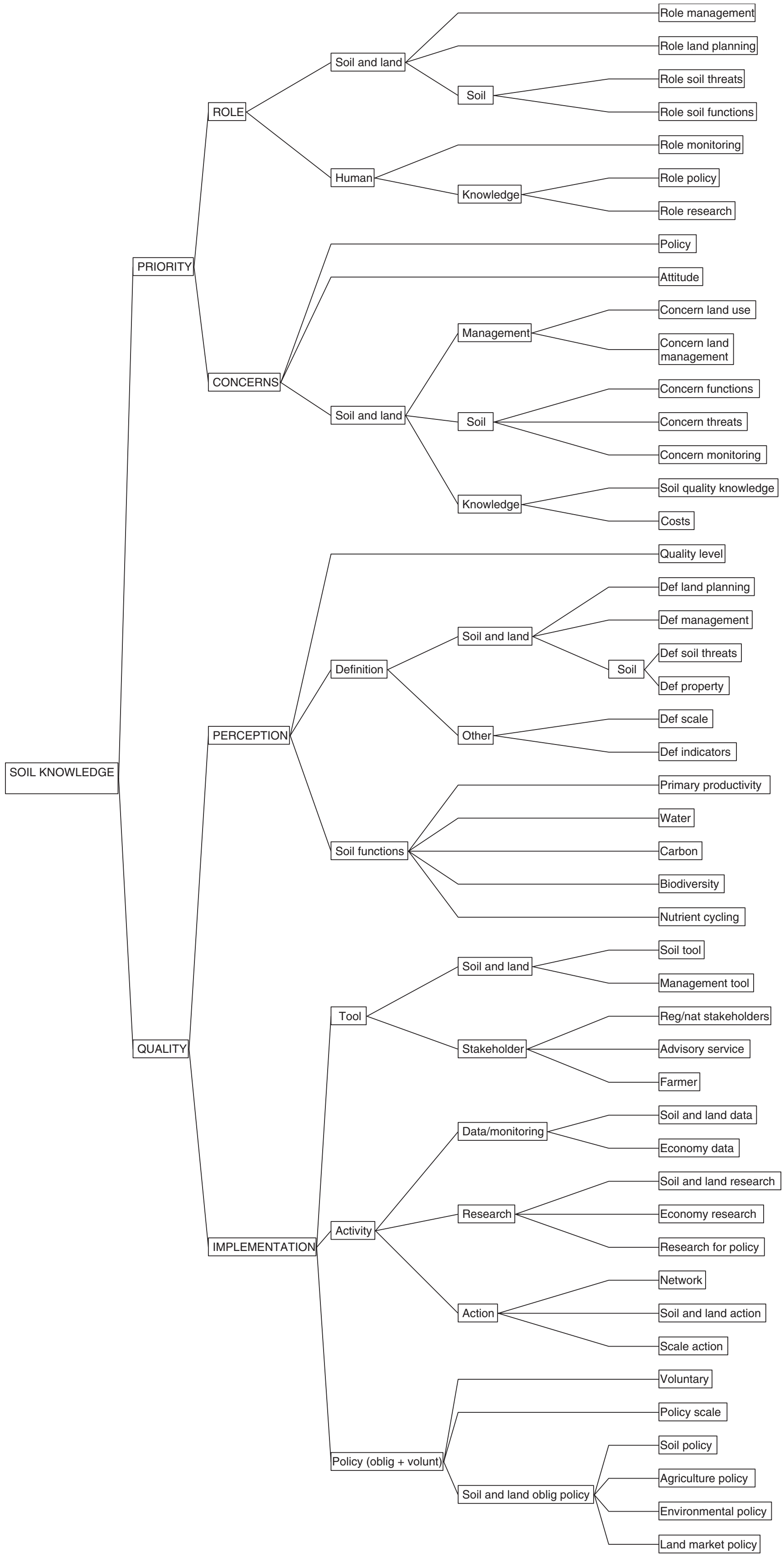

FIGURE 2 Structure of the existing soil knowledge model with a total of 76 attributes, including 47 basic attributes constituting the leaf nodes in the right side of the decision tree

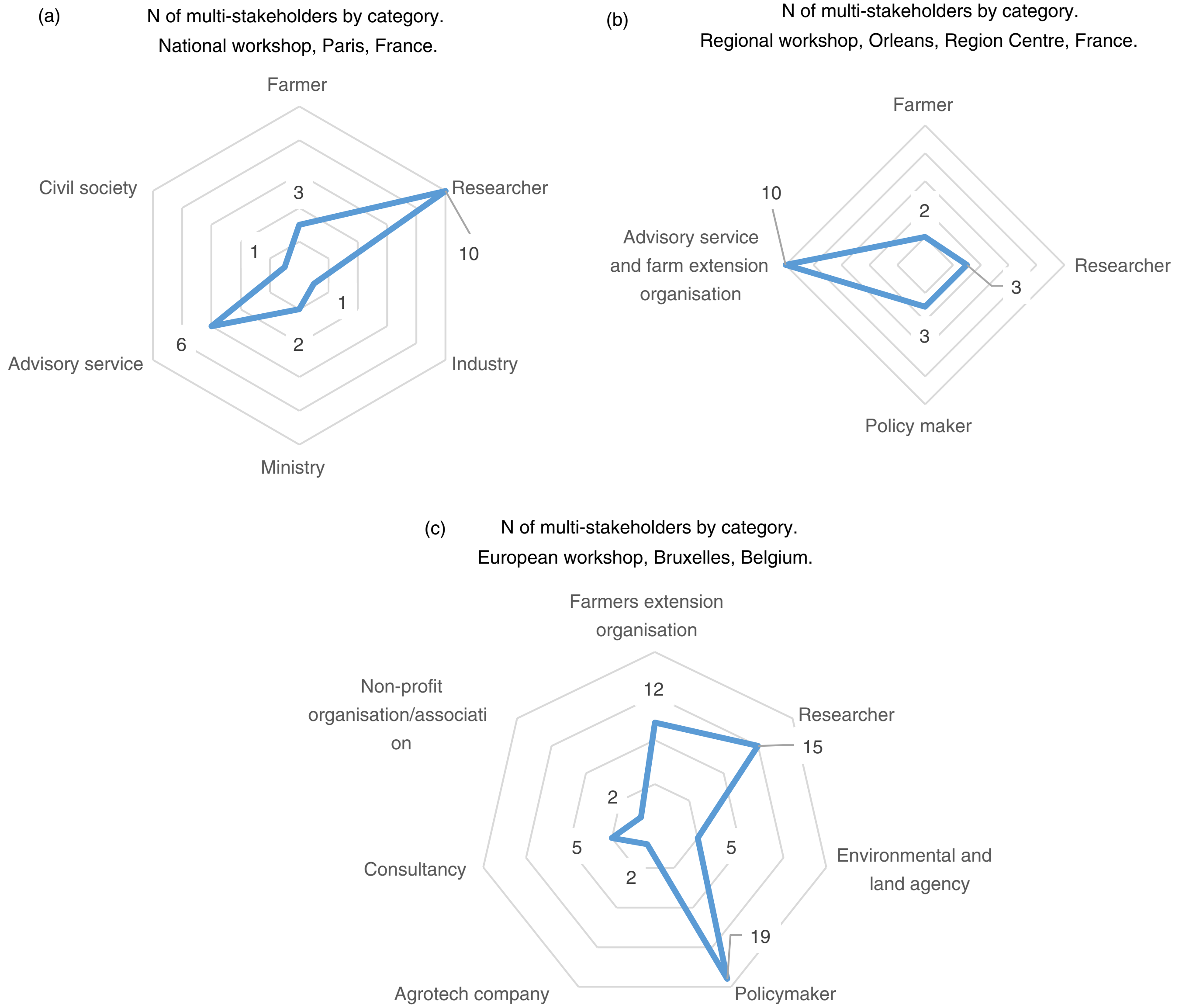

FIGURE 3 Example of the participants described by the sub-attribute "role", divided by main categories, for three multi-stakeholder workshops: (a) top left, the National workshop in Paris; (b) top right, the Regional workshop in Orleans, Region Centre; and (c) bottom, the European workshop in Brussels. (The centre is equal to zero participants) [Colour figure can be viewed at wileyonlinelibrary.com]

were ready to take further steps while others were reluctant to change, mostly due to the recent climatic conditions, declining yields or doubts about future regulations. Concerns of multi-stakeholders, especially in the national workshops, were focussed at much higher spatial scales and often referred to issues such as soil threats (in particular soil sealing), land tenure and changes in land use, indicators and monitoring systems, and the lack of a long-term soil protection strategy.

3.4 | What are stakeholders' perceptions in terms of soil quality and functions?

Consistent with studies by Ingram et al. (2010), the results captured differing opinions on soil quality perceptions and the ranking of soil functions depending on stakeholder level and the definitions and terminology used. For example, carbon sequestration was considered relevant by farmers and farm advisors predominantly in connection with increasing "organic matter" or "humus" content, which is in agreement with a review of Dutch farmers (Hijbeek et al., 2017, 2018) and the interviews and workshops conducted by Ingram et al. (2016) with UK farmers. Multi-stakeholders, however, directly linked this soil function to climate regulation. Furthermore, all stakeholders showed context-specific tacit knowledge about soil functioning that varied by location, language and culture, similar to suggestions in Carr and Wilkinson (2005) and as found in three case studies by Ingram et al. (2010). This result emphasizes the importance of understanding local, regional and pedo-climatic variations

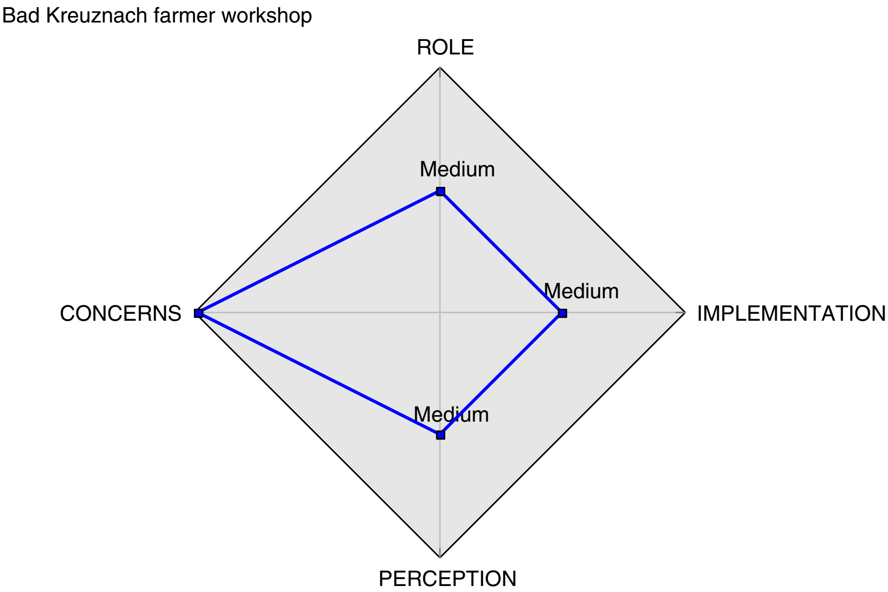

FIGURE 4 Example of the results on soil knowledge of one local farmer workshop held in Bad Kreuznach, Rhineland-Palatinate, Southwest Germany (The centre of the square means zero and the apex means very good level of knowledge) [Colour figure can be viewed at wileyonlinelibrary.com]

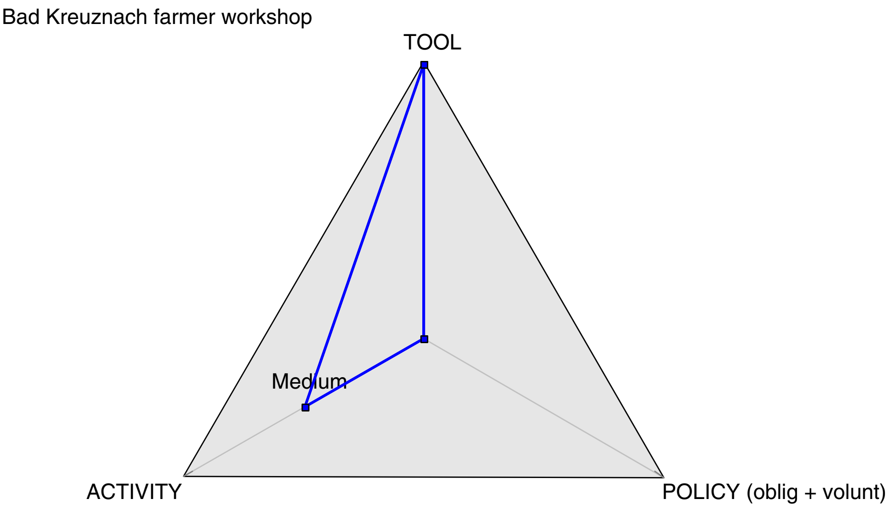

FIGURE 5 Examples of results on implementation of soil knowledge of one local farmer workshop held in Bad Kreuznach, Rhineland-Palatinate, Southwest Germany (The centre of the square means zero and the apex means very good level of knowledge in tools, activities and policies) [Colour figure can be viewed at wileyonlinelibrary.com]

in terms of soil functioning, such as cultural perception and appropriate use of language, which may vary by stakeholder.

3.5 | How is the existing soil knowledge implemented by stakeholders?

Results for the implementation of existing knowledge showed differences for three sub-attributes (Figure 5): (a) "tools" (in terms of decision support tools (DSTs), management practices, techniques and methodologies in land and soil management); (b) "activities" that refer to the human sphere, such as research projects or programmes, awareness and communication (e.g. discussion groups); and (c) "policies" (both voluntary and obligatory). All three categories have been filtered by soil function. Generally, farmers had a moderate to good level of implementation with regard to their knowledge, such as management practice techniques, methods and DSTs, although the level of activity depended largely on their attitude to taking part in discussion groups, networks, research programmes and small projects involving their farms. Some farmers, with the support of researchers and innovative farm advisors, are already involved in decision-making and testing of optimal management practices on their own farm (see Ingram & Mills; Stoate et al., this issue). During the workshops, farmers recommended small participatory research projects, such as the EIP-AGRI BIOBO Operational Group in Austria and the Artemis platform established in Franche-Comté region in France, to the other participants. These two examples demonstrate the strong engagement of farmers with participatory research and extension activities and how this builds momentum with colleagues to try new approaches, in line with the review of Farrington and Martin (1988) and the projects of Howeler (2001). Obligatory policies were rarely mentioned or when discussed, referred mainly to the

Common Agricultural Policy, Water Framework Directive and Nitrates Directive. Multi-stakeholders from national workshops showed a good to very good implementation knowledge, especially regarding policies related to soil, as described by Schulte et al. (2015) and Turpin et al. (2017). However, multi-stakeholders from regional workshops showed a weaker knowledge in terms of tools and activities.

The DEX model results describing existing soil knowledge are shown as radar diagrams for different workshop groups based on the third hierarchical attribute level in the decision model structure. For example, in Figure 2, the third level of attributes corresponds to perception of soil quality and functions, concerns towards management practices, role regarding the multi-stakeholder community and implementation of the knowledge. Figure 4 shows those four sub-attributes for the evaluation of a local workshop held in Bad Kreuznach, Rhineland-Palatinate, Southwest Germany (Continental climatic zone) with arable farmers. The centre of the square equates to zero knowledge while the apex represents a very good level of knowledge, and intermediate levels are labelled as medium in the soil knowledge radar diagrams. In this case, the German farmers showed a good level of knowledge for three areas coupled with a high level of concern related to management practices.

Exploring further the "implementation" sub-attribute (Figure 5), the sub-attribute "policy" is equal to zero, confirmed by the fact that during the workshop farmers did not mention any implemented policy. Farmers were very cautious about new regulations that would add complexity to the already intricate and sometimes conflicting regulations. Instead, they demonstrated a very good knowledge of indicators, soil management practices and techniques referring to each soil function, as indicated by the "tool" sub-attribute. This level of knowledge is reflected by the participants: 15 conventional farmers focusing on wheat, oilseed rape, corn and sugar beet production and dealing with different soil

TABLE 2 Overall modelling results of the farmer and farm advisor workshops on the existing level of soil knowledge and on future soil knowledge needs required

	Local farmer and advisor workshops	**General results**	
Date	**Place**	**What is the existing level of soil knowledge?**	**Further soil knowledge needs required**
27.11.2015	Conservation Agriculture, Toulouse, Midi-Pyrénées, France	**	***
17.12.2015	Gascogne, Toulouse, Midi-Pyrénées, France	**	**
14.03.2016	Groß-Enzersdorf, Lower Austria	***	**
15.03.2016	National farmers tillage society, Wexford, Ireland	**	**
16.03.2016	Linz, Upper Austria	***	**
22.04.2016	Valdhanon, Franche-Comté, France	**	**
25.04.2016	Maves, Loir et Cher, Centre Val de Loire, France	**	***
11.05.2016	Winemakers, Bad Kreuznach, Rhineland-Palatinate, Southwest Germany	***	**
18.05.2016	Cloppenburg, Lower Saxony, Northwest Germany	***	**
31.05.2016	Odense, Fyn Region, Denmark	**	***
02.06.2016	Bad Kreuznach, Rhineland-Palatinate, Southwest Germany	***	**
07.06.2016	Macroom, County Cork, Ireland	**	**
22.06.2016	Aurich, Lower Saxony, Northwest Germany	***	***
08.09.2016	Montlieu La Garde, Charente-Maritime, Poitou-Charente, France	***	**
09.09.2016	Chemin, Jura, Franche-Comté, France	***	***
28.09.2016	Argenton-sur-Creuse, Indre, Centre Val de Loire (+ farmers from the neighbouring départements Creuse & Haute-Vienne), France	***	**

*Poor/not required. **Moderate. ***Good/needed. ****Very good/essential.

types. They were aware of the importance but also rely on advisory services and sharing experiences, as captured in the "activity" sub-attribute. This result is in agreement with the overall workshop results: instead of regulation, farmers would prefer incentives to encourage voluntary initiatives, for example supporting groups of farmers engaged in soil-friendly practices and taking risks by experimenting with alternative techniques, such as those promoted by the EIP-AGRI Operational Groups (European Commission (EC), 2018).

Overall, in both farmer and multi-stakeholder workshops, the analysis detected a moderate to very good knowledge of soil (general results from the modelling are summarized in Table 2 for farmers and Table 3 for multi-stakeholders). Stakeholders demonstrated a good to very good understanding of what soil quality and functions mean, but were more uncertain when asked about what level of soil quality exists in their local area. During the workshops, farmers demonstrated their expertise in terms of farming practices and ability to evaluate the effects of their soil management towards soil functions. Farmers had concerns as they raised questions about the risks associated with climatic hazards, lack of knowledge regarding local soil references and insight on techniques and further more expressed concern over economic feasibility, yields and gross margins. Both farmers and multi-stakeholders had a moderate to good level of knowledge related to implementation. Consistent with other research (Bünemann et al., 2018; Campbell, Lilly, Corstanje, Mayr, & Black, 2017), knowledge gaps were identified regarding the use of soil data and soil function indicators. Other knowledge gaps related to DSTs for soil functions, research programmes, policy instruments, expert networks and discussion group activities, even when stakeholders recognized the importance of these activities. Conversely, farmer workshops revealed some innovative ideas such as simple methods of soil assessment and analysis or management techniques that should be taken into account by wider participants or upscaled to be used for future research and programme developments. None of the workshops resulted in a poor level of inherent knowledge, which signifies the importance of soil quality and functions in the agricultural and environmental sectors of society. Figure 6 provides an example to compare information collected

TABLE 3 Overall modelling results of the multi-stakeholder workshops on the existing level of soil knowledge and on future soil knowledge needs required

Multi-stakeholders workshops			General results	
Date	Level	Place	What is the existing level of soil knowledge?	Further soil knowledge needs required
11.03.2016	Regional	Tyrol, Austria	****	****
14.03.2016	Regional	Groß-Enzersdorf, Lower Austria	***	***
16.03.2016	Regional	Linz, Upper Austria	***	**
18.03.2016	Regional	Orleans, Centre Val de Loire, France	***	**
08.04.2016	Regional	Toulouse, Midi-Pyrénées, France	****	***
20.05.2016	Regional	Water quality researchers, TEAGASC, Ireland	**	***
11.08.2016	Regional	Dairy Industry Southeast, Johnstown Castle, Ireland	***	***
25.08.2016	National	Sorø, Sjælland region, Denmark	***	****
13.09.2016	Regional	Besançon, Franche-Comté, France	****	***
14.09.2016	Regional	Neustadt/Weinstraße, Rhineland-Palatinate, Southwest Germany	****	**
19.09.2016	Local/Regional	Comm. Env., Toulouse, Midi-Pyrénées, France	***	***
20.09.2016	National	Tulln, Lower Austria	****	****
06.10.2016	National	Paris, France	****	****
13.10.2016	Local/Regional	Futterkamp, Schleswig-Holstein, North Germany	***	**
17.10.2016	Regional/National	Hanover, Lower Saxony, Northwest Germany	***	****
20.10.2016	European	Brussels, Belgium	****	****

*Poor/not required. **Moderate. ***Good/needed. ****Very good/essential.

and integrated regarding the existing knowledge for three multi-stakeholder workshops: (a) one national held in Paris, France (Figure 6a); (b) one regional held in Orléans, France (Figure 6b); and (c) the European workshop held in Bruxelles, Belgium, with many multi-stakeholders belonging to Member States countries and EU decision makers (Figure 6c). The national multi-stakeholder (Figure 6a) and the European group (Figure 6c) showed a very good general knowledge, whereas the regional group (Figure 6b) had a good level of general knowledge. The sub-attribute "role" (Figure 3), describing the different stakeholder organizations present at the workshops, shows that the EU and the National groups were very diverse and coherent. In all the three workshops, some of the participants had previously also attended local/regional/national workshops. All the groups showed appreciation of the value of soil and functions (sub-attribute "perception") and expressed a high level of "concerns" in terms of soil threats. The information collected from the European workshop demonstrated a very good level of "implementation" by the participants both at EU and at Member State level. Specifically, the participants showed a very good knowledge in terms of indicators, but not much knowledge on the practical implementation of a monitoring system or gaps in technical knowledge, such as the use of tools or quantitative impacts of management practices on soil. In the five countries consulted, responses to soil monitoring often focused on physical and chemical soil properties, although data on soil biology and soil management were also sometimes available. In Austria, multi-stakeholders recognized that there is a national standard for soil function evaluation and some regions have already implemented it (Vrebos et al., 2017). As confirmed by Van Leeuwen et al. (2017), only a few countries have put a specific monitoring system in place for soil functions.

3.6 | What further soil knowledge is required?

Results for the assessment of the future soil knowledge needs are assessed as essential, needed, moderately needed or not required. In this case, the model (Figure 7) permits focus on the three most requested knowledge needs by the group consulted, represented in the decision tree by the second level of sub-attributes: (a) "techniques", (b) "activities" and (c) "policies".

Figure 8 shows a comparison between a local workshop held in Maves, Region Centre, France (Atlantic central climatic

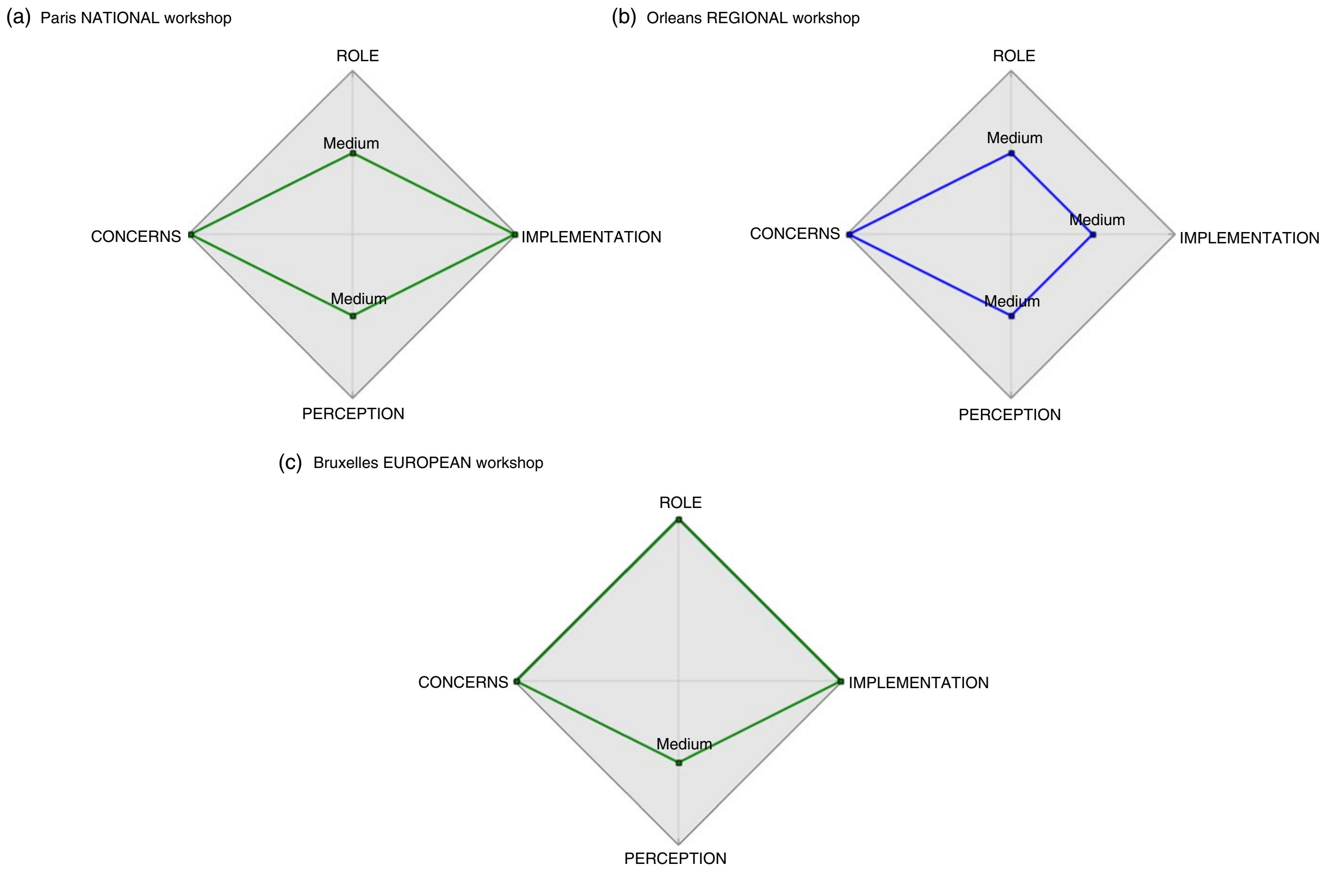

FIGURE 6 Examples of the results on soil knowledge for three multi-stakeholder workshops: (a) top left, the National workshop in Paris; (b) top right, the Regional workshop in Orleans, Region Centre; and (c) bottom, the European workshop in Brussels. (The centre of the square means zero and the apex means very good level of knowledge) [Colour figure can be viewed at wileyonlinelibrary.com]

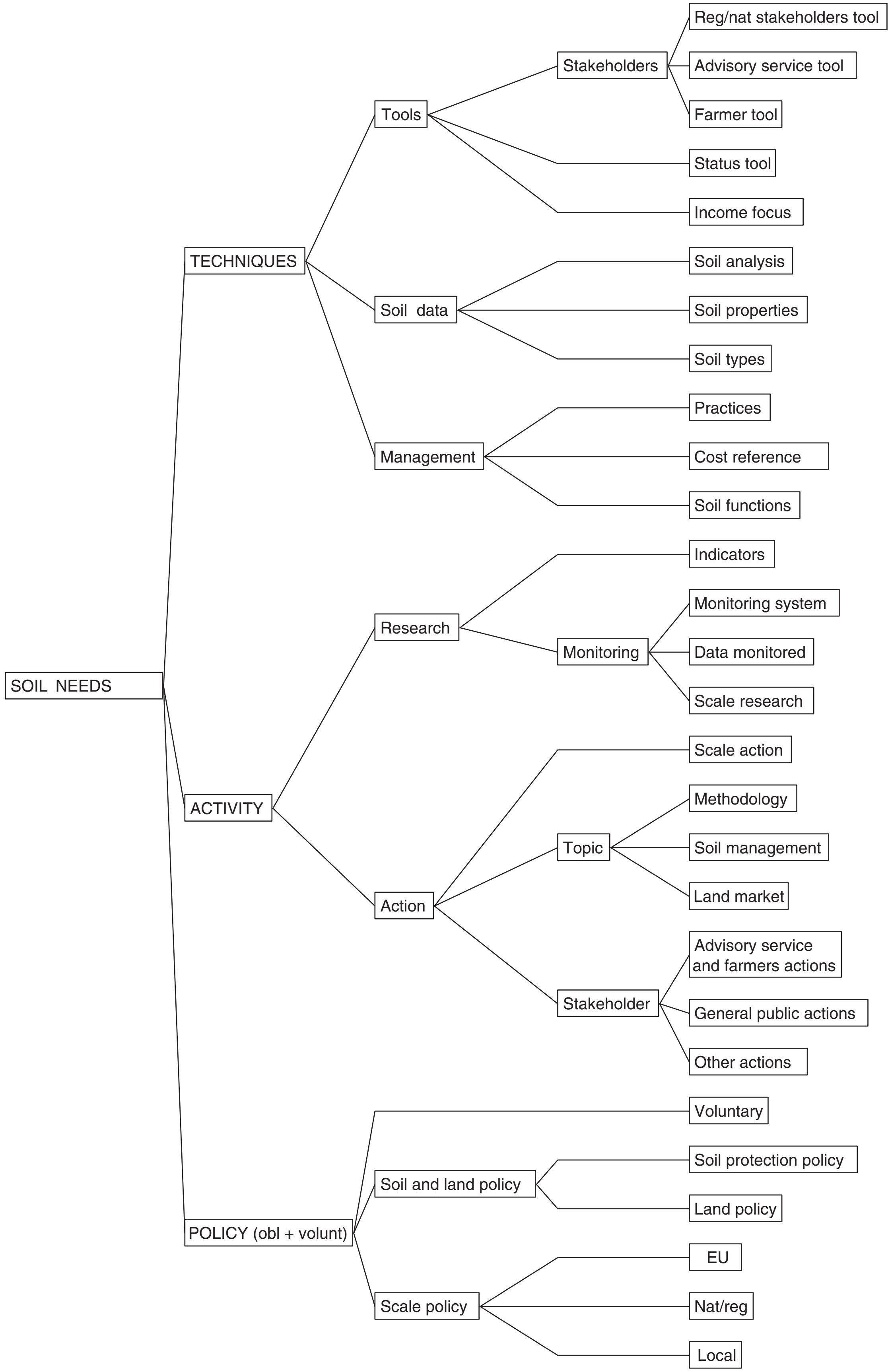

FIGURE 7 Structure of the "SOIL NEEDS" model, with a total of 43 attributes, including 28 basic attributes constituting the leaf nodes in the right side of the decision tree

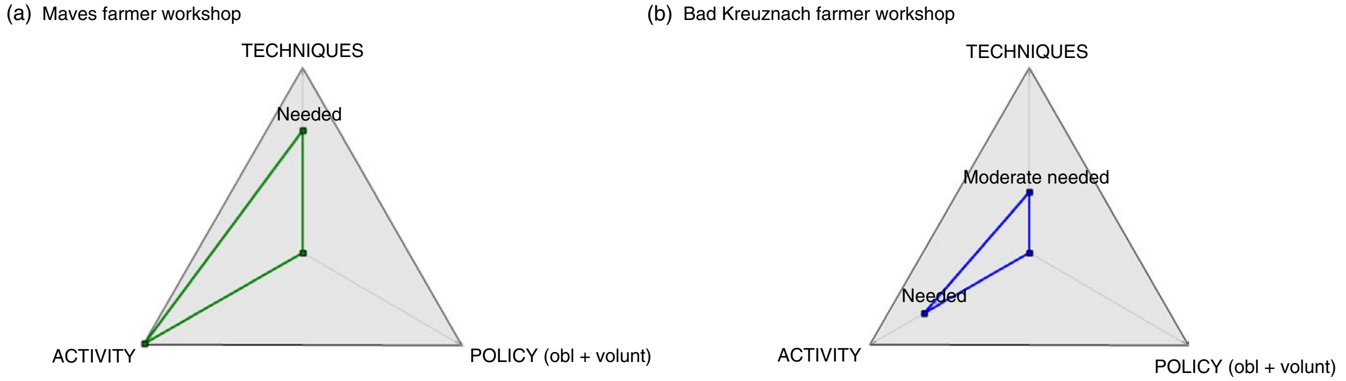

FIGURE 8 Examples of the results on future soil knowledge needs for two local farmer workshops (left – Maves, France; right – Bad Kreuznach, Germany). (The centre of the square means zero and the apex means high level of needs in terms of techniques, activities and policies) [Colour figure can be viewed at wileyonlinelibrary.com]

zone), with arable farmers (Figure 8a on the left side) and the local farmer workshop held in Bad Kreuznach, Germany, described earlier (Figure 8b on the right side). While the Maves workshop defined future knowledge needs as essential, the Bad Kreuznach workshop showed only moderate future knowledge requirements. This result is predicated on the understanding that German farmers were eager to have more knowledge about regional management practices, but were not interested in the use of IT tools (Figure 8b, apex sub-attribute techniques). Instead, they identified the need for special advisory services for soil protection and shared experiences, such as LANDMARK workshops (Figure 8b, apex sub-attribute activity). French farmers wanted to share their scientific and technical knowledge, experiences, as well as gain independent advice in soil and agronomy (Figure 8a, apex sub-attribute activity), DSTs, indicators and tools (Figure 8a, apex sub-attribute techniques). Both groups very clearly indicated that they did not want further regulations relating to soil and land management. This result is in agreement with the overall results: farmer groups requested access to reliable knowledge on soil quality and functions and on the effects of farming practices on them. Farmers need neutral and reliable advice on

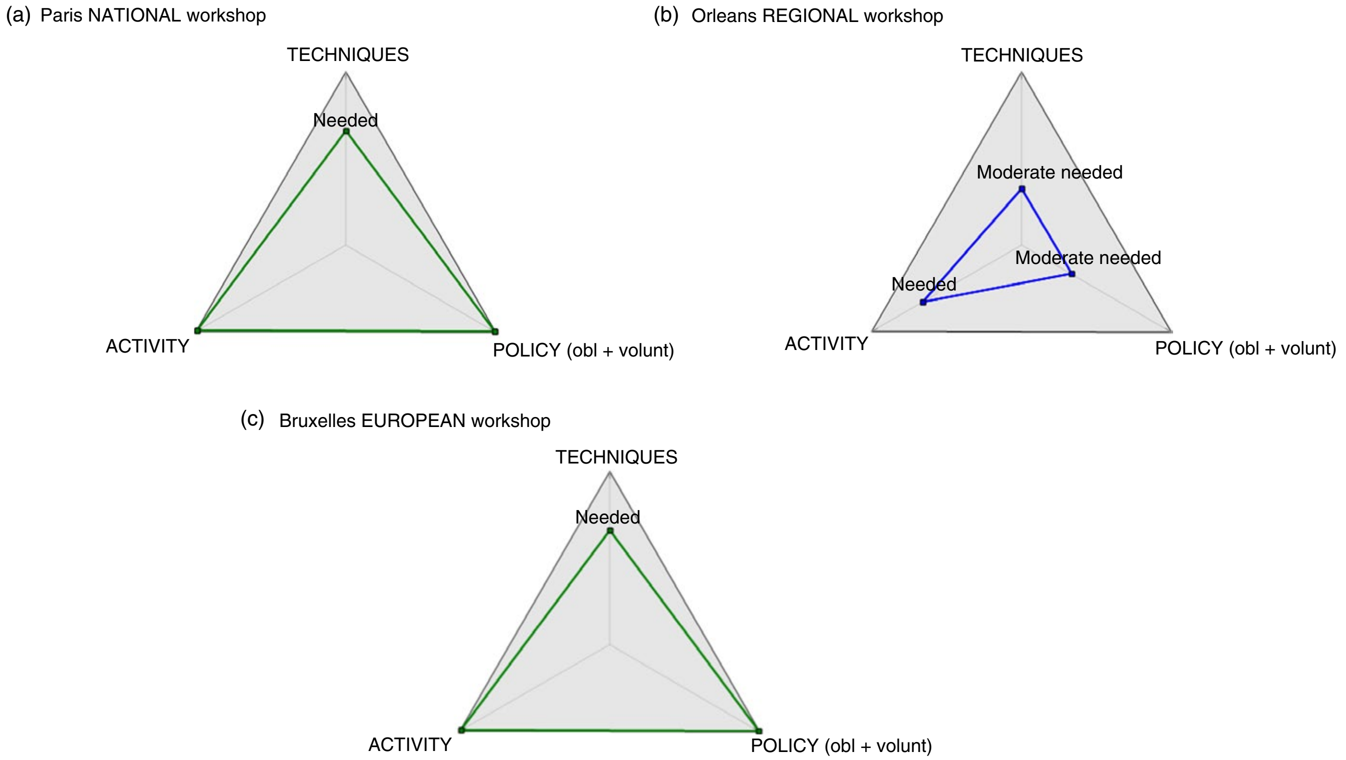

FIGURE 9 Examples of the results on future soil knowledge needs for three multi-stakeholder workshops: (a) top left, the National workshop in Paris; (b) top right, the Regional workshop in Orleans, Region Centre; (c) bottom, the European workshop in Brussels. (The centre of the square means zero and the apex means high level in terms of techniques, activities and policies) [Colour figure can be viewed at wileyonlinelibrary.com]

soil, but there is a lack of soil scientists and agronomy advisers working at the field level. In general, there is little farmer demand in terms of DSTs and methods since many farmers give priority to the acquisition of practice-oriented knowledge and "know-how" rather than to IT tools (consistent with Ingram et al., 2010). Farmers are interested in easy-to-use methods for observing soil in the field and indicators to assess soil quality, as also shown by Bünemann et al. (2018). Many farmers, as shown here, are interested in exchanging experiences on soil management with other farmers (peer to peer learning), especially within discussion groups organized by advisory services (O'Sullivan et al., 2018). Generally, there is a need to reinforce soil science both in initial education and through continuous training, as stated by Bouma (2015), Bouma et al. (2015) and Campbell et al. (2017).

In terms of future soil knowledge needs, the model results show the comparison between the three multi-stakeholder workshops, previously discussed (Figure 9). While the national workshop (Figure 9a) and the European workshop (Figure 9c) showed essential knowledge requirements, the Orléans regional workshop (Figure 9b) showed only moderate needs (Table 3). National multi-stakeholders and EU decision makers were very knowledgeable about the existing knowledge, gaps and problems at their level on land management and for this reason were very keen in acquiring more knowledge in all of the sub-attributes: techniques (e.g. data on trends), policies and activities. At the regional level, some of the multi-stakeholders seemed to be less directly involved and interested in terms of land management programmes. Some of the regional multi-stakeholders were experts in terms of techniques operating at the regional level (Region Centre in France is quite advanced in tools and soil data analysis thanks to the collaboration with the INRA Soil unit). For this reason, their main needs converged in terms of activities (such as network of experts and soil function monitoring systems). The importance of preventing soil sealing and taking into account soils functions in land-use planning was emphasized in the French and in the Austrian regional and national workshops.

In summary, the main findings of the multi-stakeholder workshops were a request for knowledge directed towards research projects or programmes, monitoring systems and data availability, while farmer workshops demonstrated only a moderate interest on those sources of information. Some participants proposed the use of data that is currently collected systematically for monitoring soil functions. Those proposals are in line with recent discussions at a global level (Tóth et al., 2018), at European level (Campbell et al., 2017; Van Leeuwen et al., 2017) and at national level (O'Sullivan, Bampa, Knights, & Creamer, 2017).

Generally, stakeholders need to have long-term insight into public policies, which should not change too often. Some workshop stakeholders recommended improving and harmonising the existing policies and seeking synergies between them, rather than creating new ones. Additionally, they also requested that regional differences need to be considered. Other workshop participants, in line with the farmer workshops, insisted on financial issues and stressed the importance of sufficient funding for applied research, education and training on soil in future policy development. Finally, EU multi-stakeholders wished to explore broader policy scenarios, including the impact of urbanization on soil functions, the potential for carbon sequestration in relation to land use and the design of agri-environment measures focusing on soil. Overall assessment of the future knowledge requirement shows a divergence in opinion between stakeholders, especially in the EU and national workshops and farmer/advisor workshops. The farmer workshops were focussed at the local scale with emphasis on implementation of knowledge and techniques, while the multi-stakeholder workshops had discussions focussed at much higher spatial scales and often referred to relevant policy information.

This research has demonstrated an inter- and transdisciplinary and interactive way of communicating between scientists and stakeholders (from farmers to policymakers) based upon a stakeholder engagement framework. This research goes further and implements an Internet-accessible platform at http://landmark2020.eu/stakeholders-platform/ to facilitate further comparisons of the results and legacy of the information. Public users can find the workshops guides and the 32 reports online, with the facility to further investigate the two DEX model structures and the underlying database of the results for each workshop, using the map.

4 | CONCLUSIONS

This paper identifies the existing knowledge and future knowledge needs of stakeholders of soil functioning and land management obtained from 32 focussed workshops and the implementation of two qualitative models. The existing "soil knowledge" model captured the perceptions of soil quality and what factors support stakeholder expertise on soil and land management across Europe. Furthermore, the analysis identifies knowledge gaps on implementation of soil data, research programmes, policy instruments and discussion groups. The second model, addressing future soil knowledge needs, summarized the main knowledge requirements for land management and level of demand by stakeholders for financial incentives to change their land management and commodity risk. Further, the results show the contrast between the stakeholder levels: farmer and farm advisors are focussed on tools for improving local knowledge, while multi-stakeholders discuss policies and research solutions. The novelty of this paper is the DEX methodology that permitted the representation of a large qualitative data set in a condensed and comprehensible way.

Discussions and feedback evaluations from workshops demonstrated that stakeholders strongly appreciate (farmer) participatory research as a transparent means to address potential problems and solutions. Stakeholders were involved in face-to-face discussions from the start and accordingly the participatory multi-actor approach taken proved successful in creating a sense of ownership, trust and reciprocity towards the project results. The need for knowledge brokers to tailor and disseminate this knowledge on soil quality and functions is essential. On the other hand, this study confirmed the constraints of participatory research explained by Farrington and Martin (1988) and Bentley (1994), with a high demand of labour and the running costs of workshops, the number of workshops possible within this European Union funding framework was limited. However, this paper emphasizes that the benefits of participatory research significantly outweigh the constraints for understanding the application of science into practice.

4.1 | Future steps

The results of this paper provide important input for the ongoing activities at EU level such as EIP-AGRI. Furthermore, our conclusions can be incorporated into national stakeholder initiatives, such as farmers' discussion groups, training programmes and increasing the presence of soil science in education, as a crosscutting element. The expert knowledge investigated will be integrated into the development of (a) a DST for soil and land management; (b) a soil function monitoring schema; and (c) guidelines for a Functional Land Management policy framework, to optimize the sustainable use of Europe's soil resource.

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