The social side of spatial decision support systems: Investigating knowledge integration and learning

Romina Rodela\textsuperscript{a,b,*}, Arnold K. Bregtb, Arend Ligtenbergb, Marta Pérez-Sobac, Peter Verweijc
\textsuperscript{a} Södertörn University, School of Natural Sciences, Technology and Environmental Studies, Alfred, Nobels allé 7, 141 89 Huddinge, Sweden
\textsuperscript{b} Wageningen University and Research, Laboratory of Geo-information Science and Remote Sensing, Dreeuwenlaan 2, 6708 PB, Wageningen, The Netherlands
\textsuperscript{c} Wageningen University & Research (Alterra), P.O. Box 8130, 6700 EW, Wageningen, the Netherlands

\begin{abstract}
Spatial decision support systems (SDSS) represent a step forward in efforts to account for the spatial dimension in environmental decision-making. The aim of SDSS is to help policymakers and practitioners access, interpret and understand information from data, analyses and models, and guide them in identifying possible actions during a decision-making process. Researchers, however, report difficulties in up-take of SDSS by the intended users. Some suggest that this field would benefit from investigation of the social aspects involved in SDSS design, development, testing and use. Borrowing insights from the literature on science-policy interactions, we explore two key social processes: knowledge integration and learning. Using a sample of 36 scientific papers concerning SDSS in relation to environmental issues, we surveyed whether and how the selected papers reported on knowledge integration and learning. We found that while many of the papers mentioned communication and collaboration with prospective user groups or stakeholders, this was seldom underpinned by a coherent methodology for enabling knowledge integration and learning to surface. This appears to have hindered SDSS development and later adoption by intended users.
\end{abstract}

1. Introduction

Many environmental issues today are pressing and require immediate action. In identifying long-term protection objectives (e.g., halting biodiversity loss by 2020) and selecting measures to achieve them (e.g., designation of NATURA 2000 sites) policy plays a paramount role. Yet, policymakers face a daunting task: they must make forward-looking decisions that are complex, balance different claims and relate to impacts that extend far into the future and are therefore difficult to predict (French and Geldermann, 2005; Pérez-Soba and Maas, 2015). Access to scientific knowledge for environmental decision-making is crucial in such processes.

The literature on interactions between science and policy examines how science is, and should be, contributing to address such issues (Pellizzoni, 2010; Rodela et al., 2015; Simon and Schiemer, 2015). Input is usually involved, in the form of expert advice, assessments, modelling of future scenarios and decision-support systems (Pérez-Soba and Maas, 2015). That last, decision support systems, is of interest here.

Decision support systems are computer-based information systems designed to support policymakers and practitioners in decision-making processes. They help users access, interpret and understand information from data, analyses and models, and help them in identification of possible actions (Arnott and Pervan, 2005; McIntosh et al., 2007; Van Delden et al., 2011; Santoro et al., 2013; Rose et al., 2016). In the years since research into decision support systems emerged it has developed a number of different sub-fields (see Arnott and Pervan, 2005, 2008). One of these is decision support systems that integrate spatial data to support group work and so are referred to as spatial decision support systems (SDSS). SDSS represent a step forward in efforts to account for the spatial dimension in environmental issues. This benefits decision-making processes in several ways (Ramsey, 2009; Sterk et al., 2009). First, it improves the accessibility of outcomes to stakeholders. When stakeholders see data summarised on maps of places they are familiar with, it is easier for them to understand the implications of a given policy across space (from local to supranational) and time (future projections). Numerical and tabular representations, in contrast, may remain more abstract. Note, however, that while SDSS contributes to opening up decision-making processes to different stakeholders, they do not remove the challenge of dealing with conflicting expectations, demands and viewpoints, for example, over land use.

A further aspect of interest is that SDSS allow to bring together scientific knowledge from different disciplines and support the
emergence, and integration of tacit, local and traditional knowledge in decision-making (Mcnerny et al., 2014; Pelzer et al., 2015). This makes SDSS suitable for use at various levels. They can be applied from the local level, where small-scale day-to-day management decisions are made, up to the national and supranational level, where the implications of policy choices span larger territories and longer periods of time (Dick et al., 2017; Dicks et al., 2017; Rodela et al., 2015; Verweij et al., 2016).

Yet, despite their potential, studies have found low adoption of SDSS by user groups, even when SDSS are pilot tested in close collaboration with prospective users (see Poch et al., 2004; McIntosh et al., 2011; Uran and Janssen, 2003; Valls-Donderis et al., 2013). McIntosh et al. (2007: 643) identify one problem in the approach taken to user receptivity, defined as “the ability of an individual, community or organisation to be aware of, to identify and to take effective advantage of a technology”. Van Delden et al. (2011) discuss differences in expectations between developers and users. Users of SDSS need solutions and certainty, while developers and scientists offer probabilities and multiple scenarios. Moreover, while scientists work towards problem-solving, SDSS users would benefit more from problem exploration, reflection and critical exchange (see also McIntosh et al., 2007; Ramsey, 2009).

McIntosh et al. (2007) argue for a shift in focus away from the technical features of SDSS (e.g., system functionalities, coupling opportunities with GIS and integrating models), to the soft contextual aspects of receptivity, design and use. They point to the need to understand what users require, and can utilise, and also how SDSS fit into organisational structures and support users in their tasks, which often involve collaboration with others and integration of the knowledge that others have. This, indeed, shifts the research focus to questions like the following: How and when might prospective users (e.g., policymakers, practitioners and stakeholders) be involved? How might different types of knowledge (e.g., scientific, expert and traditional) be pooled, used and integrated (see Van Delden et al., 2011; McIntosh et al., 2011)?

What learning opportunities might arise from such exchanges? How could these influence understanding of the problem domain and the use of the SDSS?

Inquiries of this type are rare in the SDSS literature. Nonetheless, they form the core of a neighbouring speciality, that of science-policy interactions (see, e.g., Pelzer et al., 2015; Scheer, 2015; Sutherland et al., 2012; Van den Hove, 2007; Van Stigt et al., 2015; Young et al., 2014). That research field offers valuable insights for the current analysis of the social side of SDSS development and use. Specifically, that literature identifies a number of soft and contextual aspects (e.g., communication, participation and motivation) pertaining to the social dimension of technology design and use. The current study uses knowledge integration and learning to conceptualise the social dimension of SDSS development and use. Both are recognised as key social aspects of initiatives to address contemporary environmental challenges (see Mcnerny et al., 2014; Pelzer et al., 2015).

The current study seeks to understand how and to what extent current SDSS research considers and accommodates knowledge integration and learning. To this end, we undertook a configurative review (see Gough et al., 2012) focusing on a sample of selected papers from which information was extracted and compared in search of trends.

2. Science-policy interactions: knowledge integration and learning

2.1. The role of scientific knowledge in science-policy interactions

Scientific knowledge has a central role in most scholarly debates on science-policy interactions and is key to environmental policymaking (Pielke, 2007; Van den Hove, 2007; Sutherland and Burgman, 2015). Yet, the use of scientific knowledge depends on many things, such as the type of policy problem at hand, the phase of the policy cycle and the governance level (e.g., national vs. international) (Engels, 2005). Furthermore, problems differ in complexity, potential to provoke political conflict and solution availability. According to Engels (2005), the greater the complexity of a problem the greater the need is for scientific input, scientific assessment and scientific modelling. Scientific knowledge—often seen as knowledge with “authority”—to many is a robust understanding of phenomena that is produced with rigour, method and is subject to expert scrutiny and validation meant to prevent bias, chance and subjectivity. Yet, when it comes to contemporary environmental challenges, which are characterised by complexity and for which solutions are uncertain, questions emerge as to how, when and to what extent scientific knowledge can best serve society.

Some scholars claim that many pressing questions cannot be answered by scientific knowledge alone, because of incomplete or imprecise data and inconclusive evidence. They point to the pervasiveness of ambiguity and ignorance, as well as to the irreducible plurality of valid standpoints (Van der Sluijs et al., 2008; Sutherland et al., 2014). Accordingly, Van den Hove (2007) advocates acknowledgement of the assumptions, choices, uncertainties and limits of scientific knowledge in science-policy interactions. This position recognises that more scientific knowledge might not be enough to reach a better decision, rather this seems to depend on the match between the information provided and the needs, processing capacity and ways competing interests are dealt with (Scheer, 2015; Van Stigt et al., 2015). It follows that contemporary interactions between science and policy might also benefit from other knowledge systems, as these may help refine understanding of natural processes (see Sutherland et al., 2014).

2.2. Role of local and traditional knowledge in science-policy interactions

Acknowledging the limitations of science opens the door to local and traditional knowledge (LTK), defined by Berkes (1999) as information, understanding and wisdom accumulated by individuals based on experience shared within a group or community. LTK is contextual and derived from observations and lived experience in a natural area. As such, LTK is rooted in a different set of values concerning truth and validity compared to scientific knowledge, which aims to be value free. It is interesting to note, nonetheless, that a growing number of academics now recognise LTK as an important source of information about natural processes (see Berkes, 1999; Fazey et al., 2014; Raymond et al., 2010). For instance, some see in LTK an opportunity to extend our scientific understanding of the spatial and temporal dynamics of biodiversity in domains where scientific research is limited or absent (see Sutherland et al., 2014). Others suggest that LTK could advance the search for solutions to numerous current issues (Armitage et al., 2011) and be used to validate scientific outcomes (Scheer, 2015).

LTK has gained the attention of policymakers as well, and their increased appreciation. Biodiversity governance is one of the areas in which LTK has gained currency (see Díaz et al., 2015). The Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES) exemplifies this process of LTK acceptance (Sutherland et al., 2014; Turnhout et al., 2012). However, when policy opens to different ways of knowing beyond science it soon also confronts the need to communicate and coordinate with very different worldviews. SDSS can incorporate meanings, values and objectives regarding, say, biodiversity governance, to support discussions and exchanges about priorities and policy options.

2.3. Role of knowledge integration and learning in science-policy interactions

Recognising value in knowledge other than that which is scientifically produced brings opportunities for collaboration with practitioners, local inhabitants, community groups and others. A growing body of studies documents the use of LTK, alongside scientific
knowledge, in the search for solutions to contemporary environmental challenges (Díaz et al., 2015; Raymond et al., 2010). Collaborations of this type open up opportunities for knowledge integration, defined as a process of mixing and blending different knowledge to produce an improved understanding of the issue at hand (Klein, 2004, 2008). However, these collaborations also raise questions about how different ontological and epistemological perspectives can come together to produce an improved understanding of a current environmental issue.

Van Daalen et al. (2002: 223) note that SDSS, in linking scientific knowledge to information relevant for policy support, “help policy makers get to grips with the dynamics, uncertainties and judgements involved in the issue at hand”. For this reason, SDSS can serve as a learning device. Similarly, Van Delden et al. (2011: 273) advocate iterative development of processes facilitated by SDSS, underpinned by communication and learning among those who “work together towards shared goals as active co-producers in the social process of knowledge construction”. Illeris (2002: 87) points out that learning involves “an external interaction process between the learner and his or her social, cultural and material environment, and an internal psychological process of acquisition and elaboration”. Learning is therefore a dynamic process and happens in interaction with people, objects and situations or by reflection, all of which represent opportunities for the individual to learn.

There are many approaches and theories to the study of learning, each emphasizing different aspects of interest and formulating assumptions about the expected outcomes of a learning process (Merriam and Caffarella, 1998; Wals and Rodela, 2014). Some theories identify knowledge, skills and enhanced understanding as learning outcomes, while others focus on behavioural change and personal growth.

With regard to SDSS, Squires and Renn (2011) describe an interesting example of learning interactions. They report that stakeholder involvement in validating a bio-economic model became an opportunity for stakeholders to challenge the model’s underlying (scientific) assumptions, resulting in changes to the scientific parameters initially used. This led Squires and Renn (2011) to concur that the SDSS development process should be iterative, allowing all those involved to learn from each other. SDSS would therefore appear valuable not only for helping decision-makers assess complex environmental processes, but also for offering learning opportunities to those involved in decision-making. To serve this purpose, however, SDSS cannot be a “black box”. Rather, they need to be developed in ways that those with limited domain knowledge can also follow and understand. This is acknowledged as a challenge (Castelein et al., 2013; Vonk and Litgenberg, 2010)

### 3. Research method

The current analysis is based on a review of selected literature. We started by preparing and agreeing upon a research protocol and code book (Appendix A in the Supplementary data). We also agreed on inclusion and exclusion criteria for paper selection. Together this defined the breadth and depth of the analysis. Our inclusion criteria were three. Included papers had to (1) be peer-reviewed and published from 2008 to 2013, (2) report on a decision support system that used spatial data and (3) relate to a real-world case. Accordingly, we excluded (1) papers that had a theoretical focus only, were reviews of literature or were opinions or editorials and (2) papers not focusing on a real-world environmental issue. For instance during the bibliographic search an hit was retrieved and from its title and abstract we understood that

Though this is a well-published field many contributions are in other applicable areas than those of our interest. For instance by focusing on real-world environmental issues, papers about SDSS usage in medicine, transport, logistics, management and other domains than environmental protection were excluded (e.g. a paper reporting on a SDSS for land consolidation by Uyan et al. (2013) was retrieved, but excluded). Also, papers reporting about technical aspects only, or descriptive papers without a real-world empirical application were excluded.

Note also that our combination of inclusion and exclusion criteria left the selection process open to different SDSS development phases, from design to implementation and pilot testing. Our aim was to select not only papers discussing technical aspects, but also those illuminating SDSS use in relation to actual environmental challenges.

After agreeing on the research protocol and selection criteria, we did a bibliographic search of the Web of Science and Scopus. First, we tested the search strings to determine how to handle compound words (Table 1, Appendix B in the Supplementary data). We then continued with the actual search applying filters based on our selection criteria. The hits retrieved were screened by reading titles and abstracts. This resulted in a list of potential papers, which were read and selected by the first author. Fig. 1 presents the process, with the numbers of included and excluded publications.

Decision support systems took their “participatory turn” only in the late 2000s (see Valls-Donderis et al., 2013). We therefore chose not to look too far back in time. The period selected, 2008–2013, appeared suitable, as these years exhibited growth in the literature on the science-policy interface and knowledge integration (e.g., Turnhout et al., 2012; special issue Environmental Governance and Policy).

It bears mentioning that the present research did not evaluate technical characteristics or tool performance, nor did it aim to assess the quality of the outcomes produced by an SDSS. The aim, rather, was to map whether, and if so how, researchers approached and reported on the social aspects of interest here: knowledge integration and learning. The code book served to identify and extract information relevant to these. Item identification was informed by previous research on learning, knowledge integration and SDSS conducted by our team (e.g., Rodela, 2013, 2014; Rodela et al., 2012). Appendix A in the Supplementary data presents the study code book.

Last but not the least we like to comment on the generalisability of our results. The sample we have analysed was retrieved with the application of a rigorous process of paper selection during which we applied a set of inclusion and exclusion criteria. We are aware that the broader SDSS speciality is much larger than our sample, but on the basis of the criteria applied we assume it is representative of research on SDSS in the environmental context.

### 4. Results and discussion

#### 4.1. General description of the selected publications

A total of 36 unique, peer-reviewed journal articles were left for analysis after screening (Fig. 1, full sample listed in Appendix C). The selected papers reported on activities or research in which a spatial decision support tool had been developed or used in relation to environmental issues. Specifically, 10 studies pertained to water management, 11 to land use planning, 4 to forestry, 6 to biodiversity, 3 to marine resources and 2 to climate and adaptation. Furthermore, 11
studies reported on activities meant to test or pilot a decision support tool and so can be seen as science-driven enquiry. Twenty-five studies reported on efforts to find solutions to current issues or to respond to stakeholder needs (Fig. 2). This distinction between science-driven and issue-driven research, however, was not clear cut for several of the papers, which reported on activities somewhat between the two.

The empirical cases reported on in the selected papers were located in Europe (n = 13), North America (n = 10), Africa (n = 1), Asia (n = 4) and Oceania (n = 4). Regarding funding sources, 12 of the papers reported on research funded by national bodies, 5 on research funded by EU programmes, 6 on research supported by cash contributions and service contracts and 6 by multiple sources. The remaining 7 made no mention of funding.

Because we were interested in the social aspects of SDSS, we analysed whether and how the selected papers reported on interactions with prospective users. About half of the papers mentioned the researchers establishing contact, communicating or collaborating with decision-makers, stakeholders and local inhabitants. Some of these stakeholders were identified as prospective users (Table 1). Most papers included very little, or no, detail about the methodology underpinning the collaborative and participatory activities. A few of the papers in our sample did not mention whether any type of contact had been established, focusing instead on the technical aspects involved. Omission and under-reporting make it difficult to determine how researchers dealt...
with aspects commonly encountered in collaborative interactions, such as prioritisation of the objectives to be achieved, conflicting priorities and values, power issues and expectations.

The selected papers were found in a variety of journal types. Some of these journals were profiled as disciplinary and technical, while others could be described more as interdisciplinary in scope. Papers published in the latter category paid more attention to social interaction, and provided more descriptive information than those in the more disciplinary-oriented journals.

4.2. User and stakeholder involvement and social aspects of SDSS development and use

We sought to establish whether users and stakeholders had been involved in SDSS development, as well as whether the systems had been applied in real-world policymaking processes. Traditionally, papers reporting on SDSS do not provide details on the needs, concerns and involvement of potential users and relevant stakeholders (McIntosh et al., 2007). In recent years, however, this omission has been contested. For instance, Sojda et al. (2012) question the extent that SDSS can offer support in real decision-making processes if stakeholders and prospective users are absent or poorly involved. These authors make a strong case for stakeholder involvement.

It is interesting to note that a number of papers in our sample did offer information about stakeholder involvement, though in varied levels of detail. For instance, Kalabokidis et al. (2012) briefly reports on how components were added to an SDSS after the user requested them (e.g. resource management and communication). Ferretti et al. (2011) mention having organised a focus group of experts to discuss standardisation and weighting procedures. However, these authors provide no further detail on what this entailed. Other papers provide more exhaustive descriptions. For instance, Santoro et al. (2013) centres on end-user involvement, reporting on a survey administered to potential users to obtain information about their needs and concerns and SDSS functionalities of interest. The data collected was then used to develop DESYCO — the Decision Support System for Coastal Climate Change Impact Assessment. Morehouse et al. (2010) report at length on how they went about collecting information on values and risk perceptions within a given group, and then integrated this into an SDSS.

Others chose to report on the lessons learned from interactions. For instance, Fürst et al. (2010) describe an iterative process led by researchers that resulted in the “Pimp Your Landscape” tool. Serrat-Capdevila et al. (2009) describe a collaborative process involving interviews with different stakeholders to underpin development of an SDSS in the San Pedro Basin. Merrifield et al. (2013) provide information about the collaborative activities involved in their research. They offer a thick description of the process involved in upgrading an internet mapping service, named “Doris”, relying on GIS. Though this tool had originally been poorly used by stakeholders, the improved version, “MarineMap”, was said to have been very well received.

Anderson et al. (2009: 2087) clarify up-front that “[a] participatory methodology and the development and delivery of a participatory decision-support tool were not among our original objectives”. These researchers’ main focus was the SDSS and the need to make it simple and user-friendly. Yet, the final result was not as effective as expected. At the end of the process it turned out that the prospective user lacked the needed GIS expertise and resources to utilise the SDSS. Anderson et al. (2009) reflect on the implications of the lack of stakeholder involvement in their case. In doing so they raise a number of interesting, often overlooked and under-reported issues.

The studies mentioned above are interesting in another aspect as well. They indicate, albeit in different ways, the importance of the context in which users are embedded. Useful descriptions are provided of the many and different ways that context influences SDSS development and later use. Merrifield et al. (2013) report on collaborative activities that were set up in response to formal requirements arising from the law, but which nevertheless created the institutional circumstances that, in conjunction with other factors, led to positive outcomes. In contrast, lack of collaboration, and resources, appears to have influenced the case described by Anderson et al. (2009).

These papers corroborate the proposition advanced by Uran and Janssen (2003) and by McIntosh et al. (2007) suggesting that challenges in SDSS up-take often lie on the “social side” of SDSS development and use. Communication, mismatches with user demands, institutional constraints, late involvement and poor commitment are some of the hurdles mentioned.

In addition to stakeholder and user involvement, we were interested in the use of SDSS in real-world policymaking. Our sample offered no cases where an SDSS had been used directly to inform policy at the national or supranational level (e.g., to set biodiversity targets or, say, EU agricultural policy). Eleven of the selected papers touched indirectly on international or national environmental policy. These, however,
considered the broader policy context in relation to a topic being addressed at a lower level of decision-making. For instance, Bottero et al. (2013) discuss an SDSS for biodiversity conservation assessment in the Varese Province of Italy, establishing links with requirements arising from European directives on nature protection. Holzkämper et al. (2012) link the development of their prototype SDSS for water management to the European Water Framework Directive.

Thus, within this sample, attention was cast mainly on practice: the role of SDSS in helping those in the field select among management options or cope with current issues. Sojda et al. (2012), in their own review of the literature on SDSS, reach a similar conclusion. They find the literature on SDSS dominated by cases concerning management issues at lower spatial scales. While this may promote tailor-made solutions in a given locality, there are questions about how boundaries can be meaningfully accounted for. Natural processes and most environmental issues, such as for instance, loss of biodiversity and maintenance of ecosystem services, do not stop at administrative or state borders. They cross territories and span multiple administrative divisions. This suggests collaborative efforts need to overcome political, administrative and linguistic barriers, in addition to disciplinary boundaries.

As noted, the papers in our sample differed in focus. Most were published in disciplinary journals, the exception being papers in the journal *Environmental Modelling and Software* (n = 2) with its emphasis on modelling and those in the *Journal of Environmental Management* (n = 5) with its emphasis on management; these cut across disciplinary lines. Examples of the disciplinary journals in which selected papers appeared are *Ocean & Coastal Management* (n = 2), *Applied Geography* (n = 1) (Appendix C).

This distribution of papers by journal type could explain some observations from our sample. For instance, while several of the selected papers provide information about the environmental issue at stake, and its context, we could identify no particular trend in methodologies for including social aspects pertaining to SDSS development and use (e.g., user involvement). Most papers provided minimal information on this, stating only the format of interaction (e.g., a workshop, interview or survey) and its logistics. A few papers, however, did provide more information (e.g., Merrifield et al., 2013).

Across our sample of selected papers there is information about non-technical aspects in SDSS design, development and use which points to awareness, and in selected cases also interest toward collaborative and communicative aspect. However, these references were formulated in such a way as to suggest a hesitance among researchers to blend questions and analytical methods on social and technical aspects within one publication. A reason for this can be linked to disciplinary traditions in how authors report on research.

### 4.3. Exchange, integration and co-construction of knowledge

One of our aims was to look closer at studies that recognise the value of non-scientific knowledge and take note of the steps researchers take to identify and collect such knowledge and how it was used. In our sample, 16 papers report using scientific knowledge only. Five reported using expert knowledge in addition to scientific knowledge. One reported using local knowledge, and 12 reported using a combination of these. Identification, elicitation and selection of the needed non-scientific knowledge requires an amount of effort and careful design. Papers in our sample reported using interviews and questionnaires with prospective users/stakeholders to gather information needed by the SDSS development team (i.e., Liu et al., 2011; Oliver et al., 2012; Santoro et al., 2013), as well as focus groups, workshops and expert advisory boards or panels (i.e., Ferretti and Pomarico, 2013; Greene et al., 2010; Holzkämper et al., 2012; Oliver et al., 2012).

However, the passage from collecting useful “information” to blending LTK with scientific knowledge remained unclear in most of the selected papers. For instance, questions appearing in the surveys administered by Oliver et al. (2012) and Santoro et al. (2013) asked for information on habits, behaviours and opinions of the respondents. These were then used by the researchers to approximate system conditions, which the tool was designed to capture. This information, however, is not LTK, but rather represents personal views and perceptions of individuals about the subject matter.

We defined LTK following Berkes (1999), as information, understanding and wisdom that individuals accumulate based on experience shared within a group or a community. Thus, to be considered LTK information would need to extend beyond personal opinions and views. Clearly using a survey questionnaire to elicit LTK presents multiple challenges. Only Oliver et al. (2012) acknowledge this openly. They note that other methods, such as map-based processes, might be used to stimulate farmers to talk about land management approaches and their implications for a given location and context.

Our interest in knowledge integration led us to search within the selected papers for information on how different knowledge was retrieved and subsequently used. In our sample, researchers tended to turn to stakeholders, experts and locals for information, expertise and input not with the intent of integration, but most often with the aim of transferring information and knowledge from prospective users and stakeholders to system developers. The study that most closely approximates a process of knowledge integration to be that by Holzkämper et al. (2012), which reports on the involvement of domain experts based at an environmental agency with academics to develop a model for decision support in integrated catchment management.

Therefore, from the information found within the selected papers it would seem that opening up to LTK is done for instrumental reasons at given steps. It typically stems from specific needs emerging during, for example, tool calibration and validation. Interest and willingness to reflect on how the encounter of different epistemological perspectives influences the way teams discuss, define, prioritise and come to tackle a problem situation, and the type of implications this has for SDSS development, evaluation and use, did not attract much interest in our sample. Nevertheless, this is a relevant topic for discussion. Researchers are increasingly defending, and providing evidence for, the need to organise more participatory and transparent user involvement. Future research would benefit from reflections on this. Future research would also benefit from exploration of the challenges and opportunities that arise from the encounter of different epistemical positions during SDSS design and development.

### 4.4. Learning and the outcomes of learning processes

In line with our expectations, none of the selected studies investigated learning in relation to SDSS in any rigorous or systematic way. Nor were there attempts to establish empirical or theoretical links with the academic literature on learning. However, 16 of the papers mentioned, or commented on, learning processes and outcomes in relation to SDSS development and use. This was done in a non-systematic way and at various levels of detail. In most of the 16 papers, authors reported on personal observations or provided anecdotes of their own, or others’, experiences and assumptions. The fact that this field has traditionally focused on technical aspects makes descriptions about learning all the more interesting. We observed a trend across these descriptions in relation to who is exposed to learning, how and what is to be learned and clustered papers in two groups. Thus, (1) studies commenting on learning (i.e. about the issue) as a process experienced by user groups and stakeholders when these are involved in SDSS design, development and testing (2) studies reporting on the work done and then providing the researchers’ own view of the “lessons learned” about how to go about SDSS design, development and testing.

The first group of papers, for instance, Arciniegas et al. (2011); Bohnet et al. (2011); Chang et al. (2008), comments on the learning by users and participants that occurs during interaction with other people, as by sharing information, knowledge and viewpoints participants...
acquire a better understanding of the problem at hand. Greene et al. (2010); Holzkämper et al. (2012) and Kalabokidis et al. (2012) emphasise the learning that emerges from using the tool and engaging with the resulting outcomes (e.g., comparing alternative scenarios or charting impacts on maps). This, they suggest, allows decision-makers to test hypothetic management alternatives, and in so doing better understand the processes the model is meant to simulate. These studies seem to propose that group discussion underpinned by an SDSS tool benefits individual participants in ways already discussed in the social learning literature, with emphasis on acquired knowledge and shared understanding of the problem domain (i.e., the cognitive and relational dimensions). However, taken together these papers offer little empirical evidence of how SDSS promote learning processes. This, we assume, is mostly because the papers focus on other aspects. Yet, looking at science-policy interface research and considering that prior knowledge influences the way decision-makers access and use models and other scientific inputs, further research may be worthwhile on how such tools enable or constrain users in acquiring knowledge and understanding the issue at stake.

The second group of papers summarises impressions and observations by the development/research team in relation to what has been learned by the team in relation to the SDSS design, development or testing process. The authors in this group of papers chose the more “neutral” role of observers reflecting on their own experience. For instance, Anderson et al. (2009) look in retrospect for reasons to explain the lack of up-take, finally attributing it to weak interest, leading to irregular input by the intended user – the Nova Forest Alliance (i.e., a partnership of individuals, organisations and industry) – which in fact had initiated and funded the project.

5. Conclusion

In result to the critique, which contends that concern with technical issues has overshadowed other important aspect of SDSS, there has been a slow turn in the recognition of the social dimensions involved in SDSS. We conceptualised the social dimension in terms of learning and knowledge integration. Analysing research papers published between 2008 and 2013 reporting on SDSS related to real-word environmental issues, we sought to identify whether and to what extent learning and knowledge integration were reported on. A number of the selected papers reported on matters not strictly technical, such as the interaction between SDSS developers and prospective users and stakeholders. Furthermore, a number of studies acknowledged the importance of user involvement. However, there seems to be no agreement on what social aspects are the most relevant for advancement of SDSS, either to further academic research or for the production of usable knowledge and outputs for the policy community. Also, there seems to be no consensus on how to investigate and subsequently report on the social aspects.

Across our sample, the knowledge used for building SDSS was mainly scientific. When this scientific knowledge was integrated with other knowledge types, this was done mainly at the “level” of SDSS development, rather than as a process component in the decision-making support underpinning the SDSS. Regarding learning, our analysis of the 36 selected papers indicates that researchers’ interest has largely been limited to communication of the scientific knowledge and the learning of the scientists who developed the SDSS. Specifically, the way the papers in our sample reported on learning suggests several underlying assumptions about who is expected to be the learner (users/stakeholders vs. developers/researchers), about how learning processes take place in these types of interactions (generative vs. additive processes) and what the resulting outcomes will be. However, given the dynamic and complex nature of the issues to which SDSS are asked to contribute to, making space for meaningful learning by all of the different groups involved may prove advantageous since helps them to use what is learned during problem-solving.

This analysis also revealed an absence across this sample of methodological approaches to support collaboration and communication between the different stakeholders involved (i.e. users, developers, researchers) that could guide day-to-day decision-making and account for the social dimension. The studies in our sample did not use an explicit and replicable (participatory) methodology that would allow a solid and reliable inquiry into social processes in SDSS design, development and use. Or, at least, no such methodologies were reported in the papers selected. An important consequence of this is a difficulty in identifying, retrieving and comparing relevant information about successes and failures. On the basis of this a suggestion here is to explore further the potential participatory methodologies could offer to this speciality and report on these with a good level of detail which would allow for future comparative and knowledge synthesis exercises to deconstruct further (social and communicative) aspects of interest.

Acknowledgment

This study was prepared as part of Work Package 3 (WP3) of the INVALUABLE research consortium (more info: www.invaluable.fr). The INVALUABLE research consortium is funded under the FP7 ERA-NET scheme, via BiodivERsA, a network of national funding organisations promoting pan-European research that offers innovative opportunities for the conservation and sustainable management of biodiversity (http://www.biodiversa.org).

Appendix A. Supplementary data

Supplementary data associated with this article can be found in the online version, at http://dx.doi.org/10.1016/j.envsci.2017.06.015.

References


