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Making differences legible: incommensurability as a vehicle for sustainable landscape management

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Abstract:

Landscape management involves tackling both systemic and social complexity: the former due to multiple interacting entities, the latter due to incommensurable knowledge and value systems of stakeholders. Current practice in landscape management makes wide use of participatory methods, which helps increase the breadth of our understanding of sustainability problems, e.g. biodiversity loss, agricultural pest damages or water penury. However, this practice also often offers a flat, harmonized picture of the landscape, which precludes observing ambiguities and out-of-the-box arguments and ideas for overcoming problems. In this article, we analyzed two research settings that tended to surface and formalize incommensurability between stakeholders regarding the sustainable management of landscapes – one focused on quantitative water management, the other on agroecological pest control. The objective was to investigate if and to which extent these 'opening-up' exercises, based on a deliberative rationale, were beneficial to landscape sustainability. The results indicated that in both cases, participants strove to position their knowledge and values relative to others: this way, they delineated a negotiation and learning space to invest in, and enhanced the quality of their arguments, allowing new insights on the focus issues. These findings offer an operational counterpoint to the prevalence of 'closing-down' approaches in landscape approaches. In the general context of ecological crisis, these examples promote methodological options that offer space to disruptive narratives, as well as tools that allow a reflexive use of the scientific knowledge, models and indicators traditionally used in sustainability appraisals, without discarding them.

Keywords: agroecological pest management, quantitative water management, social and technical incommensurability, participatory modeling and simulation, collective deliberation

1. Introduction

In sustainable development, solutions at the landscape scale (e.g. a watershed, community or agricultural production area) have been promoted for three decades already. While the UN's non-binding action plan Agenda 21 represented a switch from the global to the community scale to reach sustainable development goals, the focal scale for the agroecological transition has moved in the other direction: from a single farm to the landscape. Although these two examples reveal contrasting processes (downscaling for Agenda 21; upscaling for the agroecological transition), both illustrate the centrality acquired by the landscape in environmental policy and research. Concepts are nonetheless moving and the term 'landscape' is absent from the UN 2030 Agenda that sets 17 sustainable development goals. Despite the sectoral approach of this new agenda, the FAO and UNEP advocate for achieving sustainable development goals through 'integrated landscape management' (e.g. FAO report "Landscape for Life", in 2018; publications of the Landscapes for People, Food and Nature initiative).

The approach of "integrated landscape management" is expected to support progress towards sustainability in a systemic way: "It is at the level of landscapes where farmers, foresters, agencies, non-governmental organizations, businesses and civil society encounter concrete development demands, and where land management systems have to balance the trade-offs between them" (Mann et al., 2018). This approach entails the engagement and collaboration of stakeholders, hence the use of participatory methods, with the objective to bridge different forms of knowledge, reconcile conflicting interests or provide a holistic picture of the system under scrutiny (Mann et al., 2018; McGonigle et al., 2020; Reed et al., 2016). The same logic shapes other institutional frameworks, such as the Water Framework Directive (2000), promoting the integrated management of all water bodies at the watershed scale, or the European Landscape Convention (2000), which encourages public participation and policy integration for the protection of landscapes. Overall, the current consensus is that to be effective, landscape management should be adaptive, supported by shared values and knowledge, involving multiple stakeholders at multiple scales, should be multifunctional, transparent and fair, should enlist social learning, and be oriented towards developing socio-ecological resilience (Sayer et al., 2013).

The development of landscape approaches helped introduce a (still timid) shift of the gaze on sustainability problems, previously observed through reductionist lenses. For instance, when we regard pesticide use as a landscape-scale issue, we go beyond viewing it as a merely technical question of using the right product in the right quantity at the right time, to consider the broader question of the 'why' behind pesticide use (Hendrichs et al., 2007; Schellhorn et al., 2015). The same is the case for water quantity issues: if considered at the landscape scale, the solutions demand land-use changes, different agricultural models, regulation of water use in time and in space, and involve – at a minimum – the diverse range of water users, inhabitants and public authorities. Dimensioning reservoirs has stopped being the sole conceivable solution (Gleick, 2000), and water issues are now even starting to be considered within a broader set of interactions (e.g. nexus approaches, Biggs et al. 2015; Urbinatti et al. 2020)

A key utility of the landscape scale is that it reveals, in practice, the *systemic* and *social* complexity of many sustainability issues (Allain, Plumecocq, and Leenhardt 2020). Systemic complexity

refers to the theory of complex systems (Holland, 1992), here applied to landscapes (Chopin et al., 2014; Cumming et al., 2012; de Groot et al., 2010): many different entities and processes interact across time and space, leading to emerging functions that fulfill services to humans. In turn, social complexity refers to the plurality of stakeholders that are involved in or are affected by landscape changes, with potentially conflicting and irreconcilable views of which problems are faced, what should be sustained and how (Gómez-Sal et al., 2003; Hunziker et al., 2008; Velicu and Kaika, 2017) .

Systemic and social complexity do not raise the same challenges for sustainability. In a systemic complexity perspective, managing landscape changes in a sustainable way requires understanding diverse socio-ecological processes and interactions, and envisioning retroactions and cascading effects. From a social complexity perspective, the challenge is to construct a sustainable collective choice in the face of conflicting views, concurrent knowledge systems, power asymmetries, and different 'languages of valuation' (Martinez-Alier, 2009; O'Neill, 2001).

In this article, we sum up the question of social complexity under the term 'incommensurability', because it resonates with ecological economics frameworks. Incommensurability reflects the absence of a common standard to compare different options and preferences (Martinez-Alier, Munda, and O'Neill 1998). Incommensurability differs from other methodological problems: measurability (having a scale to measure something), or comparability (being able to compare two options, which is, under specific assumptions and algorithms, still possible when these options are described with a list of criteria scores, incommensurable to each other) (Martinez-Alier et al., 1998). According to Munda (2004), incommensurability takes different forms. Technical incommensurability is the coexistence of multiple descriptions of the same problem (depending, for instance, on dimensions or scales), while social incommensurability describes the multiple legitimate values that coexist in a society about a given problem.

In the recent years, the incommensurability question and terminology have gained new insights coming from the study of political crises and conflicts, in which the identities of the protagonists become transformed (e.g. Velicu et Kaika 2017; Varvarousis et Kallis 2017). They show how the expression of incommensurability develops, confronts traditional institutions and shapes new political arenas. We will remain here to the more classical methodological aspects, i.e. how to tackle incommensurability in sustainability appraisals. This question has triggered a large wave of research on multicriteria evaluation methods and applications by ecological economists (De Marchi et al., 2000; Douguet et al., 2010; Garmendia and Gamboa, 2012; Giampietro et al., 2009; Munda, 2004; Rauschmayer and Wittmer, 2006). Recent developments in the matter deal with the meaning and use of indicators (Allain et al., 2018b; Rafols and Stirling, 2021), the role of narratives to unfold and communicate incommensurable views (Lejano et al., 2019; Saltelli and Giampietro, 2017), or the design of models fit to surface hidden trade-offs between incommensurable values (Daw et al., 2015).

The incommensurability question, however, holds a marginal place in integrated landscape management science and practices. Indeed, having a common picture is considered necessary to achieve sustainable landscape management, justifying the prevalence of integrative approaches rather than dialogical ones. The integrative logic gave birth to different cooperative and collaborative modes of interactions with stakeholders. Territorial engineering (Piveteau, 2011) and bridging organizations (e.g. the water councils created in Denmark in 2014, Graversgaard et

al. 2017 ; the deer management groups in Scotland for 30 years, Davies and White 2012) exemplify the expectation that stakeholder engagement will produce 'better outcomes', e.g. more consensual and more effective. Scientists researching landscape management issues have also offered a range of methods to facilitate the integration of various perspectives and goals: integrated assessments (e.g. van Asselt and Rijkens-Klomp 2002) and modeling of socio-ecological systems (e.g. Bousquet et al. 2005; Voinov et al. 2016) among others.

The methods, settings and skills developed in integrated landscape management tackle with success the incompleteness and fragmentation of knowledge and the multiplicity of expectations from stakeholders. Facilitators (i.e. all individuals whose action is to ease landscape management, like researchers, decision makers, resource users or territorial engineers) have developed and tested techniques to gather and put together the different pieces of the 'landscape management puzzle'. Discourses that do not fit are, in many of these processes, reshaped through mediation (ranging from discussions to role-playing games), whose aim is often to create compatible views and avoid the expression of 'defensive routines' (Joldersma, 1997). Important ingredients to achieve this harmonization are (1) the extension of the perimeter of the landscape system under scrutiny, with for instance a better incorporation of cross-scale and nexus interactions (Biggs et al., 2015; Chopin et al., 2014; Reed et al., 2016), and (2) the inclusion of extended sets of criteria and indicators to assess changes, for instance accounting more and more for the aesthetic values of the landscape (Gómez-Sal et al., 2003; Howley, 2011). Using Stirling (2008) 's words, landscape understanding is gaining *breadth* (it is more holistic), but as a counterpart, it loses *thickness* (perspectives become unified under a global picture).

Stirling (2008) labels 'closing-down' the propensity to reduce, through participation or analysis, the range of outputs that flow from society to decision-making. 'Closing down' processes are not able to reproduce the diversity of narratives and representations present in society (i.e. incommensurability). The point raised by many authors is not the superiority of opening-up over closing-down processes (actually they are complementary, e.g. Garmendia and Stagl, 2010), but their low use. "We also need to make space for ambiguity and difference" (Velicu and Kaika, 2017); "there is as much a need for dissensus conferences as consensus conferences" (O'Neill, 2001).

In science-policy interface research, 'closing down' frameworks and methods (when used solely) are even judged problematic to the democratic ideal. Do they enrich or impoverish the debate (Frame and O'Connor, 2011; Stirling, 2008)? Do they provide capacity to say and be heard to the most marginalized (O'Neill, 2001)? Could they turn into instruments of oppression (Velicu and Kaika, 2017)? The framing biases introduced by "closing-down" exercises are especially targeted: when the indicators, models, or participatory settings offered as being "objective" or "inclusive" do actually contain a reduced range of solutions and dismiss out-of-the-box ideas (Elgert, 2013; Turnhout et al., 2014; Velicu and Kaika, 2017). In the case of sustainability assessments for instance, problem 'compressions' constitute necessary steps, but are highly controversial due to the often hidden assumptions of commensuration (Allain et al., 2018b; Frame and O'Connor, 2011; Garmendia and Gamboa, 2012; O'Neill, 2001; Vatn, 2009).

In this article, we therefore want to question the closing-down logic of participatory processes used in landscape management research and explore the potential of alternative 'opening up' practices. The opening-up practice we will focus on will be the surfacing and formalization of

incommensurability with specific artifacts (deliberation matrixes and Bayesian belief networks), used as intermediate tools to engage collective deliberation. We will here refer to collective deliberation as a specific value-articulating institution (Vatn, 2009), which recognizes the legitimacy of different problem framings, in terms of both facts and values (Funtowicz and Ravetz, 1993), and seeks to organize a quality debate among plural participants holding different views and languages of valuation (Martinez-Alier, 2009). Collective deliberation is often assumed as a vehicle for sustainability (Funtowicz and Ravetz, 1994; Garmendia and Stagl, 2010; Vatn, 2020; Zografos, 2015). The objective of the paper is then to examine, based on empirical case studies, how and to what extent the formalization of incommensurability created the conditions for sustainable landscape management.

Our analysis draws on two research projects in which we were individually involved: one regarding agroecological pest management in orchards (N. Salliou), the other regarding quantitative water management in a watershed experiencing recurring crises (S. Allain). Both case studies considered the landscape as the reference scale for tackling the issue, used modeling and simulation, involved the construction and assessment of different scenarios of change, and were based on multiple interactions with stakeholders. In particular, both sought to elicit and formalize incommensurability between stakeholders, using a mix of quantitative and qualitative methods and visualization tools. These reflections may add to the discussion around conceptual criticisms of the use of 'closing-down' methods and open up new avenues for designing and organizing participatory approaches in landscape-scale issues.

2. Presentation of case studies

2.1 Case study 1: agroecological pest management

Pest damages to agriculture have dramatic economic impacts as they account for at least one fourth of crop losses worldwide (Oerke, 2006). In France, whether certified organic or not, farmers rely on pesticides to control pests and limit such negative impacts (Guichard et al., 2017). However, pesticide-spraying leads to a range of unwanted externalities, and many public programs attempt to reduce their use (Potier 2014; Lefebvre, Langrell, & Gomez-y-Paloma 2015). One potential solution is to use biological pest control, where it is biological entities rather than chemical compounds that control pests. Farmers usually consider pesticide use at a field-by-field basis and very rarely do so at landscape scale (Ayer, 1997; Hendrichs et al., 2007). In contrast, landscape ecology scientists see the potential of biological pest control at a landscape scale (Thies and Tscharntke 1999; Bianchi, Booij, and Tscharntke 2006; Veres et al. 2013). For these scientists, one of the main problems lies in operationalizing this solution on farms within a landscape (Thies and Tscharntke 1999; Landis, Wratten, and Gurr 2000; Tscharntke et al. 2005). Indeed, as biological organisms' lifecycles are not restricted to a single field, using this solution at a landscape scale requires collective action between farmers. For example, female hoverflies can overwinter in hedgerows and then lay their eggs in fields of crops, where the larvae prey on aphids (Vialatte et al., 2007). In short, biological pest control agents do not respect farm boundaries. Therefore, neighboring farmers may have to coordinate their actions if they want to take advantage of such a pest control solution (Salliou, Muradian, and Barnaud 2019).

As a result, landscape ecology scientists are keen to engage with farmers to implement the results of their scientific findings. In particular, they are curious about hindrances that explain why farmers do not take advantage of innovations. In this context, our case study sought to better understand the absence of a landscape perspective for managing pests, by exploring how different stakeholders see the links between the landscape and damage due to pests. The study was conducted in an agricultural region specializing in fruit production in southwest France. Cultivating fruit trees is often pesticide intensive due to high pest pressure and the importance of the visual aspect of the fruit. To examine how local fruit farmers envisaged the use of biological pest control, we used a Bayesian model constructed with local stakeholders (Düspohl et al. 2012, Salliou et al. 2017). In a first step, five different stakeholders (an organic farmer, a conventional farmer, an agricultural technician , a landscape ecology scientist and a director of an agricultural school farm) built a shared conceptual model with the ARDI method (Etienne, Du Toit, and Pollard 2011). This conceptual model represented an agreed structural understanding of the system in question. This conceptual structure was then translated into a hierarchical Bayesian network with the agreement of the stakeholders. Finally, the perspective of each stakeholder was captured with an individual Bayesian belief network (BBN), in which they could parametrize the hundreds of probabilities connecting key concepts of the model according to their personal viewpoint. In other words, participants had their own BBN of the issue. In the analysis, each individual BBN was simulated with similar scenarios about biological pest control and compared (Salliou et al., 2019b).

2.2 Case study 2: quantitative water management

Many watersheds in France, especially in the southwest, have in recent years experienced repeated crises – when the river flows fall below environmental norms (i.e. the minimum requirement flow, Fernandez 2014). These crises have an ecological impact – which is more acute on the smallest rivers as these are subject to flow interruptions – as well as an economic impact, as the water restrictions that follow such crises disturb water-dependent activities. In the downstream Aveyron watershed – where this case study is located – these economic activities are for the most part linked to irrigated agricultural production (e.g. maize, fruit, maize seeds).

Water crises are also a moment when criticism of maize-cropping activities can crystallize: because it is water intensive, aimed at global markets, and often based on monocrops. Social tensions about water-use distribution (for agriculture, domestic use, recreational activities, and the environment) and controversies about agricultural models are exacerbated. These crises also reveal that the coordination mechanisms for water use (mostly achieved through monitoring river flow, setting restrictions and releasing water from dams) are unsatisfactory for stakeholders seeking a long-term, landscape-wide perspective, e.g. fishing organizations, water resource and water environment managers, local territorial development organizations and environmentalists. In such a context, the first challenge is to set the conditions for a dialogue that highlights social dilemmas.

To explore this in the Aveyron watershed, we designed a study that aimed at evaluating contrasting scenarios to make quantitative water management more sustainable. The approach was 'bottom-up' (based on the discourse of local people rather than on overarching frameworks for sustainability assessment), multi-criteria (to consider the diversity of issues linked to water resources) and multi-actor (to consider the diversity of people involved or affected).

In a first step, working with local stakeholders, we created a multi-criteria evaluation grid (featuring criteria such as adaptation to change, biodiversity conservation, employment and local development, legibility of public action) and four scenarios that offer alternatives to the current water and agricultural system. The four scenarios were: (1) implementing crop rotation instead of maize monocrops, (2) reducing the irrigated area and restoring grasslands in upstream areas, (3) mutualizing the water storage infrastructure, and (4) using decision-support tools to optimize irrigation of field crops. We then simulated and assessed the scenarios with a multi-agent computer model (MAELIA, Gaudou et al. 2013). This integrated assessment and modeling stage helped to understand the effects of each scenario on water flow, water storage, water returns to the environment, crop yields and production (Allain et al., 2018a).

Seven workshops (corresponding to seven groups of people belonging to the same or related institutions) were then organized to evaluate the scenarios. The group had to choose the indicators they judged most relevant to address each criterion in the multi-criteria grid. These indicators could come from computer simulations (see tab. 1 in (Allain et al., 2018a) for a sample) or be added on the spot. Indicators added by participants (and out of the model's scope) listed: livestock production, sanitary and technological quality of products, employment, revenues of farms, number of farms, number of agricultural workers, equity between water uses, impacts on winter low flows, pollution from plant protection chemicals, surface of soil covered with vegetation, water quality, life-supporting soils. After the group built its indicator set, it had to associate a qualitative judgment (compared to the current situation, the new scenario improves/degrades/doesn't change the situation; brings uncertain changes; cannot be assessed) for each combination (scenario x indicator), and then give a weight to the indicator. A more detailed description of the method can be found in Allain, Plumecocq, and Leenhardt (2020).

The different judgments were aggregated using the online Kerbabel Deliberation Support Tool (Chamaret, O'Connor, and Douguet 2009). We ended up with a multi-actor, multi-criteria matrix featuring three axes (stakeholder groups, scenarios, criteria) with value judgments in each cell. We then analyzed the matrix and highlighted the weaknesses, strengths and controversies raised by each scenario. Finally, we presented the results to the stakeholders, focusing on the most salient divergences between groups. We organized a discussion, asking participants to make proposals (new scenarios) to overcome these divergences. The new scenarios suggested included implementing innovative crop rotations instead of maize monocrops, avoiding the restoration of permanent grasslands and favoring instead alfalfa fields, and creating contractual requirements concerning agricultural practices for farmers using collective reservoirs.

3. Formalizing incommensurability: how and to what end?

3.1 Case study 1: agroecological pest management

The case study on agroecological pest management addressed a problem – high pesticide use – that has no formalized demand for action other than general national objectives (i.e. the French 'EcoPhyto' action plan, aiming at reducing farmers' pesticide use 50% by 2025). One potential solution comes from landscape ecology: it suggests that enhancing the complexity of the landscape mosaic by increasing semi-natural habitats can favor natural enemies of pests and reduce pest-induced crop damage. However, currently this proposed solution has found no echo in the practices or representations of local fruit growers (Salliou et al., 2017).

Considering this context, the study first targeted technical incommensurability – i.e. diverging descriptions of the landscape system – in order to better understand the dissonance between landscape ecologists' recommendations and farmers' practices. As the idea was to quantify differences in cause–effect relationships, a general structure needed to be agreed upon. This structure was the ARDI diagram and its Bayesian equivalent described in the previous section. The leeway given to stakeholders to express their own representation of the system rested in the individual parametrization of the BBNs. This allowed – at the extreme - zero probability to be given to a link, expressing the absence of a causal relationship between two recorded entities (although this eventuality did not occur).

The parametrization of the BBN was an onerous task (time consuming and not always intuitive), so to facilitate the process, we used cards with images (Fig. 1) to illustrate variables and their different states. We also opted for questions about frequency ("Considering A, B and C, in how many cases out of 100 would you observe D?") rather than probability, which is more difficult to handle cognitively (Anderson, 1998). The whole process (to elicit the 266 probabilities of the network) lasted three hours per stakeholder. Once the probabilities were collected, we presented the compiled model to each participant and asked him/her to validate it, providing it reasonably captured their own perspective of the system.

Fig 1: Using visual cards to elicit a stakeholder's perceptions of probabilities of cause–effect relationships in agroecological pest management. These were then used to link the different nodes of the Bayesian belief network. (Photo: N. Salliou)

The construction of individual models was key to observe divergent representations (in contrast with the second case study, in which the model had a more peripheral role). For each individual model, we assessed the same 'ecologically ideal' scenario (presence of sheltering hedgerows and high proportion of semi-natural habitats such as hedgerows, woods and meadows). In a Bayesian model, through belief propagation, a scenario modifies the probability distribution of the different variables and by consequence their final states (Aguilera et al., 2011). We found that while the effect of the pest-suppressing scenario on ecological entities was noticeable, the effect on the 'target node' (apple production) proved to be low in every case. This demonstrates that

although stakeholders disagreed on the intensity of the relationships between landscape complexity and pest abundance, they agreed on the relationship between landscape complexity and fruit production (Salliou et al., 2017). With such little perceived economic benefit, despite the potential enhancement of ecological processes, we found that farmers felt little incentive to coordinate at the landscape scale (Salliou et al., 2019a). The individual models indicated that parcel-based solutions, such as growing wild grass between apple tree rows, was more promising, especially as this requires no coordination efforts (Salliou et al., 2019b). Overall, the approach allowed the establishment of priorities for research in biological pest control, in particular concerning the potential for coordinated versus individual action.

This result indicates that the major divergence between stakeholders was how to measure the utility of a complex landscape: either through ecosystem functions (sheltering and food provision for useful insects) or through ecosystem services (fruit production, hence revenue to farmers). The fact that the different descriptions of the landscape system were informed by different value systems (one that values ecological functioning vs one that values economic benefits) shows that technical and social incommensurability can be intricately interwoven.

3.2 Case study 2: quantitative water management

In the case study on water management, dialogue was mostly limited to moments of crisis, when a 'drought cell', composed of government agencies, the agricultural advisory board, farmers' representatives and the local council, gathers to decide on the level of water restrictions to apply. Although crisis management is not a sufficient coordination mechanism, there was no explicit will to further collaborate. Indeed, institutionalized negotiation had the result of either aborting the dialogue or reinforcing power relations between stakeholders (Debril and Therond 2012). Recognizing that there was no convergent view of the problem of water imbalance, our project aimed to organize a collective deliberation on the subject, first examining social incommensurability.

To this end, we elicited and formalized social incommensurability at two different stages. The first corresponded to the construction of the criteria grid, based on the discourse of stakeholders. The discourse of those interviewed (N=16) showed different – and sometimes incompatible – views. One example was the perspective on hydrological variations. For some interviewees, variations were a 'natural given' that should be sustained in order to maintain the healthy functioning of rivers (e.g. "The hydrological regime is like a lung at the scale of a river"). For others, water dynamics had to serve human activities and access to water across time and space – a conception that supports the creation of reservoirs to adapt the water offer to demand. To reflect these divergences, we created different thematic categories, referring to overarching principles for a good water management advocated by interviewees. We then transformed these categories into an evaluation criteria grid containing 11 criteria: people's safety, food security, economic competitiveness and employment, biodiversity preservation, local identity, adaptability to exogenous changes, flexibility in adjusting the water offer and demand, renewal of natural capital, equity across people and space, efficiency, political legibility (Allain et al., 2020). Clarifying incommensurability at the level of criteria allowed an inclusive – though non-consensual – evaluation structure. No stakeholder contested the criteria grid in the following stages of the research (Allain et al., 2020).

The second stage was the construction of the multi-actor multi-criteria matrix (Fig. 2). In this matrix, value judgments were symbolized by colors and could be visualized at the level of indicators (least aggregated) or of criteria (most aggregated). Navigating within the matrix allowed differences between stakeholder groups to be observed. When stakeholder groups attributed different value judgments to a same scenario and a same criterion, we could infer that this reflected social incommensurability. These divergences could result from different indicator sets (different benchmarks and lines of argument), different weights (different importance given to arguments), or different interpretations of the same indicator.

In the restitution meeting, we decided to focus on the most salient controversies that appeared in the matrix and to bring their origin to the surface. Indeed, participants were interested in comparing their value systems to those of other groups, but even more, were curious to discover why their evaluations differed. We supported this curiosity by displaying the different options in the matrix: in posters featuring aggregated value judgments and the details of each cell (value judgments and weights) (Fig. 3), and by creating an additional booklet with the full information, including the indicators chosen by each group and the reasons given for their choice. The investigation of incommensurability at this stage helped to qualify the different scenarios in terms of capacity to create consensus or dissent. It also offered a basis for understanding opposition and discussing possible ways to leverage it. Participants suggested new scenarios taking into account the arguments of others rather than discarding them.

During the evaluation workshops that led to the creation of the multi-actor multi-criteria matrix, indicators from the simulation of scenarios (e.g. number of days under the minimal flow requirement) had the same status as indicators added and assessed *de novo* by participants (e.g. living soil). Both served as arguments sustaining a discourse on the desirability of water management scenarios. However, indicators coming from simulations showed more ability to generate a change of opinion within a group, given that simulations could provide counterintuitive results (see Allain et al. 2018). The stakeholder groups that relied more on computer-based indicators to formulate their value judgments (e.g. the representatives from the agricultural institute) were *de facto* more influenced by the model than the groups that preferentially used their own indicators (e.g. environmentalists).

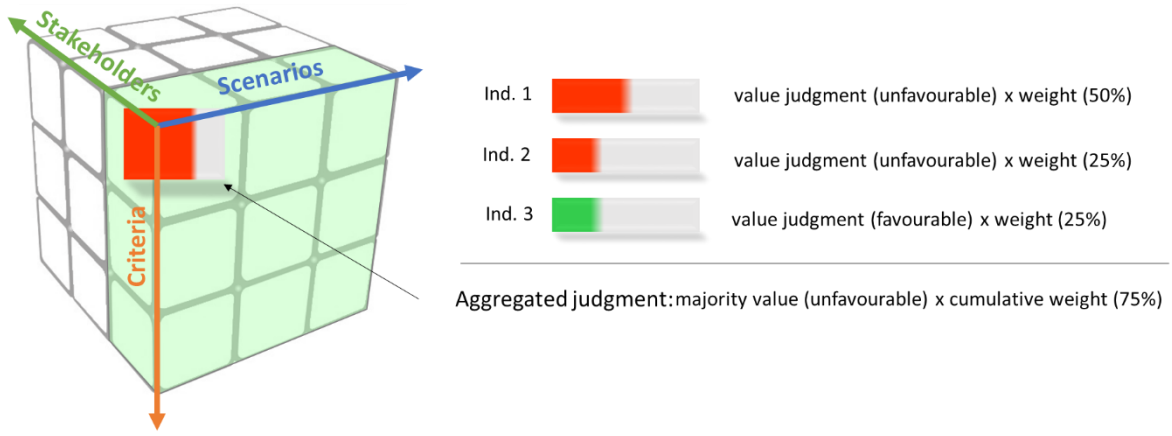

Fig. 2 Principle of the multi-actor multi-criteria matrix: aggregated judgments are compiled for each combination (scenario x criteria x stakeholder group)

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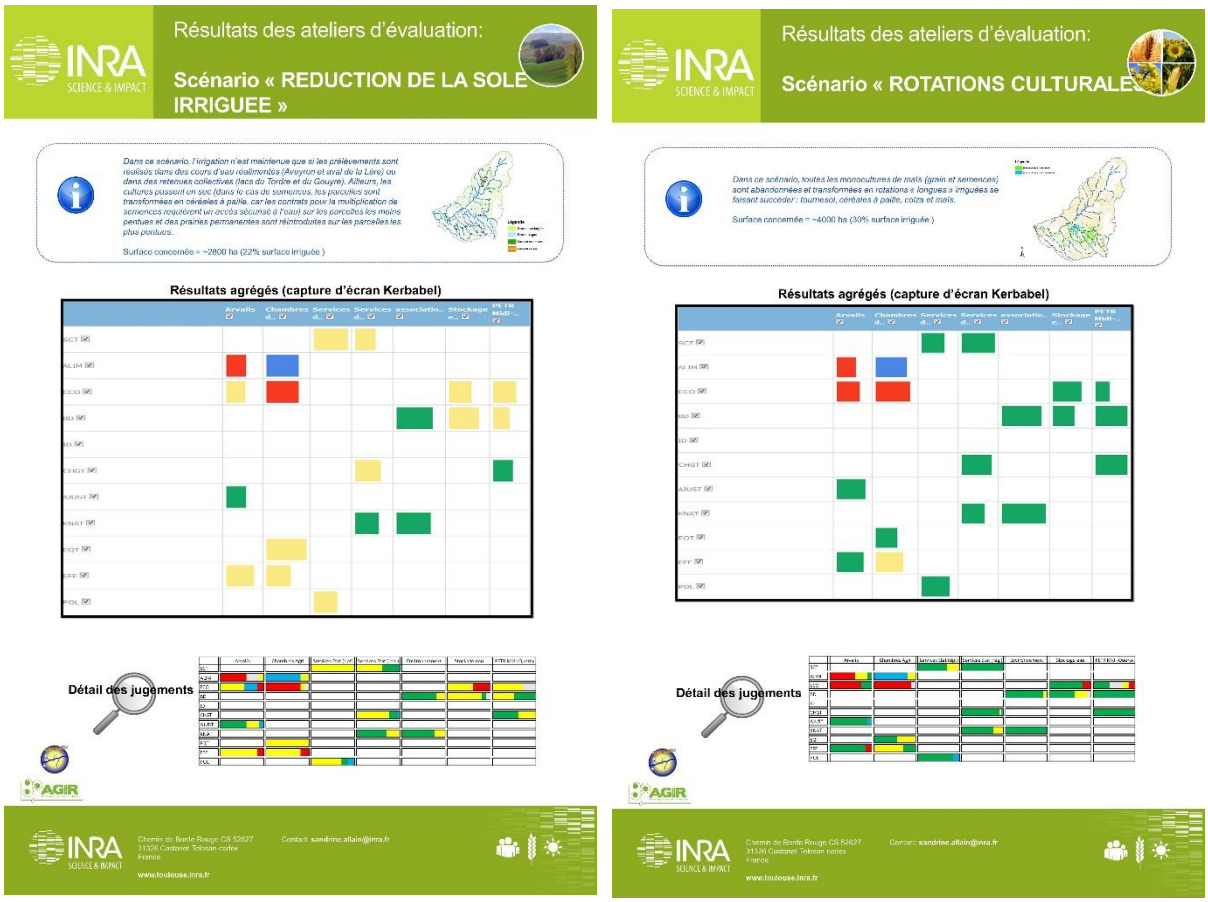

Fig. 3: Examples of posters presented at the restitution meeting on quantitative water management alternatives (left: 'Reduce irrigated land in upstream areas' scenario; right: 'Crop rotation instead of maize monocrops' scenario)

3.3 Comparison / cross-analysis

	CASE STUDY 1: AGROECOLOGICAL PEST MANAGEMENT	**CASE STUDY 2: QUANTITATIVE WATER MANAGEMENT**
Design and implementation of the participatory modeling/simulation approach		
Scenarios tested	Different agricultural practices and landscape composition to enhance biological pest control	Agricultural changes aimed at making water management more sustainable
Characteristics of the model	Participatory Bayesian network (BN) specifically created for the research project. Co-design of BN structure via a directed acyclic graph (DAG) (nodes and causalities between these, states of nodes) involving researchers and local stakeholders. Individual parametrization of the BN structure (conditional probability tables) by diverse stakeholders.	• 'Hard' model, based on expert knowledge • Multi-agent, spatialized and integrated. MAELIA represents at a fine scale (field and days) the technical operations of farmers (including irrigation) and their interactions with water flow and water management decisions, to observe emerging watershed-scale effects • Model existed prior to the participatory research project and was calibrated for the case study
Use/Role of the model in the evaluation of scenarios	The model provides results in terms of changes in the probability for each node (and its states) as a result of a scenario.	• The model as a simulation tool provides quantitative indicators at different scales and for different subsystems (hydrological, water management and agricultural). • Model-based indicators are on an equal footing with other indicators and inform the evaluation (qualitative) of scenarios by stakeholders.
Participating stakeholders	Five stakeholders (a scientist, an organic and a conventional apple farmer, an agricultural technician and the director of the farm of the local agricultural secondary school) All stakeholders helped to construct and parametrize the model and reacted to scenario outputs.	Representatives from government agencies, farming advisors, local communities, environmental organizations, fishing organizations, dams Stakeholders helped to create scenarios, define the criteria of interest, evaluate scenarios, discuss the results of the evaluation and suggest new scenarios.

Elicitation, formalization and communication of incommensurability		
Type of incommensurability addressed	Technical incommensurability between 5 stakeholders (at individual level)	Social incommensurability between 7 stakeholder groups (at group level). Technical incommensurability appeared in the discussions about indicators, but was not formalized.
Tools and methods to formalize and communicate incommensurability	• Incommensurability takes form through the individual parametrization of causalities between ecological, technical and social variables in the Bayesian belief network. • As the process involved the elicitation of more than 200 conditional probabilities, we used cards with images representing the different combinations of variables to help this elicitation. • Inter-stakeholder comparisons relied on a specific scenario and the differences in outcomes this generated. The use of this scenario was a tool to quantify the scale of divergence for a specific purpose (fruit production).	• Multi-actor multi-criteria evaluation. Incommensurability structures the criteria grid and the attribution of value judgments by stakeholders. • One can navigate in the matrix (3D) to observe where value judgments diverge and for which reasons (indicator chosen, judgment attributed, weight attributed). The focus was placed on incommensurability that generates social conflict.
Discussion stimulated by the discovery of incommensurability	There was not a formal discussion about incommensurability. The main lesson was that incommensurability was not found where we expected it.	Discussion was generated: • About the levers that would allow crystallized opposition to be overcome • About the influence of the model (and its assumptions) on evaluation results

4. Discussion

Enthusiasm to reconcile divergent views is explicit in many landscape management practices. The objective is to encourage collaboration based on the recognition of a common problem and shared objectives. Yet our findings show that such integration, though supported by skilled facilitators and techniques, is not always possible, nor does it guarantee effective results. Stakeholders may even refuse to take part in a participatory arena they judge too narrowly framed. Failure to engage dialogue based on these "closing-down" processes is probably experienced more often than it is reported (e.g. Ramsey 2009; Barreteau, Bots, and Daniell 2010). The main problem is that there is generally no debate between participants, even less so agreement, on the idea that harmonizing all the available information is the best way to reach a conclusion.

One competing theory, on which we base the discussion of our results, is that of communicative rationality (Habermas, 1984). It advocates giving voice to the diversity of viewpoints, with equal balance to information shared by each participant – two key aspects of a quality debate – but argues that the rational decision should be based on the *strength* of the arguments, not on their integration and balance. This theory has given place to multiple research and methodological advances on how to put in practice collective deliberation (Frame and Brown, 2008; Frame and O'Connor, 2011; Saltelli et al., 2020; Vatn, 2009). Collective deliberation is only one among many other 'opening-up' options (e.g. dissensual politics, agonism), and does not preclude iterations with closing-down processes. The results of our case studies join theoretical works that give precedence to the exploration of divergent views over seeking reconciliation, in the search for sustainability

Our case studies specifically emphasize the importance of formalizing divergences, as a tool to turn heterogeneous discourse into tractable information to participants (not only to experts and participation professionals). Formalization hence acts on problem structuring while counteracts on power games, providing the formalization language remains inclusive and legible. From a communicative rationality perspective, the debate's quality increases: thicker knowledge on issues at stake, richer dialogical content, lowering of representation bias towards experts. In terms of sustainability, we observed an enhanced capacity to challenge mainstream landscape management options and a better accounting for the interconnectedness of sustainability objectives.

4.1 Meeting sustainability challenges through opening-up processes – conceptual arguments

When participatory initiatives for landscape sustainability fail, the logic underlying participation – increasing the breadth of the collective understanding and closing-down knowledge (see Introduction) - is rarely questioned. Most critics of 'closing-down' approaches are based on political (the democratic ideal), ethical (fairness, inclusiveness) or social acceptability (capacity to avoid locked-in situations) reasons; not on their capacity to foster sustainability. A few works focus more explicitly on the link between sustainability and the need for opening-up processes.

While closing-down options seek a cooperative model for managing interdependency between people and activities, other models (e.g. competitive/agonistic, coordination) may also be justified to engage participants in sustainable transitions. For instance, the multi-level perspective

(Geels, 2011) highlights the importance of the rivalry between a dominant sociotechnical regime and niche innovations. In this framework, a sustainability transition occurs when the maturity of a niche innovation coincides with an institutional context that favors its spread, weakening the regime in place. Landscape management can also be analyzed as the product of a sociotechnical regime (founded on the prevalence of certain objectives, values, types of knowledge, practices, discourses and indicators that reinforce each other, e.g. Fernandez 2014 in a study on water management), which constrains transition options. In this perspective, the cooperative model might be illegitimate,as it could reinforce the expression of power relations, and unable to achieve sustainability outcomes. Rather, organizing participation as to allow the expression and confrontation of different value and knowledge systems, not their reconciliation, might be more accurate.

Machin (2020) even argues that, because status quo policies are unsustainable, only disruptive alternatives to the dominant discourse are able to generate changes towards sustainability. To her, this includes the contestation of the scientific expertise, which generally defines the terms and solutions of the environmental crisis within the boundaries of the politically acceptable. Multi-criteria, multi-attribute or multi-stakeholder settings have been discussed for more than two decades as expressions of a technocratic rationality (Espeland and Stevens, 1998; Jasanoff, 2003). Deliberative value-articulating institutions, and tools to access different forms of knowledge have then enriched sustainability appraisals (Vatn, 2009): multi-criteria mapping (Bellamy et al., 2013), social multicriteria evaluation (Munda, 2004), quantitative storytelling (Saltelli and Giampietro, 2017) etc. However, deliberative settings remain contested, especially when power relations are strong: modes of expressions that spill over instituted frameworks are then considered more fertile in the search for sustainability, as the only ones able to nourish transformative options (Machin, 2020; Velicu and Kaika, 2017).

Another important argument for matching opening-up processes with sustainability is that of uncertainties. In its oldest expression, this argument takes the form of post-normal science – when 'facts are uncertain, values in dispute, stakes high and decision urgent' (Funtowicz and Ravetz, 1993). Its proponents argue that quality decision requires the surfacing and communication of uncertainties within 'extended peer communities' (Funtowicz and Ravetz, 1990; van der Sluijs, 2002). Recent insights have distinguished ambiguity as a type of uncertainty that integrated approaches (e.g. integrated landscape management, integrated water management) tend to neglect (Brugnach and Ingram, 2012). Ambiguity refers to disagreements over frames and representations of a problem (Bond et al., 2015; Brugnach et al., 2011; Stirling, 2010), e.g. technical incommensurability. Reducing or neglecting ambiguity makes us take the risk of underestimating the overall uncertainty associated with different options for change. Urbinatti et al. (2020) have criticized the precedence given to 'sound science' and 'closed-down knowledge' over irreducible uncertainties and disagreements in current sustainability frameworks, such as nexus approaches. Precautionary and no-regret options become undervalued in comparison with those judged more effective – with the risk of having 'nasty surprises' emerge, and turning one sustainability problem into another (and potentially bigger) one (Howard, 2011). These research works, inherited from the post-normal science rationale, generally promote communicative rationality and collective deliberation within hybrid communities (academic / non-academic) (Brugnach and Ingram, 2012; Urbinatti et al., 2020; Zografos, 2015).

These different conceptual concerns support the adoption of landscape practices that allow and communicate divergence, i.e. opening-up ones. Our case studies exemplified these types of practice, and the findings highlight their potential to foster collective deliberation and sustainability. The insights gained are shared below.

4.2 Formalizing incommensurability to foster collective deliberation

According to Dryzek and List (2003), collective deliberation fulfills multiple roles that allow social-choice issues to be overcome. It can play:

- An informational role: confronting people with new information
- An argumentative role: clarifying controversies
- A reflective role: reviewing preferences
- A social role: interacting with others

The following sections describe how and to which extent collective deliberation took place in our two case studies, and allowed progress towards sustainable landscape management.

4.2.1. Informational role: confronting people with new information

In both case studies, accounting for incommensurability required 'accessing' the reasoning of the different stakeholders and communicating it to others, in order to enrich the information for all. In the case of agroecological pest management, this reasoning emerged using Bayesian belief networks, which is one way to formalize how people conceive and quantify causal links between different variables (nodes). However, the confrontation between the different representations in each stakeholder's BBN was not direct, instead scenarios were used in order to exemplify the consequences of differences. The information communicated was not about the extent of differences in representations, but the impact of these differences. The knowledge gained through this process was that, according to the different mental models tested, fruit production weakly responded to landscape-scale changes. This confrontation turned out to challenge assumptions in the field of landscape ecology and validate from a social perspective one of the reasons of landscape-based biological pest control failures identified in the literature (Tscharntke et al. 2016). The lack of perceived economic benefit (improved fruit production) of this pest control strategy might explain why the rare documented cases of a complex landscape implemented by farmers are first aiming at advertisement benefits rather than pest control benefits (Sigwalt et al. 2012). It also puts into perspective the need for collective action in pest management, and rehabilitates individual strategies developed by farmers.

In the case of quantitative water management, the communication of incommensurability was more direct, but occurred progressively. First, posters featuring the aggregated value judgments of the different groups showed which scenarios were more/less appreciated and which ones created consensus/dissent). Second, participants could access disaggregated information (the indicators used, the value judgments attributed to each indicator, and the corresponding weights given) to better understand the reasons underlying divergence between groups. Third, the elements that surprised participants were discussed in a plenary session, so that the people

concerned could explain their arguments in more detail. Here the discovery of new information depended on the questions each participant was most eager to solve, and aligned with the principle of progressive information disclosure (Pereira et al., 2003). Three types of knowledge, useful to improve the sustainability of the water management, emerged. First, we learned about the pros, cons and uncertainties of the different scenarios for the specific situation of the downstream Aveyron watershed. For instance, we realized that although the reservoir scenario had good results on the Aveyron flow and secured the agricultural production, it was also the one bearing the biggest perceived uncertainties, and lacking indicators to assess them (Allain et al., 2020). Beyond situation-specific knowledge, we acquired more generic knowledge about agriculture – water interactions, e.g. about where in a watershed, irrigation economies have a visible impact on monitored river flows (Allain et al., 2018a). Finally, a third type of knowledge improvement was about indicators themselves (knowledge *about* indicators as complementary to knowledge *based on* indicators - Frame and O'Connor, 2011). Stakeholders learned to handle different types of indicators derived from the MAELIA model, and hence were able to realize how well these indicators fitted their need for arguments. The synthesis revealed that the (mis)match between model-based indicators and stakeholder discourses was not equally shared: some stakeholder groups could rely on a much richer library of indicators than others could. This third type of knowledge fed reflexivity about the framing of the evaluation exercise (4.2.3), but also about knowledge gaps and ambiguities, which water management has to deal with.

4.2.2. Argumentative role: clarifying controversies

According to Dryzek and List (2003), collective deliberation can draw people's attention to new insights about the interdependence of issues, question their internal consistency, bring hidden assumptions to the surface and clarify the content of controversies (p. 9). In short, it pushes people to make their arguments more robust. As landscape issues are considered socially complex, this argumentative role of collective deliberation is not aimed at distinguishing right from wrong or legitimate from illegitimate views. Its goal is rather to reformulate arguments and knowledge in a more inclusive way (Brugnach and Ingram 2012).

In both case studies, this reformulation operated through artifacts that forced participants to structure their argument: conceptual diagrams and BBNs (case study 1) or a list of indicators having the status of arguments and their weights (case study 2). An additional characteristic of the collective deliberation organized in both case studies was that it was 'targeted' and not exhaustive. The discussion focused on incommensurability that generates conflicts of interpretation rather than divergences that result in similar value judgments. For agroecological pest management, the lesson was that incommensurability exists, but does not lead to fundamental differences when looking at final outcomes (apple production) (Salliou et al., 2017). For quantitative water management, the lesson was that the outcome of incommensurability depends on the scenario evaluated; in some cases it blocks the debate, while in other cases fragile consensus can be created (Allain, Plumecocq, and Leenhardt 2018). While we could have initially expected the debate to focus on hydrological questions (e.g. the capacity of each scenario to reduce severe low-flow situations), we realized that the most sensitive and controversial question was that of agricultural models (especially, over the meaning of 'agroecology'). This result echoes

other works emphasizing the role of values and narratives in the (so far difficult) ecological transition of agricultural systems (Magrini et al., 2019; Plumecocq et al., 2018; Vivien et al., 2019).

Our findings exemplify Van den Hove (2006) 's recommendation for defining the area of consensus as well as the area of negotiation in a participatory process in order to foster social learning. Formalizing technical and social incommensurability constituted in both case studies an activity that allows the delineation and exploration of such negotiation space.

4.2.3. Reflective role: reviewing preferences

The reflective aspect was particularly salient in the agroecological pest management case study. The assessment of scenarios according to the different mental models of the stakeholders showed relatively similar outcomes. Therefore, ecological knowledge about the role of the landscape structure on natural predators became less central when looking at the effects on apple production. In particular, each individual Bayesian model was simulated according to a same ecologically ideal scenario (i.e. high proportions of semi-natural habitats like hedgerows and meadows) favored by the landscape ecologist stakeholder. The landscape ecologist realized that the hypothesis about the role of a complex landscape for pest regulation benefit was not happening in this specific case study, even in her own model. The original assumption from the landscape ecologist was that other stakeholders were potentially 'blind' or 'unconscious' to the potential of the landscape in pest regulation. Because representations of the landscape ecologist of the socio-ecological system were integrated in the structure of the Bayesian model, the assumption of 'unconsciousness' could not hold. Still the reflective aspect deserves nuance: the landscape ecologist only slightly reviewed her preferences, considering that the assessment framework was only based on few individuals and one case study.

In the case of water management, something similar occurred. In many political arenas, technical language (e.g. hydrological, supported by numbers) predominates, which encourages environmentalists to adopt a discourse that emphasizes the negative consequences of reservoirs. Such discourse is quite easy to attack, because the hydrological consequences of water storage are poorly known (Carluer et al., 2016) and the creation of big reservoirs can also potentially reduce the environmental pressure on other places or in certain seasons such as summer. Our research unraveled the importance of agricultural and ethical issues in quantitative water management in relation to hydrological issues, especially in the case of the water storage scenario. For instance, we found that environmentalists moved from an 'anti-reservoir' position to a position that promoted ecological farming practices, a reduction of water consumption and the rewilding of degraded wetlands, even if the trade-off was to have reservoirs to secure farming activities.

4.2.4. Social role: interacting with others

The social role of collective deliberation was more obvious in the water management case study as the context was a blocked dialogue with crystallized power relations. In this respect, the method implemented proved successful through the simple solution of a collective restitution meeting. This occurred in a peaceful atmosphere and participants expressed their satisfaction in having communicated 'constructively' with others. This is to be noted that previous works on the same case study area had not succeeded in gathering all the different parts in the same room and that failures of negotiation had already occurred. During the evaluation workshop stage and its

preparation, resistance and mockery were encountered from the stakeholders satisfied with maintaining the status quo. However, all participated in the final meeting, and provided positive feedback. Further exchanges and research followed.

In the pest control case study, collective interactions were rich, but limited to the construction of the ARDI diagram (a convergence stage prior to the formalization of incommensurability). While stakeholders expressed enthusiasm for the whole approach, they also communicated their fatigue after the scenarios were assessed. As the BBN process did not include collective discussion (although we did receive individual feedback), this did not allow us to assess if formalizing incommensurability fostered social interactions. However, from a modeling perspective, exploring technical incommensurability helped to engage in new interactions with stakeholders. Exploring one potential innovation opened out to other needs at the farm and landscape levels. For example, a pressing landscape-scale issue related to the invasive pest *Drosophila suzukii* was subsequently explored in another round of participatory modeling (Salliou, 2017). This capacity for iterative loops and an evolving discussion platform generated by participatory modeling has already been shown by Barnaud et al. (2007).

5. Conclusion

These two case studies demonstrate how the formalization of incommensurability can lead to new insights about concrete landscape issues. In the pest control case study, it identified the need for landscape-scale pest control of a new invasive species and prioritized agroecological understory management in orchards; in the water management case study it generated 'out-of-the-box' proposals. In contrast to most closing-down participatory processes, this formalization did not seek a sort of collective catharsis, in which the sharpest disagreements are expressed in order to evacuate them and then focus on convergence. It was instead a key step in collective deliberation with the aim of eventually leading to collective action.

These examples show that using modeling does not compel a process of closing-down knowledge. The model can support the expression and confrontation of divergent representations, as in the case of Bayesian belief networks, which were parametrized differently by stakeholders. It can also generate indicators that help stakeholders construct or review their discourse. These uses provide a safeguard to framing bias. Moreover, models can be turned into tools to inform debates, dialogues or deliberations (Pereira et al., 2003; Rafols and Stirling, 2021; Saltelli et al., 2020) or play the role of bridging different 'languages'. This bridging role is not without trade-offs or constraints. In the water management case study, we abandoned the quantitative information delivered by the model to the profit of qualitative judgments. In the pest control case study, we had to create a shared model architecture before quantifying differences of representations between stakeholders, which is only possible in weakly conflicting contexts. These case studies did not reject integrative tools (e.g. models, indicators) – they even relied on them to generate knowledge on incommensurability. Their originality lies in the way these tools were used: to enhance the quality of the debate, not to close it.

The results show that the informational and argumentative role of collective deliberation grows in importance when incommensurability is formalized. The methods and artifacts (e.g. scenarios, matrixes) that make divergences legible force participants to position their discourse in comparison to others. The consequence is that people attempt to strengthen their argumentation to increase its relevance rather than to undermine the arguments of the others, and finally generate social learning on social-ecological interactions, uncertainties and dilemmas to deal with (Garmendia and Stagl, 2010). This argumentative role can even be the substrate of social interactions when the dialogue is blocked. Even if this is not the case, we argue that bringing tacit but structural disagreements to the surface can enrich the content of already existing social interactions and delineate a space for enhanced negotiation (van den Hove, 2006).

To conclude, eliciting and formalizing differences does not necessary lead to opening Pandora's box and generating endless debate. On the contrary, it can help focus and enrich discussions about the different options for change, and result in questioning the perceived legitimacy and effectiveness of collective action in the face of sustainability problems. When considering the wider challenge posed by the current ecological crisis, opening-up methodologies and experiments seem crucial. Techno-scientific narratives towards sustainability (green deal, bioeconomic strategies, industrial symbiosis, water smart strategies etc.) have a strong legitimacy for decision-making and are considered consensual. Therefore, difficulties in establishing sustainability are thought to root in inefficient, insufficiently controlled or insufficiently integrated resource systems. Alternative narratives -either disruptive or precautionary- remain marginal in the political discourse, as they do not fit the same frame nor are expressed in the same language. These narratives do not particularly lack argumentative strength – one of the most important criteria for a quality democratic debate - but they lack capacity to resonate with dominant narratives of sustainability. If they would be given more resonance, not only would they allow a better representation of people and issues, but also they would offer a chance to reflect on the implicit assumptions, ambiguities and uncertainties held by dominant narratives. The landscape scale is one where incommensurability of values and knowledge is relatively easy to capture, and therefore where methods for opening-up debates could be more routinely used.

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