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Abstract

Environmental policies are implemented in complex socio-economic settings, where numerous stakeholders hold different and potentially conflicting values. In addition to being scientifically well-founded, the experts' recommendations on which these policies are based therefore also need to be operational and legitimate.

Multi-criteria decision-analysis (MCDA) is often used to solve management problems, but studies in the literature rarely place importance on the way stakeholders perceive researchers' interventions (which implies a lack of legitimacy), and most managers lack the skills to reproduce routinely the operations involved (which implies a lack of operationality). We use MCDA methodology in a different approach: "meta-decision-analysis" (Meta-DA). As researchers, instead of striving to identify the best way for us to solve managers' problems, we identify the actors (the decision-aid providers, DAPs) who are best placed to help managers, and we provide DAPs with the necessary tools.

Implementing this approach involves three tasks: T1—identifying a legitimate DAP who will provide decision-aid to managers in routine policy implementations; T2—identifying, among the decisions involved in solving managers' problems, those for which managers and the stakeholders concerned consider that some actors have particular legitimacy; T3—designing tools that are compatible with both the DAP's skills and legitimacy constraints.

We applied this approach, structured around T1-3, to wetland prioritization in a French administrative region (Bourgogne-Franche-Comté). This application illustrates the feasibility and usefulness of our approach.

Our approach entails recommendations for various kinds of actors involved in environmental policies: For researchers, it provides a research agenda to develop new applications of MCDA. For managers and potential DAPs, it suggests that, for some of the problems they face collectively, they should seek the help of researchers to implement a Meta-DA approach. For policy-makers, it suggests that, by encouraging Meta-DA, for example through dedicated funding schemes, they could improve the effectiveness of environmental policies.

Keywords: environmental policy, prioritization, multi-criteria decision-analysis, legitimacy, wetlands, knowledge-implementation gaps.

Introduction

Environmental policies, here defined as “organized sets of actions to conserve or restore natural sites, species or ecosystems”, often suffer from “knowing-doing gaps” (Matzek et al. 2014): scientific knowledge accumulates but fails to inform action. This is largely because the decisions involved in designing and implementing environmental policies are not straightforward applications of scientific knowledge. They are applied in complex political and economic settings, where different actors and stakeholders make potentially conflicting claims and want their voice to count in collective decision-making. In such contexts, it is not enough for experts’ recommendations to have sound scientific foundations: they also need to be operational and legitimate (Jeanmougin et al. 2017).

The first requirement (operationality) means that it should be possible to use them in day-to-day policy implementation. Operationality, understood in this sense, should be distinguished from concreteness, referring to the requirement that recommendations should not be purely theoretical: operationality entails concreteness, but the reverse is not true, and many state-of-the-art scientific studies fail to provide operational recommendations despite their concreteness.

The second requirement (legitimacy) means that policies are doomed to fail if the actors concerned consider that experts overstepped their role when performing analyzes or articulating recommendations (this definition and the analysis of legitimacy issues in the rest of the article are based on Meinard (2017)).

Many authors call for tighter interactions between researchers and practitioners and point a need for researchers to address research priorities identified by practitioners (e.g. Schwartz et al. (2018)). However, this literature arguably underestimates the fact that the incentives driving researchers and actors looking for operational and legitimate decision support can diverge: whereas scientific publication requires novelty in theory and methods, actors concerned with operationality can be more interested in deploying applications of existing knowledge; whereas academic science requires state-of-the-art, highly sophisticated techniques, actors concerned with legitimacy can prefer approaches that are less sophisticated but easier to explain to concerned stakeholders. The solutions presented in the literature are limited to recommendations designed to mitigate such discrepancies (e.g. Beier et al. (2017) recommend to create new incentives to encourage researchers to focus less on publications and engage more in actionable science), but recommendations of that sort are rarely followed (Arlettaz et al. 2010). This gap in the literature calls for deeper investigations on the role that researchers can play in decision support activities and on how they can take operationality and legitimacy constraints into account.

Indeed, most studies take for granted that the only way for a research project to be relevant to decision support is for the involved researchers to solve the specific problem that a specific (sometimes fictitious) decision-maker faces, or to produce a tool that the latter can use (a so-called "decision support system" – Gilliams et al. 2005, Keith et al. 2008). For example, when Bournaris et al. (2015) produce a model integrating irrigation water use and environmental protection in Northern Greece, they assume that this decision support system can be directly used as a planning tool by the regional authorities. Similarly, when Maleki et al. (2018) use a multi-criteria spatial decision support system to plan a scheme for wetland restoration in the Hamum area (Iran), or when Ang et al. (2016) combine the use of a remote sensing and geographic information system and an avifauna survey to assess wetland restoration in the Yellow River Delta (China), their results are, respectively, a wetland prioritization and a recommendation for a land-use pattern, both directly intended for decision-makers acting on the concerned areas.

The importance of such results is undeniable. However, such studies do not question how decision-makers and concerned stakeholders perceive the decision-support that researchers provide: will the scientific credentials of the published study, or the intervention of local expert in the parametrization of models, be enough to convince them that recommendations are legitimate? Moreover, beyond hinting at possible applications of their method to other case studies (e.g. Maleki et al. (2018) in their concluding paragraph), these studies produce results that are valid only for their case-studies and are not straightforwardly transferable, as actors concerned with operationality would like them to be.

In this article, we introduce an approach, “meta-decision-analysis” (Meta-DA), which explicitly rethinks the role of researchers in decision-support to environmental policies, and thereby tackles the challenges of integrating the operationality and legitimacy requirements in research activities. This article is organized in two parts. In a first part, we present our conceptual framework and explain how it can be applied to the usage of multi-criteria decision-analysis (MCDA) (Greco et al. 2016) in the context of decision support to operational and legitimate policies. In a second part, we then illustrate a concrete implementation of our approach in the case of wetland prioritization in the Bourgogne-Franche-Comté region in France.

Conceptual framework: structuring operational and legitimate environmental policies through Meta-DA

MCDA is a branch of Operational Research (itself part of decision sciences), aimed at providing decision-makers with means to improve their decisions, through a better representation of various aspects of their problems, and a better understanding of associated constraints. MCDA methods and tools are used in numerous environmental disciplines (Esmail & Geneletti 2018), particularly in conservation planning (Regan et al. 2007, Farashi et al. 2016), but also invasive ecology (Dana et al. 2013), ecological risk assessment (Malekmohammidi & Blouchi 2014), ecosystem services valuation (Fagioli et al. 2017), among others. In such studies, MCDA methodology is used to select and apply state-of-the-art MCDA technologies, using researchers' state-of-the-art MCDA skills, to solve particular problems (e.g. Gregory & Long 2009, Robinson et al. 2016, Robinson et al. 2017). Although such studies produce important results, like the larger literature referred to above, they are often ill-equipped to feed legitimate and operational policy implementations. Indeed, although these studies make a point to take into account the values and objectives of stakeholders and decision-makers, they rarely place importance on the way the former perceive researchers' interventions. They do not investigate whether they see researchers' measurements of their values and the recommendations they derive from them as legitimate. This contrast is illustrated, for example, by Wu et al. (2012)'s use of MCDA to compare policy options to protect a nature reserve in China. Although they explicitly integrate in their analysis the acceptance of the various policy options by farmers, they do not investigate the way farmers and other relevant actors perceived their MCDA analysis (integrating farmer's acceptance) and whether they deem that a decision based on this analysis is legitimate. Among the 86 articles applying MCDA to nature conservation reviewed by Esmail et al. (2018), only Ferretti & Pomarico (2013), Van Elegem et al. (2002), Strager & Rosenberger (2006) and Zhang et al. (2013) emphasized the importance of this aspect, without devoting important analyses to it.

Besides, most decision-makers lack the skills to reproduce the operations involved in these studies routinely and, because an indefinitely continued interaction between decision-makers and MCDA researchers would be impractical, exceedingly expansive and inefficient, most decision-analysis (DA) processes do not survive the end of the research projects that launched them. Coming back to the articles reviewed by Esmail et al. (2018), although many of them mention the transferability of their results and applicability of their methods to other case studies, this mention is limited to a reference in discussion or perspective, without in-depth analysis of the actors and settings liable to ensure that operational replications are indeed implemented (notice, however, the deeper investigation in Van Elegem et al. 2002).

These two limitations of current MCDA studies, echoing the limitations in the larger literature mentioned in the introduction, highlight that innovation and scientific advances in applications of MCDA can occur at two levels:

- at a first level, which is the most extensively explored in the literature, scientific advances are about elaborating new tools, better adapted to the specific problem they are used to solve;
- at a second level, which is much less explored in the literature, innovations is about elaborating how existing MCDA tools can be put to use, so as to find a place in day-to-day policy implementations.

The approach developed in this article, which we call "Meta-DA", takes place at the second level and proposes, at this second level, a new role for researchers in policy decision support. We propose that, as decision analysts, instead of trying to identify the best way to solve a particular decision-maker's problem, we should provide decision support to the actor (thereafter called "the decision-aid provider", DAP) who is best placed to help a series of decision-makers to solve in the same way, using the same standards and methods, the problems that the implementation of a given policy creates for them (see the illustration of the contrast between Meta-DA and more "standard" approaches in the graphical abstract). Researchers themselves are candidate DAPs, but other actors may be better placed, in particular if the actors, stakeholders and decision-makers concerned consider them to be more legitimate, for example thanks to their acknowledged local expertise and involvement in the local network of actors. The first pivotal task for the implementation of a Meta-DA approach is therefore to:

T1: Identify an actor considered by decision-makers and the actors and stakeholders concerned to be sufficiently legitimate to become a routine DAP.

If the DAP uses methods that preempt the decisions made by legitimate actor(s), his/her own legitimacy may collapse. The second pivotal task is therefore:

T2: Identify, among the decisions involved in solving the decision-makers' problems (i.e. decisions concerning values of parameters, objectives to pursue, ties to cut, trade-offs to make, cases to take as exemplary, etc.), those for which decision-makers and the concerned actors and stakeholders consider that some actors have particular legitimacy (we call such decisions "political", as opposed to "technical" ones).

Notice that this task (T2) cannot be trivially solved by scientists or experts devising or calculating options or alternatives (the would-be "technical" part) and then studying the values that decision-makers, actors and stakeholders bestow on these pre-determined options or alternative (the would-be "political" part). Indeed, the very identification of alternatives and even the very formulation of the problem can, at least in some cases, be considered by decision-makers and concerned actors and stakeholders to belong to the "political" realm. Attempts to fully separate political from technical decisions have a long history of failure (Callon et al. 2011). However, in concrete situations, actors can agree on a shared understanding of this political/technical divide, and this provisional and local understanding is all that T2 requires.

Lastly, within the constraints imposed by T1-2, MCDA methodology should be used to:

- T3: Design techniques compatible with the DAP's skills and legitimacy constraints to solve the various aspects of decision-makers' problem.

Some studies already display a Meta-DA architecture of sorts (e.g. Van Elegem et al. 2002). However, they are not formally structured around T1-3, which prevents them from decisively contributing to operational and legitimate policies.

In the next section, we present such an application structured around T1-3.

Application: using Meta-DA to structure operational and legitimate wetland prioritization

Wetlands are ecosystems where water largely determines the composition of plant communities and ecological functioning (Maltby & Barker 2009). Examples include swamps, peatlands, and humid grasslands. Wetlands are targeted by numerous conservation policies justified by their contribution to biodiversity (Junk et al. 2006) and associated ecosystem services, such as pollutant filtration, flood mitigation, water storage and climate regulation (MEA 2005).

The policy that we aim to improve here encompasses all the initiatives launched in France by regional to national scale institutions (Water Agencies, administrative Regions and the Ecology Ministry), to encourage and finance wetland conservation plans, provided they are based on a rigorous wetland prioritization. More precisely, we focus on implementations in the Bourgogne-Franche-Comté administrative region, an area of nearly 50,000 km². To be coherent and fair to managers, this policy must be based on a prioritization method homogeneously applicable in the whole area.

The method currently recommended (e.g., in AERM 2014) uses weighted-sums to aggregate encoded information on wetlands. This approach has serious drawbacks (D):

- D1: Eliciting the information needed to parametrize weighted-sums is extremely difficult.

- D2: Weighted-sums are compensatory: a high mark on one criterion can compensate for a low mark or even a zero on another. In many multi-criteria problems, this is not appropriate. For example, if one wants to choose a race car, no amount of streamlining can compensate for the absence of a motor (see Bouyssou & Marchant 2007a,b for a theoretical exploration of compensatory and non-compensatory methods).
- D3: Weighted-sums treat technical and political decisions similarly and indecipherably.

We applied T1-3 to overcome these limitations.

T1: A legitimate DAP

For the purpose of providing decision support to wetland managers (which are the decision-makers in our case), many candidate DAP could be envisaged in the Bourgogne-Franche-Comté region. The institutions implementing the policy, in particular the Water Agencies, could take this task upon themselves, as they have done in the past (e.g. AERM 2014). So could also the governmental decentralized services (*Directions Régionales de l'Environnement, de l'Aménagement et du Logement*). Other prominent candidates are local administrations in charge of the management of water bodies and associated ecosystems in large parts of the region, such as the Soâne Doubs Local Public Basin Establishment (*Etablissement Public Territorial de Bassin*), local scale administrations already implementing or orchestrating management operations (*Conseil Départementaux*) or expertise institutions specialized in the conservation of natural areas and habitats such as the Botanical Conservatory (*Conservatoire Botanique*). Nonprofit organizations dedicated to foster conservation and research centers in multi-criteria decision support or environmental management could also play the role of DAP. T1 consists in selecting a legitimate DAP among these candidates (if there exist one).

To do that, we need criteria to sort out legitimate candidates from non-legitimate ones. Meinard (2017) reviewed approaches to legitimacy in the conservation literature, showed the diversity and complexity of criteria that can be used to assess legitimacy, and then suggested four criteria designed to be particularly relevant to conservation policies:

i) Transparency of procedures, where roles and statuses are clearly defined,
ii) openness to external expertise,
iii) acknowledgment of knowledge gaps,
iv) acknowledgment of moral issues.

These four criteria were introduced to assess the legitimacy of a conservation policy, rather than of an actor, and notice that, once a DAP is chosen, they can be used to assess the legitimacy of the decision support s/he provides. But they can also be understood as criteria to assess the legitimacy of candidate DAPs.

In our case, though potentially legitimate, the large scale institutions funding most wetland management initiatives did not express a willingness to play the role of DAP. They rather entrusted the "*Pôle Milieux Humides*" (PMH) (wetlands team), part of a non-profit organization, the natural areas conservatory (*Conservatoire d'Espaces Naturels*) (CEN), to create a spatialized database on wetlands at the scale of the whole region, and to elaborate and implement a prioritization method. This initiative *de facto* selected a DAP, whose legitimacy we can assess thanks to the above criteria.

The selection of the PMH, and the precise definition of the perimeter of its mission, where established during a steering committee supervising the organization of the network of wetland managers in the region on November 13th, 2015. The steering committee included all the above mentioned candidate DAP and all the recognized members of the network of managers and local actors concerned with wetlands in the region. The choice was motivated by the role that the CEN had played in the area with all the members of the network of actors for many years, and was validated by the members of the steering committee. The definition of the perimeter of the mission included the need for the PMH to work with representatives of managers and experts in a collaborative way.

The selection of the PMH and the definition of its mission therefore occurred through a transparent and clearly defined procedure, and entrusted the PMH with deploying a procedure which should itself be transparent and clear (i). The need to open the work of the PMH to external expertise was explicitly put forward by the requirement to work in a collaborative way with managers and experts (ii). By centering the work to be done on the construction of a regional-scale database gathering all the information available on wetlands and, as a corollary, the identification of data that are lacking or are not homogeneously available, the agenda also explicitly took knowledge gaps into account (iii). Lastly, the need to work with managers and to be responsive to their demands included an implicit recognition that prioritization is not entirely a scientific task and managers can have moral prerogatives (iv). According to the criteria stated above, the PMH therefore has the legitimacy needed to be a DAP for wetland prioritization.

T2: Technical versus political choices

There are *a priori* many ways through which one could split the problem facing wetland managers into a technical and a political part.

A first possibility, embodied in the standard application of the weighted-sum approach, is to ask managers to give weights to the various indicators in the database. In this case, the political part is confined to this expression of values that managers bestow on aspects of wetlands captured by the various indicators, and the "technical" part that the DAP is in charge of performing encompasses almost the whole problem-solving task. At the other extreme, the very formulation of the problem and the choice of how managers can express the values they bestow on wetlands and how these values are taken into account and aggregated, can be considered to be a political part for managers to tackle. In this second option, the “technical” work of the DAP is very limited in scope. Between these two extreme options, numerous intermediate settings are conceivable: the political part can be a choice between a series of scenarios, an ordering of management objectives, a weighting of broad aspects of wetlands captured by blocks of close indicators, etc.

The task at this stage is to choose, among these possible options, one that appears acceptable to the managers, by avoiding preempting choices for which they deem they have legitimacy. In our case, this task was performed through a series of participatory events orchestrated by the PMH that unfolded between November 2015 and January 2018. During the steering committee on November 13th, 2015, it was decided that the PMH should work with a taskforce comprising representatives of the various actors already involved in or potentially interested in being involved in wetland management. The list of those actors was based on the fact that these actors had already solicited Water Agencies to fund actions or studies on wetlands or had contacted Water Agencies to express a willingness to do so or ask questions about this procedure. The representatives were chosen by the various actors themselves to participate to the taskforce. A first session of collective work of the taskforce occurred on December 15th, 2016, during which the idea emerged that a relevant prioritization procedure would leave managers choose the objectives they want to pursue, and would provide, for each possible objective, a technical procedure to compute an objective-specific prioritization. Based on numerous informal discussions with the representatives of the different managers during the six following months, the PMH then produced several propositions of lists of possible objectives, which were iteratively improved, so as to reflect the choices that managers can be willing to make, subject to the constraint that the regional database should contain relevant information to compute a prioritization relative to these possible objectives

(Supplementary Material 1). On July 13th, 2017, a final list of objectives that managers can make the political choice to pursue (Table 1) was discussed and eventually validated by the taskforce.

During this process, the collective thereby distinguished between two sub-problems:

- The identification and aggregation of relevant information for each objective, which was considered to be a technical matter that the PMH was competent to perform (level 1 problem);
- The choice of management objectives, for which managers have a certain legitimacy (level 2 problem).

T3: Designing techniques to solve different aspects of the problem

Figure 1 schematizes how these two sub-problems are tackled in this application of Meta-DA.

Technical aggregation

Level 1 problem is a "sorting problem", which consists in assigning wetlands to predefined ordered categories reflecting how suitable they are for a given objective. The main MCDA methods to tackle sorting problems use assignment rules or analytical aggregation models. Rule-based assignments are recommended when experts are capable of articulating a logic linking the pieces of information to be aggregated (Azibi & Vanderpooten 2001). In our case, this was seen by the actors involved as a task for which the PMH was competent. We therefore chose a rule-based approach.

Drawing-up rules involved numerous meetings during which the PMH expressed provisional rules. We then verified coherence requirements (Table 2): completeness (each profile should be assigned to a category), exclusiveness (no profile should be assigned to more than one category), and monotonicity (if profile p_1 has at least as high values as p_2 for every indicator, and a higher value for at least one indicator, p_1 cannot be assigned to a lower category than p_2). Whenever a requirement failed to be respected, a second round of discussions was organized to revise the rules (Figure 2). Most of the rules initially chosen had the same four categories:

- No information suggesting that wetland W is suitable, even poorly, to pursue objective O.
- Information suggesting that W is poorly suitable.
- Information suggesting that W is moderately suitable.
- Information suggesting that W is very suitable.

Additional rounds of discussions were organized for the other objectives until they converge towards the same structure (the reasons for this homogeneity requirement are explained below). This process resulted in a rule-base (Supplementary Material 2).

Such rule-based approaches are robust because they are based on expert judgements about concrete criteria mastered by the expert, rather than on abstract parameters. The iterative process (Figure 2) also strengthens its robustness.

Political aggregation

Level 2 problem is a political problem whereby a manager selects objectives from the list collectively validated. Two kinds of situations are possible:

If the manager selects only one objective, then the solution to the level 1 problem for this objective provides a suitable prioritization.

If he/she selects several objectives, the solutions for the different objectives selected have to be aggregated. The aggregation should reflect the manager's perception of the relative importance of the objectives. Analytical aggregation models may be suitable for such purposes. Among them, MR-Sort (Majority Rule Sorting) (Leroy et al. 2011) is a version of ELECTRE-TRI (Roy & Bouyssou 1993), a method used to attribute alternatives to p predefined categories $c_1 \dots c_p$ delimited by $p\text{-}1$ profiles $b_1 \dots b_{p-1}$. Alternatives are compared to these profiles with respect to each criterion. Alternative a is said to outrank b_h (which is noted aSb_h) if a is considered better than b_h for a proportion $\lambda \epsilon [0.5,1]$ of criteria, pondered by their respective weights $w \epsilon]0,0.5]$. Alternative a is successively compared to profiles b_j, for $j=p-1,\dots,0$, and it is assigned to the first category c_j such that aSb_j (other versions of ELECTRE-TRI integrate indifference and preference thresholds, and veto values). Where to place the thresholds is a complex issue in ELECTRE-TRI. In our case, the criteria correspond to the different objectives chosen, and the thresholds are therefore straightforward, because all the objectives have the same categories.

One strength of MR-Sort is that its assignment procedure is characterized axiomatically (Bouyssou & Marchant 2007a,b). Moreover, MR-Sort is implemented in the ELECTRE-TRI plug-in on QGIS (Sobrie et al. 2013), an open-source software that the PMH uses routinely. We therefore opted for MR-Sort.

When working as DAP with managers, the PHM will ask them to choose weights (w) that reflect the relative importance of their objectives, and a majority threshold (λ) (Figure 3). These parameters are much less numerous than those required by weighted-sums (n+1 parameters for n objectives, whereas weighted-sums require as many parameters as there are indicators). In addition, in our case, w reflect the relative importance that managers give to their own objectives, which is much less abstract than giving weights to indicators. The values of λ that can make a difference depend on the number of objectives chosen and on w, and can be easily interpreted in terms of which objective or coalition of objectives is decisive (see the illustration below). That said, the difficulty involved in choosing these parameters is the subject of debate (Dias et al. 2002). It is consequently important that implementations include sensitivity analyses. The robustness and sensitivity of various ELECTRE models can involve complex analyses. In our case, these analyses should be simple ones (like those proposed by Merad et al. 2004), because the PMH should be able to implement them routinely. We discussed and validated the following procedure with the PMH:

- For weights, the PMH should start by recalling Saaty's (1980) scale, which translates weight ratios into easily understandable verbal formulations (1:1 means "equally important", 3:1 means "moderately more important", 5:1 means "strongly more important", etc.), thus helping the manager to choose. Concerning λ, the analysis can start with the lowest possible value, $\lambda = 0.5$.
- The DAP should then vary each weight by ±10% (an admittedly arbitrary figure). The proportion of wetlands moving from one category to another should then be reported. If the prioritization remains unchanged, the difficulty that the manager feels when expressing weights is not a problem; by contrast, if this proportion is "too high", this difficult choice is an important one. In practice, what counts as "too high" should be decided case-by-case: if the manager is puzzled by the extent to which the prioritization is changed by a change in weight that he/she considers insignificant, the proportion is "too high." The manager should then carefully decide if he/she endorses the original prioritization or the new one, and the analysis should be reproduced until he/she considers the choice of w satisfactory.
- DAP and the manager should then discuss the impact of variations of λ. The DAP should identify the threshold values and help the manager choose a λ that corresponds to his/her understanding of his/her objectives.
- If objectives with rules involving quantitative thresholds are chosen (O7-9), the case of wetlands with values near thresholds should also be discussed.

This procedure is too sketchy to be an irreproachable sensitivity analysis. But it is a second-best procedure that the DAP will be able to systematically implement.

Illustration

Let us illustrate possible implementations with the fictitious example of a manager (M) who would choose O5, O7 and O8 with w_{O5}=0.45, w_{O7}=0.3 and w_{O8}=0.25, in the vicinity of Doucier, an area for which the database contains 33 wetlands. This could be a local charity whose main aim is to conserve biodiversity (hence the choice of O5 with a high w_{O5}), but which lacks the means to implement management autonomously (hence O7, with a smaller w_{O7}) and would prefer to avoid land ownership problems, if possible (hence O8 with an even smaller w_{O8}). Figure 4 illustrates the resulting prioritization for λ=0.5. Changing the weights one by one by ±10% does not alter it. In fact, prioritization does not change even if the weights are equalized. This implementation hence appears very robust with respect to weights. Concerning λ, using the above weights, for $0.5 \leq \lambda < 0.55$, O7 and O8 may be decisive against O5 [a]; for $0.55 \leq \lambda < 0.7$, a coalition between O5 and O7 or O8 is decisive [b]; for $\lambda \geq 0.7$, the three objectives have to agree [c]. Compared to the basal version [a], these different values shift 3[c] and 24[d] of the 33 wetlands from one category to another. The heaviest decision would be to choose λ in range [d]. But M should easily be able to make up his/her mind, because this decision has clear implications: for a wetland to be assigned to category *C*, the wetland has to be assigned to *C* for all the objectives. The decision between [a] and [b] implies a small modification in prioritization, whereas it reflects an important and easily understandable decision about the importance of the objectives chosen. In this case, the application of the method hence also appears to be robust for λ.

The rules for O8 involve two thresholds (t_1=0.44, t_2= 0.63). Decreasing t_1 by 10% does not alter prioritization, while a 20% decrease shifts two wetlands to another category; increasing

t_1 by 10% shifts only one wetland (unchanged with +20%). Concerning t_2, a 10% decrease shifts two wetlands (unchanged with -20%), and a 10% increase shifts one wetland (unchanged with +20%). In both cases, M hence only has to examine 3 wetlands to make sure that these thresholds do not produce spurious differences in categorizations.

To sum-up, if M is able to make basic decisions about the relative importance and decisiveness of his/her own objectives and to have a qualified opinion about the suitability of a few individual wetlands for O8, the implementation of our method here appears to be very robust. However, we cannot emphasize enough that this analysis needs to be redone for all implementations.

Prospects of concrete implementations

The whole application (as opposed to the illustrative example above) was presented to a large panel of managers and local stakeholders in March, 2018, in two workshops that included role-plays in which the participants had to choose objectives and parameters, and discuss prioritization. The managers appeared to be convinced, but the real test will be real-life prioritizations for managers. Due to a new law imposing changes in environmental governance structures in France in 2018, these real-life applications are planned to start in 2019. In the meantime, it is useful to reflect on the likelihood for these applications to be successful and to unfold smoothly. The main issue that could threaten such applications is that the novelty of the tool and the procedure might discourage managers and induce costs for them to understand the tool and appropriate it. We argue that several important features of our approach ensure that such worries are exaggerated.

First, the tool that we propose and the tasks that managers will have to perform are not considerably more complex than what they are used to. The tasks that managers will be asked to perform are mainly to choose objectives, which is something that they routinely do for example when they devise management plans, and, as illustrated in our fictitious example, to express limited information about the relative importance of their objectives.

Second, although starting to work with a new tool always involve additional cognitive efforts, when managers want to prioritize their wetlands, which is not something they do very often (at most, they do it once every 5 or 10 years), they usually ask for decision support to consultancies through public procurement procedures. They thereby often end-up working with consultants who use methods or manners of applying standard methods that are also novel for them. Costs associated to novelty are accordingly pervasive, and are not especially higher with our approach.

Third, related to the previous point, whereas managers usually work with consultants that are typically new interlocutors for each public procedure they launch, with our approach managers will work with the PMH, which is a partner with whom they have been working on a regular basis since many years. The novelty in ways of doing things and interacting is therefore likely to be less costly for managers than in their standard practice.

For these various reasons, we argue that the prospects of concrete implementations of our application of the Meta-DA framework to wetland in the Bourgogne-Franche-Comté region are positive, which should encourage such implementations.

Limitations

This implementation of our approach in the case of wetland prioritization in Bourgogne-Franche-Comté could be improved in several respects.

When deploying T1, we assessed the legitimacy of the PMH as a DAP, because large-scale funding institutions had given it a particularly convenient role to become a DAP. But we did not assess the legitimacy of other candidate DAP, and in contexts where there is more liberty to choose a DAP, a more ambitious approach, comparing the respective legitimacy of various candidate DAP would strengthen the credentials of the approach. Many aspects of our discussion of the reasons why the PMH qualifies as legitimate could also deserve more in-depth analyses in future studies. For example, regarding criterion (iii), we did not assess whether the database produced by the PMH correctly identified all the relevant knowledge gaps on wetland in the region. Moreover, Meinard (2016) clearly presented the list of four criteria that we used above as preliminary and open-ended. A more complete account of the concept of legitimacy in conservation settings could therefore usefully enrich future applications of our Meta-DA approach.

The rules chosen by different experts from different institutions, and the meaning they give to categories, could be compared. Another critical issue is listing the objectives. The objectives were validated by representatives of managers, but the listing could be enriched, and should be regularly updated to take social and legal changes into account. More fundamentally, the procedure used, through the work of the taskforce on wetland prioritization, to decide that the political/technical divide should correspond to a choice of objectives by managers (described above) could be strengthened in future studies, in particular by involving more numerous meetings of the taskforce, and more sophisticated participation techniques than the simple meetings involved in our case. Such more sophisticated approaches could end-up placing the political/technical divide elsewhere. Another important issue which was left aside here is whether stakeholders, other than managers, should be integrated in the discussion concerning possible objectives, because they can bring in insights concerning possible objective, and can influence the listing. This issue echoes discussion in the literature on stakeholder identification (Schwartz et al. 2018).

Some managers can also be willing to choose more idiosyncratic objectives than the ones of the validated list. Elaborating a more fine-tuned prioritization for them is of course possible, and numerous methods, some of them considerably more sophisticated than our, can be put to use for that purpose (e.g. Lovette et al. 2018, Qu et al. 2018). But such a specific treatment would not count as an implementation of the same homogeneous policy that is implemented for other managers, and would involve additional marginal costs.

Concerning MR-Sort, instead of asking managers to express parameters, one could infer them from assignment examples (Mousseau & Slowinski 1998). Future studies should compare the two protocols in terms of their practicability, robustness and understandability for managers. Using more complete versions of ELECTRE-TRI (Greco et al. 2016, part III) could also be envisaged, especially those that are usable thanks to the existing ELECTRE-TRI Qgis plug-in. Beyond ELECTRE-TRI, many other MCDA methods can be used to address problems similar to the one tackled here (see Roy & Slowinski 2013). The results obtained with different methods, and the way managers react to the different approaches could be compared to choose the most acceptable or convenient method.

It should also be noted that this work was limited by the content of the PMH wetland database. This limitation is the price to pay to develop a tool applicable to the whole study area, which was our main aim. However, some managers will certainly want to obtain more precise prioritizations by acquiring new data, e.g. on the projected cost of different actions. Here again, such idiosyncratic prioritization are doable but involve additional marginal costs and fall outside the scope of the homogeneous policy studied here.

Conclusions

We have argued that environmental policies can be improved by implementing a meta-decision-analysis approach, deploying three tasks: T1—identifying a legitimate decision-aid provider to aid managers in routine policy implementation, T2—distinguishing political from technical choices, T3—designing tools that are compatible with both the decision-aid provider's skills and legitimacy constraints. Despite some limitations, our application to wetland prioritization in Bourgogne-Franche-Comté illustrates its feasibility and usefulness. This approach entails recommendations for various kinds of actors involved in environmental policies:

- For researchers, it provides a research agenda to develop new applications of multi-criteria decision-analysis.
- For managers and potential decision-aid providers, it suggests that, for some problems that they face collectively, they should seek the help of researchers to implement meta-decision-analysis.
- For policy-makers, it suggests that, by encouraging meta-decision-analysis, e.g. through dedicated funding schemes, they could improve the effectiveness of policies.

Whereas, in most studies in the literature, decision support is provided by researchers themselves, which raises the question of the legitimacy of researchers' recommendations, in the meta-decision-analysis approach, decision support is provided by actors selected on the basis of their legitimacy. Moreover, because decision-aiding providers involved in applications of this approach are, by definition, actors that will provide decision support to a series of decision-makers facing similar problems, a single intervention by researchers allows decision-aiding providers to participate in day-to-day policy implementations with many decision-makers.

By innovating in the methodology used to apply MCDA tools (rather than producing new tools as most studies in the literature do), this new approach hence promises to bridge "knowing-doing gaps" by fostering the applications of the rich MCDA academic literature to the routine, large-scale implementation of environmental policies.

Figure 1. General structure of the application.

Figure 2. Procedure to obtain a rule-base.

Figure 3. Aggregating prioritizations for several objectives using MR-Sort.

Figure 4. Example of prioritized map of the Doucier vicinity (background map: Open Street Maps; projection: WSG84, EPSG: 4326).

Table 1. List of objectives. O1-6 refer to the function of wetlands targeted by managers. O7-9 focus on the conditions that managers deem pivotal for the feasibility of their actions.

Table 2. Rules for objective O1 with consistency checks.

Supplementary Material 1. List of relevant indicators homogeneously available on the whole study area.

Supplementary Material 2. Rule-bases.

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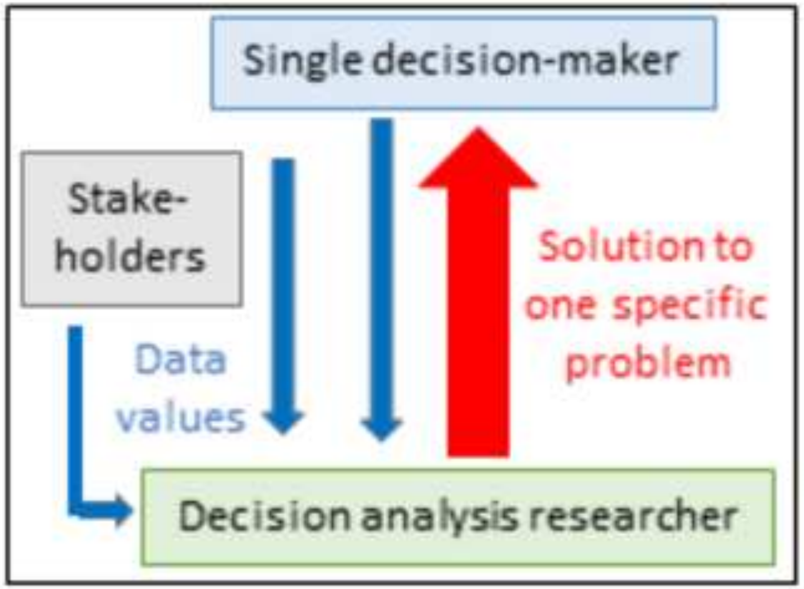
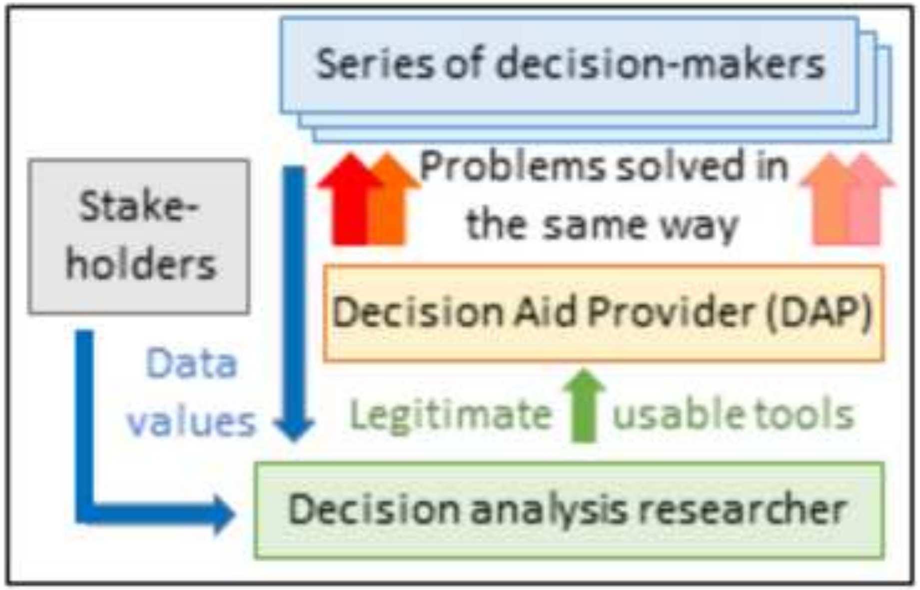
*Graphical Abstract



"Standard" decision analysis



Meta decision analysis

***Highlights (for review : 3 to 5 bullet points (maximum 85 characters including spaces per bullet point)**

- Researchers's advices on environmental policies should be operational and legitimate
- We introduce a multi-criteria decision-analysis approach satisfying these criteria
- It identifies a legitimate decision aiding provider and provides him usable tools
- It fosters applications of advances in decision science to environmental policies
- We apply this approach to prioritize wetlands in the Bourgogne-Franche-Comté region

A Meta-Decision-Analysis approach to structure operational and legitimate environmental policies – with an application to wetland prioritization

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Abstract

Environmental policies are implemented in complex socio-economic settings, where numerous stakeholders hold different and potentially conflicting values. In addition to being scientifically well-founded, the experts' recommendations on which these policies are based therefore also need to be operational and legitimate.

Multi-criteria decision-analysis (MCDA) is often used to solve management problems, but studies in the literature rarely place importance on the way stakeholders perceive researchers' interventions (which implies a lack of legitimacy), and most managers lack the skills to reproduce routinely the operations involved (which implies a lack of operationality). We use MCDA methodology in a different approach: "meta-decision-analysis" (Meta-DA). As researchers, instead of striving to identify the best way for us to solve managers' problems, we identify the actors (the decision-aid providers, DAPs) who are best placed to help managers, and we provide DAPs with the necessary tools.

Implementing this approach involves three tasks: T1—identifying a legitimate DAP who will provide decision-aid to managers in routine policy implementations; T2—identifying, among the decisions involved in solving managers' problems, those for which managers and the stakeholders concerned consider that some actors have particular legitimacy; T3—designing tools that are compatible with both the DAP's skills and legitimacy constraints.

We applied this approach, structured around T1-3, to wetland prioritization in a French administrative region (Bourgogne-Franche-Comté). This application illustrates the feasibility and usefulness of our approach.

Our approach entails recommendations for various kinds of actors involved in environmental policies: For researchers, it provides a research agenda to develop new applications of MCDA. For managers and potential DAPs, it suggests that, for some of the problems they face collectively, they should seek the help of researchers to implement a Meta-DA approach. For policy-makers, it suggests that, by encouraging Meta-DA, for example through dedicated funding schemes, they could improve the effectiveness of environmental policies.

Keywords: environmental policy, prioritization, multi-criteria decision-analysis, legitimacy, wetlands, knowledge-implementation gaps.

Introduction

Environmental policies, here defined as “organized sets of actions to conserve or restore natural sites, species or ecosystems”, often suffer from “knowing-doing gaps” (Matzek et al. 2014): scientific knowledge accumulates but fails to inform action. This is largely because the decisions involved in designing and implementing environmental policies are not straightforward applications of scientific knowledge. They are applied in complex political and economic settings, where different actors and stakeholders make potentially conflicting claims and want their voice to count in collective decision-making. In such contexts, it is not enough for experts’ recommendations to have sound scientific foundations: they also need to be operational and legitimate (Jeanmougin et al. 2017).

The first requirement (operationality) means that it should be possible to use them in day-to-day policy implementation**.** Operationality, understood in this sense, should be distinguished from concreteness, referring to the requirement that recommendations should not be purely theoretical: operationality entails concreteness, but the reverse is not true, and many state-of-the-art scientific studies fail to provide operational recommendations despite their concreteness.

The second requirement (legitimacy) means that policies are doomed to fail if the actors concerned consider that experts overstepped their role when performing analyzes or articulating recommendations (this definition and the analysis of legitimacy issues in the rest of the article are based on Meinard (2017)).

Many authors call for tighter interactions between researchers and practitioners and point a need for researchers to address research priorities identified by practitioners (e.g. Schwartz et al. (2018)). However, this literature arguably underestimates the fact that the incentives driving researchers and actors looking for operational and legitimate decision support can diverge: whereas scientific publication requires novelty in theory and methods, actors concerned with operationality can be more interested in deploying applications of existing knowledge; whereas academic science requires state-of-the-art, highly sophisticated techniques, actors concerned with legitimacy can prefer approaches that are less sophisticated but easier to explain to concerned stakeholders. The solutions presented in the literature are limited to recommendations designed to mitigate such discrepancies (e.g. Beier et al. (2017) recommend to create new incentives to encourage researchers to focus less on publications and engage more in actionable science), but recommendations of that sort are rarely followed (Arlettaz et al. 2010). This gap in the literature calls for deeper investigations on the role that researchers can play in decision support activities and on how they can take operationality and legitimacy constraints into account.

Indeed, most studies take for granted that the only way for a research project to be relevant to decision support is for the involved researchers to solve the specific problem that a specific (sometimes fictitious) decision-maker faces, or to produce a tool that the latter can use (a so-called “decision support system” – Gilliams et al. 2005, Keith et al. 2008). For example, when Bournaris et al. (2015) produce a model integrating irrigation water use and environmental protection in Northern Greece, they assume that this decision support system can be directly used as a planning tool by the regional authorities. Similarly, when Maleki et al. (2018) use a multi-criteria spatial decision support system to plan a scheme for wetland restoration in the Hamum area (Iran), or when Ang et al. (2016) combine the use of a remote sensing and geographic information system and an avifauna survey to assess wetland restoration in the Yellow River Delta (China), their results are, respectively, a wetland prioritization and a recommendation for a land-use pattern, both directly intended for decision-makers acting on the concerned areas.

The importance of such results is undeniable. However, such studies do not question how decision-makers and concerned stakeholders perceive the decision-support that researchers provide: will the scientific credentials of the published study, or the intervention of local expert in the parametrization of models, be enough to convince them that recommendations are legitimate? Moreover, beyond hinting at possible applications of their method to other case studies (e.g. Maleki et al. (2018) in their concluding paragraph), these studies produce results that are valid only for their case-studies and are not straightforwardly transferable, as actors concerned with operationality would like them to be.

In this article, we introduce an approach, “meta-decision-analysis” (Meta-DA), which explicitly rethinks the role of researchers in decision-support to environmental policies, and thereby tackles the challenges of integrating the operationality and legitimacy requirements in research activities. This article is organized in two parts. In a first part, we present our conceptual framework and explain how it can be applied to the usage of multi-criteria decision-analysis (MCDA) (Greco et al. 2016) in the context of decision support to operational and legitimate policies. In a second part, we then illustrate a concrete implementation of our approach in the case of wetland prioritization in the Bourgogne-Franche-Comté region in France.

Conceptual framework: structuring operational and legitimate environmental policies through Meta-DA

MCDA is a branch of Operational Research (itself part of decision sciences), aimed at providing decision-makers with means to improve their decisions, through a better representation of various aspects of their problems, and a better understanding of associated constraints. MCDA methods and tools are used in numerous environmental disciplines (Esmail & Geneletti 2018), particularly in conservation planning (Regan et al. 2007, Farashi et al. 2016), but also invasive ecology (Dana et al. 2013), ecological risk assessment (Malekmohammidi & Blouchi 2014), ecosystem services valuation (Fagioli et al. 2017), among others. In such studies, MCDA methodology is used to select and apply state-of-the-art MCDA technologies, using researchers' state-of-the-art MCDA skills, to solve particular problems (e.g. Gregory & Long 2009, Robinson et al. 2016, Robinson et al. 2017). Although such studies produce important results, like the larger literature referred to above, they are often ill-equipped to feed legitimate and operational policy implementations. Indeed, although these studies make a point to take into account the values and objectives of stakeholders and decision-makers, they rarely place importance on the way the former perceive researchers' interventions. They do not investigate whether they see researchers' measurements of their values and the recommendations they derive from them as legitimate. This contrast is illustrated, for example, by Wu et al. (2012)'s use of MCDA to compare policy options to protect a nature reserve in China. Although they explicitly integrate in their analysis the acceptance of the various policy options by farmers, they do not investigate the way farmers and other relevant actors perceived their MCDA analysis (integrating farmer's acceptance) and whether they deem that a decision based on this analysis is legitimate. Among the 86 articles applying MCDA to nature conservation reviewed by Esmail et al. (2018), only Ferretti & Pomarico (2013), Van Elegem et al. (2002), Strager & Rosenberger (2006) and Zhang et al. (2013) emphasized the importance of this aspect, without devoting important analyses to it.

Besides, most decision-makers lack the skills to reproduce the operations involved in these studies routinely and, because an indefinitely continued interaction between decision-makers and MCDA researchers would be impractical, exceedingly expansive and inefficient, most decision-analysis (DA) processes do not survive the end of the research projects that launched them. Coming back to the articles reviewed by Esmail et al. (2018), although many of them mention the transferability of their results and applicability of their methods to other case studies, this mention is limited to a reference in discussion or perspective, without in-depth analysis of the actors and settings liable to ensure that operational replications are indeed implemented (notice, however, the deeper investigation in Van Elegem et al. 2002).

These two limitations of current MCDA studies, echoing the limitations in the larger literature mentioned in the introduction, highlight that innovation and scientific advances in applications of MCDA can occur at two levels:

- at a first level, which is the most extensively explored in the literature, scientific advances are about elaborating new tools, better adapted to the specific problem they are used to solve;
- at a second level, which is much less explored in the literature, innovations is about elaborating how existing MCDA tools can be put to use, so as to find a place in day-to-day policy implementations.

The approach developed in this article, which we call "Meta-DA", takes place at the second level and proposes, at this second level, a new role for researchers in policy decision support. We propose that, as decision analysts, instead of trying to identify the best way to solve a particular decision-maker's problem, we should provide decision support to the actor (thereafter called "the decision-aid provider", DAP) who is best placed to help a series of decision-makers to solve in the same way, using the same standards and methods, the problems that the implementation of a given policy creates for them (see the illustration of the contrast between Meta-DA and more "standard" approaches in the graphical abstract). Researchers themselves are candidate DAPs, but other actors may be better placed, in particular if the actors, stakeholders and decision-makers concerned consider them to be more legitimate, for example thanks to their acknowledged local expertise and involvement in the local network of actors. The first pivotal task for the implementation of a Meta-DA approach is therefore to:

T1: Identify an actor considered by decision-makers and the actors and stakeholders concerned to be sufficiently legitimate to become a routine DAP.

If the DAP uses methods that preempt the decisions made by legitimate actor(s), his/her own legitimacy may collapse. The second pivotal task is therefore:

T2: Identify, among the decisions involved in solving the decision-makers' problems (i.e. decisions concerning values of parameters, objectives to pursue, ties to cut, trade-offs to make, cases to take as exemplary, etc.), those for which decision-makers and the concerned actors and stakeholders consider that some actors have particular legitimacy (we call such decisions "political", as opposed to "technical" ones).

Notice that this task (T2) cannot be trivially solved by scientists or experts devising or calculating options or alternatives (the would-be "technical" part) and then studying the values that decision-makers, actors and stakeholders bestow on these pre-determined options or alternative (the would-be "political" part). Indeed, the very identification of alternatives and even the very formulation of the problem can, at least in some cases, be considered by decision-makers and concerned actors and stakeholders to belong to the "political" realm. Attempts to fully separate political from technical decisions have a long history of failure (Callon et al. 2011). However, in concrete situations, actors can agree on a shared understanding of this political/technical divide, and this provisional and local understanding is all that T2 requires.

Lastly, within the constraints imposed by T1-2, MCDA methodology should be used to:

- T3: Design techniques compatible with the DAP's skills and legitimacy constraints to solve the various aspects of decision-makers' problem.

Some studies already display a Meta-DA architecture of sorts (e.g. Van Elegem et al. 2002). However, they are not formally structured around T1-3, which prevents them from decisively contributing to operational and legitimate policies.

In the next section, we present such an application structured around T1-3.

Application: using Meta-DA to structure operational and legitimate wetland prioritization

Wetlands are ecosystems where water largely determines the composition of plant communities and ecological functioning (Maltby & Barker 2009). Examples include swamps, peatlands, and humid grasslands. Wetlands are targeted by numerous conservation policies justified by their contribution to biodiversity (Junk et al. 2006) and associated ecosystem services, such as pollutant filtration, flood mitigation, water storage and climate regulation (MEA 2005).

The policy that we aim to improve here encompasses all the initiatives launched in France by regional to national scale institutions (Water Agencies, administrative Regions and the Ecology Ministry), to encourage and finance wetland conservation plans, provided they are based on a rigorous wetland prioritization. More precisely, we focus on implementations in the Bourgogne-Franche-Comté administrative region, an area of nearly 50,000 km². To be coherent and fair to managers, this policy must be based on a prioritization method homogeneously applicable in the whole area.

The method currently recommended (e.g., in AERM 2014) uses weighted-sums to aggregate encoded information on wetlands. This approach has serious drawbacks (D):

- D1: Eliciting the information needed to parametrize weighted-sums is extremely difficult.

- D2: Weighted-sums are compensatory: a high mark on one criterion can compensate for a low mark or even a zero on another. In many multi-criteria problems, this is not appropriate. For example, if one wants to choose a race car, no amount of streamlining can compensate for the absence of a motor (see Bouyssou & Marchant 2007a,b for a theoretical exploration of compensatory and non-compensatory methods).
- D3: Weighted-sums treat technical and political decisions similarly and indecipherably.

We applied T1-3 to overcome these limitations.

T1: A legitimate DAP

For the purpose of providing decision support to wetland managers (which are the decision-makers in our case), many candidate DAP could be envisaged in the Bourgogne-Franche-Comté region. The institutions implementing the policy, in particular the Water Agencies, could take this task upon themselves, as they have done in the past (e.g. AERM 2014). So could also the governmental decentralized services (*Directions Régionales de l'Environnement, de l'Aménagement et du Logement*). Other prominent candidates are local administrations in charge of the management of water bodies and associated ecosystems in large parts of the region, such as the Soâne Doubs Local Public Basin Establishment (*Etablissement Public Territorial de Bassin*), local scale administrations already implementing or orchestrating management operations (*Conseil Départementaux*) or expertise institutions specialized in the conservation of natural areas and habitats such as the Botanical Conservatory (*Conservatoire Botanique*). Nonprofit organizations dedicated to foster conservation and research centers in multi-criteria decision support or environmental management could also play the role of DAP. T1 consists in selecting a legitimate DAP among these candidates (if there exist one).

To do that, we need criteria to sort out legitimate candidates from non-legitimate ones. Meinard (2017) reviewed approaches to legitimacy in the conservation literature, showed the diversity and complexity of criteria that can be used to assess legitimacy, and then suggested four criteria designed to be particularly relevant to conservation policies:

i) Transparency of procedures, where roles and statuses are clearly defined,
ii) openness to external expertise,
iii) acknowledgment of knowledge gaps,
iv) acknowledgment of moral issues.

These four criteria were introduced to assess the legitimacy of a conservation policy, rather than of an actor, and notice that, once a DAP is chosen, they can be used to assess the legitimacy of the decision support s/he provides. But they can also be understood as criteria to assess the legitimacy of candidate DAPs.

In our case, though potentially legitimate, the large scale institutions funding most wetland management initiatives did not express a willingness to play the role of DAP. They rather entrusted the "*Pôle Milieux Humides*" (PMH) (wetlands team), part of a non-profit organization, the natural areas conservatory (*Conservatoire d'Espaces Naturels*) (CEN), to create a spatialized database on wetlands at the scale of the whole region, and to elaborate and implement a prioritization method. This initiative *de facto* selected a DAP, whose legitimacy we can assess thanks to the above criteria.

The selection of the PMH, and the precise definition of the perimeter of its mission, where established during a steering committee supervising the organization of the network of wetland managers in the region on November 13th, 2015. The steering committee included all the above mentioned candidate DAP and all the recognized members of the network of managers and local actors concerned with wetlands in the region. The choice was motivated by the role that the CEN had played in the area with all the members of the network of actors for many years, and was validated by the members of the steering committee. The definition of the perimeter of the mission included the need for the PMH to work with representatives of managers and experts in a collaborative way.

The selection of the PMH and the definition of its mission therefore occurred through a transparent and clearly defined procedure, and entrusted the PMH with deploying a procedure which should itself be transparent and clear (i). The need to open the work of the PMH to external expertise was explicitly put forward by the requirement to work in a collaborative way with managers and experts (ii). By centering the work to be done on the construction of a regional-scale database gathering all the information available on wetlands and, as a corollary, the identification of data that are lacking or are not homogeneously available, the agenda also explicitly took knowledge gaps into account (iii). Lastly, the need to work with managers and to be responsive to their demands included an implicit recognition that prioritization is not entirely a scientific task and managers can have moral prerogatives (iv). According to the criteria stated above, the PMH therefore has the legitimacy needed to be a DAP for wetland prioritization.

T2: Technical versus political choices

There are *a priori* many ways through which one could split the problem facing wetland managers into a technical and a political part.

A first possibility, embodied in the standard application of the weighted-sum approach, is to ask managers to give weights to the various indicators in the database. In this case, the political part is confined to this expression of values that managers bestow on aspects of wetlands captured by the various indicators, and the “technical” part that the DAP is in charge of performing encompasses almost the whole problem-solving task. At the other extreme, the very formulation of the problem and the choice of how managers can express the values they bestow on wetlands and how these values are taken into account and aggregated, can be considered to be a political part for managers to tackle. In this second option, the “technical” work of the DAP is very limited in scope. Between these two extreme options, numerous intermediate settings are conceivable: the political part can be a choice between a series of scenarios, an ordering of management objectives, a weighting of broad aspects of wetlands captured by blocks of close indicators, etc.

The task at this stage is to choose, among these possible options, one that appears acceptable to the managers, by avoiding preempting choices for which they deem they have legitimacy. In our case, this task was performed through a series of participatory events orchestrated by the PMH that unfolded between November 2015 and January 2018. During the steering committee on November 13th, 2015, it was decided that the PMH should work with a taskforce comprising representatives of the various actors already involved in or potentially interested in being involved in wetland management. The list of those actors was based on the fact that these actors had already solicited Water Agencies to fund actions or studies on wetlands or had contacted Water Agencies to express a willingness to do so or ask questions about this procedure. The representatives were chosen by the various actors themselves to participate to the taskforce. A first session of collective work of the taskforce occurred on December 15th, 2016, during which the idea emerged that a relevant prioritization procedure would leave managers choose the objectives they want to pursue, and would provide, for each possible objective, a technical procedure to compute an objective-specific prioritization. Based on numerous informal discussions with the representatives of the different managers during the six following months, the PMH then produced several propositions of lists of possible objectives, which were iteratively improved, so as to reflect the choices that managers can be willing to make, subject to the constraint that the regional database should contain relevant information to compute a prioritization relative to these possible objectives

(Supplementary Material 1). On July 13^{th}, 2017, a final list of objectives that managers can make the political choice to pursue (Table 1) was discussed and eventually validated by the taskforce.

During this process, the collective thereby distinguished between two sub-problems:

- The identification and aggregation of relevant information for each objective, which was considered to be a technical matter that the PMH was competent to perform (level 1 problem);
- The choice of management objectives, for which managers have a certain legitimacy (level 2 problem).

T3: Designing techniques to solve different aspects of the problem

Figure 1 schematizes how these two sub-problems are tackled in this application of Meta-DA.

Technical aggregation

Level 1 problem is a "sorting problem", which consists in assigning wetlands to predefined ordered categories reflecting how suitable they are for a given objective. The main MCDA methods to tackle sorting problems use assignment rules or analytical aggregation models. Rule-based assignments are recommended when experts are capable of articulating a logic linking the pieces of information to be aggregated (Azibi & Vanderpooten 2001). In our case, this was seen by the actors involved as a task for which the PMH was competent. We therefore chose a rule-based approach.

Drawing-up rules involved numerous meetings during which the PMH expressed provisional rules. We then verified coherence requirements (Table 2): completeness (each profile should be assigned to a category), exclusiveness (no profile should be assigned to more than one category), and monotonicity (if profile p_1 has at least as high values as p_2 for every indicator, and a higher value for at least one indicator, p_1 cannot be assigned to a lower category than p_2). Whenever a requirement failed to be respected, a second round of discussions was organized to revise the rules (Figure 2). Most of the rules initially chosen had the same four categories:

- No information suggesting that wetland W is suitable, even poorly, to pursue objective O.
- Information suggesting that W is poorly suitable.
- Information suggesting that W is moderately suitable.
- Information suggesting that W is very suitable.

Additional rounds of discussions were organized for the other objectives until they converge towards the same structure (the reasons for this homogeneity requirement are explained below). This process resulted in a rule-base (Supplementary Material 2).

Such rule-based approaches are robust because they are based on expert judgements about concrete criteria mastered by the expert, rather than on abstract parameters. The iterative process (Figure 2) also strengthens its robustness.

Political aggregation

Level 2 problem is a political problem whereby a manager selects objectives from the list collectively validated. Two kinds of situations are possible:

If the manager selects only one objective, then the solution to the level 1 problem for this objective provides a suitable prioritization.

If he/she selects several objectives, the solutions for the different objectives selected have to be aggregated. The aggregation should reflect the manager’s perception of the relative importance of the objectives. Analytical aggregation models may be suitable for such purposes. Among them, MR-Sort (Majority Rule Sorting) (Leroy et al. 2011) is a version of ELECTRE-TRI (Roy & Bouyssou 1993), a method used to attribute alternatives to p predefined categories $c_1 \ldots c_p$ delimited by $p\text{-}1$ profiles $b_1 \ldots b_{p\text{-}1}$. Alternatives are compared to these profiles with respect to each criterion. Alternative a is said to outrank b_h (which is noted aSb_h) if a is considered better than b_h for a proportion $\lambda \epsilon [0.5,1]$ of criteria, pondered by their respective weights $w \epsilon]0,0.5]$. Alternative a is successively compared to profiles b_j, for $j=p\text{-}1,\ldots,0$, and it is assigned to the first category c_j such that aSb_j (other versions of ELECTRE-TRI integrate indifference and preference thresholds, and veto values). Where to place the thresholds is a complex issue in ELECTRE-TRI. In our case, the criteria correspond to the different objectives chosen, and the thresholds are therefore straightforward, because all the objectives have the same categories.

One strength of MR-Sort is that its assignment procedure is characterized axiomatically (Bouyssou & Marchant 2007a,b). Moreover, MR-Sort is implemented in the ELECTRE-TRI plug-in on QGIS (Sobrie et al. 2013), an open-source software that the PMH uses routinely. We therefore opted for MR-Sort.

When working as DAP with managers, the PHM will ask them to choose weights (w) that reflect the relative importance of their objectives, and a majority threshold (λ) (Figure 3). These parameters are much less numerous than those required by weighted-sums (n+1 parameters for n objectives, whereas weighted-sums require as many parameters as there are indicators). In addition, in our case, w reflect the relative importance that managers give to their own objectives, which is much less abstract than giving weights to indicators. The values of λ that can make a difference depend on the number of objectives chosen and on w, and can be easily interpreted in terms of which objective or coalition of objectives is decisive (see the illustration below). That said, the difficulty involved in choosing these parameters is the subject of debate (Dias et al. 2002). It is consequently important that implementations include sensitivity analyses. The robustness and sensitivity of various ELECTRE models can involve complex analyses. In our case, these analyses should be simple ones (like those proposed by Merad et al. 2004), because the PMH should be able to implement them routinely. We discussed and validated the following procedure with the PMH:

- For weights, the PMH should start by recalling Saaty's (1980) scale, which translates weight ratios into easily understandable verbal formulations (1:1 means "equally important", 3:1 means "moderately more important", 5:1 means "strongly more important", etc.), thus helping the manager to choose. Concerning λ, the analysis can start with the lowest possible value, $\lambda = 0.5$.
- The DAP should then vary each weight by ±10% (an admittedly arbitrary figure). The proportion of wetlands moving from one category to another should then be reported. If the prioritization remains unchanged, the difficulty that the manager feels when expressing weights is not a problem; by contrast, if this proportion is "too high", this difficult choice is an important one. In practice, what counts as "too high" should be decided case-by-case: if the manager is puzzled by the extent to which the prioritization is changed by a change in weight that he/she considers insignificant, the proportion is "too high." The manager should then carefully decide if he/she endorses the original prioritization or the new one, and the analysis should be reproduced until he/she considers the choice of *w* satisfactory.
- DAP and the manager should then discuss the impact of variations of λ. The DAP should identify the threshold values and help the manager choose a λ that corresponds to his/her understanding of his/her objectives.
- If objectives with rules involving quantitative thresholds are chosen (O7-9), the case of wetlands with values near thresholds should also be discussed.

This procedure is too sketchy to be an irreproachable sensitivity analysis. But it is a second-best procedure that the DAP will be able to systematically implement.

Illustration

Let us illustrate possible implementations with the fictitious example of a manager (M) who would choose O5, O7 and O8 with w_{O5}=0.45, w_{O7}=0.3 and w_{O8}=0.25, in the vicinity of Doucier, an area for which the database contains 33 wetlands. This could be a local charity whose main aim is to conserve biodiversity (hence the choice of O5 with a high w_{O5}), but which lacks the means to implement management autonomously (hence O7, with a smaller w_{O7}) and would prefer to avoid land ownership problems, if possible (hence O8 with an even smaller w_{O8}). Figure 4 illustrates the resulting prioritization for λ=0.5. Changing the weights one by one by ±10% does not alter it. In fact, prioritization does not change even if the weights are equalized. This implementation hence appears very robust with respect to weights. Concerning λ, using the above weights, for $0.5\leq\lambda<0.55$, O7 and O8 may be decisive against O5 [a]; for $0.55\leq\lambda<0.7$, a coalition between O5 and O7 or O8 is decisive [b]; for $\lambda\geq0.7$, the three objectives have to agree [c]. Compared to the basal version [a], these different values shift 3[c] and 24[d] of the 33 wetlands from one category to another. The heaviest decision would be to choose λ in range [d]. But M should easily be able to make up his/her mind, because this decision has clear implications: for a wetland to be assigned to category *C*, the wetland has to be assigned to *C* for all the objectives. The decision between [a] and [b] implies a small modification in prioritization, whereas it reflects an important and easily understandable decision about the importance of the objectives chosen. In this case, the application of the method hence also appears to be robust for λ.

The rules for O8 involve two thresholds (t_1=0.44, t_2= 0.63). Decreasing t_1 by 10% does not alter prioritization, while a 20% decrease shifts two wetlands to another category; increasing

t_1 by 10% shifts only one wetland (unchanged with +20%). Concerning t_2, a 10% decrease shifts two wetlands (unchanged with -20%), and a 10% increase shifts one wetland (unchanged with +20%). In both cases, M hence only has to examine 3 wetlands to make sure that these thresholds do not produce spurious differences in categorizations.

To sum-up, if M is able to make basic decisions about the relative importance and decisiveness of his/her own objectives and to have a qualified opinion about the suitability of a few individual wetlands for O8, the implementation of our method here appears to be very robust. However, we cannot emphasize enough that this analysis needs to be redone for all implementations.

Prospects of concrete implementations

The whole application (as opposed to the illustrative example above) was presented to a large panel of managers and local stakeholders in March, 2018, in two workshops that included role-plays in which the participants had to choose objectives and parameters, and discuss prioritization. The managers appeared to be convinced, but the real test will be real-life prioritizations for managers. Due to a new law imposing changes in environmental governance structures in France in 2018, these real-life applications are planned to start in 2019. In the meantime, it is useful to reflect on the likelihood for these applications to be successful and to unfold smoothly. The main issue that could threaten such applications is that the novelty of the tool and the procedure might discourage managers and induce costs for them to understand the tool and appropriate it. We argue that several important features of our approach ensure that such worries are exaggerated.

First, the tool that we propose and the tasks that managers will have to perform are not considerably more complex than what they are used to. The tasks that managers will be asked to perform are mainly to choose objectives, which is something that they routinely do for example when they devise management plans, and, as illustrated in our fictitious example, to express limited information about the relative importance of their objectives.

Second, although starting to work with a new tool always involve additional cognitive efforts, when managers want to prioritize their wetlands, which is not something they do very often (at most, they do it once every 5 or 10 years), they usually ask for decision support to consultancies through public procurement procedures. They thereby often end-up working with consultants who use methods or manners of applying standard methods that are also novel for them. Costs associated to novelty are accordingly pervasive, and are not especially higher with our approach.

Third, related to the previous point, whereas managers usually work with consultants that are typically new interlocutors for each public procedure they launch, with our approach managers will work with the PMH, which is a partner with whom they have been working on a regular basis since many years. The novelty in ways of doing things and interacting is therefore likely to be less costly for managers than in their standard practice.

For these various reasons, we argue that the prospects of concrete implementations of our application of the Meta-DA framework to wetland in the Bourgogne-Franche-Comté region are positive, which should encourage such implementations.

Limitations

This implementation of our approach in the case of wetland prioritization in Bourgogne-Franche-Comté could be improved in several respects.

When deploying T1, we assessed the legitimacy of the PMH as a DAP, because large-scale funding institutions had given it a particularly convenient role to become a DAP. But we did not assess the legitimacy of other candidate DAP, and in contexts where there is more liberty to choose a DAP, a more ambitious approach, comparing the respective legitimacy of various candidate DAP would strengthen the credentials of the approach. Many aspects of our discussion of the reasons why the PMH qualifies as legitimate could also deserve more in-depth analyses in future studies. For example, regarding criterion (iii), we did not assess whether the database produced by the PMH correctly identified all the relevant knowledge gaps on wetland in the region. Moreover, Meinard (2016) clearly presented the list of four criteria that we used above as preliminary and open-ended. A more complete account of the concept of legitimacy in conservation settings could therefore usefully enrich future applications of our Meta-DA approach.

The rules chosen by different experts from different institutions, and the meaning they give to categories, could be compared. Another critical issue is listing the objectives. The objectives were validated by representatives of managers, but the listing could be enriched, and should be regularly updated to take social and legal changes into account. More fundamentally, the procedure used, through the work of the taskforce on wetland prioritization, to decide that the political/technical divide should correspond to a choice of objectives by managers (described above) could be strengthened in future studies, in particular by involving more numerous meetings of the taskforce, and more sophisticated participation techniques than the simple meetings involved in our case. Such more sophisticated approaches could end-up placing the political/technical divide elsewhere. Another important issue which was left aside here is whether stakeholders, other than managers, should be integrated in the discussion concerning possible objectives, because they can bring in insights concerning possible objective, and can influence the listing. This issue echoes discussion in the literature on stakeholder identification (Schwartz et al. 2018).

Some managers can also be willing to choose more idiosyncratic objectives than the ones of the validated list. Elaborating a more fine-tuned prioritization for them is of course possible, and numerous methods, some of them considerably more sophisticated than our, can be put to use for that purpose (e.g. Lovette et al. 2018, Qu et al. 2018). But such a specific treatment would not count as an implementation of the same homogeneous policy that is implemented for other managers, and would involve additional marginal costs.

Concerning MR-Sort, instead of asking managers to express parameters, one could infer them from assignment examples (Mousseau & Slowinski 1998). Future studies should compare the two protocols in terms of their practicability, robustness and understandability for managers. Using more complete versions of ELECTRE-TRI (Greco et al. 2016, part III) could also be envisaged, especially those that are usable thanks to the existing ELECTRE-TRI Qgis plug-in. Beyond ELECTRE-TRI, many other MCDA methods can be used to address problems similar to the one tackled here (see Roy & Slowinski 2013). The results obtained with different methods, and the way managers react to the different approaches could be compared to choose the most acceptable or convenient method.

It should also be noted that this work was limited by the content of the PMH wetland database. This limitation is the price to pay to develop a tool applicable to the whole study area, which was our main aim. However, some managers will certainly want to obtain more precise prioritizations by acquiring new data, e.g. on the projected cost of different actions. Here again, such idiosyncratic prioritization are doable but involve additional marginal costs and fall outside the scope of the homogeneous policy studied here.

Conclusions

We have argued that environmental policies can be improved by implementing a meta-decision-analysis approach, deploying three tasks: T1—identifying a legitimate decision-aid provider to aid managers in routine policy implementation, T2—distinguishing political from technical choices, T3—designing tools that are compatible with both the decision-aid provider's skills and legitimacy constraints. Despite some limitations, our application to wetland prioritization in Bourgogne-Franche-Comté illustrates its feasibility and usefulness. This approach entails recommendations for various kinds of actors involved in environmental policies:

- For researchers, it provides a research agenda to develop new applications of multi-criteria decision-analysis.
- For managers and potential decision-aid providers, it suggests that, for some problems that they face collectively, they should seek the help of researchers to implement meta-decision-analysis.
- For policy-makers, it suggests that, by encouraging meta-decision-analysis, e.g. through dedicated funding schemes, they could improve the effectiveness of policies.

Whereas, in most studies in the literature, decision support is provided by researchers themselves, which raises the question of the legitimacy of researchers' recommendations, in the meta-decision-analysis approach, decision support is provided by actors selected on the basis of their legitimacy. Moreover, because decision-aiding providers involved in applications of this approach are, by definition, actors that will provide decision support to a series of decision-makers facing similar problems, a single intervention by researchers allows decision-aiding providers to participate in day-to-day policy implementations with many decision-makers.

By innovating in the methodology used to apply MCDA tools (rather than producing new tools as most studies in the literature do), this new approach hence promises to bridge "knowing-doing gaps" by fostering the applications of the rich MCDA academic literature to the routine, large-scale implementation of environmental policies.

Figure 1. General structure of the application.

Figure 2. Procedure to obtain a rule-base.

Figure 3. Aggregating prioritizations for several objectives using MR-Sort.

Figure 4. Example of prioritized map of the Doucier vicinity (background map: Open Street Maps; projection: WSG84, EPSG: 4326).

Table 1. List of objectives. O1-6 refer to the function of wetlands targeted by managers. O7-9 focus on the conditions that managers deem pivotal for the feasibility of their actions.

Table 2. Rules for objective O1 with consistency checks.

Supplementary Material 1. List of relevant indicators homogeneously available on the whole study area.

Supplementary Material 2. Rule-bases.

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Table 1

Management objective	Description
O1: Conserving wetlands performing a flood regulation function	Objective pursued by managers willing to conserve wetlands because they perform ecosystem services pertaining to flood mitigation. These are mainly wetlands occupying expanding flood areas. Managers focussed on this objective are, for example, joint associations or municipalities in charge of flood mitigation, or municipalities wishing to reshuffle their land use plan.
O2: Conserving wetlands for low water replenishment	Objective pursued by managers concerned to take advantage of the water replenishment ecosystem services performed by some wetlands, such as those located at the river basin head, or those which are closely associated with rivers subject to severely low level discharges in summer. Managers concerned are mainly joint associations and municipalities, or structures in charge of implementing large-scale watershed management schemes, in areas where water replenishment is a serious issue.
O3: Conserving wetlands important for drinking water abstraction	Objective pursued by managers focussed on pollutant filtering functions performed by wetlands, especially when they are located in areas where they play a role in the water quality of aquifers used for drinking water abstraction. Managers concerned are mainly joint associations and municipalities, or structures in charge of implementing large-scale watershed management schemes.
O4: Conserving wetlands important for the integrity of large-scale water bodies	Objective pursued by managers in charge of improving the ecological and chemical quality of underground and surface water bodies, for whom the main point of conserving wetlands it to take advantage of the role they play in filtering pollutants originating from agricultural lands or other human infrastructures. Managers focussed on this objective are mainly structures in charge of implementing large-scale watershed management schemes.
O5: Conserving wetlands which shelter rare or endemic species or habitats	Objective pursued mainly by environmental associations or local administrations, whose main aim is to conserve or restore rare or protected habitats or populations of rare or protected species.
O6: Conserving wetlands of important cultural or social value	Objective pursued by actors concerned with the role that some wetlands play in local cultural or social life, for example because they are key tourist attractions, or are associated with local human traditions. Such actors could be local associations or administrations.
O7: Acting on wetlands equipped with an existing management structure	This feasibility objective is important for managers who lack the technical skills and workforce to implement organized environmental actions on their own, and therefore look for existing management structures they can support.
08: Targeting sites with limited land ownership fragmentation	This feasibility objective is pursued by managers who want to avoid land property problems. For example, environmental associations who lack the workforce to organize a complex consultation with landowners.
O9: Targeting mainly publicly owned sites	This feasibility objective is pursued by managers working in public institutions (such as local administrations) or who have agreements with public institutions (for example environmental associations), so that they can easily use publicly owned lands to implement conservation or restoration projects.

Table 2

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Management objective	Source of the indicator	Encoded indicator	Rule base		Consistency checks
			Textual formulation	Algebraic formulation	
O1: Conserving wetlands performing a flood regulation function	Area characterized by a high risk of inundation according to SDAGE	x_{1i}=1 if the wetland *i* is in an area characterized by a high risk of inundation, otherwise x_{1i}=0	*R1*: IF there is no indicator testifying that wetland *i* plays a role in flood mitigation, THEN *i* is affected to the category "No information in the database suggesting that i is suitable, even poorly, to pursue this objective" *R2*: IF wetland *i* is within the approximate envelope of potential inundations but in none of the other types of area, then *i* is affected to the category "Information suggesting that i is poorly suitable" *R3*: IF wetland *i* is within an area rarely inundated and/or if a dedicated expertise	*R1:* IF $x_{1i}+ x_{2i}+ x_{3i}+ x_{4i}+ x_{5i}=0$ THEN *i* is affected to the category "No information in the database suggesting that i is suitable, even poorly, to pursue this objective" *R2:* IF $x_{5i}- x_{1i}- x_{2i}- x_{3i}- x_{4i}=1$ THEN *i* is affected to the category "Information suggesting that i is poorly suitable" *R3:* IF $x_{3i}+ x_{4i}> 3.(x_{1i}+ x_{2i})$ THEN *i* is affected to the category "Information suggesting that i is moderately suitable" *R4:* IF $x_{1i}+ x_{2i}>0$ *i* is affected to the category "Information suggesting that i is very suitable"	*Completeness* To check completeness, we check if there can exist a profile ($x_{1i}, x_{2i}, x_{3i}, x_{4i}, x_{5i}$) that satisfies none of the conditions encapsulated in rules *R1-4*. Such a profile would be a solution to the following system of linear equations: $x_{1i}+ x_{2i}+ x_{3i}+ x_{4i}+ x_{5i}>0$ and $x_{5i}- x_{1i}- x_{2i}- x_{3i}- x_{4i}<1$ and $x_{3i}+ x_{4i}<= 3.(x_{1i}+ x_{2i})$ and $x_{1i}+ x_{2i}<=0$ Because this system has no solution, the rule base is complete. *Exclusiveness* To check exclusiveness, we check if there can exist a profile ($x_{1i}, x_{2i}, x_{3i}, x_{4i}, x_{5i}$) satisfying more than one rules *R1-4*. Such a profile would be a solution to the following system of linear equations: $x_{1i}+ x_{2i}+ x_{3i}+ x_{4i}+ x_{5i}=0$ and $x_{5i}- x_{1i}- x_{2i}- x_{3i}- x_{4i}=1$ or $x_{1i}+ x_{2i}+ x_{3i}+ x_{4i}+ x_{5i}=0$ and $x_{3i}+ x_{4i}> 3.(x_{1i}+ x_{2i})$ or $x_{1i}+ x_{2i}+ x_{3i}+ x_{4i}+ x_{5i}=0$ and $x_{1i}+ x_{2i}>0$ or $x_{5i}- x_{1i}- x_{2i}- x_{3i}- x_{4i}=1$ and $x_{3i}+ x_{4i}> 3.(x_{1i}+ x_{2i})$ or $x_{5i}- x_{1i}- x_{2i}- x_{3i}- x_{4i}=1$ and $x_{1i}+ x_{2i}>0$ or $x_{3i}+ x_{4i}> 3.(x_{1i}+ x_{2i})$ and $x_{1i}+ x_{2i}>0$ Because this system has no solution, the rule base is exclusive. *Monotonicity* To check monotonicity, we check if there can exist two profiles ($x_{1i}, x_{2i}, x_{3i}, x_{4i}, x_{5i}$) and ($x_{1j}, x_{2j}, x_{3j}, x_{4j}, x_{5j}$) such that *i* is affected to a category higher than the one to which *j* is affected, despite the fact that *j* dominates *i* (that is: there is at least one criterion

			has established that it performs a flood regulation function, THEN *i* is affected to the category “Information suggesting that i is moderately suitable”. *R4*: IF wetland *i* is within an area frequently inundated and/or within an area characterized by a high risk of inundation, THEN *i* is affected to the category “Information suggesting that i is very suitable”.		on which j has a higher value than *i*, and no criterion on which *i* has a higher value than *j*). Such profiles would be solutions to the following system of linear equations: $x_{1i}+x_{2i}>0$ and $x_{3j}+x_{4j}>3.(x_{1j}+x_{2j})$ or $x_{1i}+x_{2i}>0$ and $x_{5j}-x_{1j}-x_{2j}-x_{3j}-x_{4j}=1$ or $x_{1i}+x_{2i}>0$ and $x_{1j}+x_{2j}+x_{3j}+x_{4j}+x_{5j}=0$ or $x_{3i}+x_{4i}>3.(x_{1i}+x_{2i})$ and $x_{5j}-x_{1j}-x_{2j}-x_{3j}-x_{4j}=1$ or $x_{3i}+x_{4i}>3.(x_{1i}+x_{2i})$ and $x_{1i}+x_{2i}+x_{3i}+x_{4i}+x_{5i}=0$ or $x_{5i}-x_{1i}-x_{2i}-x_{3i}-x_{4i}=1$ and $x_{1j}+x_{2j}+x_{3j}+x_{4j}+x_{5j}=0$ $x_{1i}-x_{1j}+s_1=0$ $x_{2i}-x_{2j}+s_2=0$ $x_{3i}-x_{3j}+s_3=0$ $x_{4i}-x_{4j}+s_4=0$ $x_{5i}-x_{2j}+s_5=0$ $s_1+s_2+s_3+s_4+s_5>=1$ Because this system has no solution, the rule base is monotonic.
	Area frequently inundated according to the PPRI	$x_{2i}=1$ if the wetland *i* is in an area frequently inundated, otherwise $x_{2i}=0$			
	Area rarely inundated according to the PPRI	$x_{3i}=1$ if the wetland *i* is in an area frequently inundated, otherwise $x_{3i}=0$			
	Flood regulation function	$x_{4i}=1$ if a dedicated expertise has established that wetland *i* performs a flood regulation function, otherwise $x_{4i}=0$			
	Approximate envelope of potential inundations	$x_{5i}=1$ if wetland *i* is in the approximate envelope if potential inundations, otherwise $x_{4i}=0$			

Figure 1

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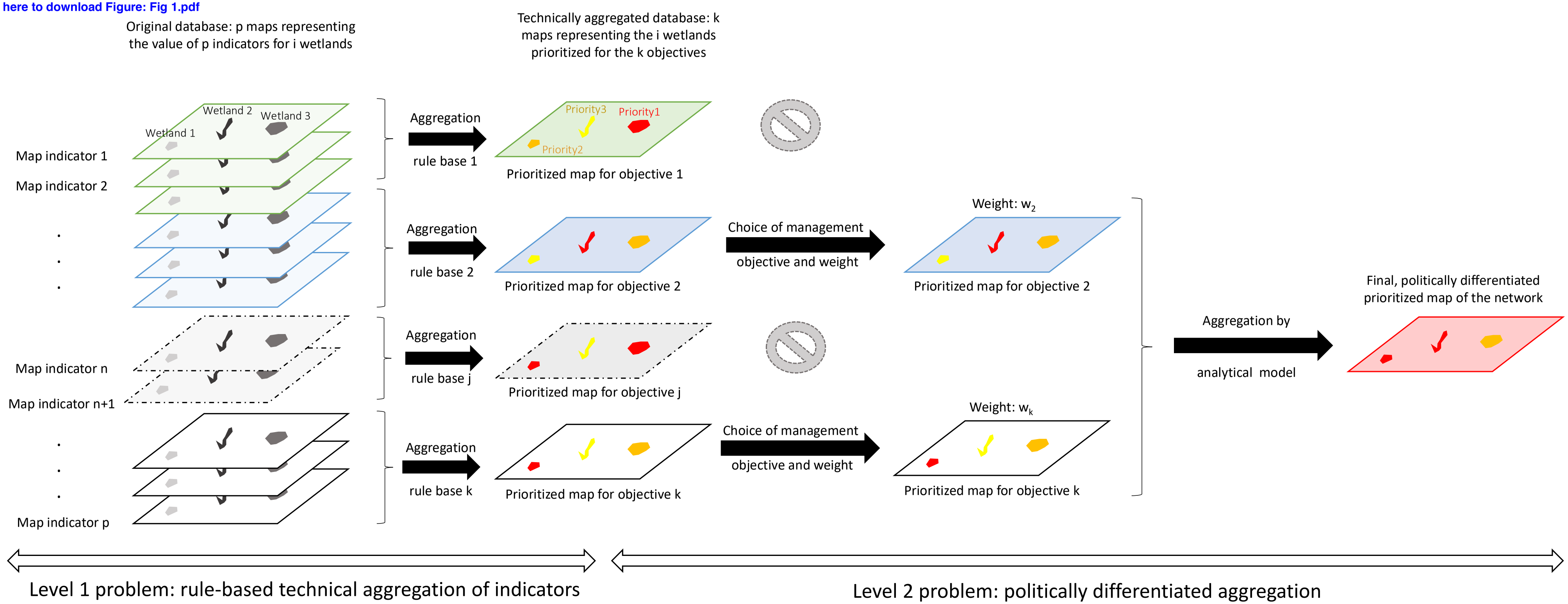

Figure 2

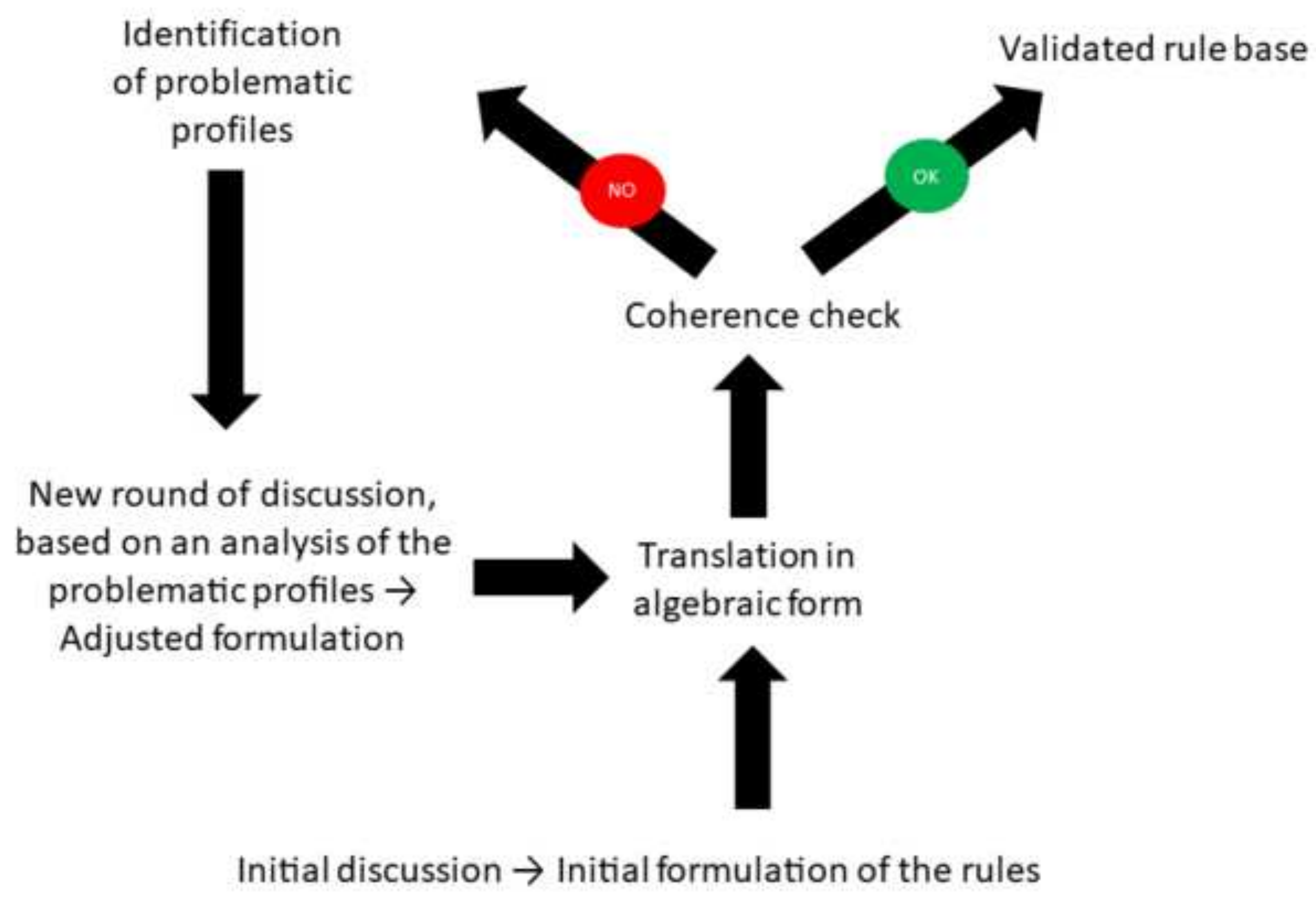
Identification of problematic profiles
Validated rule base
NO
OK
Coherence check
New round of discussion, based on an analysis of the problematic profiles → Adjusted formulation
Translation in algebraic form
Initial discussion → Initial formulation of the rules

Figure 3

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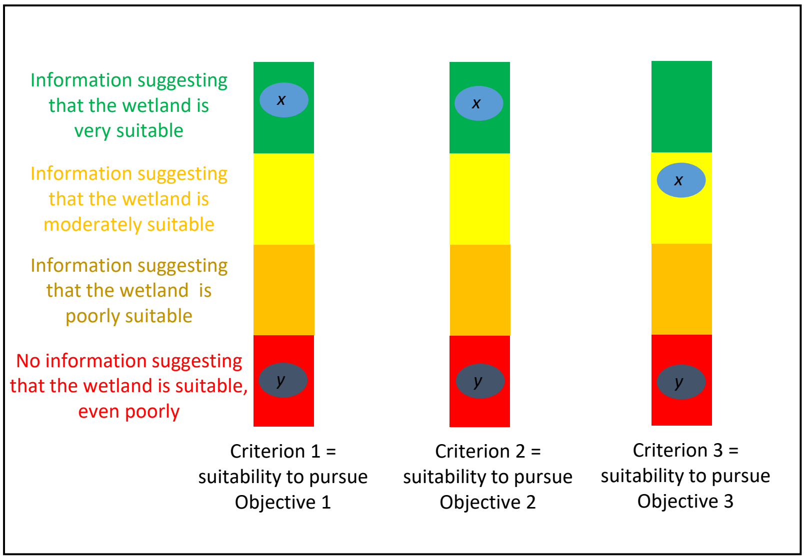
The manager picks up more than one objective

In this example: 3 objectives

Thanks to the rule-base, the DAP computes the suitability of the wetlands of interest (in this example: *x* and *y*) for each of the objectives chosen



For wetlands falling in the same category for all the objectives (case of wetland *y*), the overall priority is straightforward

For wetlands falling in different categories (case of wetland *x*), MR-Sort is used

The DAP asks the manager to choose:

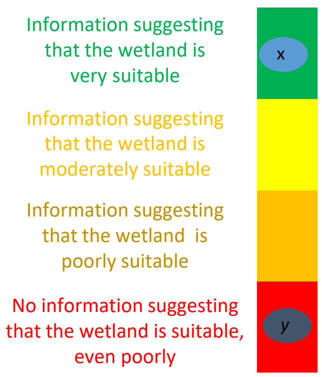
- a weight for each of the objective chosen: w_1, w_2, w_3
- a majority threshold λ

In this example, MR-Sort is used to decide if the information for *x* points towards "highly suitable" despite the fact that it is in this category only for objectives 1 and 2, but not 3

For that purpose, MR-Sort checks if the weights given to 1 and 2 are enough to reach the majority threshold λ:

If $w_1 + w_2 \geq \lambda$ then *x* is affected to « Information suggesting that the wetland is very suitable »

Small variations of w_1, w_2, w_3 and λ are tested with the manager to choose the figures that best reflect his values



Overall prioritization

Figure 4

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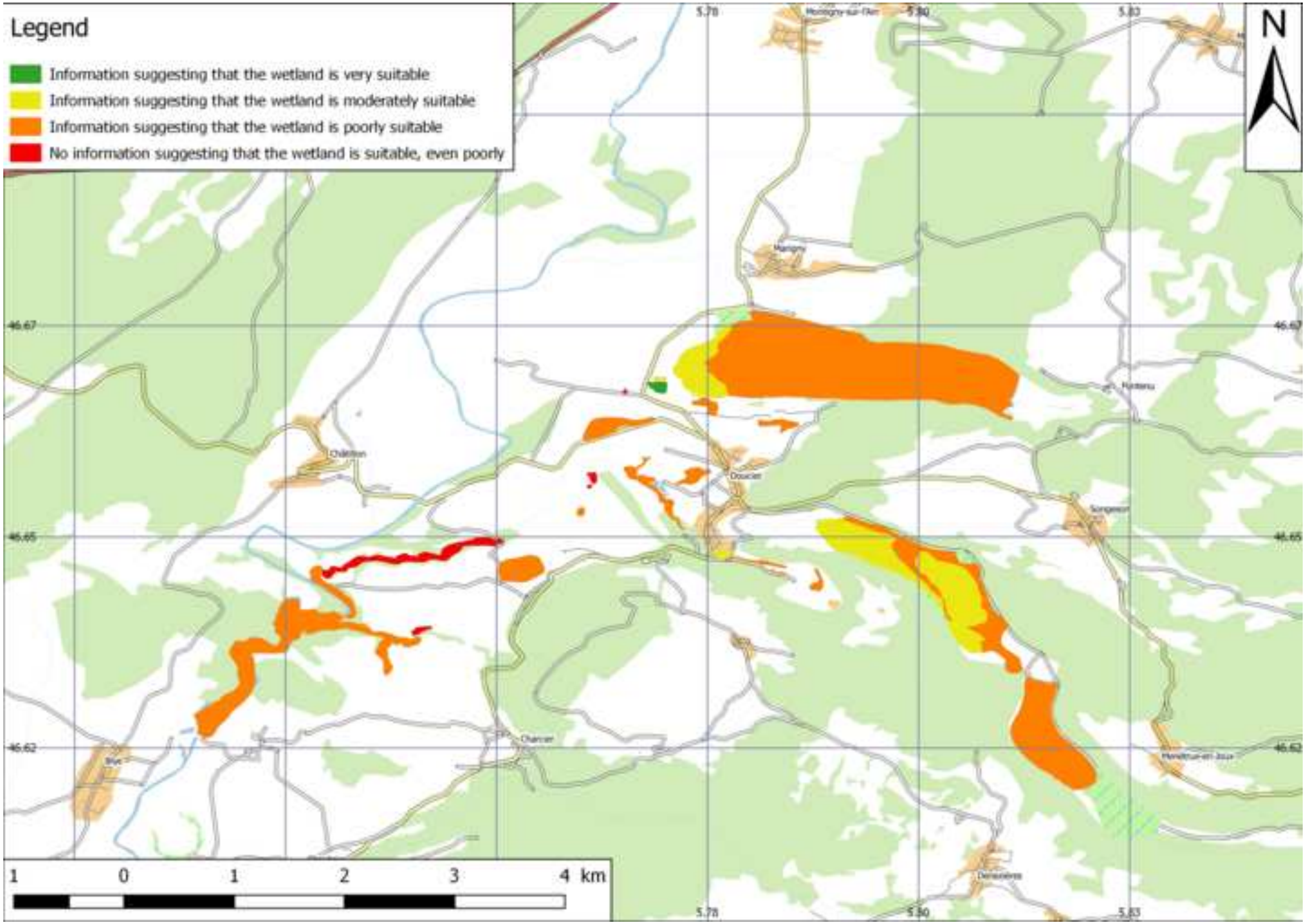

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