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

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11

12 Abstract

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

17 Multi-criteria decision-analysis (MCDA) is often used to solve management problems,
18 but studies in the literature rarely place importance on the way stakeholders perceive
19 researchers' interventions (which implies a lack of legitimacy), and most managers
20 lack the skills to reproduce routinely the operations involved (which implies a lack of
21 operationality). We use MCDA methodology in a different approach: “meta-decision-
22 analysis” (Meta-DA). As researchers, instead of striving to identify the best way for us
23 to solve managers' problems, we identify the actors (the decision-aid providers,

24 DAPs) who are best placed to help managers, and we provide DAPs with the
25 necessary tools.

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

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

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

42

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

45 **Introduction**

46 Environmental policies, here defined as “organized sets of actions to conserve or restore
47 natural sites, species or ecosystems”, often suffer from “knowing-doing gaps” (Matzek et al.
48 2014): scientific knowledge accumulates but fails to inform action. This is largely because the
49 decisions involved in designing and implementing environmental policies are not
50 straightforward applications of scientific knowledge. They are applied in complex political
51 and economic settings, where different actors and stakeholders make potentially conflicting
52 claims and want their voice to count in collective decision-making. In such contexts, it is not
53 enough for experts’ recommendations to have sound scientific foundations: they also need to
54 be operational and legitimate (Jeanmougin et al. 2017).

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

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

65 Many authors call for tighter interactions between researchers and practitioners and point a
66 need for researchers to address research priorities identified by practitioners (e.g. Schwartz et
67 al. (2018)). However, this literature arguably underestimates the fact that the incentives
68 driving researchers and actors looking for operational and legitimate decision support can
69 diverge: whereas scientific publication requires novelty in theory and methods, actors

70 concerned with operationality can be more interested in deploying applications of existing
71 knowledge; whereas academic science requires state-of-the-art, highly sophisticated
72 techniques, actors concerned with legitimacy can prefer approaches that are less sophisticated
73 but easier to explain to concerned stakeholders. The solutions presented in the literature are
74 limited to recommendations designed to mitigate such discrepancies (e.g. Beier et al. (2017)
75 recommend to create new incentives to encourage researchers to focus less on publications
76 and engage more in actionable science), but recommendations of that sort are rarely followed
77 (Arlettaz et al. 2010). This gap in the literature calls for deeper investigations on the role that
78 researchers can play in decision support activities and on how they can take operationality and
79 legitimacy constraints into account.

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

93 The importance of such results is undeniable. However, such studies do not question how
94 decision-makers and concerned stakeholders perceive the decision-support that researchers

95 provide: will the scientific credentials of the published study, or the intervention of local
96 expert in the parametrization of models, be enough to convince them that recommendations
97 are legitimate? Moreover, beyond hinting at possible applications of their method to other
98 case studies (e.g. Maleki et al. (2018) in their concluding paragraph), these studies produce
99 results that are valid only for their case-studies and are not straightforwardly transferable, as
100 actors concerned with operability would like them to be.

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

110

111 **Conceptual framework: structuring operational and legitimate environmental policies** 112 **through Meta-DA**

113 MCDA is a branch of Operational Research (itself part of decision sciences), aimed at
114 providing decision-makers with means to improve their decisions, through a better
115 representation of various aspects of their problems, and a better understanding of associated
116 constraints. MCDA methods and tools are used in numerous environmental disciplines
117 (Esmail & Geneletti 2018), particularly in conservation planning (Regan et al. 2007, Farashi
118 et al. 2016), but also invasive ecology (Dana et al. 2013), ecological risk assessment
119 (Malekmohammidi & Blouchi 2014), ecosystem services valuation (Fagioli et al. 2017),

120 among others. In such studies, MCDA methodology is used to select and apply state-of-the-art
121 MCDA technologies, using researchers' state-of-the-art MCDA skills, to solve particular
122 problems (e.g. Gregory & Long 2009, Robinson et al. 2016, Robinson et al. 2017).
123 Although such studies produce important results, like the larger literature referred to above,
124 they are often ill-equipped to feed legitimate and operational policy implementations.
125 Indeed, although these studies make a point to take into account the values and objectives of
126 stakeholders and decision-makers, they rarely place importance on the way the former
127 perceive researchers' interventions. They do not investigate whether they see researchers'
128 measurements of their values and the recommendations they derive from them as legitimate.
129 This contrast is illustrated, for example, by Wu et al. (2012)'s use of MCDA to compare
130 policy options to protect a nature reserve in China. Although they explicitly integrate in their
131 analysis the acceptance of the various policy options by farmers, they do not investigate the
132 way farmers and other relevant actors perceived their MCDA analysis (integrating farmer's
133 acceptance) and whether they deem that a decision based on this analysis is legitimate.
134 Among the 86 articles applying MCDA to nature conservation reviewed by Esmail et al.
135 (2018), only Ferretti & Pomarico (2013), Van Elegem et al. (2002), Strager & Rosenberger
136 (2006) and Zhang et al. (2013) emphasized the importance of this aspect, without devoting
137 important analyses to it.
138 Besides, most decision-makers lack the skills to reproduce the operations involved in these
139 studies routinely and, because an indefinitely continued interaction between decision-makers
140 and MCDA researchers would be impractical, exceedingly expensive and inefficient, most
141 decision-analysis (DA) processes do not survive the end of the research projects that launched
142 them. Coming back to the articles reviewed by Esmail et al. (2018), although many of them
143 mention the transferability of their results and applicability of their methods to other case
144 studies, this mention is limited to a reference in discussion or perspective, without in-depth

145 analysis of the actors and settings liable to ensure that operational replications are indeed
146 implemented (notice, however, the deeper investigation in Van Elegem et al. 2002).
147 These two limitations of current MCDA studies, echoing the limitations in the larger literature
148 mentioned in the introduction, highlight that innovation and scientific advances in
149 applications of MCDA can occur at two levels:

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

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

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

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

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

178 Notice that this task (T2) cannot be trivially solved by scientists or experts devising or
179 calculating options or alternatives (the would-be "technical" part) and then studying the
180 values that decision-makers, actors and stakeholders bestow on these pre-determined options
181 or alternative (the would-be "political" part). Indeed, the very identification of alternatives
182 and even the very formulation of the problem can, at least in some cases, be considered by
183 decision-makers and concerned actors and stakeholders to belong to the "political" realm.

184 Attempts to fully separate political from technical decisions have a long history of failure
185 (Callon et al. 2011). However, in concrete situations, actors can agree on a shared
186 understanding of this political/technical divide, and this provisional and local understanding is
187 all that T2 requires.

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

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

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

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

195

196 **Application: using Meta-DA to structure operational and legitimate wetland** 197 **prioritization**

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

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

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

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

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

222 We applied T1-3 to overcome these limitations.

223

224 *T1: A legitimate DAP*

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

240 To do that, we need criteria to sort out legitimate candidates from non-legitimate ones.

241 Meinard (2017) reviewed approaches to legitimacy in the conservation literature, showed the
242 diversity and complexity of criteria that can be used to assess legitimacy, and then suggested
243 four criteria designed to be particularly relevant to conservation policies:

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

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

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

259 The selection of the PMH, and the precise definition of the perimeter of its mission, where
260 established during a steering committee supervising the organization of the network of
261 wetland managers in the region on November 13th, 2015. The steering committee included all
262 the above mentioned candidate DAP and all the recognized members of the network of
263 managers and local actors concerned with wetlands in the region. The choice was motivated
264 by the role that the CEN had played in the area with all the members of the network of actors

265 for many years, and was validated by the members of the steering committee. The definition
266 of the perimeter of the mission included the need for the PMH to work with representatives of
267 managers and experts in a collaborative way.

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

280

281 *T2: Technical versus political choices*

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

284 A first possibility, embodied in the standard application of the weighted-sum approach, is to
285 ask managers to give weights to the various indicators in the database. In this case, the
286 political part is confined to this expression of values that managers bestow on aspects of
287 wetlands captured by the various indicators, and the “technical” part that the DAP is in charge
288 of performing encompasses almost the whole problem-solving task. At the other extreme, the
289 very formulation of the problem and the choice of how managers can express the values they

290 bestow on wetlands and how these values are taken into account and aggregated, can be
291 considered to be a political part for managers to tackle. In this second option, the “technical”
292 work of the DAP is very limited in scope. Between these two extreme options, numerous
293 intermediate settings are conceivable: the political part can be a choice between a series of
294 scenarios, an ordering of management objectives, a weighting of broad aspects of wetlands
295 captured by blocks of close indicators, etc.

296 The task at this stage is to choose, among these possible options, one that appears acceptable
297 to the managers, by avoiding preempting choices for which they deem they have legitimacy.
298 In our case, this task was performed through a series of participatory events orchestrated by
299 the PMH that unfolded between November 2015 and January 2018. During the steering
300 committee on November 13th, 2015, it was decided that the PMH should work with a
301 taskforce comprising representatives of the various actors already involved in or potentially
302 interested in being involved in wetland management. The list of those actors was based on the
303 fact that these actors had already solicited Water Agencies to fund actions or studies on
304 wetlands or had contacted Water Agencies to express a willingness to do so or ask questions
305 about this procedure. The representatives were chosen by the various actors themselves to
306 participate to the taskforce. A first session of collective work of the taskforce occurred on
307 December 15th, 2016, during which the idea emerged that a relevant prioritization procedure
308 would leave managers choose the objectives they want to pursue, and would provide, for each
309 possible objective, a technical procedure to compute an objective-specific prioritization.

310 Based on numerous informal discussions with the representatives of the different managers
311 during the six following months, the PMH then produced several propositions of lists of
312 possible objectives, which were iteratively improved, so as to reflect the choices that
313 managers can be willing to make, subject to the constraint that the regional database should
314 contain relevant information to compute a prioritization relative to these possible objectives

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

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

- 319 - The identification and aggregation of relevant information for each objective, which
320 was considered to be a technical matter that the PMH was competent to perform (level
321 1 problem);
- 322 - The choice of management objectives, for which managers have a certain legitimacy
323 (level 2 problem).

324

325

326 *T3: Designing techniques to solve different aspects of the problem*

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

328

329 *Technical aggregation*

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

337 Drawing-up rules involved numerous meetings during which the PMH expressed provisional
338 rules. We then verified coherence requirements (Table 2): completeness (each profile should

339 be assigned to a category), exclusiveness (no profile should be assigned to more than one
340 category), and monotonicity (if profile p_1 has at least as high values as p_2 for every indicator,
341 and a higher value for at least one indicator, p_1 cannot be assigned to a lower category than
342 p_2). Whenever a requirement failed to be respected, a second round of discussions was
343 organized to revise the rules (Figure 2). Most of the rules initially chosen had the same four
344 categories:

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

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

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

356

357 *Political aggregation*

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

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

362 If he/she selects several objectives, the solutions for the different objectives selected have to
363 be aggregated. The aggregation should reflect the manager's perception of the relative

364 importance of the objectives. Analytical aggregation models may be suitable for such
365 purposes. Among them, MR-Sort (Majority Rule Sorting) (Leroy et al. 2011) is a version of
366 ELECTRE-TRI (Roy & Bouyssou 1993), a method used to attribute alternatives to p
367 predefined categories $c_1 \dots c_p$ delimited by $p-1$ profiles $b_1 \dots b_{p-1}$. Alternatives are compared to
368 these profiles with respect to each criterion. Alternative a is said to outrank b_h (which is noted
369 aSb_h) if a is considered better than b_h for a proportion $\lambda \in [0.5, 1]$ of criteria, pondered by their
370 respective weights $w \in [0, 0.5]$. Alternative a is successively compared to profiles b_j , for $j = p-$
371 $1, \dots, 0$, and it is assigned to the first category c_j such that aSb_j (other versions of ELECTRE-
372 TRI integrate indifference and preference thresholds, and veto values). Where to place the
373 thresholds is a complex issue in ELECTRE-TRI. In our case, the criteria correspond to the
374 different objectives chosen, and the thresholds are therefore straightforward, because all the
375 objectives have the same categories.

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

380 When working as DAP with managers, the PHM will ask them to choose weights (w) that
381 reflect the relative importance of their objectives, and a majority threshold (λ) (Figure 3).
382 These parameters are much less numerous than those required by weighted-sums ($n+1$
383 parameters for n objectives, whereas weighted-sums require as many parameters as there are
384 indicators). In addition, in our case, w reflect the relative importance that managers give to
385 their own objectives, which is much less abstract than giving weights to indicators. The values
386 of λ that can make a difference depend on the number of objectives chosen and on w , and can
387 be easily interpreted in terms of which objective or coalition of objectives is decisive (see the
388 illustration below). That said, the difficulty involved in choosing these parameters is the

389 subject of debate (Dias et al. 2002). It is consequently important that implementations include
390 sensitivity analyses. The robustness and sensitivity of various ELECTRE models can involve
391 complex analyses. In our case, these analyses should be simple ones (like those proposed by
392 Merad et al. 2004), because the PMH should be able to implement them routinely. We
393 discussed and validated the following procedure with the PMH:

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

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

416

417 *Illustration*

418 Let us illustrate possible implementations with the fictitious example of a manager (M) who
419 would choose O5, O7 and O8 with $w_{O5}=0.45$, $w_{O7}=0.3$ and $w_{O8}=0.25$, in the vicinity of
420 Doucier, an area for which the database contains 33 wetlands. This could be a local charity
421 whose main aim is to conserve biodiversity (hence the choice of O5 with a high w_{O5}), but
422 which lacks the means to implement management autonomously (hence O7, with a smaller
423 w_{O7}) and would prefer to avoid land ownership problems, if possible (hence O8 with an even
424 smaller w_{O8}). Figure 4 illustrates the resulting prioritization for $\lambda=0.5$. Changing the weights
425 one by one by $\pm 10\%$ does not alter it. In fact, prioritization does not change even if the
426 weights are equalized. This implementation hence appears very robust with respect to
427 weights. Concerning λ , using the above weights, for $0.5 \leq \lambda < 0.55$, O7 and O8 may be decisive
428 against O5 [a]; for $0.55 \leq \lambda < 0.7$, a coalition between O5 and O7 or O8 is decisive [b]; for
429 $\lambda \geq 0.7$, the three objectives have to agree [c]. Compared to the basal version [a], these different
430 values shift 3[c] and 24[d] of the 33 wetlands from one category to another. The heaviest
431 decision would be to choose λ in range [d]. But M should easily be able to make up his/her
432 mind, because this decision has clear implications: for a wetland to be assigned to category C,
433 the wetland has to be assigned to C for all the objectives. The decision between [a] and [b]
434 implies a small modification in prioritization, whereas it reflects an important and easily
435 understandable decision about the importance of the objectives chosen. In this case, the
436 application of the method hence also appears to be robust for λ .

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

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

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

448

449 *Prospects of concrete implementations*

450 The whole application (as opposed to the illustrative example above) was presented to a large
451 panel of managers and local stakeholders in March, 2018, in two workshops that included
452 role-plays in which the participants had to choose objectives and parameters, and discuss
453 prioritization. The managers appeared to be convinced, but the real test will be real-life
454 prioritizations for managers. Due to a new law imposing changes in environmental
455 governance structures in France in 2018, these real-life applications are planned to start in
456 2019. In the meantime, it is useful to reflect on the likelihood for these applications to be
457 successful and to unfold smoothly. The main issue that could threaten such applications is that
458 the novelty of the tool and the procedure might discourage managers and induce costs for
459 them to understand the tool and appropriate it. We argue that several important features of our
460 approach ensure that such worries are exaggerated.

461 First, the tool that we propose and the tasks that managers will have to perform are not
462 considerably more complex than what they are used to. The tasks that managers will be asked
463 to perform are mainly to choose objectives, which is something that they routinely do for

464 example when they devise management plans, and, as illustrated in our fictitious example, to
465 express limited information about the relative importance of their objectives.

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

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

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

481

482 *Limitations*

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

485 When deploying T1, we assessed the legitimacy of the PMH as a DAP, because large-scale
486 funding institutions had given it a particularly convenient role to become a DAP. But we did
487 not assess the legitimacy of other candidate DAP, and in contexts where there is more liberty
488 to choose a DAP, a more ambitious approach, comparing the respective legitimacy of various

489 candidate DAP would strengthen the credentials of the approach. Many aspects of our
490 discussion of the reasons why the PMH qualifies as legitimate could also deserve more in-
491 depth analyses in future studies. For example, regarding criterion (iii), we did not assess
492 whether the database produced by the PMH correctly identified all the relevant knowledge
493 gaps on wetland in the region. Moreover, Meinard (2016) clearly presented the list of four
494 criteria that we used above as preliminary and open-ended. A more complete account of the
495 concept of legitimacy in conservation settings could therefore usefully enrich future
496 applications of our Meta-DA approach.

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

511 Some managers can also be willing to choose more idiosyncratic objectives than the ones of
512 the validated list. Elaborating a more fine-tuned prioritization for them is of course possible,
513 and numerous methods, some of them considerably more sophisticated than our, can be put to

514 use for that purpose (e.g. Lovette et al. 2018, Qu et al. 2018). But such a specific treatment
515 would not count as an implementation of the same homogeneous policy that is implemented
516 for other managers, and would involve additional marginal costs.

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

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

532

533 **Conclusions**

534 We have argued that environmental policies can be improved by implementing a meta-
535 decision-analysis approach, deploying three tasks: T1—identifying a legitimate decision-aid
536 provider to aid managers in routine policy implementation, T2—distinguishing political from
537 technical choices, T3—designing tools that are compatible with both the decision-aid

538 provider's skills and legitimacy constraints. Despite some limitations, our application to
539 wetland prioritization in Bourgogne-Franche-Comté illustrates its feasibility and usefulness.
540 This approach entails recommendations for various kinds of actors involved in environmental
541 policies:

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

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

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

561

562 Figure 1. General structure of the application.

563 Figure 2. Procedure to obtain a rule-base.

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

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

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

569 Table 2. Rules for objective O1 with consistency checks.

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

572 Supplementary Material 2. Rule-bases.

573

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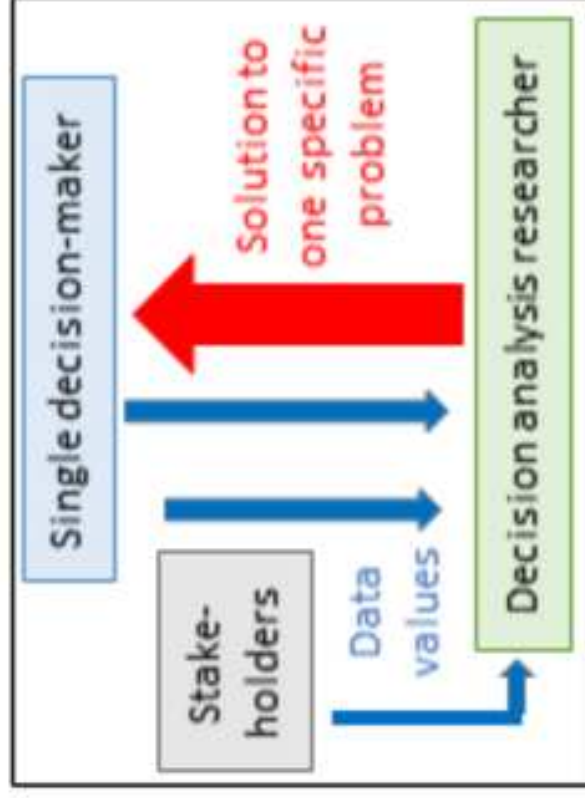
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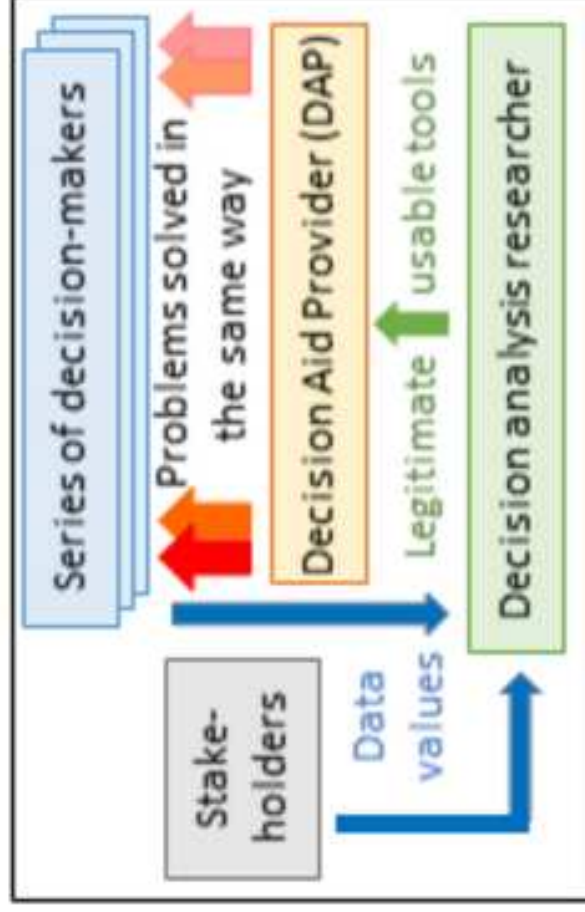
686

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"Standard" decision analysis



Meta decision analysis

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

- Researchers' 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

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

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11

12 Abstract

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

17 Multi-criteria decision-analysis (MCDA) is often used to solve management problems,
18 but studies in the literature rarely place importance on the way stakeholders perceive
19 researchers' interventions (which implies a lack of legitimacy), and most managers
20 lack the skills to reproduce routinely the operations involved (which implies a lack of
21 operationality). We use MCDA methodology in a different approach: “meta-decision-
22 analysis” (Meta-DA). As researchers, instead of striving to identify the best way for us
23 to solve managers' problems, we identify the actors (the decision-aid providers,

24 DAPs) who are best placed to help managers, and we provide DAPs with the
25 necessary tools.

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

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

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

42

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

45 **Introduction**

46 Environmental policies, here defined as “organized sets of actions to conserve or restore
47 natural sites, species or ecosystems”, often suffer from “knowing-doing gaps” (Matzek et al.
48 2014): scientific knowledge accumulates but fails to inform action. This is largely because the
49 decisions involved in designing and implementing environmental policies are not
50 straightforward applications of scientific knowledge. They are applied in complex political
51 and economic settings, where different actors and stakeholders make potentially conflicting
52 claims and want their voice to count in collective decision-making. In such contexts, it is not
53 enough for experts’ recommendations to have sound scientific foundations: they also need to
54 be operational and legitimate (Jeanmougin et al. 2017).

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

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

65 Many authors call for tighter interactions between researchers and practitioners and point a
66 need for researchers to address research priorities identified by practitioners (e.g. Schwartz et
67 al. (2018)). However, this literature arguably underestimates the fact that the incentives
68 driving researchers and actors looking for operational and legitimate decision support can
69 diverge: whereas scientific publication requires novelty in theory and methods, actors

70 concerned with operationality can be more interested in deploying applications of existing
71 knowledge; whereas academic science requires state-of-the-art, highly sophisticated
72 techniques, actors concerned with legitimacy can prefer approaches that are less sophisticated
73 but easier to explain to concerned stakeholders. The solutions presented in the literature are
74 limited to recommendations designed to mitigate such discrepancies (e.g. Beier et al. (2017)
75 recommend to create new incentives to encourage researchers to focus less on publications
76 and engage more in actionable science), but recommendations of that sort are rarely followed
77 (Arlettaz et al. 2010). This gap in the literature calls for deeper investigations on the role that
78 researchers can play in decision support activities and on how they can take operationality and
79 legitimacy constraints into account.

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

93 The importance of such results is undeniable. However, such studies do not question how
94 decision-makers and concerned stakeholders perceive the decision-support that researchers

95 provide: will the scientific credentials of the published study, or the intervention of local
96 expert in the parametrization of models, be enough to convince them that recommendations
97 are legitimate? Moreover, beyond hinting at possible applications of their method to other
98 case studies (e.g. Maleki et al. (2018) in their concluding paragraph), these studies produce
99 results that are valid only for their case-studies and are not straightforwardly transferable, as
100 actors concerned with operationality would like them to be.

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

110

111 **Conceptual framework: structuring operational and legitimate environmental policies** 112 **through Meta-DA**

113 MCDA is a branch of Operational Research (itself part of decision sciences), aimed at
114 providing decision-makers with means to improve their decisions, through a better
115 representation of various aspects of their problems, and a better understanding of associated
116 constraints. MCDA methods and tools are used in numerous environmental disciplines
117 (Esmail & Geneletti 2018), particularly in conservation planning (Regan et al. 2007, Farashi
118 et al. 2016), but also invasive ecology (Dana et al. 2013), ecological risk assessment
119 (Malekmohammidi & Blouchi 2014), ecosystem services valuation (Fagioli et al. 2017),

120 among others. In such studies, MCDA methodology is used to select and apply state-of-the-art
121 MCDA technologies, using researchers' state-of-the-art MCDA skills, to solve particular
122 problems (e.g. Gregory & Long 2009, Robinson et al. 2016, Robinson et al. 2017).
123 Although such studies produce important results, like the larger literature referred to above,
124 they are often ill-equipped to feed legitimate and operational policy implementations.
125 Indeed, although these studies make a point to take into account the values and objectives of
126 stakeholders and decision-makers, they rarely place importance on the way the former
127 perceive researchers' interventions. They do not investigate whether they see researchers'
128 measurements of their values and the recommendations they derive from them as legitimate.
129 This contrast is illustrated, for example, by Wu et al. (2012)'s use of MCDA to compare
130 policy options to protect a nature reserve in China. Although they explicitly integrate in their
131 analysis the acceptance of the various policy options by farmers, they do not investigate the
132 way farmers and other relevant actors perceived their MCDA analysis (integrating farmer's
133 acceptance) and whether they deem that a decision based on this analysis is legitimate.
134 Among the 86 articles applying MCDA to nature conservation reviewed by Esmail et al.
135 (2018), only Ferretti & Pomarico (2013), Van Elegem et al. (2002), Strager & Rosenberger
136 (2006) and Zhang et al. (2013) emphasized the importance of this aspect, without devoting
137 important analyses to it.
138 Besides, most decision-makers lack the skills to reproduce the operations involved in these
139 studies routinely and, because an indefinitely continued interaction between decision-makers
140 and MCDA researchers would be impractical, exceedingly expensive and inefficient, most
141 decision-analysis (DA) processes do not survive the end of the research projects that launched
142 them. Coming back to the articles reviewed by Esmail et al. (2018), although many of them
143 mention the transferability of their results and applicability of their methods to other case
144 studies, this mention is limited to a reference in discussion or perspective, without in-depth

145 analysis of the actors and settings liable to ensure that operational replications are indeed
146 implemented (notice, however, the deeper investigation in Van Elegem et al. 2002).
147 These two limitations of current MCDA studies, echoing the limitations in the larger literature
148 mentioned in the introduction, highlight that innovation and scientific advances in
149 applications of MCDA can occur at two levels:

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

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

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

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

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

178 Notice that this task (T2) cannot be trivially solved by scientists or experts devising or
179 calculating options or alternatives (the would-be "technical" part) and then studying the
180 values that decision-makers, actors and stakeholders bestow on these pre-determined options
181 or alternative (the would-be "political" part). Indeed, the very identification of alternatives
182 and even the very formulation of the problem can, at least in some cases, be considered by
183 decision-makers and concerned actors and stakeholders to belong to the "political" realm.

184 Attempts to fully separate political from technical decisions have a long history of failure
185 (Callon et al. 2011). However, in concrete situations, actors can agree on a shared
186 understanding of this political/technical divide, and this provisional and local understanding is
187 all that T2 requires.

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

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

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

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

195

196 **Application: using Meta-DA to structure operational and legitimate wetland** 197 **prioritization**

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

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

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

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

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

222 We applied T1-3 to overcome these limitations.

223

224 *T1: A legitimate DAP*

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

240 To do that, we need criteria to sort out legitimate candidates from non-legitimate ones.

241 Meinard (2017) reviewed approaches to legitimacy in the conservation literature, showed the
242 diversity and complexity of criteria that can be used to assess legitimacy, and then suggested
243 four criteria designed to be particularly relevant to conservation policies:

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

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

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

259 The selection of the PMH, and the precise definition of the perimeter of its mission, where
260 established during a steering committee supervising the organization of the network of
261 wetland managers in the region on November 13th, 2015. The steering committee included all
262 the above mentioned candidate DAP and all the recognized members of the network of
263 managers and local actors concerned with wetlands in the region. The choice was motivated
264 by the role that the CEN had played in the area with all the members of the network of actors

265 for many years, and was validated by the members of the steering committee. The definition
266 of the perimeter of the mission included the need for the PMH to work with representatives of
267 managers and experts in a collaborative way.

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

280

281 *T2: Technical versus political choices*

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

284 A first possibility, embodied in the standard application of the weighted-sum approach, is to
285 ask managers to give weights to the various indicators in the database. In this case, the
286 political part is confined to this expression of values that managers bestow on aspects of
287 wetlands captured by the various indicators, and the “technical” part that the DAP is in charge
288 of performing encompasses almost the whole problem-solving task. At the other extreme, the
289 very formulation of the problem and the choice of how managers can express the values they

290 bestow on wetlands and how these values are taken into account and aggregated, can be
291 considered to be a political part for managers to tackle. In this second option, the “technical”
292 work of the DAP is very limited in scope. Between these two extreme options, numerous
293 intermediate settings are conceivable: the political part can be a choice between a series of
294 scenarios, an ordering of management objectives, a weighting of broad aspects of wetlands
295 captured by blocks of close indicators, etc.

296 The task at this stage is to choose, among these possible options, one that appears acceptable
297 to the managers, by avoiding preempting choices for which they deem they have legitimacy.
298 In our case, this task was performed through a series of participatory events orchestrated by
299 the PMH that unfolded between November 2015 and January 2018. During the steering
300 committee on November 13th, 2015, it was decided that the PMH should work with a
301 taskforce comprising representatives of the various actors already involved in or potentially
302 interested in being involved in wetland management. The list of those actors was based on the
303 fact that these actors had already solicited Water Agencies to fund actions or studies on
304 wetlands or had contacted Water Agencies to express a willingness to do so or ask questions
305 about this procedure. The representatives were chosen by the various actors themselves to
306 participate to the taskforce. A first session of collective work of the taskforce occurred on
307 December 15th, 2016, during which the idea emerged that a relevant prioritization procedure
308 would leave managers choose the objectives they want to pursue, and would provide, for each
309 possible objective, a technical procedure to compute an objective-specific prioritization.

310 Based on numerous informal discussions with the representatives of the different managers
311 during the six following months, the PMH then produced several propositions of lists of
312 possible objectives, which were iteratively improved, so as to reflect the choices that
313 managers can be willing to make, subject to the constraint that the regional database should
314 contain relevant information to compute a prioritization relative to these possible objectives

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

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

- 319 - The identification and aggregation of relevant information for each objective, which
320 was considered to be a technical matter that the PMH was competent to perform (level
321 1 problem);
- 322 - The choice of management objectives, for which managers have a certain legitimacy
323 (level 2 problem).

324

325

326 *T3: Designing techniques to solve different aspects of the problem*

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

328

329 *Technical aggregation*

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

337 Drawing-up rules involved numerous meetings during which the PMH expressed provisional
338 rules. We then verified coherence requirements (Table 2): completeness (each profile should

339 be assigned to a category), exclusiveness (no profile should be assigned to more than one
340 category), and monotonicity (if profile p_1 has at least as high values as p_2 for every indicator,
341 and a higher value for at least one indicator, p_1 cannot be assigned to a lower category than
342 p_2). Whenever a requirement failed to be respected, a second round of discussions was
343 organized to revise the rules (Figure 2). Most of the rules initially chosen had the same four
344 categories:

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

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

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

356

357 *Political aggregation*

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

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

362 If he/she selects several objectives, the solutions for the different objectives selected have to
363 be aggregated. The aggregation should reflect the manager's perception of the relative

364 importance of the objectives. Analytical aggregation models may be suitable for such
365 purposes. Among them, MR-Sort (Majority Rule Sorting) (Leroy et al. 2011) is a version of
366 ELECTRE-TRI (Roy & Bouyssou 1993), a method used to attribute alternatives to p
367 predefined categories $c_1 \dots c_p$ delimited by $p-1$ profiles $b_1 \dots b_{p-1}$. Alternatives are compared to
368 these profiles with respect to each criterion. Alternative a is said to outrank b_h (which is noted
369 aSb_h) if a is considered better than b_h for a proportion $\lambda \in [0.5, 1]$ of criteria, pondered by their
370 respective weights $w \in [0, 0.5]$. Alternative a is successively compared to profiles b_j , for $j = p-$
371 $1, \dots, 0$, and it is assigned to the first category c_j such that aSb_j (other versions of ELECTRE-
372 TRI integrate indifference and preference thresholds, and veto values). Where to place the
373 thresholds is a complex issue in ELECTRE-TRI. In our case, the criteria correspond to the
374 different objectives chosen, and the thresholds are therefore straightforward, because all the
375 objectives have the same categories.

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

380 When working as DAP with managers, the PHM will ask them to choose weights (w) that
381 reflect the relative importance of their objectives, and a majority threshold (λ) (Figure 3).
382 These parameters are much less numerous than those required by weighted-sums ($n+1$
383 parameters for n objectives, whereas weighted-sums require as many parameters as there are
384 indicators). In addition, in our case, w reflect the relative importance that managers give to
385 their own objectives, which is much less abstract than giving weights to indicators. The values
386 of λ that can make a difference depend on the number of objectives chosen and on w , and can
387 be easily interpreted in terms of which objective or coalition of objectives is decisive (see the
388 illustration below). That said, the difficulty involved in choosing these parameters is the

389 subject of debate (Dias et al. 2002). It is consequently important that implementations include
390 sensitivity analyses. The robustness and sensitivity of various ELECTRE models can involve
391 complex analyses. In our case, these analyses should be simple ones (like those proposed by
392 Merad et al. 2004), because the PMH should be able to implement them routinely. We
393 discussed and validated the following procedure with the PMH:

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

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

416

417 *Illustration*

418 Let us illustrate possible implementations with the fictitious example of a manager (M) who
419 would choose O5, O7 and O8 with $w_{O5}=0.45$, $w_{O7}=0.3$ and $w_{O8}=0.25$, in the vicinity of
420 Doucier, an area for which the database contains 33 wetlands. This could be a local charity
421 whose main aim is to conserve biodiversity (hence the choice of O5 with a high w_{O5}), but
422 which lacks the means to implement management autonomously (hence O7, with a smaller
423 w_{O7}) and would prefer to avoid land ownership problems, if possible (hence O8 with an even
424 smaller w_{O8}). Figure 4 illustrates the resulting prioritization for $\lambda=0.5$. Changing the weights
425 one by one by $\pm 10\%$ does not alter it. In fact, prioritization does not change even if the
426 weights are equalized. This implementation hence appears very robust with respect to
427 weights. Concerning λ , using the above weights, for $0.5 \leq \lambda < 0.55$, O7 and O8 may be decisive
428 against O5 [a]; for $0.55 \leq \lambda < 0.7$, a coalition between O5 and O7 or O8 is decisive [b]; for
429 $\lambda \geq 0.7$, the three objectives have to agree [c]. Compared to the basal version [a], these different
430 values shift 3[c] and 24[d] of the 33 wetlands from one category to another. The heaviest
431 decision would be to choose λ in range [d]. But M should easily be able to make up his/her
432 mind, because this decision has clear implications: for a wetland to be assigned to category C,
433 the wetland has to be assigned to C for all the objectives. The decision between [a] and [b]
434 implies a small modification in prioritization, whereas it reflects an important and easily
435 understandable decision about the importance of the objectives chosen. In this case, the
436 application of the method hence also appears to be robust for λ .

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

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

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

448

449 *Prospects of concrete implementations*

450 The whole application (as opposed to the illustrative example above) was presented to a large
451 panel of managers and local stakeholders in March, 2018, in two workshops that included
452 role-plays in which the participants had to choose objectives and parameters, and discuss
453 prioritization. The managers appeared to be convinced, but the real test will be real-life
454 prioritizations for managers. Due to a new law imposing changes in environmental
455 governance structures in France in 2018, these real-life applications are planned to start in
456 2019. In the meantime, it is useful to reflect on the likelihood for these applications to be
457 successful and to unfold smoothly. The main issue that could threaten such applications is that
458 the novelty of the tool and the procedure might discourage managers and induce costs for
459 them to understand the tool and appropriate it. We argue that several important features of our
460 approach ensure that such worries are exaggerated.

461 First, the tool that we propose and the tasks that managers will have to perform are not
462 considerably more complex than what they are used to. The tasks that managers will be asked
463 to perform are mainly to choose objectives, which is something that they routinely do for

464 example when they devise management plans, and, as illustrated in our fictitious example, to
465 express limited information about the relative importance of their objectives.

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

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

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

481

482 *Limitations*

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

485 When deploying T1, we assessed the legitimacy of the PMH as a DAP, because large-scale
486 funding institutions had given it a particularly convenient role to become a DAP. But we did
487 not assess the legitimacy of other candidate DAP, and in contexts where there is more liberty
488 to choose a DAP, a more ambitious approach, comparing the respective legitimacy of various

489 candidate DAP would strengthen the credentials of the approach. Many aspects of our
490 discussion of the reasons why the PMH qualifies as legitimate could also deserve more in-
491 depth analyses in future studies. For example, regarding criterion (iii), we did not assess
492 whether the database produced by the PMH correctly identified all the relevant knowledge
493 gaps on wetland in the region. Moreover, Meinard (2016) clearly presented the list of four
494 criteria that we used above as preliminary and open-ended. A more complete account of the
495 concept of legitimacy in conservation settings could therefore usefully enrich future
496 applications of our Meta-DA approach.

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

511 Some managers can also be willing to choose more idiosyncratic objectives than the ones of
512 the validated list. Elaborating a more fine-tuned prioritization for them is of course possible,
513 and numerous methods, some of them considerably more sophisticated than our, can be put to

514 use for that purpose (e.g. Lovette et al. 2018, Qu et al. 2018). But such a specific treatment
515 would not count as an implementation of the same homogeneous policy that is implemented
516 for other managers, and would involve additional marginal costs.

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

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

532

533 **Conclusions**

534 We have argued that environmental policies can be improved by implementing a meta-
535 decision-analysis approach, deploying three tasks: T1—identifying a legitimate decision-aid
536 provider to aid managers in routine policy implementation, T2—distinguishing political from
537 technical choices, T3—designing tools that are compatible with both the decision-aid

538 provider's skills and legitimacy constraints. Despite some limitations, our application to
539 wetland prioritization in Bourgogne-Franche-Comté illustrates its feasibility and usefulness.
540 This approach entails recommendations for various kinds of actors involved in environmental
541 policies:

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

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

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

561

562 Figure 1. General structure of the application.

563 Figure 2. Procedure to obtain a rule-base.

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

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

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

569 Table 2. Rules for objective O1 with consistency checks.

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

572 Supplementary Material 2. Rule-bases.

573

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686

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Management objective	Description
01: 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.
02: 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.
03: 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.
04: 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 is 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.
05: 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.
06: 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.
07: 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.
09: 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
[Click here to download Table: Table2.docx](#)

Management objective	Source of the indicator	Encoded Indicator	Rule base		Consistency checks
			Textual formulation	Algebraic formulation	
<p>O1: Conserving wetlands performing a flood regulation function</p>	<p>Area characterized by a high risk of inundation according to SDAGE</p>	<p>$x_{i1}=1$ if the wetland / is in an area characterized by a high risk of inundation, otherwise $x_{i1}=0$</p>	<p>R1: IF there is no indicator testifying that wetland / plays a role in flood mitigation, THEN / is affected to the category "No information in the database suggesting that / is suitable, even poorly, to pursue this objective"</p> <p>R2: IF wetland / is within the approximate envelope of potential inundations but in none of the other types of area, then / is affected to the category "Information suggesting that / is poorly suitable"</p> <p>R3: IF wetland / is within an area rarely inundated and/or if a dedicated expertise</p>	<p>R1: IF $x_{i1}+x_{i2}+x_{i3}+x_{i4}+x_{i5}=0$ THEN / is affected to the category "No information in the database suggesting that / is suitable, even poorly, to pursue this objective"</p> <p>R2: IF $x_{i5}-x_{i1}-x_{i2}-x_{i3}-x_{i4}=1$ THEN / is affected to the category "Information suggesting that / is poorly suitable"</p> <p>R3: IF $x_{i3}+x_{i4} > 3.(x_{i1}+x_{i2})$ THEN / is affected to the category "Information suggesting that / is moderately suitable"</p> <p>R4: IF $x_{i1}+x_{i2} > 0$ / is affected to the category "Information suggesting that / is very suitable"</p>	<p>Completeness To check completeness, we check if there can exist a profile $(x_{i1}, x_{i2}, x_{i3}, x_{i4}, x_{i5})$ 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: $x_{i1}+x_{i2}+x_{i3}+x_{i4}+x_{i5} > 0$ and $x_{i5}-x_{i1}-x_{i2}-x_{i3}-x_{i4} < 1$ and $x_{i3}+x_{i4} <= 3.(x_{i1}+x_{i2})$ and $x_{i1}+x_{i2} <= 0$ Because this system has no solution, the rule base is complete.</p> <p>Exclusiveness To check exclusiveness, we check if there can exist a profile $(x_{i1}, x_{i2}, x_{i3}, x_{i4}, x_{i5})$ satisfying more than one rules R1-4. Such a profile would be a solution to the following system of linear equations: $x_{i1}+x_{i2}+x_{i3}+x_{i4}+x_{i5}=0$ and $x_{i5}-x_{i1}-x_{i2}-x_{i3}-x_{i4}=1$ or $x_{i1}+x_{i2}+x_{i3}+x_{i4}+x_{i5}=0$ and $x_{i3}+x_{i4} > 3.(x_{i1}+x_{i2})$ or $x_{i1}+x_{i2}+x_{i3}+x_{i4}+x_{i5}=0$ and $x_{i1}+x_{i2} > 0$ or $x_{i5}-x_{i1}-x_{i2}-x_{i3}-x_{i4}=1$ and $x_{i3}+x_{i4} > 3.(x_{i1}+x_{i2})$ or $x_{i5}-x_{i1}-x_{i2}-x_{i3}-x_{i4}=1$ and $x_{i1}+x_{i2} > 0$ or $x_{i3}+x_{i4} > 3.(x_{i1}+x_{i2})$ and $x_{i1}+x_{i2} > 0$ Because this system has no solution, the rule base is exclusive.</p> <p>Monotonicity To check monotonicity, we check if there can exist two profiles $(x_{i1}, x_{i2}, x_{i3}, x_{i4}, x_{i5})$ and $(x_{i1}, x_{i2}, x_{i3}, x_{i4}, x_{i5})$ such that / is affected to a category higher than the one to which / is affected, despite the fact that / dominates / (that is: there is at least one criterion</p>

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

Figure 1
[Click here to download Figure: Fig 1.pdf](#)

Original database: p maps representing the value of p indicators for i wetlands

Technically aggregated database: k maps representing the i wetlands prioritized for the k objectives

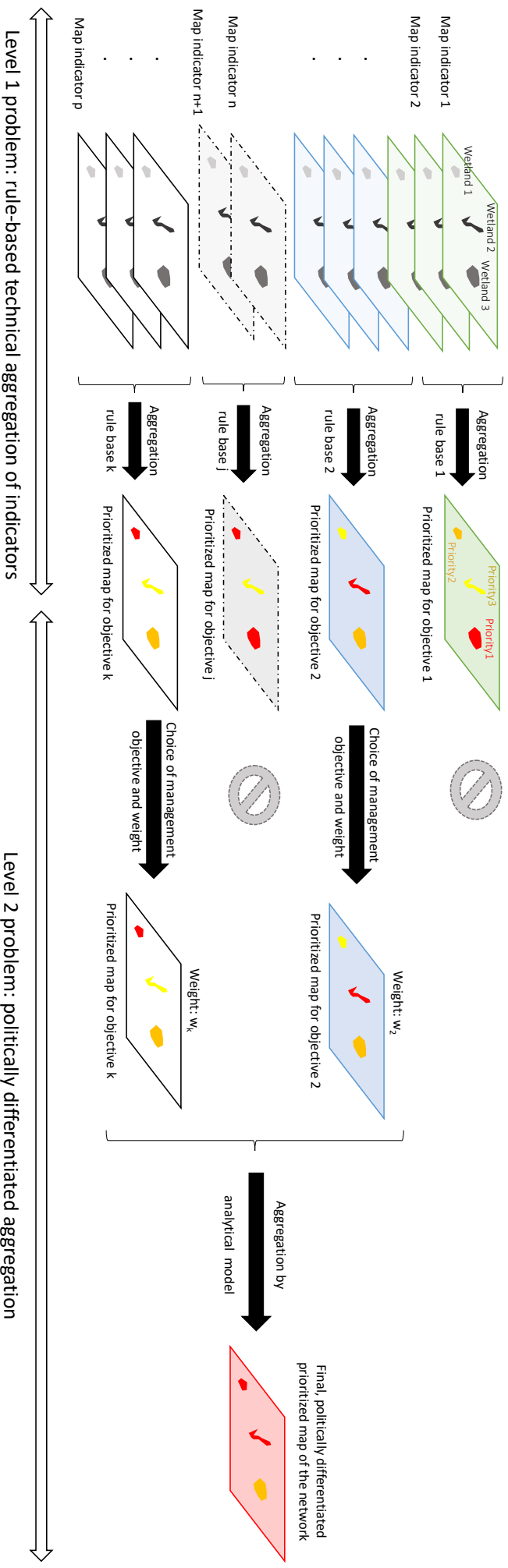


Figure 2
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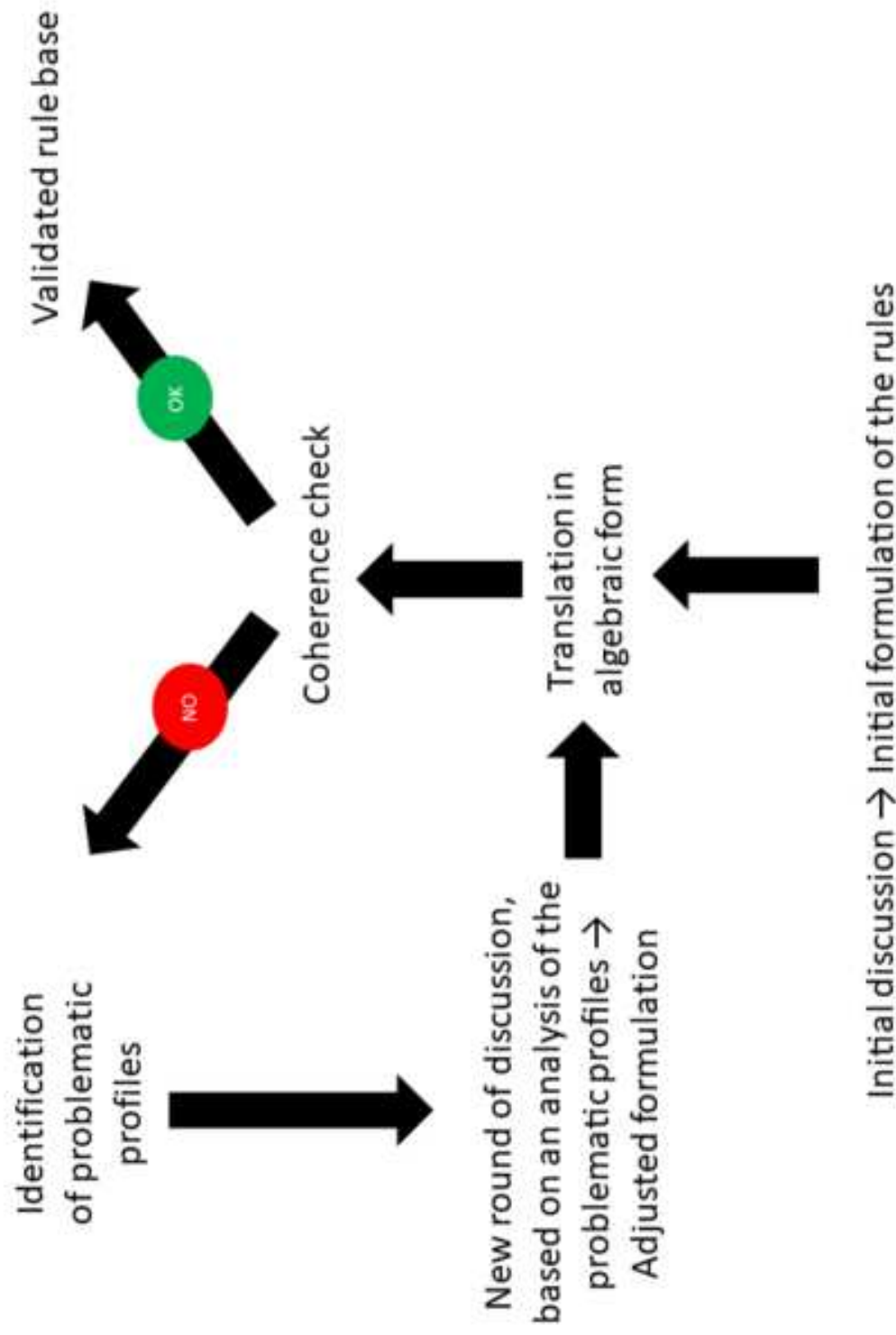


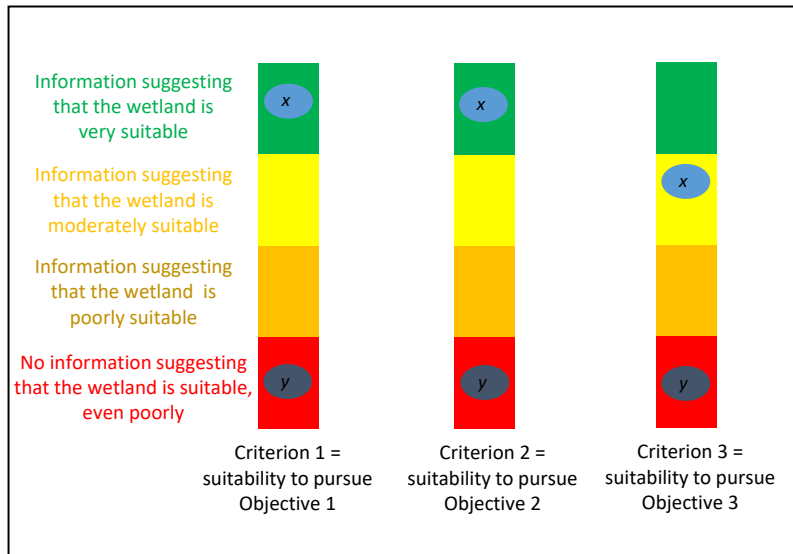
Figure 3

[Click here to download Figure: Fig 3.pdf](#)

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:

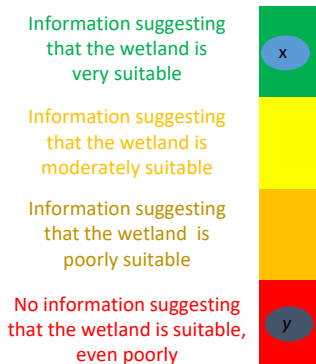
- a weight for each of the objective chosen: w_1, w_2, w_3
- a majority threshold λ



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 »



Overall prioritization

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

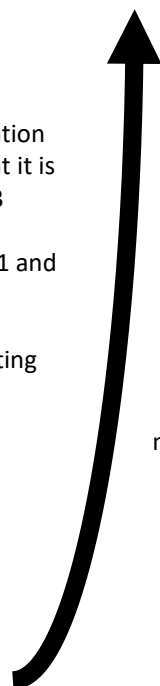
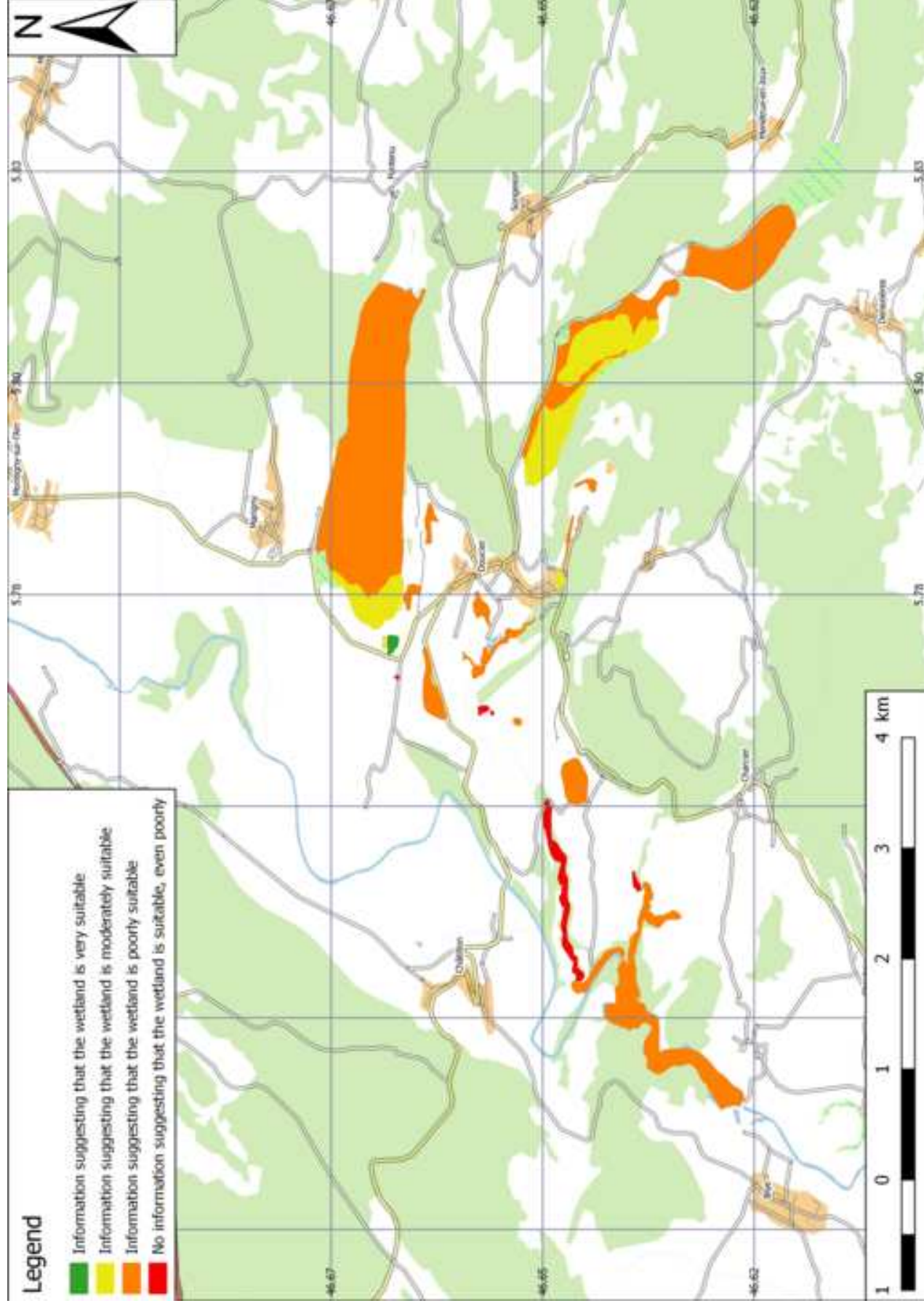


Figure 4
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