Post-normal science in practice: a method proposal and its application to agricultural water management

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Abstract: *Agricultural water management in a typical case of problems requiring a post-normal approach: when facts are uncertain, values in dispute, stakes high and decision urgent. Notwithstanding, putting in practice the principles of post-normal science is a difficult task, which challenges our capacity to bring together analytical and deliberative tools and methods, as well as our academic representations and models, as they often mask diversity. In this communication we report on a method we developed and implemented to have diverse stakeholders evaluate alternatives for water management in a French agricultural landscape suffering from water imbalance and social tensions. The method, which we labelled multi-actor multi-criteria evaluation combined with integrated assessment and modelling (MAMCE-IAM), is comprised of six steps: problem structuring, translation for modelling, integrated assessment and modelling, translation for evaluation, group evaluation and analysis and collective discussion. In the application of the method, we used the tool MAELIA, a modelling and simulation platform for water management issues, and the tool Kerbabel, a deliberation-support tool. The method proved successful in addressing post-normal challenges and especially useful for creating synergies between analytical stages and deliberation stages. Our understanding of water management issues progressed along with our capability to point out the most salient elements of debate in the case study. However, meeting those challenges raised new challenges. Especially, time constraints and reception of post-normal approach outside academia need to be better accounted for in the practice of post-normal science.*

Keywords: *post-normal science and technologies, multi-criteria evaluation, integrated assessment and modelling, agricultural water management, collective deliberation, science-policy interface, transdisciplinarity.*

Introduction

Natural resource management problems often fall in the realm of a post-normal approach of science: “when facts are uncertain, values in dispute, stakes high and decision urgent” (Funtowicz and Ravetz, 1990). One of the most famous principle of the post-normal science is to break the dichotomy between facts (“hard”, “unquestionable”) and values (“soft”, “unscientific”) by producing and evaluating knowledge within “extended peer communities” (Funtowicz and Ravetz, 1993). Extended peer communities should embrace people with plural skills, perspectives and commitments, hence not only covering plural fields of expertise but also making expert and lay knowledge dialogue (Funtowicz and Ravetz, 1994).

Agricultural water management is an illustrative case of the problems post-normal science deals with. First, it is one of the topic yielding to the most violent debates and conflicts over the world, even in temperate regions and established democracies (Temper et al., 2015). Second, water management systems bear numerous and radical uncertainties (Pahl-Wostl et al., 2007) ; predictions are therefore impossible (Jakeman and Letcher, 2003). Third, water management systems have encountered multiple failures, either social, ecological or both (Budds, 2009; Walker et al., 2002) ; hence making changes urgent.

The failure of technical approaches to respond to sustainability challenges led institutions, such as the European Union or the Global Water Partnership, to press for a paradigm shift towards more integration, adaptation and participation. Such shift is however slow to implement given the deep socio-cultural roots of the technical approach to water management, which starts with the very conception of water and water flows in Western societies. Linton and Budds (2014) insisted that conceiving water as a natural resource flowing along a hydrologic cycle implies that water management belongs to hydraulic engineering, often centralized. By consequence, water management has long consisted in increasing water supply to meet increasing water needs of populations and economic activities (Gleick, 2000), rather than being the object of a democratic debate.

Another possible reason precluding the switch from a technical to a post-normal approach to water management lies in the methodological difficulty of democratizing knowledge production. For instance, Petersen et al. (2011) reported on the difficulties the Netherlands Environmental Assessment Agency faced after institutionalizing the Post-Normal Science. Effectively representing plural worldviews, finding appropriate ways for the expression and incorporation of non-expert knowledge or structuring the problem under scrutiny while not refraining the creativity and motivation of the people involved were some of the most reluctant challenges they faced. Coming back to water management, in French agricultural areas this time, several authors (Debril and Therond, 2012; Vergote and Petit, 2016) showed that in different cases stakeholder participation contributed to narrowing the solution space and refraining change. Fostering dialogue between scientists, policy-makers and the civil society proves difficult to implement in practice; specific methods and frameworks to articulate existing tools are still required to produce transdisciplinary knowledge and tackle “real-world” sustainability problems (Brandt et al., 2013; Tress et al., 2005). This paper, which describes a methodological framework and its application aims to contribute to meeting this need.

Tools and methods which help mediating or structuring a dialogue between expert and lay knowledge and among stakeholders are already varied. They embrace . decision analysis methods (Failing et al., 2007), sustainability assessment (Chamaret et al., 2009), discourse analysis (Swedeen, 2006), information communication and technology (ICT) (Pereira et al., 2003), companion modelling (Barreteau et al., 2003; Bousquet et al., 2005). Each of them bear different strengths and weaknesses. Schematically, when used for mediation and dialogue structuring, decision-analysis methods help integrating plural knowledge and values in the evaluation of different decision options. Sustainability assessment clarifies the terms of a social-choice debate as attributes of choices are represented as the intersection of issues, stakeholders and perspectives for change. Discourse analysis is a powerful method to investigate the diversity of discourses around a specific issue and highlight convergences and divergences between groups and statements. Still in this same context of mediation and dialogue, ICT allows to make scientific knowledge available to non-experts and usable in collective deliberation. Companion modelling can either contribute to foster a common understanding of the problem or to facilitate the coordination of stakeholders. However, those “post-normal science technologies” (Frame and Brown, 2008) do not yet articulate a lot analysis and deliberation (Frame and O’Connor, 2011; Rauschmayer and Wittmer, 2006) and hardly account for complex problems in which spatial heterogeneity combines with plural viewpoints (Allain et al., 2017). Those challenges are of special salience in the case of agricultural water management.

Deliberation and analysis are two major and interdepending issues in waterscapes. Deliberation is required because stakeholder positions can be so polarized that gathering the different parts in the same place becomes impossible (e.g. our case study) and because of numerous asymmetries, including geographical given that water flows in one direction.

Analysis is necessary because of the special complexity of water management systems, in which interact many biophysical processes spread in time and space, many users including some remote from the resource at stake, and a multi-level governance involving public (State and local) and private actors; overall, there is still a lot to learn about water management functioning and processes. Modelling the interaction of water dynamics, water management, and agricultural practices through the integration of different sub-models is a privileged way to increase the understanding of water management issues at landscape scale (Bergez et al., 2012; Jakeman and Letcher, 2003), but it is at odds with the idea that the models to be used in participatory setting should be co-designed with stakeholders (Barreteau et al., 2003; van der Sluijs, 2002). Articulating analysis and deliberation therefore meets with a contradiction.

A second challenge lies in the “compression problem”, e.g. the switch from an infinite and unstructured universe to a representative and actionable diversity of discourses (Giampietro, 2003). The compression problem entails a specific dimension with landscape-scale or watershed-scale issues: space, which adds to the already non-trivial problem of representing plural views. Most sustainability assessments endorsing a multi-actor rationale do not explicitly deal with spatial heterogeneity and vice-versa (Allain et al., 2017). The tools and methods explicitly dealing with space (e.g. integrating geographic information systems) are turned towards contextualizing and processing spatial information and are therefore “ill-suited” (Ramsey, 2009) for exploring or reconciling diverse problem understandings. Conversely, most post-normal technologies designed to support deliberative processes or the coordination of different actors neglect the spatial dimension of social-ecological interactions. This becomes a strong limitation when dealing with a spatial common such as water, as the geographical distribution of water shapes social interactions and institutions, and conversely water flows are heavily modified by human uses, material infrastructures and norms (Moss, 2014). Companion modelling constitutes an exception as many of the models and roleplays used under this approach do represent spatial interactions between agents or players; however, this methodological framework is not turned towards the evaluation of different scenarios. Integrating two sources of complexity, spatial heterogeneity and multiple stakeholders, when evaluating different options for change, isn’t so far fully addressed by any method.

To overcome those challenges – articulating analysis and deliberation and addressing jointly multiple views and spatial heterogeneity -, there is no such way as sharing experience in the design, application and combination of tools and methods intending to give body to the principles of the post-normal science. Here we report on an experience conducted in a South-Western France watershed exhibiting water imbalance and related use conflicts. The method we implemented to evaluate different alternatives to solve the water imbalance tends to combine elements of analysis and deliberation and to account for space as well as multiple viewpoints. Central to the method are the MAELIA (multi-agent for environmental norms impact assessment) simulation platform (Gaudou et al., 2013) and the Kerbabel deliberation-support tool (Chamaret et al., 2009). On the whole, it can be called a multi-actor multi-criteria evaluation method combined to integrated assessment and modelling (MAMCE-IAM). Drawing on this experience, we answer the question: to which extent and at which costs can we address, in practice and in the specific case of quantitative water management problems, the challenge of “producing knowledge in an extended peer community”? Which trade-offs and contradictions do we face when doing so?

We will first detail the different stages of the method and its implementation in our case-study area; then present some results of the evaluation in order to illustrate the potential of the method as a post-normal tool; and finally discuss the method and the trade-offs we faced during implementation.

Materials and method

Study area

The study area is located in the Adour-Garonne hydrographic basin (South-Western France). In this hydrographic basin, many composing watersheds suffer from structural water imbalance, meaning that the water demand structurally exceed the water availability. They consequently follow specific water-use policies, e.g. imperatives to reduce water withdrawals and plan the allocation of water volumes between farmers.

The Aveyron watershed is one of the Adour-Garonne watersheds exhibiting structural water imbalance, as the river flow regularly falls below a regulatory threshold, which is supposed to ensure the proper functioning of the water environment and the satisfaction of all water uses. Each time the river flow falls under this threshold, a “drought cell” meets in order to state on the level of irrigation restrictions to apply. Also, to avoid or compensate such crises, flow-supporting reservoirs were built, mostly upstream, in the 1990s and 2000s, and contracts with hydropower companies passed in order to release water volumes in the rivers during the low-flow.

From an ecological point of view, the repetition of crises means that the water environment does not suffer from an episodic drought but from a structural deficit, deleterious to ecosystems and even more acutely those of little tributaries. From an economic point of view, irrigation restrictions are measures that do not allow farmers to anticipate and adapt their farming practices: if crops are sensitive to water stress (e.g. maize), yields can quickly decrease, hence the revenues of farmers. Crises also mean flow-support, which depends on costly infrastructure and contracts. From a social point of view, water restrictions tend to exacerbate conflicts between agricultural use and other water uses, such as recreational activities (fishing, bathing, canoe-kayak) and the water environment. Many additional elements show that the social climate is tensed: the failure of the flow-support management plan, the exemptions obtained for the application of withdrawals reductions (Debril and Therond, 2012), the absence of a local scheme for water management and of any new conciliation process since 2012.

Our study focuses more specifically on the downstream of the Aveyron watershed (fig. 1), where are located most of its irrigated fields. Among the 800 km^2 of the study area, half is agricultural, and mainly covered by field crops, among which the most water-demanding are maize mono-crops. There are also large patches of fruits and seed-maize crops, which provide high added-value but require secured water inputs to be contracted. During the last 15 years, the Aveyron river has been under the regulatory flow threshold around 40 days per year. Nonetheless, crises measures remain and the discussion about structural changes are at a standstill.

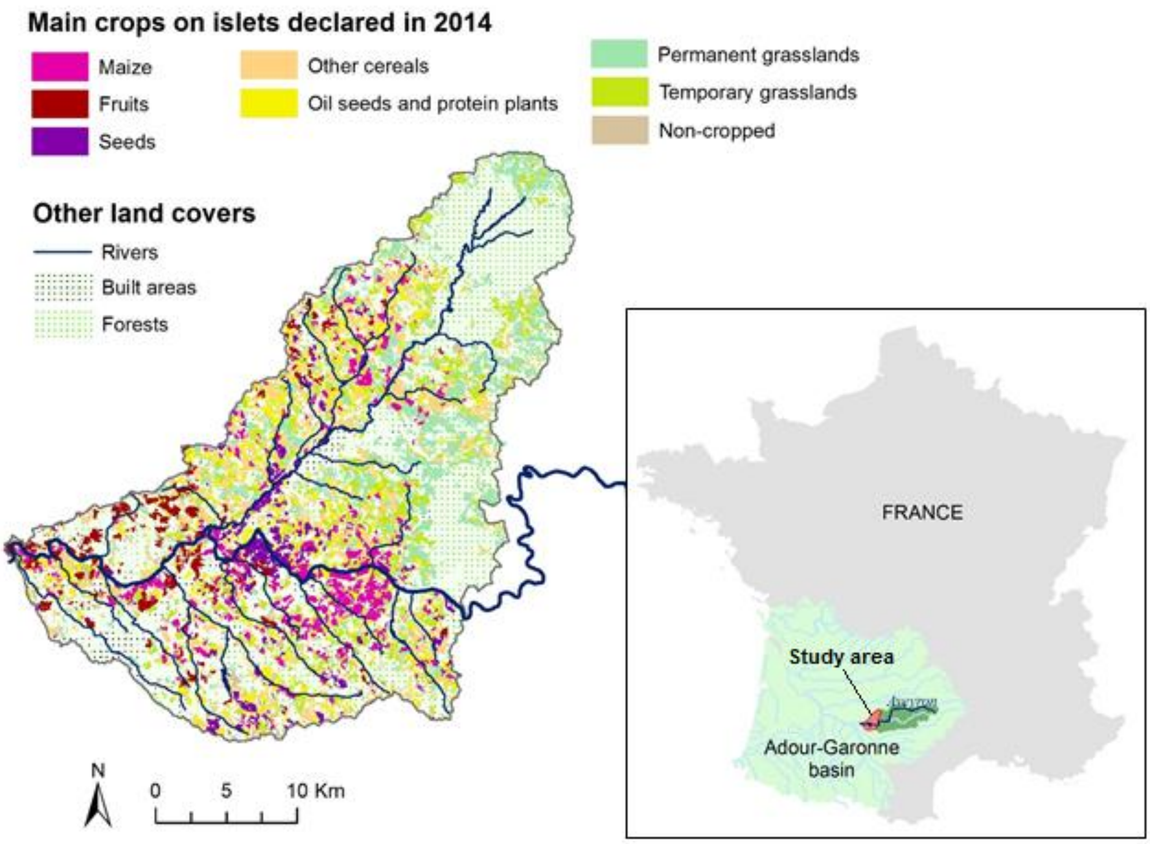


Figure 1. Location of the study area and main land covers

Method

We developed and experimented a structured method combining analytical and deliberative stages in order to have different stakeholders discuss structural water management alternatives for their watershed. Reflexively, the method can be re-constructed as a multi-actor multi-criteria evaluation method combined to integrated assessment and modelling (MAMCE-IAM). The method is made of 6 stages: problem structuring, problem translation for modelling, simulation and integrated assessment, integration of simulation outputs into a multi-actor evaluation device, group evaluation, and collective discussion. The method has many proximities with the INTEGRAAL framework for sustainability evaluations (O'Connor et al., 2010), but adds to it specific stages linked to the use of simulation models (Leenhardt et al., 2012), i.e. translation of narratives into simulation inputs and customization of simulation outputs for use by non-experts.

The six stages of the method are detailed below, with more emphasis on the two last stages (group evaluation and collective discussion), as we focus on their results afterwards.

Problem structuring

The list of issues and alternatives to consider was built through a bottom-up approach, involving 16 interviews based on a card-sorting game and a collective workshop. The 16 stakeholders interviewed were State services agents (from The Water Agency, the regional and local State services in charge of water and the environment), local government agents and elected representatives (from the district and local communities), environmental associations (including the fishing federation), irrigating farmers, advisors from agricultural extension services and technicians from agricultural cooperatives and suppliers.

The collective workshop aimed at settling the grid of evaluation criteria and drawing guidelines for the alternatives to evaluate (fig. 2). Based on the results of the interviews, participants agreed on a list of 11 criteria: safety, food security, economy, biodiversity, local identity, adaptation to exogenous changes, flexibility to adjust the water demand and offer, natural capital, equity, efficiency and political legibility. We also provided them with different levers for quantitative water management and asked them to hierarchize and modify them according to what they would be the more eager to learn about (independently of their desirability or feasibility). The final four alternatives resulting from this workshop and on which we continued to work were: reducing the irrigated area, improving irrigation management at the field scale, generalizing environmentally-friendly cropping systems, concentrating the water storage capacities.

Figure 2. Workshop with stakeholder to agree on evaluation criteria (left) and alternatives to evaluate (right)

Translation for modelling

Using model simulations implies that both the alternatives and the evaluation criteria are translated into inputs and outputs fitting the model characteristics and capabilities. In our case, we used the MAELIA multi-agent model (Gaudou et al., 2013, http://maelia-platform.inra.fr/) which represent the interactions between farming practices, hydrology and water management. The alternatives expressed in the form of narratives by stakeholders had to be translated into input files for the agricultural and hydrological modules of MAELIA. This translation exercise was done “in lab”, with no further inputs from stakeholders. The stakeholder alternatives were turned into the following four model-compatible alternatives:

1. Reduction of the irrigated area: irrigated cropping systems were turned into rain-fed cropping systems on the areas not benefitting from flow-support releases. On half of this surface turned to rain-feeding, permanent grasslands were reintroduced.
2. Irrigation using decision-support tools: The decision rules for irrigating field crops were modified in order to follow plant needs and not the actual decision rules of farmers. In the MAELIA platform, it consisted in activating a “theoretical irrigation strategy” which defines the moment for launching irrigation (but not the dose) depending on the soil’s humidity and the vegetation stage of the crop.
3. Crop rotations: Each field with maize mono-cropping (either grain or seeds) was turned into a 4-year rotation alternating sunflower, straw cereals, oil rape and maize.
4. Concentration of water storage capacities: all agricultural reservoirs in the watershed were erased, and replaced by three large reservoirs, disconnected from rivers and fed through winter pumping in the Aveyron river (two of the three reservoirs, already existing were actually enlarged). The total water storage capacity in the watershed remained unchanged, as well as the irrigated surface.

Also, the evaluation criteria had to be translated into model outputs. This translation occurred through two main stages: the construction of indicator profiles, through expert interviews, and the selection of some for simulation. The indicator profiles (O’Connor and Spangenberg, 2008) comprised between other elements the names of the indicators, their definition, unit, justification, relevant scales, estimation mode, and representation. Following various exchanges with the modelling team, we selected from the indicator-profile list (containing 146 potential indicators) those most able to be impacted by the alternatives, easily simulated (with no or nearly no additional model development), and with reliable estimates. Although the indicator profiles covered the whole list of criteria, the list of indicators (28) we could finally calculate was much more reduced and did not suffice to account for all the criteria of interest to stakeholders.

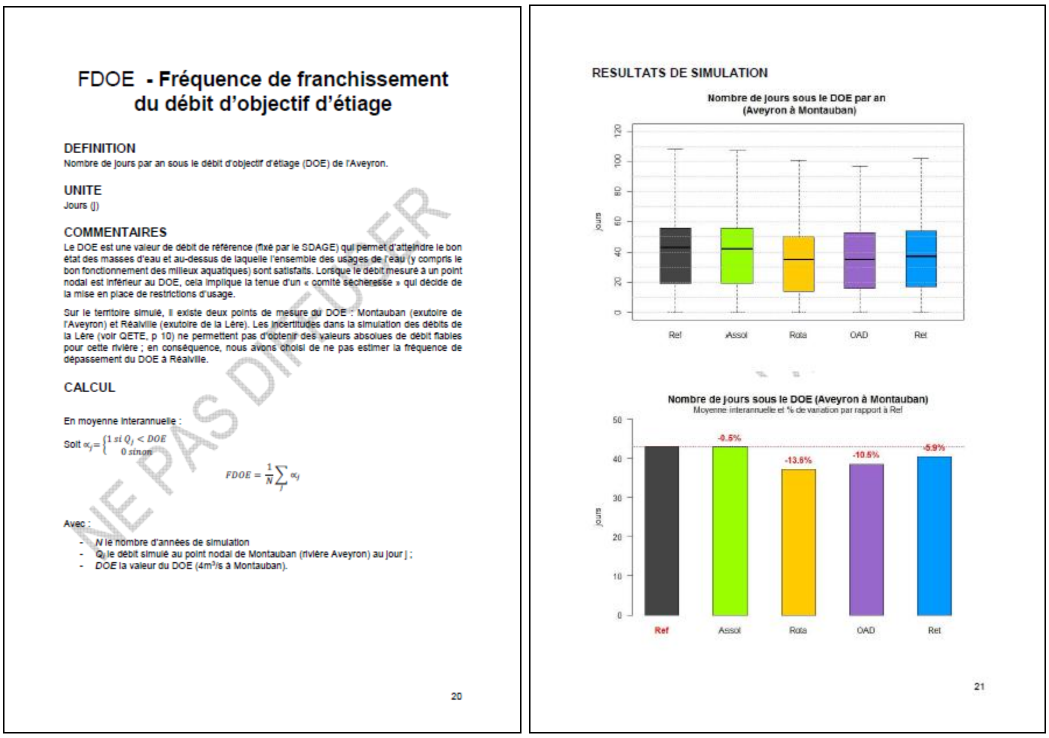
Simulation and integrated assessment

This stage consisted in running simulations with the MAELIA model for the four alternatives described above, checking the coherence of model's outputs and analysing them. Simulation runs were based on a 2001 – 2013 climate series. If model outputs were considered incoherent, we either looked for problems in the input data or in the model code itself. Simulation was therefore a trial-and-error process involving strong collaboration with our computer-modelling colleagues. When found coherent, the outputs of the model were further customized to produce indicators and analysed in order to understand the processes behind simulation results. This assessment stage is the object of a specific article (in progress).

Translation into a multi-actor evaluation device

Simulation outputs are not directly usable, even by experts. Their customization is necessary to researchers in order for them to analyse the results of the evaluation; it is also necessary to stakeholders in order to understand and evaluate the meaning of those results (Allain et al., 2018). From the 28 indicators we were able to estimate, we created a booklet addressed to stakeholders. For each indicator, one page detailed the definition of the indicator, its calculation, unit of measurement but also commented on the origin of the indicator and its purpose as well as limitations of the model especially in terms of reliability. A second page comprised the results of the simulation for each water management alternatives, in the shape of graphs (generally box and barplots) or maps (fig.3).

In addition to the "indicator booklet", we created an "alternative booklet" summarizing the characteristics of each of the four water management alternative, i.e. rationale and specification for modelling. The "indicator booklet" and the "alternative booklet" were first prototyped and tested with students in agronomy who had to evaluate the alternatives using the Kerbabel online deliberation support tool (Chamaret et al., 2009). It led to minor format changes. Also, it made us opt for a paper version of the Kerbabel evaluation matrix.


FDOE - Fréquence de franchissement du débit d'objectif d'étiage

DEFINITION
Nombre de jours par an sous le débit d'objectif d'étiage (DOE) de l'Aveyron.

UNITE
Jours (j)

COMMENTAIRES
Le DOE est une valeur de débit de référence (fixé par le SDAGE) qui permet d'atteindre le bon état des masses d'eau et au-dessus de laquelle l'ensemble des usages de l'eau (y compris le bon fonctionnement des milieux aquatiques) sont satisfaits. Lorsque le débit mesuré à un point nodal est inférieur au DOE, cela implique la tenue d'un « comité sécheresse » qui décide de la mise en place de restrictions d'usage.

Sur le territoire simulé, il existe deux points de mesure du DOE : Montauban (exutoire de l'Aveyron) et Réalville (exutoire de la Lère). Les incertitudes dans la simulation des débits de la Lère (voir QETE, p 10) ne permettent pas d'obtenir des valeurs absolues de débit fiables pour cette rivière ; en conséquence, nous avons choisi de ne pas estimer la fréquence de dépassement du DOE à Réalville.

CALCUL

En moyenne interannuelle :

Soit $\alpha_j = \begin{cases} 1 \; si \; Q_j < DOE \\ 0 \; sinon \end{cases}$

$$FDOE = \frac{1}{N}\sum_j \alpha_j$$

Avec :
- N le nombre d'années de simulation
- Q_j le débit simulé au point nodal de Montauban (rivière Aveyron) au jour j ;
- DOE la valeur du DOE ($4 m^3/s$ à Montauban).

20

Figure 3. Example of double page from the "indicator booklet", here for the indicator "number of days below low-water regulatory flow".

Group evaluation

We organized a series of 7stakeholder workshops with a total of 31 participants:

- Agronomists from a technical institute for field crops
- Agricultural advisors
- Managers of reservoirs supporting agricultural water use (local government and private managers)
- Agents from State services – local level
- Agents from State services – regional level
- Members of associations for environmental protection (local, regional and national organizations)
- Members of the local group of rural communities (project managers and representatives)

The evaluation workshops, aimed at completing an evaluation matrix for each major criteria of interest for the group. A presentation of the alternatives and some of the simulation result introduced the exercise. Then, the participants had to choose from the list of evaluation criteria (defined during the problem structuring stage) the top-five of most relevance to them as a group. They started with the criteria ranked first and evaluated each of the four alternatives by completing an evaluation matrix (fig. 4). They continued with the criteria ranked second and so on until the time went up.

The completion of the evaluation matrix (for one criterion) occurred according to the following scheme:

1. The participants decided together which indicators they would need, e.g. the most relevant for the criteria under scrutiny, with a proposed limit of 5 indicators. These indicators could be found in the indicator booklet but also, as the booklet could not cover all aspects of interests, be added *de novo* by the participants.
2. For each cell (alternative x indicator), the participants had to evaluate the performance of the alternative by comparison with the current situation. To do so, they had to choose between five possible judgments depicted by coloured stickers: satisfactory improvement (green), insignificant change (yellow), displeasing degradation (red), uncertain change or difficult to interpret (blue), do not know (grey).
3. Once the normative judgment attributed, participants had to allocate a weight to each indicator (for a total of 100%), reflecting the importance of the indicator in the argumentation. Although weight could theoretically vary among alternatives, all stakeholders chose to keep the same weighting system among alternatives.

Figure 4. Evaluation workshop using the indicator booklet (left photo) and evaluation matrix completed by participants with indicators, values judgments (colored stickers) and weights (right photo).

We (researchers) then fulfilled the online Kerbabel tool. In this interface, the problem is represented as a cube made of the following three axes: the stakeholder groups, the alternatives compared and the evaluation criteria (Fig. 5). Each cell of the cube contains a synthetic judgment, represented by a coloured bar. In the variation with indicators, the Kerbabel tool calculates for each cell (stakeholder group x alternative x criterion) the majority judgments i.e. the colour with the highest cumulative %. Hence, the colour of the bar corresponds to the majority judgment and the length of the bar is proportionate to the percentage. In case two value judgments are equally high, the Kerbabel interface displays the colour of the worst (e.g. red if green and red both weight 50%).

We sent extracts from the Kerbabel DST matrix to the stakeholder groups in order to have them check their results and discover their majority judgments. Stakeholders had the possibility to provide new comments or new judgments by email.

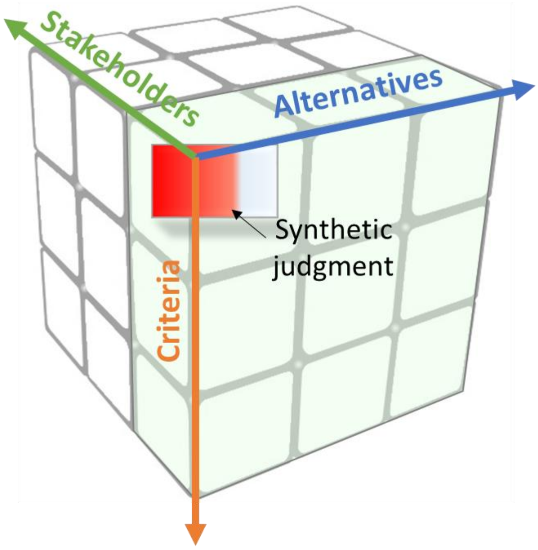


Figure 5. Representation of the multi-actor multicriteria problem in the Kerbabel DST interface.

Analysis and collective discussion

The Kerbabel tool allows to visualise the results of the evaluation workshops under different angles. Moving along the different sides of the cube, we can either look at differences among alternatives, stakeholders or criteria. In addition, we created new tables showing the % of each value judgment for each combination stakeholder group x alternative in order to visualise minority judgments.

A restitution meeting was organized afterwards in order to present and discuss the results of this analysis. Results were presented alternative after alternative, in order to highlight their weaknesses, strengths and zones of debate between stakeholder evaluations. Additional time was devoted to the “most liked” and “less disliked” alternatives in order to go further in their analysis and discussion. The most salient problems revealed by the evaluations were summed up and discussed in group (can they be levered and how). The new proposals made by the groups were then presented to the whole assembly.

Summary

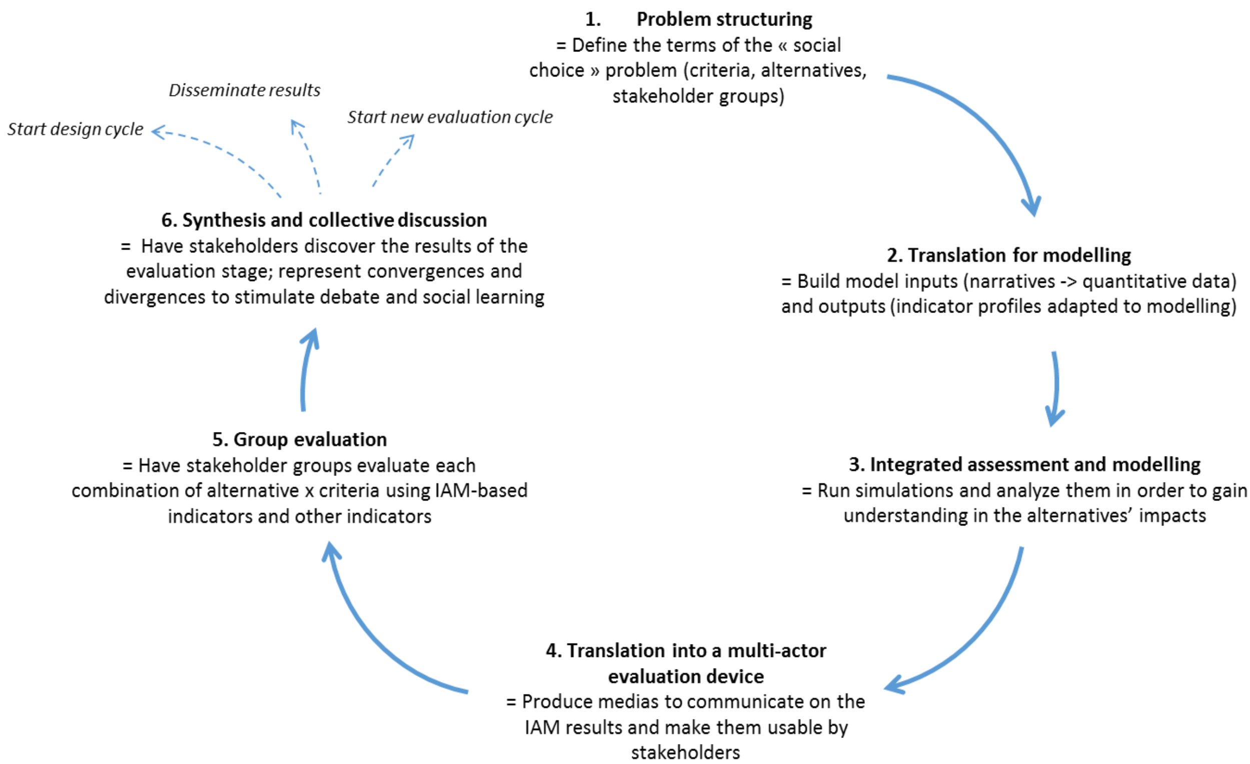


Figure 6. Summary of the 6 steps of multi-actor multi-criteria evaluation coupled to integrated assessment and modelling (MAMCE-IAM)

Figure 6 sums up the different stages of the method. Each stage correspond to an information transformation, which can be of different types: information translation (steps 2 and 4), analysis (steps 1 and partly 6) or use as input for producing new information or knowledge, through integration to computer or mental models (steps 3 and 5, and partly 6). The method can be conceived as self-sufficient to stimulate social learning, as one loop within an iterative method (with subsequent evaluation loops), or as a preparatory cycle for designing solutions and triggering collective action.

Results

In this section, we present some of the results of the group evaluation sessions and their analysis, which can be used in the following stage of the collective discussion (articulation between stage 5 and 6). Results of the IAM stage, purely analytical, are developed in another article.

We expose the results from the entry of each stakeholder group, and then, from the entry of each alternative. We do not offer here an extensive view of our results but rather tend to illustrate the potential of the method through some chosen examples.

First entry: results by groups

Fig. 7 provides the aggregated results obtained for each of the 7 stakeholder groups using the Kerbabel interface. This aggregation draws some general trends about stakeholder group's preferences. For instance, for the technical institute, the alternative of decision-support tools appears as their favourite while crop rotations is their most disliked one. For local communities, by contrast, crop rotations is their most liked alternative, followed by decision-support tools, then reduction of the irrigated area and finally, their most disliked alternative is the concentration of water storage.

Such analysis can be completed in two ways. First by looking at the indicators chosen by each group, which reflect the arguments they mustered to formulate a value judgment on a given criterion. For instance, the difference between local communities and the agricultural advisors on the way alternatives are evaluated against the economic criteria lies, for a large part, on the indicators chosen and their weights. Agricultural advisors based their judgment mainly on the gross margin of farms and to a lesser extent on other agricultural accounting indicators (e.g. the total revenue of farms, the number of farm employees). Local communities gave much more importance (30%) to non-agricultural activities depending on the Aveyron summer flows (e.g. canoe-kayak, fishing etc.) and, for the agricultural sector, used indicators referring to what they judged determining for newcomers to set up in the area (number of farms, revenue drawn from each m3 of water withdrawn, etc.). This difference of appreciation can be an interesting point to submit to debate during the collective discussion.

Second, the analysis "by stakeholder group" can be refined by looking at minority judgments. For instance, fig. 6 shows that the water storage managers and the local communities both judged that the alternative of irrigation reduction does not bring any significant change for the economy and the preservation of biodiversity (i.e. the bar is yellow). However, if we consider minority judgments, this alternative appears much more criticized by the water storage managers that by local communities. For the economic criteria, the former group gives 40% of negative judgments (red) while negative judgments are absent from the local communities evaluation. In addition, local communities give 50% of positive judgments (green) to this alternative from the point of view of biodiversity preservation, while the positive judgments of the water storage managers reach only 10%.

Hence, looking at minority judgments allows to have a more subtle analysis of the proximities between stakeholder groups and can be a decisive point to order the preferences of a group. Based on the analysis of minority judgments, we could distinguish which groups have the most similar or different patterns. We therefore drew a diagram of coalitions between groups (fig. 8). Such diagram shows that there is a gap between stakeholders from the agricultural sector and others, based on their opposed appreciation of the cultural-rotation alternative. State services, local communities and water storage managers form a relatively homogenous group, whose appreciation of the decision-support tool alternative converge with the one of the agricultural sector. Environmentalists are by contrast poles apart with agricultural advisers: their two favourite alternatives (crop rotations and reduced irrigated area) are the two most disliked ones of the agricultural advisers and vice-versa. Because we could not have every stakeholder groups make an evaluation on every criteria, it would be difficult to draw definitive conclusions from fig. 8 diagram. However, this representation has the merit to point out possible coalitions of stakeholders and nodes of the problem, especially in terms of social acceptability.

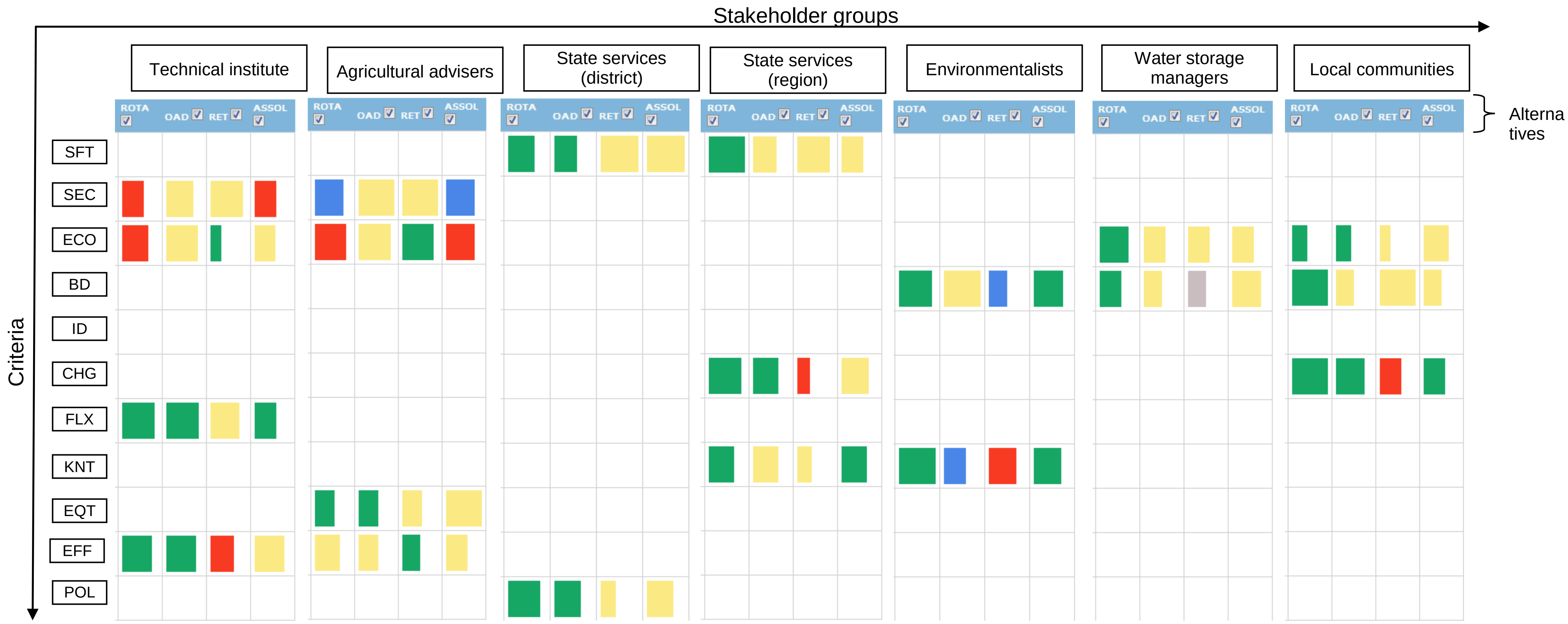


Figure 7. Aggregated results of the evaluation for each stakeholder group (screenshots from the Kerbabel DST web interface). Alternatives under evaluation: crop rotation (ROTA), decision-support tool (OAD), concentration of water storage (RET) and reduction of the irrigated area (ASSOL). Evaluation criteria : safety (SFT), food security (SEC), economy and employment (ECO), biodiversity (BD), local identity (ID – no stakeholder group chose to evaluate in priority this criteria), adaptation to exogenous changes (CHG), flexibility to adjust the water offer and demand (FLX), natural capital (KNT), equity (EQT), efficiency (EFF), political legibility (POL). The colour code reflects the majority judgment given by a stakeholder group to an alternative for a specific criterion: green = satisfactory improvement; yellow = no significant change; red = displeasing degradation; blue = uncertain; grey = do not know.

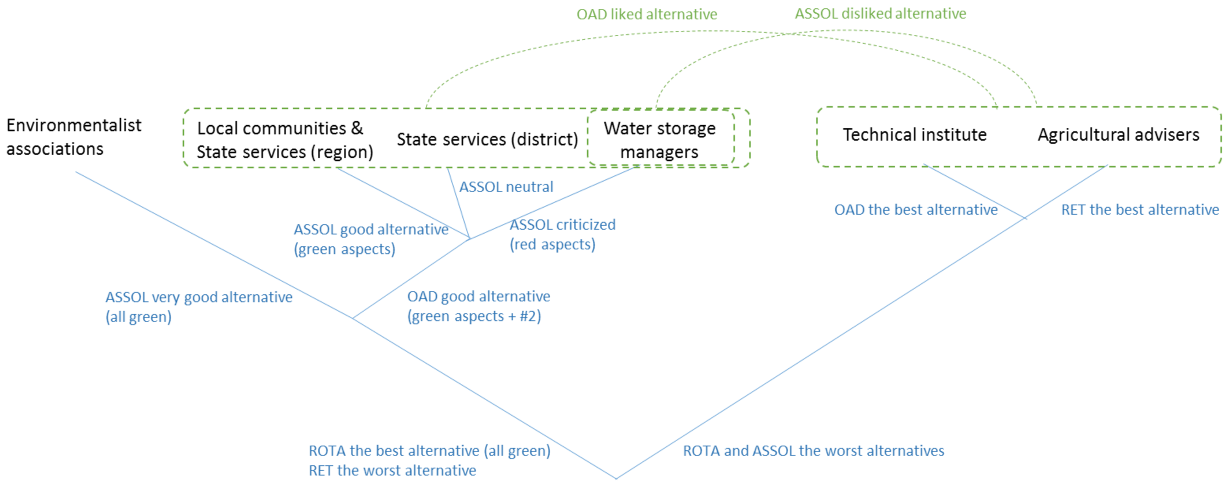


Figure 8. Diagram of coalitions between stakeholder groups based on the analysis of their minority judgments.

OAD = Decision-support-tool alternative; ROTA = crop-rotation alternative; ASSOL = reduced-irrigated-area alternative; RET = concentration-of-water-storage alternative.

Second entry: results by alternative

As with the analysis "by stakeholder group", the Kerbabel DST interface offers a first level for the analysis of the evaluation results by alternative. Looking at the indicators chosen and the minority judgments allows to enter a second level of analysis, more detailed.

Majority judgments are presented in fig. 9. This figure, presenting screenshots from the Kerbabel DST, can be read "in columns", to look at differences and convergences between stakeholder groups, or "in lines", to look at trade-offs between criteria. Fig. 9 clearly shows that two alternatives positively distinguish from the others. First, the crop-rotation alternative is the one receiving the highest number of positive majority judgments (green). Five out of the seven stakeholder groups judged it as an improvement for all the criteria they evaluated. Also, it brings out globally positive changes on 8 out of the 10 criteria evaluated. About its economic performance, a debate exists as half of the evaluations were positive and the other half negative. The second alternative highlighted by fig. 8 is the decision-support-tool alternative. This alternative is the only one to be free from negative judgments (i.e. no red cells). Hence, there is no major dissent among stakeholder groups nor trade-off between criteria, i.e. a gain in one criterion does not imply a loss in another criterion.

The two other alternatives, reduction of the irrigated area and concentration of water storage, exhibit much more reserved appreciations (a lot of yellow cells and some red and green ones). Minority judgments for those alternatives (fig. 10) reveal clearly different patterns. With the concentration-of-water-storage alternative, negative judgments (red) are disseminated across stakeholder groups and criteria. Even for the group whose preference goes to this alternative (agricultural advisers), the alternative bears some weaknesses. This means that the evaluation of the alternative is very sensitive to the weights given to indicators and that in terms of social acceptability, this alternative is open to many attacks. Also, this alternative appears as the one bearing the highest percentage of uncertain or unknown value judgments (blue and grey), which means that further knowledge could help clarify the judgments of some groups, but also that it is currently the most "worrying" alternative. To the contrary, the negative judgments of the reduced-irrigation alternative are more localized. They concern only three groups of stakeholders and are concentrated on food security, economy and to a lesser extent on efficiency criteria. Such pattern might be more easily manageable, for instance by introducing a reflection on how to compensate these drawbacks.

Analysing evaluation results through the entry of alternatives can therefore be useful to focalise the discussion on some of them, depending on the aim of the collective restitution. In the case study, because tensions between stakeholder groups are already sharp, we privileged this entry and drew more attention on the preferred and most consensual alternatives, respectively the crop-rotation and decision-support tool alternatives. Concretely, in the collective restitution, we decided to allocate more time to their presentation and discussion, and enrich the debate thanks to complementary communications on connected issues (logistic issues in the case of crop rotations; and obstacles to the use and spread of decision-support tools among farms).

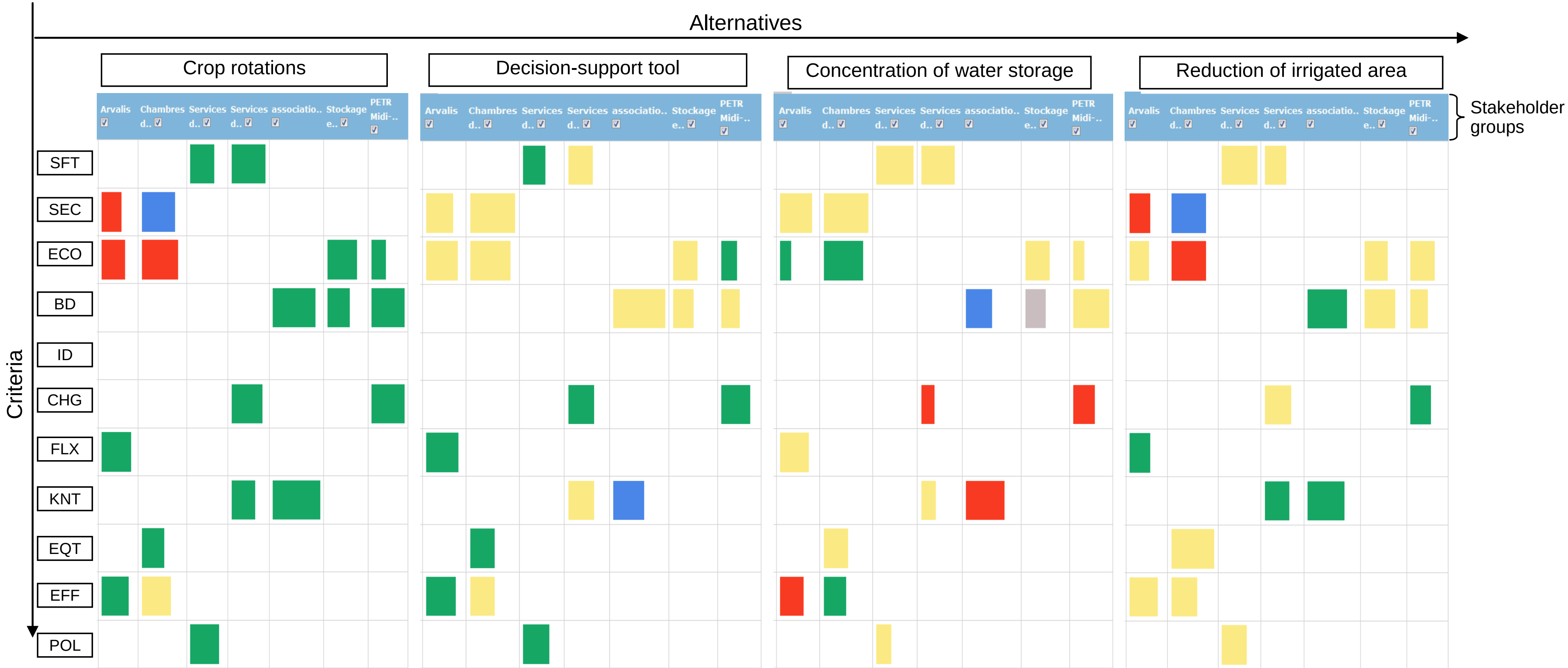


Figure 9. Aggregated results of the evaluation for each alternative (screenshots from the Kerbabel DST web interface). Evaluation criteria : safety (SFT), food security (SEC), economy and employment (ECO), biodiversity (BD), local identity (ID – no stakeholder group chose to evaluate in priority this criteria), adaptation to exogenous changes (CHG), flexibility to adjust the water offer and demand (FLX), natural capital (KNT), equity (EQT), efficiency (EFF), political legibility (POL). Stakeholder groups (left to right columns): technical institute, agricultural advisers, State services (district), State services (region), environmentalist associations, water storage managers, local communities.

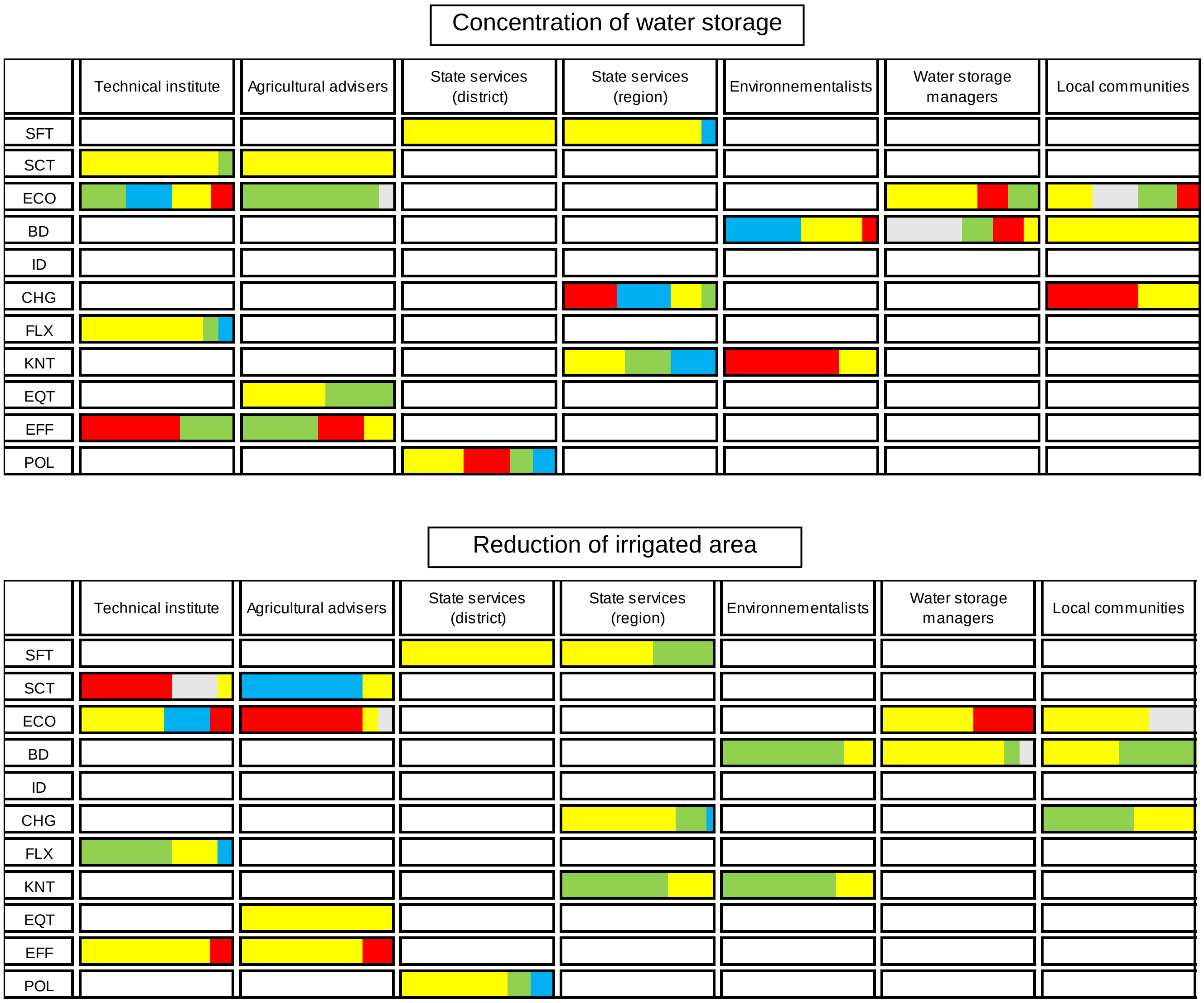


Figure 10. Detail of minority judgments for two alternatives.

Discussion

In the result section, we emphasized the potential of the method to articulate analysis with deliberation and to offer a „compressed“ representation of the problem that doesn't mask diversity nor heterogeneity. We can even argue that analysis and deliberation were not only combined but used in synergy: the IAM stage (analytical) provided us with new understandings that helped answer the questions of stakeholders, and in return, the group evaluations (deliberative) gave us new keys for interpreting the results of our simulations. On the whole, we can assert that the method was successful in addressing the challenges we aimed to address. However, throughout its implementation, other methodological challenges appeared in the form of trade-offs or contradictions.

Promises of the method for democratizing knowledge production and meeting post-normal challenges

A transdisciplinary dialogue based on a critical and non-obligatory use of simulation outputs

The methodological framework we developed showed successful in fostering dialogue between researchers and stakeholders and lowering the barrier between „hard facts“ and „soft values“ (Funtowicz and Ravetz, 1993). Generally, when models are used within participatory settings, they are supposed to provide the „hard facts“ that would help stakeholders making the „right decisions“ (Elgert, 2013). It is therefore a „one-way“ communication in which stakeholders are either data suppliers or recipients of scientific knowledge (Antunes et al., 2009; Barreteau et al., 2010). In our case study, communication and dialogue were rather reciprocal.

Researchers provided stakeholders with simulation outputs on the alternatives of interest to them, without making the use of those simulations a prerequisite for judging the alternatives. It fostered intra-group deliberation (which indicators are the most relevant, are they sufficient, should other indicators be added etc.) and also, in some cases, contributed to reshaping group preferences. With most people, the evaluation exercise was well received. Some took pleasure in “moving out of the frame” (i.e. contesting model hypotheses, using new indicators), others appreciated the workshop format as a way to discuss “horizontally” with researchers, while others were interested in discovering the simulation results and trying to understand them.

Conversely, during the workshops, stakeholders expressed surprise regarding some simulation outputs, compared them with their „ground“ expertise, questioned modelling hypotheses, asked for explanations about underlying processes, and formulated new indicators. This benefitted to our interpretation of the simulation results; for instance, the feedback of different persons helped us nuance the results obtained for the decision-support-tool alternative in terms of water savings. It was also useful to question the relevance of the model and of the indicators we provided, and observe which types of alternatives and whose concerns were best represented in the model. These questions open up perspectives for future model development and combination with other models or modes of expertise.

“Common language” and problem-oriented deliberation

Another success of our methodological framework was to allow groups holding different attitudes towards modelling and quantitative water management to find a common language to exchange their views. Finding a common language has already been pointed as a necessity in transdisciplinary research and multi-actor problems (Brandt et al., 2013; Ramos et al., 2015). In our case study, the crucial elements of this common language were not definitions but artefacts that contributed to legitimize different types of arguments and concerns:

- the criteria grid, constructed through a bottom-up approach, allowed different stakes to be represented, even those not benefitting from powerful spokespersons or not inscribed in regulatory frameworks and management norms;
- the term “indicator” gave authority to the arguments of every group, even the arguments that were “out of the box” of the model ;
- The use of qualitative value judgments (expressed by colours), which certainly frustrated some stakeholders willing to be “more precise”, contributed to put “softer” judgments, based on general appreciations of the alternatives, on an equal footing with quantitative estimates of impacts.

Apart from this “common language”, a collective discussion became possible because the multi-actor multicriteria representation of the problem, based on the Karbabel interface, helped focusing on specific issues. Using this representation, the collective discussion could target problems or divergences refraining change, sometimes resulting from irreducible value conflicts, but not turn into a discussion about the legitimacy or foundation of the values underlying stakeholder judgments. Participants collectively discussed specific problems and made proposals to overcome the most salient ones. For instance, they suggested to implement crop rotations with alfalfa instead of maize, or to restrain the access to collective water resources to farmers engaged in an agroecological transition, hence widening the space of possible solutions to water imbalance.

Methodological trade-offs

Time

In the method, we allocated a lot of time to structuring the problem and carefully compressing information. Many authors have argued that problem structuring is the one crucial element in any multi-criteria evaluation (Allain et al., 2017; Garmendia and Gamboa, 2012; Giampietro, 2003; Munda, 2004) and transdisciplinary work in general (Brandt et al., 2013).This – in addition to the tensed social context of the case study – made us adopt a bottom-up approach to define criteria, and a mixed top-down / bottom-up approach to define alternatives and indicators. If such approach is justified by the theory and the context, it is also very timely and therefore at odds with the idea that “decisions are urgent” (Funtowicz and Ravetz, 1993).

Reception of the approach

Researchers adopting a post-normal stance look for hybridizing their knowledge with that of “profanes” or local experts, but this is not always well received. “Help us, tell us what to choose or I will quickly get fed up with it!” urged one of the participants during the evaluation exercise. We were also criticized for standing apart from operational problems, as some people were hoping the model could be used for every-day water management. Other critics rather targeted the incompleteness of the model and the lack of ambition in the indicators by comparison with the evaluation criteria.

One major difference between the receptive and less-receptive groups lies in their culture, familiarity with participatory research and habit of working with our research team. One group clearly endorsed a technical approach of agricultural water management and expected the indicators we provided to be standards for objectifying a decision. Therefore, ambiguity and flexibility in the use of indicators, which we looked for, was seen as a drawback. The other group whose expectations were not fulfilled were new partners who became involved in the method only at the evaluation stage, at their demand. Although we communicated documents to them and exchanged by phone before the evaluation workshop, this was not enough to create a mutual understanding. Finally, we must notice that we could not manage to have the local agricultural advisers participating to the evaluation, first because of their time constraints but more probably because of a rejection of the deliberative approach and/or the scenarios.

These mismatches show that on many respects the scientists and their tools (indicators, models) remain considered under a positivist rationale which is incompatible with a post-normal approach. Moving out of the culture of positivism is more or less welcomed by partners, and can even produce some frustrations. Is it a problem? If we consider that frustration is part of learning, no. For instance, participants may have learnt about the model’s limitations. But the feeling of disappointment may also refrain them from participating to other reflections about quantitative water management. Stimulating a change of mentalities, not only within academia, but also out of it, is certainly the most salient challenge for the practice of post-normal science.

Perspectives

Here we draw some perspectives to answer those new challenges. Some are operational and constitute direct perspectives for improving the method, while others are longer-term and broader perspectives for the practice of post-normal science.

1) Design joint and formalized project with stakeholders, including decision-makers. This way, the approach would have more chances to be shared, participation be less costly (not considered as an „extra-activity“) and more “willing”. Tighter collaboration with decision-making could convince the most reluctant groups to participate. Also, multiplying such experiences would gradually help create a “new social contract” for science (Gallopín et al., 2001) which not only relates scientists to policy-makers but also to other stakeholders, often considered as “agents”, such as practitioners.
2) Create mechanisms for a continuous and open dialogue, adapted to institutional realities. On this respect, being in long-term relations with persons who have a strong

capability to mobilize others and benefitting from external funding is a plus. In practical terms, having a continuous and open dialogue also means to accept that people will change along the process and have time constraints. Developing media to help them following up or catching up (information letters, blogs etc.), developing facilitation skills, even for communication within supposedly homogenous groups, and experimenting methods of short duration for interviews or group sessions could help to do so.

3) Capitalize on other experiences and strengthen networks of partners. Our approach was possible because we could benefit from a model already calibrated and instantiated for our study area; in this sense we capitalized on our knowledge base and tools. But in other stages of the method, for instance for the development of indicators, we could have probably been more "effective" if we would not have started from the ground to define indicator profiles. On the whole, developing and using tools to capitalize on other experiences and share information would help meeting the need for plurality in parallel with the need for urgent decisions.

Conclusion

Have we met the challenge of combining analysis with deliberation? Yes, as our results show, we even elaborated on analytical stages to enhance deliberation and reversely, we could benefit from deliberation stages to enrich our analysis and create social learning. Have we met the challenge of compressing information without standardising it? Although there is wide room for improvement, we managed to make divergences and convergences between stakeholders and criteria legible and started to reflect on how to use GIS technologies (integrated in a model) to serve the expression of these differences. On the whole, our multi-actor multi-criteria evaluation method combined with integrated assessment and modelling (MAMCE-IAM) offers a rich experience for dealing with water management conflicts in an imbalance context. If the specific tools are not necessarily transferable, the general framework can be useful to deal with other problems requiring a post-normal approach. Our experience opens up new challenges and calls for strengthening partnerships within academia and with practitioners and decision-makers.

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