G-Eau Working Paper/Rapport de Recherche No.13

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Barreteau, O.; Bonte, B.; Caballero, Y.; Dubois, E.; Farolfi, S.; Garin, P.; Hérivaux, C.; Jourdain, D.; Le Coent, Ph.; Malard, J.; Montginoul, M.; Morardet, S. and Neverre, N. 2022. Analysing practices, social representations and behaviours of socio-hydro systems' actors. G-EAU Working Paper/Rapport de Recherche No.13. Montpellier, France. http://www.g-eau.net/

[1] This collective paper was designed and discussed within the PRECOS Team of the Joint Research Unit G-Eau (http://www.g-eau.fr/index.php/en/umr-g-eau/teams/item/416-practices-social-representations-and-behaviours-within-socio-hydrosystems-precos). The members of the Team appearing as authors contributed written texts to the paper.

Abstract: This working paper presents and discusses the approaches and methods used by the PRECOS Team of the G-Eau research unit to analyse practices, social representations and behaviours of socio-hydro systems' actors. Four groups of methods are presented: 1) surveys, interviews, and focus groups, 2) stated preferences, 3) experimental economics, 4) hybrid methods. A wide literature review is provided for each group of methods, facilitating a better understanding of the tools proposed. Through examples and concrete applications, the methods are compared and their advantages and limitations discussed. The paper concludes that there is no ideal method for the analysis of actors' practices, social representations and behaviours in socio-hydro systems, and suggests moving in the direction of transversality and interdisciplinarity, by adapting the existing methods to the specificities of the socio-hydro systems and producing hybrid methods that benefit from the complementarity of the original methods.

Keywords: Actors, Practices, Social representations, Behaviour, Water, Socio-Hydro systems, Hybrid methods

TABLE OF CONTENT

1 Introduction and rationale

Water dynamics are closely linked to a wide set of intricate human uses, whether as a resource, a vehicle, a landscape feature or as a receptacle for waste, among other uses. These uses depend as well on various characteristics of water, including, availability, biological and chemical quality, reliability, and variability. Since indicators of water resource status will depend on the particular interest of the uses involved, this complexity of interactions between water and its uses complicates the task of characterising the current status of a given water resource. Understanding these complex webs of interaction is important, as water is key to the resilience of many social ecological systems (Falkenmark et al. 2019).

In the follow up to the literature on socio-ecological system, we name social-hydrological systems (or socio-hydro systems – SHS), those socio-ecological systems where water is a key factor of resilience. In practice, socio-hydro systems are a set of resources, actors, institutions and infrastructures. As specialisation of socio-ecological systems they comprise four main categories of components: (1) users, (2) governance systems, (3) resource units, and (4) resource settings (Ostrom 2009). As far as water plays a key role in their evolution, infrastructures are prominent components; engineering of water systems to control its availability has structured the fate of societies since antiquity (eg. Anderies 2006, Wittfogel 1957). These human-made hardware infrastructures interact with the natural infrastructures water systems provide (e.g. wetlands) and with the human-made soft infrastructures (i.e. institutions') established to manage them. Socio-hydro systems face specific management challenges (Brelsford et al. 2020).

The study of socio-hydro systems is currently an active field of research, with emergence of domains such as sociohydrology (Sivapalan et al. 2012) or hydrosocial cycles (Wesselink et al., 2017). Beyond these scholarly fields specialising in water, the literature on coupled infrastructure systems and the robustness framework (Anderies et al. 2004; Anderies et al. 2019) enable us to understand the articulation between components with a focus on the role of infrastructures and infrastructure providers.

The analysis of socio-hydro systems pays particular attention to the concrete ways humans interact with the objects and living beings that make up these ecosystems, which we will qualify, for simplicity, as practices and behaviours. But it is equally interested in the consequences of these practices and behaviours for hydro systems and society, in a dynamic vision of these interactions. The mechanisms and determinants of these practices and behaviours constitute a central research object of the PRECOS team (Practices, Social Representations and Behaviours within Socio-Hydrosystems), which is part of the Joint Research Unit G-Eau[2]. Schematically, the origin of these practices is sought in two complementary spheres of analysis: i) the logic of actions of each person, having the capacity to analyse his/her environment and sufficient independence to carry out choices according to individual preferences; ii) the various societal structures which will delimit these logics of individual actions: norms, institutions, values, incentives, knowledge and know-how, information. This duality of spheres of analysis leads to the mobilisation of a diversity of approaches and disciplines.

The central object of our analyses is therefore the individual behaviour of the actors within the socio-hydro systems. Even if this behaviour takes place within groups, as it often does, we are interested in studying individual choices, how they evolve and the factors that influence them. We include in our analysis individual behaviours taking into account the strategies of other actors within the group (cooperative and non-cooperative equilibria in game theory models, for example) and the effect of collective rules established by (endogenous) or imposed on (exogenous) groups. We also study whether and under what conditions these individual choices influence the decisions taken by the groups and by the institutions that manage the systems within which the actors studied act and evolve.

[2] http://g-eau.fr/index.php/fr/

The aim of this paper is to present and discuss a non-exhaustive body of methods and approaches that we[3] have put in place to analyse practices, social representations and behaviours of socio-hydro systems' actors in different geographical zones and to study various problems in connection with socio-hydro systems over the last fifteen years.

We present four groups of methods: surveys/focus groups for the analysis of practices, social representations, preferences; stated preferences; experimental economics and field experiments; hybrid methods.

In Section 2, for each group of methods, we provide a short literature and the conceptual bases that underpin the methods, some examples of our application to the analysis of socio-hydro systems, a discussion about the particularity of their adoption in these systems, and a discussion about the advantages/limits of the methods.

Section 3 compares and discusses the groups of methods, referring particularly to their application to the analysis of socio-hydro systems' actors. It concludes that there is no ideal method for the proposed analysis and provides paths for further research in this field.

2 Methods

2.1 Practices, social representations and preferences on the regulation of water uses

2.1.1 Introduction: objectives and approaches

Adaptation to global change implies not only a change in collective rules, but also a change in individual practices (consumption, limiting the ecological footprint, involvement in collective action, etc.). These individual behaviours are based on social representations of the relationship between Humans and Nature. These representations allow people to justify their practices by using a set of arguments that combine economic, social, ecological and ethical considerations (Di Méo, 2008). The aim of our research is to characterise water use practices and the social representations underlying them in order to identify ways of transforming them for sustainable management. They combine the methods described above in a schematic way:

- Individual surveys on a representative sample of the population,[4] to identify behaviours, attitudes and associated social representations;
- Individual semi-directive interviews and discussion groups to specify the components of social representations, the norms and values that drive them;
- Discussion groups to discuss options for regulating these behaviours, using a variety of media depending on the context and the challenge: prospective scenarios, collective simulation (role-playing games), discussions with experts, etc.;
- The feedback of individual and collective preferences on the rules to be promoted.

2.1.2 Conceptual bases

This approach is inspired by the principle of methodological triangulation (Caillaud and Flick, 2016). It is based on two main theoretical frameworks in social psychology. The first one, the theory of an individual's planned behaviour (Ajzen, 1991), postulates that behaviour results from a decision driven by personal intention, according to the following functional scheme:

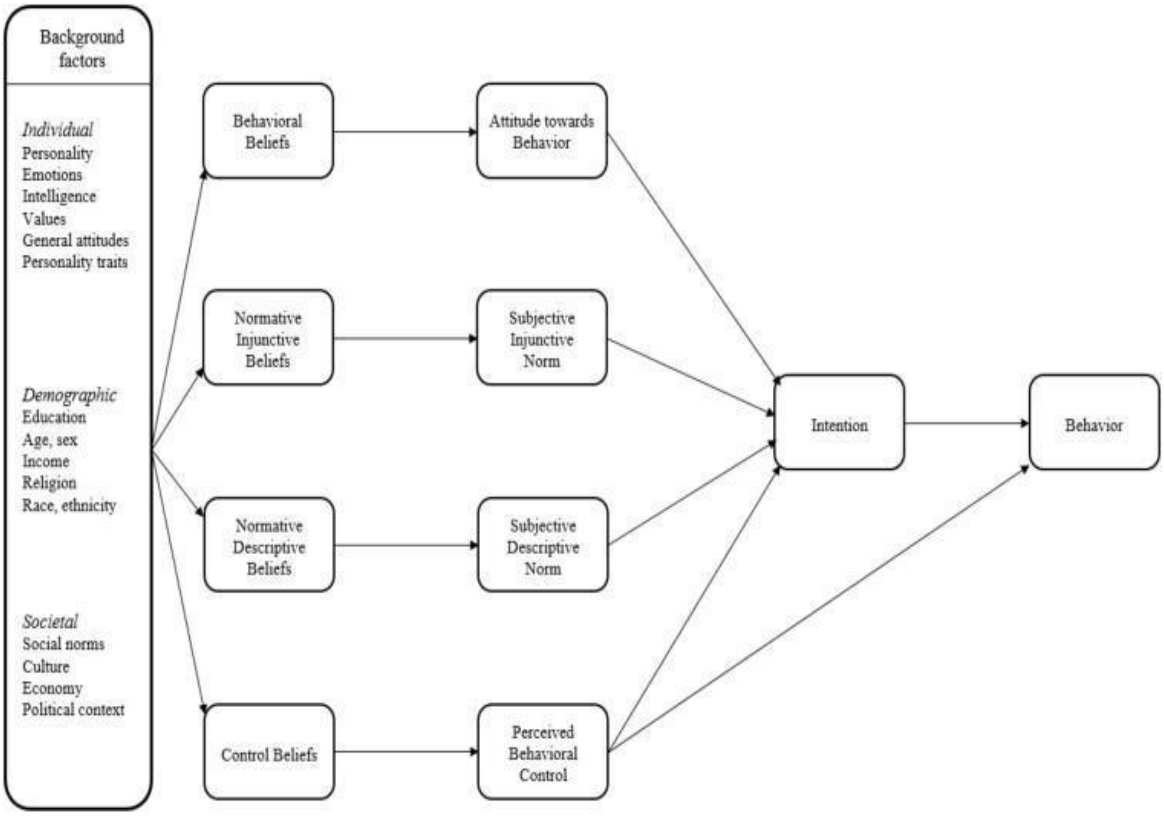
Attitude characterises the positive or negative feelings about the feasible behaviour in a given situation. The subjective norm encompasses the set of beliefs shared with the social group(s) to which

[3] 'We' in this paper refers to the PRECOS team.

[4] Examples: 1 out of 5 irrigators in a survey of the Louts, in another, 845 consumers in the Pic Saint Loup community.

the individual is sensitive. The perception of a greater or lesser personal ability to adopt the behaviour, in terms of skills and control over the self and the action situation, also influences the intention to act and then the behaviour.

Figure 1. The theories of reasoned action and planned behaviour (Ajzen 1991)



All of these determinants result from the influence of socio-demographic factors, values, information sources, etc. The calibration of the parameters of this model in a given behaviour is carried out through quantitative surveys on a large panel representative of the population. The respondents register their degree of agreement or disagreement on Likert scales with propositions concerning these different beliefs and perceptions. Attitudes and behaviours towards wastewater reuse in Australia were analysed using this method by Nancarrow et al. (2008).

The second theoretical field focuses on the social roots of behaviour, through the theory of social representations (Moscovici, 1961). Social representations are "*organized and structured sets of information, beliefs, opinions and attitudes*" (Abric, 2001), which guide perceptions of challenging situations, guide behaviour and are used to justify opinions. They are specific to each person, according to his or her experiences and knowledge. However, if the topic has been the subject of concerns and exchanges with others, *individual* representations are then integrated into *social* representations, influenced by the norms, values and knowledge developed and shared by the group or groups in which this individual has discussed them (Jodelet, 1993).

The structural approach of representations distinguishes the *core of representations*, which determines its overall meaning and its organization, and is resistant to change (Abric, 2001) from more *peripheral elements,* which define more personal attitudes, more likely to evolve under the effect of external influence (Tafani, 1997). Identifying these components may clarify why gaps persist between knowledge, attitudes and behaviours, or why people globally qualify a problem as important for society without recognizing its existence locally or adopting practices aimed at resolving it (Michel-Guillou, 2014).

Many controversies over water issues were analysed using social representations theories : pollution (Michel-Guillou, 2011), vulnerability of water to climate change (Michel-Guillou, 2014), phytoremediation (Amalric and Cirelli, 2017), river ecological restoration (Germaine and Barraud 2013), water sharing in conflictual contexts (Navarro Carrascal, 2009), risks of floods (Baggio and Rouquette, 2006) and for health (Dos Santos, 2011), exchanges between surface and groundwater (Besteiro and Rivière-Honegger, 2018).

From an operational point of view, several complementary methods may be used:

- The structural analysis of the social representations of a topic required quantitative survey on a representative panel, using the associative method (Abric, 2001). The respondents are asked to react to the statement of an inductive word by formulating and classifying word-pictures. The most frequent and most important word-images form the core of representations common to a social group. This core composition can be confirmed by the *calling into question* technique (CIQ) (Lo Monaco et al., 2008);
- The spatial and territorial dimensions of water representations can be addressed by mobilising the production of commented handmade maps by a limited number of individuals (Gieseking, 2013 ; Girard et al., 2016) ;
- Semi-structured interviews reveal the functional relationships that people establish between the different components of their representations;
- Representations are transformed during social interactions where perceptions, attitudes, experiences and opinions are confronted. Participatory devices are similar to moments of reproduction of a thinking micro-society. In particular, focus groups (Kitzinger, Markova et al., 2004), citizens' juries integrating debates with experts (Barbier, Bedu et al., 2009), serious game debriefings (Hassenforder, Dray et al., 2020), and foresight events are opportunities for exchanges, especially when they offer social dilemmas as stimuli (Caillaud, 2010). They reinforce objectification processes, making abstract concepts concrete. They help anchor new features, by integrating fresh knowledge, in order to make them familiar and transform the meaning of representations (Pianelli, Abric et al., 2010). This anchoring process occurred in particular through the analogies and differences mobilised, the virtual dialogues (the "it is said that") when certain norms or value judgments are difficult to endorse publicly (Wibeck, Adelswärd et al., 2004). The virtual situation of a serious game accelerates the lived experience - through the trial and error of several options - and also favours a second learning loop necessary for the questioning of values and norms (Medema, Wals et al., 2014), particularly when expressing disagreements (Duchesne and Haegel, 2008).

2.1.3 Advantages and drawbacks of the approach

This approach offers certain advantages in terms of improving knowledge:

- It reveals the reasons for preferences-refusals on behavioural regulation tools, based on values, dominant knowledge and beliefs, and perceptions of social justice, thus providing a point of view complementary to the standard cost and benefit analysis;
- It is very effective in addressing the psychological distancing process (territorial, temporal or personal) of certain groups of actors towards the consequences of climate change, which is one of the major obstacles to climate change adaptation (Spence et coll. 2012);
- It can help define an information strategy: which knowledge gap for which audience, which issues of concern, which political or ethical principle is at stake.

Table 1. Methods for the analysis, practices, social representations and preferences used within the PRECOS team

Goals	Themes	Targeted population	Tools	Results	References[5]
To define the ways of managing groundwater in response to climate change, in line with the irrigators' demands.	- Social representations of climate change, threats and opportunities, and potential adaptations; - Principles of social justice to reform water rights	Farmers extracting water from the aquifer	- Semi-structured interviews - Focus groups - Prospective scenarios (in the Roussillon field)	- Economic and social factors (market, labour, land, etc.) that dominate the possible effects of the climate; - Difficulty for the irrigators to imagine the future of their practices due to the uncertainties of the parameters useful for their decision (frost, wind, etc.); - Very different conceptions of social justice according to the socio-historical trajectories of access to water.	1 & 2
To track the real-time irrigation consumption to adjust water supply and access rules	Social representations of metering and smart meters; The role of water meters in irrigation management; Exchanging water abstraction permits	Farmers, State services, water managers (CACG, Institution Adour)	- Associative method - Semi-structured interview - Focus group and prospective	- Smart meters are perceived as intrusive and stigmatising; - Irrigators reject smart meters as a tool for managing irrigation - Smart meters relaunch the debate about the equity of water sharing between irrigators in the basin; - Criticism from irrigators has led to new management rules based on smart meters' data.	3
To follow real-time household consumption to adapt water supply and access rules	Social representations of metering and smart meters; Metering in consumption practices	Households (Montpellier Méditerranée Métropole)	Associative method	- Well-intentioned households not, however, using the associated services - Smart meters are perceived as useful, simple and allowing better monitoring of consumption.	4

[5] The list of references for all tables is presented after the general reference list.

To identify household water saving measures adapted to the households' behaviour	Social representations of drinking water and perceptions of vulnerability to climate change; Changes in consumption practices	Inhabitants and elected representatives (Drôme and Cèze)	- Associative method - Semi-structured interview - Drawing cards - Focus groups and role-playing games	- The inhabitants' representations disconnect the domestic water cycle from the global water cycle - A temporal and spatial distancing of the climate change effects on domestic water - Cognitive learning that struggles to transform routine consumption practices	5
To identify the obstacles and opportunities for the deployment of REUSE for agricultural irrigation and public areas	Social representations of REUSE; Attitudes and consumption behaviour of products made with treated wastewater	Inhabitants (Pic Saint Loup), students of the Master Eau, institutional actors involved in the project steering committee	- Associative method - Closed surveys on a representative sample - Tasting test	- The REUSE has not yet been debated locally, and therefore has no social representation; - A typology of contrasting attitudes, including a group of 20% reluctant to use REUSE, suspicious of the control of treatment and often disgusted; - The information removes the reluctance of a part of the inhabitants unfamiliar with REUSE, but does not persuade the reluctant. Twenty percent of those who know (students of the Master's degree in water, steering committee of the study) refuse to taste the products irrigated with TMEs.	6

On the other hand, this approach requires a rigorous implementation, but also triangulation of the sources of analysis and therefore does not rely simply on the dominant voices of focus groups, which may carry a strategic message. This explains the two identified drawbacks:

- Being time-consuming and complex in the articulation of the different methods, which sometimes mobilise large representative samples, more qualitative approaches sometimes occurring in restricted groups;
- Being limited in understanding and regulating water use practices anchored in daily routines, for which the behaviour is no longer the result of a conscious decision process (e.g. hygiene practices, eating habits, etc.) (Spurling, McMeekin *et al.*, 2013).

2.2 Stated preferences methods

2.2.1 Literature review

Understanding the preferences of stakeholders for the environment, anticipating their responses to agro-environmental policies remains a challenge. This is because policies are established in complex and dynamic contexts and a great diversity of stakeholders is involved. Surveys based on hypothetical choices offered to stakeholders, often referred to as stated preference methods, can improve our ability to assess these preferences. Stated preference methods have been widely used in the environmental economics literature and their use in interdisciplinary research is increasing; this allows for the *ex-ante* estimation of people's preferences and the values they associate with new technologies, services, policies, or programs (e.g., Favre, 2021; Hérivaux and Grémont, 2019; Jourdain, Lairez, Striffler, et al., 2022; Mokaddem et al., 2016)

Contingent valuation methods allow for the direct elicitation of the stakeholders' willingness to pay for a hypothetical scenario of environmental improvement (Mitchell and Carson, 1989). The assumption is that the stated values reflect the benefits each respondent derives from the scenario. Discrete choice experiments (DCE) elicit respondents' preferences through controlled experiments also based on hypothetical scenarios (Hensher et al., 2015; Train, 2009). Using a survey format, respondents are asked to make choices between different hypothetical versions of policy instruments and/or their environmental outcomes, which are described by their characteristics/attributes. The combinations of features/attributes are proposed to respondents according to a predefined experimental design that maximizes the reliability of respondents' calculations of trade-offs between the different attributes (Rose and Bliemer, 2009).

Both methods are based on standard economic theory and assume that the decision maker is a rational utility-maximizing agent who will choose the alternative that provides him or her with the highest utility. In addition, DCEs also assume that respondents are willing and able to make trade-offs between the desirable and undesirable aspects of each alternative. Finally, DCEs assume that respondents consider all aspects or attributes of the alternatives in the same manner.

The application of stated preference methods to the study of socio-hydrosystems can include estimations of the value of water-related ecosystem services generated by policy interventions (e.g., Favre, 2021; Hérivaux and Le Coent, 2021; Kanyoka et al., 2008; Vivithkeyoonvong and Jourdain, 2017) or an estimation of the factors influencing stakeholders' willingness to participate in water-related policy instruments (e.g., Cottet et al., 2019; Manganyi et al., 2022)

2.2.2 Examples of use within PRECOS

Uses of valuation methods based on stated preferences within the PRECOS team are very varied, in terms of purposes, surveyed population, themes, and application fields (Table 2). In our work, we can distinguish four main purposes of evaluation and four types of objects evaluated:

Table 2. Stated preferences methods within the PRECOS team

Goals	Themes (location of case studies)	Targeted population	Tools	Results	References
Design of incentive-based agricultural policy instruments	Preferences for weather index-based drought insurances (RSA)	Small scale farmers	Choice Experiment and analysis of farmers' risk aversion	Identification of potential barriers to insurance take-up related to preferences and risk aversion	7
	Type of erosion control measures and Payment for Environmental Services (Morocco)	Farmers	Choice experiment	A combination of individual and collective conservation measures under individual subscription, and incentives in the form of technical assistance to improve production performances may facilitate the implementation of PES and encourage collective action for the conservation of pastures as a common good	8
	Type of agri-environmental contract (France: Vistre river)		Choice experiment (mixed logit model with interactions between attitudes and preferences for environmental contracts)	Behavioural analysis of preferences for an agri-environmental contract (mix of CE and behavioural economics)	9
Preferences for water-related environmental policies	Preferences/WTP for different improvements of the service of provision of good quality water (South Africa, Tunisia)	Users and non-users of drinking water supply services	Choice experiment Contingent valuation	Preferences for water services for different subgroups (with/without individual access, water collection methods, price, income level, cultural preferences)	10 and 11
	Preferences for groundwater protection	Inhabitants living on the groundwater	Contingent valuation	• WTP for groundwater protection and restoration	12

	(Lower Triassic Sandstone, Lorraine, France) and groundwater restoration (Meuse alluvial aquifer, Belgium)	catchments (users and non-users)		• Main motivation underlying WTP: to guarantee the well-being of future generations • Analysis of the main limits of applying contingent valuation to groundwater: limited prior knowledge and specific embedding effects	
	Preferences Nature-based solutions aiming at reducing water risks in an urban watershed	Residents of the Lez (France) watershed	Choice experiment (Latent class)	• Perception of ecosystem services and negative effects associated with NBS • Heterogeneity of residents' preferences along an urban-rural gradient	13
	Valuation of ecosystem services provided by irrigated rice agriculture in Thailand: a choice experiment considering attribute non-attendance (Thailand)	General users of water ecosystem services	Choice Experiment	• Preferences for different ecosystem services affected by agricultural systems • Heterogeneity of preferences • Heterogeneity of heuristics (ANA)	14 & 15
	Relative importance of the characteristics of the cycling facility and the natural or restored character of the riverscape in the choice of use (France: Rhone River)	Users of a river-related cycling infrastructure	Distance-based choice experiment, attitudinal variables (motivation for leisure, place attachment)	• Analysis of motivations for river-related leisure choices and role of the river ecological restoration	16

2.2.3 Advantages and limitations

The advantages and limitations of stated preference valuation methods have been widely discussed in the economic literature (for recent review and discussion of good practices see Brouwer and Neverre, 2020; Johnston et al., 2017). With regard to their use in our research, we identify two main categories of limitations:

The first category includes technical difficulties related to the design of the survey questionnaire. Indeed, meta-analyses show that survey design characteristics (WTP elicitation format, payment vehicle, statistical estimation procedure, etc.) explain almost 10% of the variance across WTP estimates, highlighting the importance of methodological and survey design choices (Brouwer and Neverre, 2020). Limiting possible biases, therefore, calls for a high degree of expertise and compliance with constantly evolving good practices. The construction of realistic hypothetical scenarios that are understandable to respondents is a difficult exercise, requiring the integration of different fields of knowledge, especially as the subject of the evaluation is complex. Meta-analyses also highlight the importance of the information provided to characterise the valued scenario, but also the reference scenario, as (i) WTP values are sensitive to scope and reference dependence; (ii) WTP values are sensitive to uncertainty in the baseline scenario; and (iii) the use of a single word with emotional overtone can influence the evaluation, e.g., mentioning "cancer" in the questionnaire significantly increases WTP for good groundwater quality (Brouwer and Neverre, 2020). This becomes particularly important when valuing environmental goods and services that are unfamiliar to the respondents (e.g., groundwater ecosystems). The use of pictograms and pictures may help convey the changes to be valued, but could be misleading when designed by researchers unfamiliar with the cultural codes of the countries where they are conducting the survey. Finally, the size of the sample of respondents needed for a robust statistical analysis is important, especially if one of the objectives of the research is to analyse the heterogeneity of preferences. Surveys conducted in less developed countries and with target populations that are difficult to reach (e.g., farmers in remote areas as in Jourdain, Lairez, Striffler, et al. (2022)) seriously limit the number of respondents when compared to internet-based interviews conducted with respondents provided by professional panel providers. All this leads to significant costs and implementation.

The second category of limitations, in particular when analysing DCE results, relates to the differences between the hypotheses of the respondents' behaviour or way of reasoning and their real behaviour and choice heuristics: the use of these methods is based on the assumption that individuals make trade-offs between the different attributes of the subject of the evaluation (including the financial consequences for the respondents). It has, however, been shown that some people use different choice heuristics, e.g., elimination by aspect, ANA, etc. (Hensher and Greene, 2010; Jourdain, Lairez, et al., 2022; Jourdain and Vivithkeyoonvong, 2017; Scarpa et al., 2009). Prior surveys to identify sub-populations of preferences may help to solve this problem (e.g., Armatas et al., 2014; Jensen, 2019; Mahlalela et al., 2022). On the other hand, even if people do reason by making compromises, the high number of attributes and of attribute levels as well as the way they are presented to surveyed people increases the cognitive difficulty of choices, in particular for people with low levels of education. Furthermore, despite the precautions taken in designing the questionnaire, the possibility of a discrepancy between people's real and declared choices remains. Finally, on a more ethical and philosophical level, one may criticise the utilitarian and anthropocentric conception of values of the neo-classical framework on which these methods are based (Vatn, 2004; Kallis et al., 2013; Parks and Gowdy, 2013).

With the exception, perhaps, of the intrinsic complexity of our valuation subjects, whether they are public policy options or hydrosystem conditions, those limits are not specific to the application of stated preference methods to socio-hydrosystems.

Despite these various limitations, valuation methods based on stated preferences, and in particular the choice experiment, present several points of interest for our research: first, these methods can be

adapted to a great diversity of subjects (hydrosystems, public policies). These are the only valuation methods that consider both the values that people attach to a hydrosystem or parts of it, because of their use, and non-use values (bequest value, intrinsic value), and research has shown that in the case of socio-hydrosystems the latter can be as important as the former (Johnston et al., 2003). Compared with contingent valuation, choice experiment makes it possible to estimate the value placed on specific attributes of socio-hydrosystems or public policies and to propose more diverse scenarios of change. Provided certain precautions are taken in the design of the questionnaire, sample size, and choice of econometric model (Johnston et al., 2017), it is possible to analyse the heterogeneity of preferences within the considered population. This may reveal potential conflicts between stakeholders or help take into account the attitudes of those concerned in the subsequent implementation of policies.

2.2.4 Specificity of our use of the method for the analysis of socio-hydrological systems

As a preamble, it is important to note that the PRECOS researchers are mainly "users" of stated preference methods: they adapt them to socio-hydrosystems issues, but they do not necessarily seek to develop new econometric models. Besides, they are often mostly interested in the analysis of the heterogeneity of preferences, motivations, attitudes, and decision-process (for example the conception of human-nature relationships, risk aversion, etc.). As such they do not always emphasise the WTP or WTA results but, instead, discuss the heterogeneity of the preferences in order to anticipate potential conflicts between stakeholders.

The purpose of the stated-preference research conducted by the PRECOS team is to support public policies and decision-making. Consequently, the research questions are co-constructed with the stakeholders involved in the management and use of the socio-hydrosystems at stake, such as ministries, water agencies, regions, chambers of agriculture, mixed syndicates, and water services. In the same way, the surveys are designed in consultation with them. The research results are used to help design public policy instruments or to conduct analyses to justify public policy choices. Therefore, the results are also shared with the stakeholders to increase the impact of the research.

An abundant literature describes the potential biases associated with the use of SP methods for valuing environmental goods (Johnston et al., 2017). Our research suggests that there are additional problems related to the specific characteristics of socio-hydrosystems. They include:

1. Unfamiliarity with the goods and services evaluated by the respondents (e.g., groundwater ecosystems) and the important role (and bias) played by the information provided to the respondents. This task is even more complex when the information has to be conveyed via interpreters.
2. Complexity of the goods and services evaluated because of multiple uses and multiple scales (e.g., for the evaluation of the benefits of hydrosystems)
3. Uncertainties of the effects of proposed policies on socio-hydrosystems and the resulting uncertainty in the statements of the scenarios
4. Multiplicity of stakeholders and views, and the resulting issues for properly evaluating the preferences (e.g., the presence of ANA for some part of the respondents)
5. Non-monetary reasoning. Adapting the choice of payment vehicle or EC without a price and the necessity to adapt the payment vehicle to non-monetary equivalents

On the first point, a major concern when applying SP methods to socio-hydrosystems is the very limited knowledge respondents may have of the environmental asset they are asked to value. In theory, SP methods should be used only when respondents have what Lazo et al. (1992) call "perfect information". Evidence from various surveys shows that this is rarely the case. People generally have very limited knowledge of groundwater resources and related management issues, even when they have a direct link to the resource through private wells. In such situations, SP specialists acknowledge that the method can still be used (Arrow et al. 1993). The burden of informing respondents then falls on the survey instrument. To avoid information bias, special attention should be paid to designing the survey protocol and questionnaire, especially to selecting the nature, format, and quantity of

information provided to respondents (Hérivaux and Rinaudo, 2016). In that respect, when working in countries of the south, lower education levels of the population surveyed and the necessity to use interpreters render this task even more crucial. Factoring in the possibility of more uncertain respondent choices is also important (Jourdain, Lairez, and Affholder, 2022)

On the second point, two types of observed embedding effects, closely related to the "mental model" of joint products highlighted by Schulze et al. (1998): respondents may have different mental models, often strongly held, which will replace whatever mental model the researcher intended to impose on the respondent. For example, in the case of groundwater, some respondents perceive groundwater as a uniformly distributed resource, rather than a collection of well-defined and spatially delineated reservoirs. These respondents are therefore not able to make a clear distinction between protecting groundwater in a broad sense on the one hand and protecting a specific aquifer on the other. The second embedding effect is linked to situations where actions to protect / restore groundwater also generate a wide range of environmental benefits (e.g., biodiversity, air quality regulation, positive landscape amenities…). Respondents may face difficulties in disentangling those benefits derived from groundwater protection from those of other environmental benefits (Hérivaux and Rinaudo, 2016).

On the third point, another important concern is to develop credible scenarios. However, the potential outcome of projects aiming at modifying hydrosystems, or of policies, are indeed prone to many uncertainties. Recognizing these uncertainties and factoring them into the design of the surveys is also important (Manganyi et al., 2022).

On the fourth point, water resources and the benefits of water-related ecosystems are often shared among stakeholders that have different views and different interests. While some stakeholders may value particular attributes of the ecosystems, others may value different ones. This may present some difficulties when designing the choice experiment, as some attributes may not be relevant to all respondents. In such a situation, some of the respondents may show a lack of interest in the survey, or develop various specific heuristics to make their choices. To minimize this possibility, some recent research argued that prior research to detect the diversity of views about the ecosystems may be warranted (Armatas et al., 2014; Jensen, 2019; Mahlalela et al., 2022).

On the fifth point, PRECOS researchers are sometimes working with communities and farmers who are not well connected to markets. In such cases, respondents may not respond to monetary incentives or may not reason in terms of monetary equivalent and then CE without specific monetary attributes may be used (Jourdain et al., 2020), or the use of other research methods may be required to evaluate the diversity of attitudes towards the services (e.g., Mahlalela et al., 2022).

2.3 Experimental economics in the lab and in the field

For a long time considered a non-experimental science (Samuelson and Nordhaus, 1985), economics moved in the last decades of the 20th Century towards a growing trend of experimental studies. The trend culminated in the Nobel prize awarded to V. Smith and D. Kahneman in 2002, for their work based on laboratory experiments involving market structures and agents' decisions under uncertainty.

Experimental economics consists of controlled experiments where the observed behaviour of the participants is a function of the environment (endowments, monetary rewards that motivate exchanges, etc.) and of an institution (instructions that describe the messages and the procedures of the market) (Smith, 1994).

2.3.1 Conceptual foundations and literature review

By controlling the variables representing the environment and the institution, the participants' behaviour is observed when only one variable is changed at the time (ceteris paribus condition). The clear advantage of this method is the possibility of isolating one variable at the time that has an influence on the economic behaviour of agents and avoiding the 'noise' provoked by variables coexisting in other empirical studies based on data in uncontrolled setting.

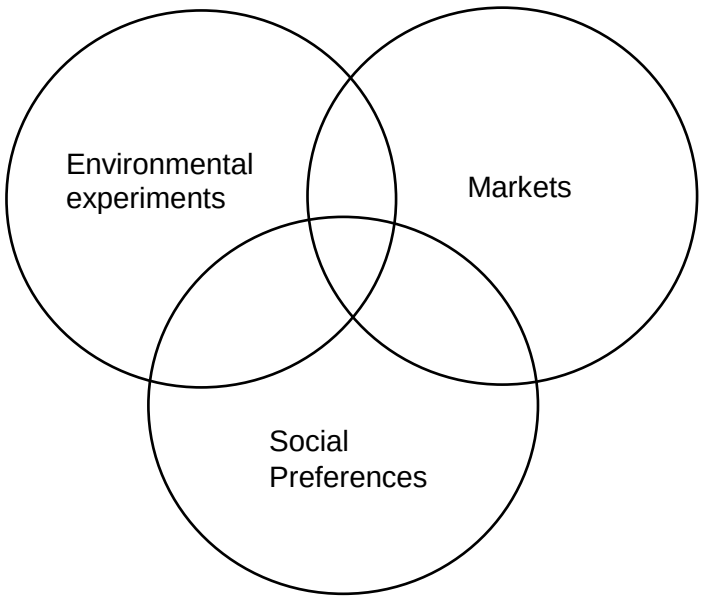
Economic experiments are typically conducted in a laboratory, as this allows the control of environmental and institutional variable. Participants in these experiments are usually university students. This highly controlled setting allows the unbiased identification of exogenous treatments. The external validity of this type of setting remains however limited unless one wants to insist *a priori* that those aspects of economic behaviour under study be perfectly general (Harrison and List, 2004). Field experiments have been developed in complementarity with lab experiments in order to improve the external validity of economic experiments. *Artefactual field experiment*s are the same as conventional lab experiments but with a nonstandard subject pool such as farmers or water users. A *framed field experiment* also includes in the environment and institutions a field context in either the task or information set that the subjects can use. Finally, in *a natural field experiment* the environment is one where the subjects naturally undertake these tasks and where the subjects do not know that they are part of an experiment (Harrison and List 2004). Recently, the terminology of Randomized Controlled Trials to designate natural experiments has gained momentum in the context of the "Nobel" prize awarded to Esther Duflo, Michael Kremer and Abhijit Banerjee.

Experimental economics has been used for several goals. Roth (1988) identifies three main objectives: 1) test theories; 2) produce facts to identify behavioural regularities still unknown and that can integrate economic models; 3) help decision-making, by testing the consequences and implications of the adoption of a new policy tool.

In the analysis of behaviour of actors in socio-hydro systems, the main goal of experimental economics is the third, looking for instance at the effectiveness or the acceptability of a local regulation tool for water allocation. Moreover, an economic experience can be used to elicit the risk and time preferences of local farmers when faced with a decision whether to invest in an innovative irrigation technique.

The experiments conducted in SHS in a scheme derived from a conceptual framework proposed by Ehmke and Shrogen (2008) might be placed to represent the experimental mindsets in social sciences (Figure 2). The scheme is composed of three broad and overlapping areas: Markets, Social preferences, and Environmental experiments.

Figure 2. Experimental mindsets (Adapted from: Ehmke and Shrogen, 2008)



According to this representation, economists have focused on market-centred experiments, psychologists and behavioural economists have explored social preferences experiments, and environmental/resource economists have examined social preferences and environmental experiments.

There are clear overlapping areas because people make their decisions within market and non-market contexts simultaneously, and this overlap of exchange institutions (i.e. institutions that allow transactions such as markets or agencies) can affect their decisions.

Socio-hydro systems, such as socio-ecological systems may easily be put in the area of Environmental experiments, where markets do exist, but are characterised by generalised market failure (common pool resources and absence of the excludability criterion for these economic goods). Experiments in this area are designed to evaluate: i) the rules that define new exchange institutions and incentive systems, ii) efficiency impacts of property rights and access to resources, iii) conventions creating conflicts and cooperation over resources.

However, experiments about socio-hydro systems seem particularly relevant in the overlapping areas between the Environmental experiments area and the other two.

The Markets - Environmental experiments overlap is where economists and environmental economists test policy instruments (taxes, subsidies, permits, etc.) to control environmental production (Cason et al., 2003). The Social preferences-Environmental experiments overlap is where authors such as Ostrom et al. (1994) and Walker and Gardner (1992) apply experimental economics to the analysis of the common pool resource use and governance. Issues such as the consequences on the use of common pool resources of communication and participation in the design of management policies have been extensively studied. Studies of the role of non-monetary enforcement (Masclet et al., 2003) on the use of common pool resources was also analysed, and on the impact of trust, social capital, and social networks for the management of natural resources (Ensminger, 2001) can also be put in this overlap area.

Finally, the Markets-Social preferences-Environmental experiments overlap area includes studies such as the rationality spill-over and the analysis of corruption, which seem to us currently less relevant to experiments in socio-hydro systems.

2.3.2 Examples in the PRECOS team

Table 3 includes some examples of studies about the behaviour of actors in socio-hydro systems that have been approached by the PRECOS team through experimental economics.

Farolfi et al. (2018) studied to what extent information provided to users on the functioning of the system ("institutional" information) and/or on the decisions taken by other users ("social" information) can affect their WTP. The analysis was twofold. A field survey first revealed the farmers' demand for better information provision. A laboratory experiment then allowed isolating the impact of the two types of information on subjects' decisions through a framed game, with properties similar to those observed in the field. Data collected in the lab confirmed the existence of a causality relation between information provided to users and their WTP for a common resource such as irrigation water. External validity of the results obtained in the laboratory should be tested by a lab-in the field experiment with real stakeholders. This work would fit in the Environmental experiments-markets overlap in Figure 2.

Table 3. Economic experiments on Socio-hydro systems within the PRECOS team

Goals	Topics	Targeted population	Tools	Results	References
Understand the influence of information on decision-making in socio-hydro systems. This can foster policies towards more or different information available to water users	Influence of social and institutional information on the willingness to pay water in Tunisian water users' associations	Farmers (preliminary survey), University Students (Lab experiment)	Experimental Economics in the Laboratory. A non-linear Public Good game framed to represent the irrigation water context was used.	Existence of a causality relation between information provided to users and their WTP for a common resource such as irrigation water	17
Understand whether the relational links in a group (social capital) influence common pool resource use and uncertainty perception. This can foster policies facilitating the establishment of better relations and improved social capital among water users	Influence of relational links in a group on the perception of uncertainty and on the use of common pool resources, particularly water	University Students (Lab experiment)	Experimental Economics in the Laboratory. An asymmetric game including a Public Good component and a Common Pool Resource one was used. It was framed to represent an irrigation system.	Initial tests confirmed the importance that the relationships established among players have for coping with uncertainty in managing water resources.	18
Test the impact of social comparison information on decisions with high economic stakes in socio-hydro-systems	Influence of social comparison information on irrigation decision of farmers in South West France	Farmers	Randomized controlled trial with 200 farmers	No significant effect on average water use by farmers but reduction of water use of largest users and increase of the lowest users.	19

Chabé Ferret et al. (2019) studied the impact of social comparison information on farmers' irrigation decisions. Although social norms and social comparison nudges have proved to have a significant impact on a variety of behaviour, it is questionable whether this type of information may have an impact in real-life socio-hydro systems, especially for decisions that involve large economic stakes such as irrigation decisions. In order to test this hypothesis in a real-life context, the authors conducted a randomised controlled trial among 200 farmers equipped with irrigation smart meters in South-West France. Treated farmers received weekly information on individual and group irrigation water use over

four months. Our results rule out medium to large average effect-sizes of the nudge. They nevertheless suggest that the social comparison was effective at reducing the consumption of those who irrigate the most, although it appears to backfire and reduce the proportion of those who do not consume water at all. This work would fit into the Environmental experiments-markets overlap in Figure 2.

The goal of the Brugnach et al. (2021) paper was to understand if and how the socio relational environment in which decisions are made shapes decision-making under uncertainty in common pool water resource management. The aim of this paper was twofold: methodological and analytical. It consisted in designing experiments for carrying out uncertainty analysis to explore the influence that the relationships established among decision actors have in making decision choices under uncertainty in management processes. To this end, the authors developed one experimental game protocol, representing a typical water management scenario: *irrigation*, in which they tested three different conjectures about the combined effects of uncertainty and relationships. In doing so, authors played close attention to the quality of relationships developed among players (acting as water managers), and how these relationships were structured and organised. Initial laboratory tests, to be confirmed through lab in the field experiments, initially confirmed the importance that the relationships established among players have for coping with uncertainty in managing water resources. This work would fit in the Environmental experiments-Social preferences overlap in Figure 2.

2.3.3 Specific features of experimental protocols in socio-hydro systems

It is important to ask ourselves at this stage whether there is a particular specificity in the use of economic experiments for the analysis of socio-hydro systems. The following characteristics require in our opinion particular attention in designing the protocols adopted in the analysis of socio-hydro systems (Table 4).

The **Complexity** of the system, both in the social and in the hydrological components. Interdependency among the various components of the system is an immediate consequence of complexity. The **Asymmetry of access** to the resource: in an irrigation system for instance, farmers are placed in a sequence where head-enders are privileged over tail-enders in the access to water. Water is also a **dynamic** resource, which flows through the system. The latter are two quite specific (while not exclusive) characters of socio-hydro systems compared to socio ecosystems. The **multiple facets** of water as natural resource represent another characteristic of SHS (for instance water is characterised by its quantitative availability, but also by the quality of the resource). Water also has **multiple uses**, and is a **particular economic good**, which can, in different contexts, assume different economic values (private good, public good, common pool resource, or even club good). **Uncertainty** in the availability and the **difficulty to observe** (particularly groundwater) the resource are two additional characteristics of SHS. Important aspects concerning the management of SHS are the crucial **role of institutions** for the governance of the resource and the **relevance of information** provision and **communication** for water management. As is often the case, the results of our research have direct policy implications so there is a pressing n**eed to verify the external validity** of our analyses. Finally, in this not exclusive list of characteristics of the SHS, we cite the relevance of the analysis of **interrelations** (relational quality, presence of social capital) among the members of the social component of our systems.

Within PRECOS, we analyse several of the mentioned aspects in socio-hydro systems using experimental economics. For instance, in addition to the case studies presented above (Table 2), Figureau et al. (2012) analysed different instruments for groundwater management combining economic incentives and social preferences. Chabé-Ferret et al. (2019) studied the influence of social information on the water use decisions of farmers. Dubois et al., (2020) studied the influence of information sharing by CPR users on the resource management.

We consider that **framing** matters in economic experiments on SHS. Several authors state (Laury and Taylor, 2008; Michel-Guillou and Moser, 2006; Cooper and Kagel, 2003) that context in an economic experiment is essential to facilitate the understanding of the problem by players and their explication of behavioural variables otherwise masked by an abstract experimental protocol. The work of our

team, such as Farolfi et al. (2014), therefore tests the effects of framing and confirmed the effects of the water contexts on players' behaviour. What can be observed at this stage is that SHS have some specific characteristics (while not exclusive) and many other characteristics common to all socio-eco systems that are already widely studied in experimental economics through the research on CPR (Walker, Gardner and Ostrom, 1990). We may then conclude that there is no need for a specific method or approach to study socio-hydro systems through economic experiments. On the other side, there are some specificities in socio-hydro systems that characterise these systems. These specificities, namely the asymmetry of access to the resource, the dynamic and flowing nature of water, and the difficulty of observing the resource (limited to groundwater) require particular attention in the use of experimental economics to analyse the socio-hydro systems. Janssen et al. (2011) develop an experimental set-up for irrigation water that takes into consideration these characteristics, and that is so framed that the so-called 'micro-situational variables' can play their role.

Some of our more recent studies (Bonte et al., 2019; Brugnach et al., 2021) use experimental set-ups in line with the work by Janssen et al. (2011). Other studies in our group (Farolfi et al. 2018, Dubois et al., 2020) are based on more 'conventional' experimental economic protocols (not framed, considering water as a CPR with symmetric access by users, etc.), particularly when we want to go deeper into some specific aspects of the observed behaviours that emerged from previous analysis.

Table 4. Characteristics of socio-hydrosystems in relation to the use of experimental economics

Characteristic	Specific to socio-hydro systems	Common to all socio-eco systems
Complexity		X
Asymmetry of access to the resource	X	
Dynamic nature of the resource	X	
Multiple facets of the resource		X
Multiple uses of the resource		X
Different economic values of the resource		X
Uncertainty in the availability of the resource		X
Difficulty of observing the dynamics of the resource	x*	
Relevance of information provision		X
Relevance of communication		X
Need to verify external validity of results		X
Stakeholders' interrelations and social capital		X

* limited to groundwater

2.3.4 Advantages and limitations

Some final considerations may be necessary about the advantages and limits of the use of experimental economics methods to approach the research questions presented.

A clear advantage comes from the possibility of isolating the effect of specific variables on the actors' behaviour and testing, through a rigorous protocol and with quantitative indicators, the hypotheses made. Another important advantage, with respect to the stated preferences methods, resides in the fact that subjects participating in an experiment reveal their 'real' economic preferences by making their choices as they act, knowing that their performance will be remunerated immediately after the experiment. Conversely, stated preference methods are biased by the fact that subject declare their preferences without a corresponding payment, and therefore are more prone to 'lie' for many reasons. Hypothetical bias arises in stated preference valuation studies when respondents report a willingness to pay (WTP) that exceeds what they actually pay using their own money in laboratory or field experiments (Loomis, 2011). Experiments nevertheless usually require reductionist approaches that do not allow for accounting for the multiple specificities of SHS. This may limit the so-called external validity, or generalisation of results of the experiments (Levitt and List, 2007).

One of the main constraints of the use of experimental methods is their applicability to exploring the various contexts of SHS. Indeed, practical limits still exist in the implementation of lab experiments in the field, due to the difficulty of recreating laboratory conditions (lack of electric power, internet network, etc.) particularly in southern fields. Also, in several communities, the use of monetary incentives is seen with scepticism and sometimes distrust, while NGOs and development agencies are reticent in the use of monetary incentives as they 'spoil' the stakeholders. Consequently, alternatives to the use of monetary incentives (ex. seeds, food, etc.) are often to be found.

2.4 Hybrid methods

2.4.1 Literature review

As illustrated in the other sections of the paper, our group mobilises several methods to carry out our research. It is sometimes necessary to use methods from distinct scientific disciplines and this brings us to inter / multi / trans disciplinary studies. This section is dedicated to such approaches, ones that we have considered as hybrid methods. Based on Alvargonzalez (2011), we use the following definitions: a multi-disciplinary study consists in a study using several disciplines jointly but staying within the boundaries of each discipline; an inter-disciplinary study consists of analysis and synthesis coordinated as a coherent whole; and a trans-disciplinary study consists of integrated natural, social and health science in a humanities context transcending the traditional boundaries of each discipline. The disciplines and approaches on which we focus here, in the context of analysing behaviours of individuals involved in SHS questions, are developed in this section, divided into four categories of hybridization.

1. Combining behavioural economics together with social psychology: Actors enrolled in socio-environmental contexts, such as common pool resource (CPR) dilemmas, are faced with economical behavioural choices (e.g., self-interest, altruistic) that may influence their cognition (e.g., attitudes, opinions, economical preferences). Hence, it seems useful to address research questions, and consequently to develop hybrid methods relative to the interaction between behavioural economics and social psychology. We develop methods using experimental CPR dilemmas (e.g., Gardner et al., 1994) ; literature related to strategic behavioural choices in game theory research (e.g., Cox et al., 2004) and field experiment research (e.g, Cardenas et al., 2000 ; Fehr and Fischbacher, 2002 ; Velez et al., 2009) ; literature related to attitude change (e.g., Festinger, 1959), explicit attitude measures (e.g., Krosnick et al., 2005), implicit attitude measures (e.g. Greenwald et al., 1998) and to relations between explicit and implicit attitude changes (e.g., Gawronski et Bodenhausen, 2006).

2. Combining social psychology theories with social simulation: In our research unit, we use participatory methods, such as role-playing games, to support natural resource management.

However, we need to be aware of the influence of game settings on participants' behavioural patterns and attitudes, before fine tuning the design and use of the games. To this end, we developed a method to assess the framing induced by the conditions of implementation of a game. Our methodology was first to formalize theories from social psychology on attitude change and attitude-behaviours relationships (Glasman and Albarracin, 2006 ; Azjen, 1991, 2004 ; Albarracin, 2000). And, second, to implement them into an agent-based model representing a role-playing game, in accordance with the literature on opinion dynamics (e.g., Holley and Liggett, 1975 ; Galam, 2002 ; Sznajd-Weron and Snajd, 2000 ; Latané, 1981 ; Deffuant et al., 2000 ; Hegselmann and Krause, 2002).

3. Combining participatory modelling together with agent-based modelling and experimental economics: Although Agent Based Modelling (ABM) is a very powerful tool for integration of disciplines in interdisciplinary or transdisciplinary studies (Bousquet et al., 1993; Bousquet and Le Page, 2004), they have, in this research group, more the role of a method that we want to hybridize with others. We use them for their ability to formalise the situation of an economic agent, in relation to other agents and to their environment.

4. Combining economic modelling together with water-resource modelling: in our team, we developed several multi-model couplings integrating economical and water-resource dimensions. Researche is aimed at using these models as computational tools for different purposes, such as helping water managers with their adaptation strategy to global change, or with understanding the sustainability trade-offs of subsistence versus market-based agriculture. Regarding the PRECOS team focus, we aim at integrating these models into experimental frameworks to support the economical behavioural choices of participants. The models we develop in order to couple them with economical modelling include hydrological / hydrogeological modelling, that consists in using mathematical equations to simulate the way precipitation over a given river basin / territory is transformed into river flow and infiltration to recharge aquifers, using several different computation methods (Semenova and Beven, 2015; Refsgaard et al., 2012). Water demand modelling methods mobilise the mathematical combination of economic, social, demographic and environmental variables at the scale of the territory that depends on surface and/or groundwater resources (Collet et al., 2013; Terrasson et al., 2014). Climate change modelling consists in handling complex mathematical models able to describe the land surface and atmosphere dynamics and interactions (O'Neill et al., 2016). Note that hybrid methods generally do not carry out climate models that are too computational costly, but rather use future projections of the climate variables they provide to force hydrological and water demand models. As an integrative modelling and simulation approach, we can cite System Dynamics (SD) modelling (Forrester, 1961); originally developed for the business consulting field, it consists in representing a complex system through a series of stocks, flows, and auxiliary variables that complete feedback loops. While the dynamic behaviour of agent-based models stems from the interaction between many individual agents interacting according to (generally simple) set rules, in the case of SD modelling, dynamic behaviour emerges from the structure of the feedback loops incorporated into the model. Since its conception, SD modelling has been applied to many fields outside of business management, in particular hydrology (Mirchi et al., 2012) and natural resource management more generally (e.g., Arshad et al., 2015).

2.4.2 Examples from the PRECOS team

We illustrate these hybrid approaches through five case studies presented in Table 5, illustrating our four categories of hybridization explained in Section 2.4.1. (the fourth and fifth case studies being part of the fourth category).

1. We designed an experimental protocol based on a CPR dilemma inspired by Gardner et al., 1994 and representing appropriation of water during periods of drought in the Aude watershed (France). We set two treatments, the first one representing the actual state (at the time of the experiment) of the water management at the political level in the area, and the second introducing a new political measure aimed at reducing the lack of water during periods of drought. Our objective was to identify and discriminate between the behavioural strategies used by the participants in the two treatments,

and analyse the impacts of those behaviours on the attitude change of participants toward the sharing of water.

2. We designed an agent-based model representing the dynamics occurring in a role-playing game developed to support the management of runoff issues in the *Pays de Caux* (Normandie, France). The agent-based model is focused on the exploration of framings caused by game design and implementation of attitude dynamics occurring through successions of negotiations within the game. Mechanisms of attitude change were formalised with regard to social psychology theories and implemented in the model. Results of simulations bring possible explications of the underlying mechanisms of the framings caused by design and implementation choices, such as giving feedback to participants about the consequences of their actions.

3. This study attempts to gain knowledge of participatory modelling for natural resources management but this time using experimental economics combined with an ABM converted to an on-line game for the sake of experimental economics. In this case, we formalise our approach from a modelling and simulation perspective.

4. This example is devoted to the exploration of the interest of using the framework of interdisciplinary water resources and demand and econometric modelling to help water managers develop their adaptation strategy to global change at the river-basin scale. To that end, climate modelling projections are applied to hydrological and water uses modelling methods and the results are combined with ecological, economics, agronomical and civil engineering factors to build adaptation strategies through participative methods. The framework was tested on the Orb river basin, a Mediterranean basin in southern France, where global change is expected to exacerbate the difficulties of meeting the growing water demands and the WFD environmental in-stream flow requirements. It showed that optimisation models for the least-cost allocation of measures to satisfy all the constraints at the river basin scale may help to design global change adaptation strategies. It was also shown that it was useful to prioritize the type of actions to be implemented (for instance some conservation measures must be systematically implemented) in the adaptation strategy plan. Finally, the proposed modelling framework can help evaluate possible trade-offs between development of water uses, environmental objectives and costs of water management.

5. This example is similar to the fourth one in the sense that it uses a modelling and simulation approach to combine knowledge from various disciplines in an interdisciplinary framework. It uses system dynamics modelling to combine a micro-economic approach with physically-based crop modelling in the context of policy analysis for Indigenous food systems in Guatemala. In this case study, the main aim was to test the resilience of self-subsistence and market-oriented small-scale agriculture to climate change and socioeconomic shocks. The SD model was initially built from causal loop diagrams generated with stakeholders during (mostly) individual interviews before quantification with survey data, and it contains local microeconomic dynamics of labour and land allocation (agricultural versus salaried work for labour; agricultural, forest or shrubland for land use) based on the expected economic yield of each activity. Agricultural yield, in turn, was predicted with an external model (PCSE) that combined different climatic scenarios and soil conditions to predict the frequency and agronomic severity of droughts. Both models were then coupled with Tinamït software (Malard et al., 2017) to predict the reciprocal effects of drought impacts, vulnerability and societal (economic) response in the two different study cases.

2.4.3 Specific features of our hybrid methods in the landscape of socio-hydro systems studies

Hybridization of methods in general is of course not restricted to socio-hydro systems studies. In socio-hydro systems studies, we note that several dynamics co-exist in interdisciplinary work about social and hydrological systems (or hydrological territories according to the groups) such as socio-hydrology (Sivapalan et al. 2012; Wesselink et al., 2017) that includes social dynamics into hydrological models (and to which our fourth case could refer) or hydro-sociology (Massuel et al., 2018) trying to combine points of view from natural and social science in order to understand more profoundly the dynamics

observed on a territory. Researchers from all these integrative approaches acknowledged the benefits of their combined approaches even though these are expensive in terms of time and effort because of the intricate nature of social and hydrological dynamics. We are not at the point where we can propose a clear view of hybrid methods for analysing practices, social representations and behaviours of socio-hydro systems' actors but we hope that we are, through these works, contributing to building bridges that are needed for the study of socio-hydro-systems in general.

The formal quantification presented in the fourth example, through the modelling methods of the flows and balances between the different compartments of the socio-hydrosystems makes it possible to communicate in a concrete manner about their relative importance. This facilitates the prioritisation of the problems to be addressed when building adaptation strategies for climate change.

In the case of coupled SD modelling (fifth example), while there are no limitations to the nature of the external biophysical model (hydrological, cropping, ecological), the majority of published studies have used either a cropping or a hydrological model. This may be due to the fact that these model types are particularly complex and that many well-established and well-tested models already exist for these fields; this adds to the advantage of adopting a coupled modelling approach when dealing with socio-hydro systems.

2.4.4 Advantages and limitations

Considering that our use of hybrids methods within the team is substantially different across the studies, we list the advantages and limitations regarding each example of case study:

1. Advantage: the development of a protocol integrating economical and psychological features allowed us to show relationships between two intra-disciplinary objects, i.e., strategic behaviours and attitudes, and then gives us a better understanding of the effects of a new political measure for water management on individuals.

Limitation: This kind of interdisciplinary study is very specific, which hinders us from enrolling in an existent scientific literature that fits our global approach to the research questions.

2. Advantages: Developing an agent-based model of attitude change based on social psychological theories enables us to give more realism to the mechanisms underlying the dynamics observed through the simulation of the model. Using an agent-based model as a virtual laboratory instead of laboratory experiments enables us to explore multiple variations of parameter values, as well as to catch the equilibriums of the dynamics only visible on large time scales.

Limitation: Subjective assumptions are still needed to model attitude changes occurring in a role-playing game. This is due to the yet unknown mechanisms if human behaviour and cognitions. 3. Advantage and limitation: Using complex models, initially designed for participatory modelling, in experimental economics can bring "noise" to the protocols. However, it raises new kinds of research questions.

4. The type of optimisation framework proposed in the fourth example has the advantage of the integrative approaches that force participants to enter into dialogue and share their conceptual and methodological choices, which stand in contrast to multidisciplinary research where various disciplines may follow their priorities in parallel. Among the limitations associated with the fourth example, it may be mentioned that the type of optimisation framework adopted makes it difficult to quantify uncertainties. Indeed, they are of different types depending on the processes or factors considered (physical behaviour of the systems versus behaviour of the populations in terms of water use for example) and are too complicated to extrapolate from future situations.

Table 5: Hybrid methods within the PRECOS team

Hybrid methods and type of inter-pluri-trans-disciplinarity	Goals	Topics	Targeted population	Tools	Results	References
1. Behavioural economics and social psychology - Interdisciplinarity between two experimental sciences where the coherence is ensured by a common experimental protocol for answering the question of the relation between attitude and behaviour - Transdisciplinarity concerning the question of the influence of the new water supply in Aude	- Understand the effects of water supply political measures on pure Nash behavioural strategies of participants included in a Common Pool Resource dilemma. - Understand the effects of pure Nash behavioural strategies on implicit and explicit attitude change of participants	Influence of the implementation of a water supply system in the Aude watershed (France) on behaviours and attitude of farmers towards irrigation during periods of drought	- University students (lab experiment), - Farmers (mobile lab experiment)	- Experimental Economics in the laboratory. A CPR dilemma game framed to represent appropriation of water during periods of drought was used. - Psychological measures of attitudes. A questionnaire based on Likert scales was used to grasp explicit attitudes. An Implicit association Test was used to grasp implicit attitudes.	Treatments underway	20
2. Social psychology and social simulation Multi-disciplinary	Understand how the game design and use of role-playing games (RPGs) used as participatory simulation methods for environmental management influence attitudes of participants	Influence on attitude dynamics of the design and use of the RPG CauxOpération (Souchère and al., 2010), aiming to facilitate coordinated management of a watershed which is prone to erosive runoff in Normandie (France)	Stakeholders of a watershed (farmers, mayors, agricultural watershed advisors)	Multi-agent system. An agent-based model of attitude/behaviour dynamics was used within which hypotheses at the individual level are based on psychological theories	Results showed how game design of RPGs can lead to different shaped outcomes. The relative simplicity of the model enabled us to understand the underlying processes responsible for those shaped outcomes	21
3. Agent-Based-Modelling / Role Playing Games and experimental economics.	Analyse experimentally the effect of participatory modelling on water users' cooperation when they	Common pool resource management, Companion modelling, lab experiments	Academic research. Students and other people	Experimental economics, laboratory of experimental economics, Agent-Based Modelling (NetLogo), INI-Wat-A-Game Role Playing	In the laboratory, participatory modelling fosters water users 'cooperation in a situation of common pool resources.	22

- Interdisciplinarity where the coherence is ensured by a conceptual framework? Or - Multidisciplinarity because in experimental economics we used an ABM, which, however, raised questions.	are in a situation of common pool resource, increasing theoretical knowledge and reflection on the effect of participatory methods		participating to the experiments .	Game, literature on companion Modelling	When the situation is contextualised in a RPG. In the same economic situation with no context, modelling does not foster cooperation.	
4. Optimisation of water resource to demand - Interdisciplinarity, where the approach coherence is insured by the formalisation in a single computation model for optimisation - Transdisciplinarity as the purpose is to help water managers (humanities) and not only to answer academic questions.	help water managers for their adaptation strategy to global change at the river-basin scale	programme of measures designed for the Orb river basin (France), based on a catalogue of potential adaptation measures, using a least-cost procedure for a given future climate projection.	Surface and groundwater managers	Conceptual modelling for water resources, econometric models for water demand, climate projections and qualitative/participatory methods for future scenario building,	least-cost allocation of measures helpful for global change adaptation strategies design. Prioritisation of adaptation measures. Trade-offs characterisation.	23
5. Coupled modelling (system dynamics with physically-based models). Interdisciplinary; models are coupled at runtime to simulate reciprocal impacts of socioeconomic and environmental systems on each other.	Understanding the sustainability trade-offs of subsistence versus market-based agriculture in Indigenous smallholder farming villages in Guatemala in the context of climate change.	Agriculture and food system management in the context of climate change	Food security and agricultural project developers and managers	System dynamics modelling for the socioeconomic subsystem; PCSE crop model for the hydrological system. Coupling with Tinamït software.	Results highlighted different vulnerabilities to climate change and other threats in each community, as well as different strategies for adaptation. Socioeconomic strategies generally led to stronger and more sustainable results than purely environmental interventions.	24

5. In the case of Guatemala, the use of a hybrid (coupled modelling) approach allowed for the use of the most appropriate models for each of the socioeconomic and hydrological domains. While some efforts have been made to translate hydrological or cropping models to SD language, these efforts are time-consuming and result in less efficient models that are inflexible and computationally expensive to run. The coupling approach used here allows us to keep the hydrological and other biophysical aspects of the socio-environmental system within the framework of specialist models that have already been developed and well tested. At the same time, the use of a SD framework for the socioeconomic part of the system allows for the representation of these processes in a clear and visual form that is easy for stakeholders to understand. The coupling of the two systems then leads to the emergence of dynamic behaviour and feedback between the two. Such approaches facilitate the use analysis of the interactions between economic and hydrological (as well as other environmental) processes from a system dynamics point of view. At the same time, the use of SD as opposed to agent-based modelling precludes the representation of the behaviour of individual agents, meaning that economic processes must instead be modelled at the village or regional scale.

3 Discussion and conclusion

Analysing practices, social representations and behaviours of socio-hydro systems' actors is a complex task, as the system's object of study are complex ones, where individual subjects interact with other subjects (socio systems) and with the biophysical and ecological components of the hydro system. These interactions create multiple consequences and feedbacks, making it very difficult to isolate the relations of causality at the origin of the impacts that humans' actions have on the hydro systems and on other humans.

To study those complex interactions and try to represent practices, social representations and behaviours of socio-hydro systems' actors, our team PRECOS proposes the groups of methods presented in the previous section, and illustrated in the table below (Table 6), where a comparison is presented in terms of several criteria. These groups of methods are surveys/focus groups for the analysis of practices, social representations, preferences and stated preferences, experimental economics and field experiments, and hybrid methods.

Table 6. Comparison of the presented groups of methods

	Surveys/focus groups for the analysis of practices, social representations, preferences	**Stated preferences**	**Experimental economics/field experiments**	**Hybrid methods**
Qualitative/quantitative	Quali	Quanti	Quanti	Quali/quanti
Participatory	Y	N/Y	N	Y
Field/laboratory	Field	Field	Both	Both
Hybridation, transdisciplinary	++	+	+	+++
Hypotheses on subjects' behaviour	Planified action (Ayzen, 1991) Social representations (Moscovici, 1961)	Economic rationality	Economic rationality/social preferences	Depending on the original methods

Stated preferences methods and experimental economics produce more quantitative results, and are less adapted to the use of participatory approaches and procedures for their implementation than surveys and focus groups (although new developments in stated preferences have recently allowed some flexibility in the introduction of more participatory approaches). Surveys and stated preferences methods are usually implemented in field contexts, while experimental economics and hybrid methods can take place in both laboratory and field situations.

Following the examples presented in Section 2, surveys and focus groups have a higher tendency towards hybridisation and transdisciplinary approaches, even though stated preferences and experimental economics are progressively moving in this direction.

Stated preferences and experimental economics move from the same neoclassic mainstream economics foundations (economic rationality), while the analysis of practices, social representations and preferences based on survey and focus groups are rooted in other references, such as theories of planned action and of social representations.

Hybrid methods are influenced by the methods and approaches that constitute them, and this is true for all the criteria presented in the table.

All methods have advantages and limitations in terms of applicability to the studied systems and capacity to isolate the observed phenomena.

The analysis of practices, social representations and preferences through surveys and focus groups allows for depicting the emergence of preferences (or refusals) of regulation tools based on values and beliefs and on social justice perception; they are to be compared and put into perspective with the usual benefit-cost analysis. For these reasons, these methods inform managers and decision makers about the right information to disseminate and the best media to favour. On the other hand, these methods are relatively complex, take time to put in place, and sometimes require large samples that require expensive surveys.

Stated preferences are a well-established method that benefits from an extensive literature and from thousands of applications around the world, including in situations where socio-hydro systems are studied. These methods allow for eliciting both use and non-use values, the latter being particularly important in the case of socio-hydro systems. Choice modelling allows for estimating the value placed on specific attributes of socio-hydro systems and it is possible through them to analyse the heterogeneity of preferences within the considered population. On the other hand, these methods are relatively complex to put in place, and require a high level of technical skills, not often found in the field, and particularly not in developing countries. Another limit of the method is represented by the main hypotheses behind it (choice heuristics, neoclassical individualistic rationality), that are the targets of criticism from a large community of scientists that consider these hypotheses too 'restrictive' and not fully representative of human behaviour. Finally, stated preferences often do not fully reflect the real behaviour of economic agents. This 'hypothetical' bias favours the use of other methods complementary to those based on stated preferences.

Experimental economics and field experiments have their main strength in the capacity to analyse economic subjects' behaviour in controlled environments (laboratory or lab-in-the field) and in economically incentivised situations. Therefore, the hypothetical bias resulting from declarative methods such as the stated preferences ones is minimized. The possibility of isolating the variables at stake in specific treatments allows a precise analysis of the causality in the observed phenomena. On the other hand, laboratory experiments are questioned in terms of generalisation of the results obtained (external validity), and for this reason field experiments (lab-in-the-field) are often required, especially when the experiments aim at supporting decision making about public policies. The complexity and technicality of these methods are common to the stated preferences ones, and practical limits in the field, such as the difficulty to implement a lab, economically incentivised, protocol in rural areas of developing countries need to be mentioned. Randomised field trials require large samples and therefore are expensive and complicated to implement.

Hybrid methods have the advantage of their adaptation to a specific situation at stake and benefit from the complementarity of the original methods that constitute them. The main inconvenience is represented by the lack of seminal studies and texts for reference, as hybrid methods are crafted 'on the spot' based on the specific needs of the case study, and each case is 'unique.'

Our review of the groups of methods revealed that there are some specificities in socio-hydro systems that need to be considered with particular attention when designing and implementing the protocols for the analysis of practices, social representations and behaviours of socio-hydro systems' actors. These specificities, namely the asymmetry of access to the resource, the dynamic and flowing nature of water, and the difficulty of observing the resource (limited to groundwater), while not requiring a radical recrafting of the methods used in other contexts of socio-eco systems, suggest their adjustment to the specific cases.

Our position, in conclusion, is that there is no 'ideal' method for the study of practices, social representations and behaviours of socio-hydro systems' actors, and every case study deals with a very specific situation where the choice of the method to be applied is a new challenge. What we suggest in this paper is to proceed in two parallel directions:

1) Adapting as much as possible the proposed groups of methods to the specificities of SHS;

2) Moving in the direction of transversality and interdisciplinarity, by producing hybrid methods able to take into account the complexity of the systems at stake and benefit from the complementarity of different methods.

The main limitation of this study resides in the incomplete review of methods and tools proposed for the analysis of the practices, social representations and behaviours of socio-hydro systems' actors. We chose to present in this paper only the methods used by the PRECOS team. This choice was driven by the aim to provide the reader with a panel of methods that have proved their effectiveness and utility in real contexts and with real actors. On the other side, there are certainly more methods for realising the aims described in the text that have not been presented here. A future research pathway is represented by a larger methodological review for the analysis of the practices, social representations and behaviours of socio-hydro systems' actors, followed by a reasoned comparison between the methods presented in this work and those included in the review.

4 References

Abric J.-C., 2001, L'approche structurale des représentations sociales : développements récents, Psychologie et société, vol 4, n°2, p. 81-104.

Ajzen I. 1991. The theory of planned behavior. Organizational Behavior and Human Decision Processes 50: 179-211. doi: http://dx.doi.org/10.1016/0749-5978(91)90020-T.

Alvargonzález, D. 2011. Multidisciplinarity, interdisciplinarity, transdisciplinarity, and the sciences. International studies in the philosophy of science, 25(4), 387-403.

Amalric M., Cirelli C. , 2017, L'ingénierie écologique face aux territoires: enjeux et représentations sociales d'une innovation dans le domaine du traitement de l'eau, Géocarrefour vol. 91, n° 4, https://doi.org/10.4000/geocarrefour.10103

Anderies, J. M. 2006. Robustness, institutions, and large-scale change in social-ecological systems: The Hohokam of the Phoenix Basin. *Journal of Institutional Economics* 2(2): 133-155.

Anderies, J. M., Barreteau, O., Brady, U. 2019. Refining the Robustness of Social-Ecological Systems Framework for comparative analysis of coastal system adaptation to global change. *Regional Environmental Change* 19(7): 1891-1908

Anderies, J., Janssen, M., Ostrom E. 2004. A framework to analyze the robustness of social-ecological systems from an institutional perspective. *Ecology and Society* 9(1): 18.

Armatas, C. A., Venn, T. J., and Watson, A. E. 2014. Applying Q-methodology to select and define attributes for non-market valuation: A case study from Northwest Wyoming, United States. *Ecological Economics, 107*(2014), 447-456. doi:https://doi.org/10.1016/j.ecolecon.2014.09.010

Baggio S., Rouquette M.- L., 2006, La représentation sociale de l'inondation: influence croisée de la proximité au risque et de l'importance de l'enjeu, Bulletin de psychologie(1), p. 103-117.

Barbier R., Bedu C., Buclet N., 2009, Portée et limites du dispositif « jury citoyen », Politix (2), p. 189-207.

Besteiro A. G. , Riviere-Honegger A. 2018, Les représentations sociales du Alto Guadiana (Espagne): entre eaux superficielles et souterraines. Un obstacle pour imaginer son devenir ? Géocarrefour, vol. 92, n°1, https://doi.org/10.4000/geocarrefour.10438.

Bousquet F, Cambier C, Mullon C, Morand P, Quensière J, Pavé A, 1993 : Simulating the interaction between a society and a renewable resource. Journal of Biological Systems 1 (2): 199-214.

Bousquet F, Le Page C, 2004 : Multi-agent simulations and ecosystem management : A review. Ecological Modelling 176: 313-32. doi: 10.1016/j.ecolmodel.2004.01.011.

Brelsford, C., et al. 2020. Developing a sustainability science approach for water systems. *Ecology and Society* 25(2): 1-6.

Brouwer, R., N. Neverre, 2020, A global meta-analysis of groundwater quality valuation studies, *European Review of Agricultural Economics*, 47(3): 893-932.

Caillaud S., 2010, Représentations sociales et significations des pratiques écologiques : Perspectives de recherche, *VertigO-la revue électronique en sciences de l'environnement*, 10(2).

Caillaud S., Flick U. 2016, Triangulation méthodologique. Ou comment penser son plan de recherche, in Lo Monaco G., Delouvee S., Rateau P. (eds.), *Les représentations sociales. Théories, méthodes et applications*, Bruxelles, De Boeck Supérieur, p. 227-240.

Cason, T. N., L. Gangadharan, and C. Duke. 2003. A laboratory study of auctions for reducing non-point source pollution. *Journal of Environmental Economics and Management* no. 46 (3):446-471.

Cooper, D. J., and J. H. Kagel. 2003. The impact of meaningful context on strategic play in signaling games. *Journal of Economic Behavior and Organization* no. 50 (3):311-337. doi: Pii S0167-2681(02)00025-2

Cox, J. C. 2004. How to identify trust and reciprocity. *Games and Economic Behavior*, *46*(2), 260-281.

Di Meo, G. 2008. Une géographie sociale entre représentations et action. *Montagnes Méditerranéennes et Développement Territorial*, 23: 13-21.

Dubois, D., S. Farolfi, P. Nguyen-Van, and J. Rouchier. 2020. Contrasting effects of information sharing on common-pool resource extraction behavior: Experimental findings. *Plos One* no. 15 (10). doi: ARTN e0240212

Duchene S., Haegel F., 2008, L'enquête et ses méthodes: l'entretien collectif, Paris, Armand Colin, 128p.

Ehmke, M., and J. F. Shogren. 2010. The Experimental Mindset within Development Economics: Proper Use and Handling Are Everything. Applied Economic Perspectives and Policy no. 32 (4):549-563.

El Mokaddem, A., S. Morardet, C. Lejars, R. Doukkali, F. Benchekroun, 2016, Conception d'un paiement pour services environnementaux en pâturages collectifs : une expérimentation des choix, Economie rurale, (355): 67-89.

Ensminger, J. 2001; Reputation, trust, and the principal agent problem, in K. Cook (ed.), Trust in society, Volume II, New York: Russell Sage Foundation.

Farolfi, S., M. Désolé, and P. Rio. 2014. Influence of Context on Player Behavior. Simulation and Gaming no. 45 (4-5):627-665. doi: 10.1177/1046878114563647.

Figureau, A.G. 2015. Conception et évaluation d'instruments de gestion de l'eau combinant incitations économiques et préférences sociales – Cs des prélèvements agricoles en eau souterraine. Thèse de doctorat, SupAgro Montpellier, 252p.

Germaine M.-A., Barraud R., 2013, Restauration écologique et processus de patrimonialisation des rivières dans l'Ouest de la France. VertigO-la revue électronique en sciences de l'environnement (Hors-série 16), https://doi.org/10.4000/vertigo.13583.

Gieseking J.J., 2013, Where We Go from Here: the Spatial Mental Mapping Method and Its Analytic Components for Social Science Data Gathering. Qualitative Inquiry n°19, p. 637-649.

Girad S., Rolland L., Rivière-Honegger A., 2016, Saisir la territorialité par le dessin. Retours méthodologiques, Sciences de la Société. « Les SHS et les questions environnementales. Manières de voir, manières de faire », n°96, p.47-69.

Greenwald, A. G., McGhee, D. E., and Schwartz, J. L. 1998. Measuring individual differences in implicit cognition: the implicit association test. *Journal of personality and social psychology*, *74*(6), 1464.

Harrison, G. W., and J. A. List. 2004. Field experiments. Journal of Economic Literature no. 42 (4):1009-1055. doi: Doi 10.1257/0022051043004577.

Hassenforder E., Dray A., Dare W., 2020, Manuel d'observation des jeux sérieux, ComMod, CIRAD, 68 p.

Hensher, D., and Greene, W. 2010. Non-attendance and dual processing of common-metric attributes in choice analysis: a latent class specification. *Empirical Economics, 39*(2), 413-426. doi:10.1007/s00181-009-0310-x

Hensher, D.A., J.M. Rose, W.H. Greene, 2015, Applied choice analysis, Cambridge, U.K.: Cambridge University Press.

Hérivaux, C., and Grémont, M. 2019. Valuing a diversity of ecosystem services: The way forward to protect strategic groundwater resources for the future? *Ecosystem Services, 35*, 184-193. doi:https://doi.org/10.1016/j.ecoser.2018.12.011

Janssen, M. A., J. M. Anderies, and J. C. Cardenas. 2011. Head-enders as stationary bandits in asymmetric commons: Comparing irrigation experiments in the laboratory and the field. Ecological Economics no. 70 (9):1590-1598.

Jensen, A. K. 2019. A Structured Approach to Attribute Selection in Economic Valuation Studies: Using Q-methodology. *Ecological Economics, 166*(December 2019), 106400. doi:https://doi.org/10.1016/j.ecolecon.2019.106400

Jodelet D., 1993, Les représentations sociales: regard sur la connaissance ordinaire, Sciences humaines, vol. 27, n°4, p. 22-24.

Johnston et al. 2003. Modeling relationships between use and nonuse values for surface water quality: A meta-analysis. Water Resources Research, 39:12.

Johnston, R. J., Boyle, K. J., Adamowicz, W., Bennett, J., Brouwer, R., Cameron, T. A., . . . Vossler, C. A. 2017. Contemporary Guidance for Stated Preference Studies. *Journal of the Association of Environmental and Resource Economists, 4*(2), 319-405. doi:10.1086/691697

Jourdain, D., J. Lairez, B. Striffler, F. Affholder, 2020, Farmers' preference for cropping systems and the development of sustainable intensification: a choice experiment approach, Review of Agricultural, Food and Environmental Studies, 101(4): 417-437.

Jourdain, D., Lairez, J., and Affholder, F. 2022. Identify Lao farmers' goals and their ranking using best-worst scaling experiment and scale-adjusted latent class models. *Journal of Multi-criteria Decision Analysis*. doi:10.1002/mcda.1785

Jourdain, D., Lairez, J., Striffler, B., and Lundhede, T. 2022. A choice experiment approach to evaluate maize farmers' decision-making processes in Lao PDR. *Journal of Choice Modelling, 44*, 100366. doi:https://doi.org/10.1016/j.jocm.2022.100366

Kallis, G., E. Gómez-Baggethun, C. Zografos, 2013, To value or not to value? That is not the question, Ecological Economics, 94: 97-105.

Kitzinger J., Markova, I., Kalampalikis N., 2004, Qu'est-ce que les focus groups ? Bulletin de psychologie - N° spécial "Les groupes centrés (Focus groups)", vol. 57, n° 3, p. 237-244.

Krosnick, J. A., Judd, C. M., and Wittenbrink, B. 2005. Attitude measurement. Handbook of attitudes and attitude change. Mahwah, NJ: Erlbaum, 21-76.

Laury, S. K., and L. O. Taylor. 2008. Altruism spillovers: Are behaviors in context-free experiments predictive of altruism toward a naturally occurring public good? Journal of Economic Behavior and Organization no. 65 (1):9-29. doi: DOI 10.1016/j.jebo.2005.05.011.

Le Coent, P., R. Préget, S. Thoyer, 2017, Compensating Environmental Losses Versus Creating Environmental Gains: Implications for Biodiversity Offsets, Ecological Economics, 142: 120-129.

Levitt, S. D., and J. A. List. 2007. What do laboratory experiments measuring social preferences reveal about the real world? Journal of Economic Perspectives no. 21 (2):153-174.

Likert, R. 1932. A technique for the measurement of attitudes. *Archives of psychology*.

Lo Monaco, G., Lheureux, F., Halimi-Falkowicz, S., 2008. Test d'indépendance au contexte (TIC) et structure des représentations sociales. Swiss Journal of Psychology/Schweizerische Zeitschrift für Psychologie/Revue Suisse de Psychologie, 67(2), 119.

Loomis, J. 2011. What's to Know About Hypothetical Bias in Stated Preference Valuation Studies? Journal of Economic Surveys no. 25 (2):363-370. doi: 10.1111/j.1467-6419.2010.00675.x.

Mahlalela, L. S., Jourdain, D., Mungatana, E. D., and Lundhede, T. H. 2022. Diverse stakeholder perspectives and ecosystem services ranking: Application of the Q-methodology to Hawane Dam and Nature Reserve in Eswatini. *Ecological Economics, 197*, 107439. doi:10.1016/j.ecolecon.2022.107439.

Masclet, D., C. Noussair, S. Tucker, and M. C. Villeval. 2003. Monetary and nonmonetary punishment in the voluntary contributions mechanism. American Economic Review no. 93 (1):366-380. doi: Doi 10.1257/000282803321455359.

Massuel S., Riaux J., Molle F., Kuper M., Ogilvie A., Collard A-L., Leduc C., and Barreteau, O. 2018. Inspiring a Broader Socio-Hydrological Negotiation Approach With Interdisciplinary Field-Based Experience. Water Resources Research no. 54(4), p. 2510-2522.

Medema W., Wals A., Adamowski J., 2014, Multi-Loop Social Learning for Sustainable Land and Water Governance: Towards a Research Agenda on the Potential of Virtual Learning Platforms, NJAS - Wageningen Journal of Life Sciences n° 69, p. 23-38.

Michel-Guillou É., 2011, La construction sociale de la ressource en eau, Pratiques Psychologiques Vol. 17, n°3, p. 219-236.

Michel-Guillou É., 2014, La représentation sociale du changement climatique : enquête dans le sens commun, auprès de gestionnaires de l'eau, Les Cahiers Internationaux de Psychologie Sociale n°104(4), p. 647-669.

Michel-Guillou, E., and G. Moser. 2006. Commitment of farmers to environmental protection: From social pressure to environmental conscience. Journal of Environmental Psychology no. 26 (3):227-235. doi: DOI 10.1016/j.jenvp.2006.07.004.

Mitchell, R. C., and Carson, R. T. 1989. *Using Surveys to Value Public Goods: The Contingent Valuation Method*. Washington, DC: Resources for the Future.

Moliner P., 1988, Validation expérimentale de l'hypothèse du noyau central des représentations sociales, Bulletin de psychologie, 41(387), p. 759–762.

Morardet, S., L. Kuhfuss, R. Lifran, 2015, What do People Want for the Vistre River? Using Choice Experiment to Support an Ordinary Stream Restoration Project, the 11th International Conference of the European Society for Ecological Economics (ESEE) : "Transformations", Leeds, United Kingdom, 36.

Moscovici S., 1961, 1976 2è éd. La psychanalyse, son image et son public: étude sur la représentation sociale de la psychanalyse, Presses universitaires de France, 512 p.

Nancarrow, B.E. Leviston, Z., Po, M., Porter, N. B., Tucker, D. I., 2008. What drives communities' decisions and behaviors in the reuse of wastewater. Water Science and Technology, 57(4), 485-491.

Navarro Carrascal O., 2009, Représentations sociales de l'eau dans un contexte de conflits d'usage : le cas de la Sierra Nevada de Santa Marta, Colombie, Les Cahiers Internationaux de Psychologie Sociale, n°81(1), p. 65-86.

Ostrom, E. 2009. A General Framework for Analyzing Sustainability of Social-Ecological Systems. *Science* 325: 419-422.

Ostrom, E., Gardner, R., and Walker, J. 1994. Rules, games, and common pool resources, Ann Arbor, MI: University of Michigan press.

Parks, S., Gowdy, J., 2013. What have economists learned about valuing nature? A review essay. Ecosystem Services 3 (0), e1-e10.

Pianelli C., Abric J.-C., Saad F., 2010, Rôle des représentations sociales préexistantes dans les processus d'ancrage et de structuration d'une nouvelle représentation, Les Cahiers Internationaux de Psychologie Sociale (2), p. 241-274.

Rose, J., Bliemer, M., 2009. NGENE User Manual and Reference guide. Choice Metrics, Sydney, Australia.

Rose, J.M., M.C.J. Bliemer, 2008, Stated preference experimental design strategies, Handbook of transport modelling: 151-180.

Roth, A. E. 1988. Laboratory Experimentation in Economics - a Methodological Overview. *Economic Journal* no. 98 (393):974-1031. doi: Doi 10.2307/2233717.

Samuelson, P.A., and Nordhaus, W.D. 1985. Economics, New York: McGra-Hill, 12th Edition.

Scarpa, R., Gilbride, T. J., Campbell, D., and Hensher, D. A. 2009. Modelling attribute non-attendance in choice experiments for rural landscape valuation. *European Review of Agricultural Economics, 36*(2), 151-174.

Sivapalan, M., Savenije, H.H.G., Blöschl, G. 2012. Socio-hydrology: A new science of people and water. *Hydrological Processes* 26(8): 1270-1276.

Smith, V. L. 1994. Economics in the Laboratory. *Journal of Economic Perspectives* no. 8 (1):113-131. doi: DOI 10.1257/jep.8.1.113.

Spence A., Poortinga W., Pidgeon N., 2012, The psychological distance of climate change, Risk Analysis: An International Journal 32(6), p. 957-972.

Spurling N., McMeekin A., Shove E., Southerton D., Welch, D., 2013, Interventions in practice: re-framing policy approaches to consumer behavior, University of Manchester, Sustainable Practices Research Group, 57 p.

Tafani E., 1997, Attitude et approche structurale des représentations sociales: de l'ancrage psychologique à l'ancrage sociologique, Thèse de doctorat. Aix-Marseille 1.

Train, K., 2009. Discrete choice methods with simulation, 2nd ed. Cambridge University, Cambridge, M.A.

Vatn, A., 2004, Environmental valuation and rationality, *Land Economics*, 80(1): 1-18.

Velez, M. A., Stranlund, J. K., and Murphy, J. J. 2009. What motivates common pool resource users? Experimental evidence from the field. Journal of Economic Behavior and Organization, 70(3), 485-497.

Walker, J. M., and R. Gardner. 1992. Probabilistic Destruction of Common-Pool Resources - Experimental-Evidence. *Economic Journal* no. 102 (414):1149-1161. doi: Doi 10.2307/2234382.

Walker, J. M., R. Gardner, and E. Ostrom. 1990. Rent Dissipation in a Limited-Access Common-Pool Resource - Experimental-Evidence. *Journal of Environmental Economics and Management* no. 19 (3):203-211. doi: Doi 10.1016/0095-0696(90)90069-B.

Wesselink, A., Kooy, M., Warner, J. 2017. Socio-hydrology and hydrosocial analysis: Toward dialogues across disciplines. *Wiley Interdisciplinary Reviews: Water* 4(2): e1196.

Wibeck V., Adelsvärd V., Linell P., 2004, Comprendre la complexité : les focus groups comme espace de pensée et d'argumentation sur les aliments génétiquement modifiés, Bulletin de psychologie, vol. 57, n° 3, (471) p. 253-261.

Wittvogel, K. 1964. Le despotisme oriental. Etude comparative du pouvoir total, Editions de minuit.

Yang, Y., and Hobbs, J. E. 2020. The Power of Stories: Narratives and Information Framing Effects in Science Communication. *American Journal of Agricultural Economics, 102*(4), 1271-1296. doi:https://doi.org/10.1002/ajae.12078.

References of Table 1

1. Faysse, N., Rinaudo, J. D., Bento, S., Richard-Ferroudji, A., Errahj, M., Varanda, M., Imache, A., Dionnet, M., Rollin, D., Garin, P., Kuper, M., Maton, L., Montginoul, M. 2014. Participatory analysis for adaptation to climate change in Mediterranean agricultural systems: possible choices in process design. Regional Environmental Change, 1-14
2. Moreau, C., Rinaudo, J. D., Garin, P., 2015. La justice sociale dans la construction du jugement d'acceptabilité. Analyse des réactions d'agriculteurs face à différentes règles de partage de l'eau souterraine. Économie rurale 2/2015 (n° 346), p. 31-48.
3. Collard, A.L., Garin, P. Montginoul, M. 2019. Un compteur « intelligent » pour mesurer les usages de l'eau : l'entrée en scène d'une nouvelle connaissance, Développement durable et territoires, Vol. 10, n°3 | Décembre 2019. URL : ttp://journals.openedition.org/developpementdurable/16226 ; DOI : https://doi.org/ 10.4000/developpementdurable.16226
4. Montginoul M. et Vestier A. Smart metering: A water-saving solution? Consider communication strategies and user perceptions first. Evidence from a French case study. In Environmental Modelling and Software, 2018, 104, p. 188-198, https://www.sciencedirect.com/science/article/pii/S1364815217305339
5. Garin P,. Girard, S, Rivière –Honegger, A., Degache, A., Gouton, C., Pellen, M. A paraître 2022. Manquer un jour d'eau au robinet ? la mise à distance territoriale des effets du changement climatique. Géocarrefour
6. Garin, P., Montginoul, M., and Noury, B. 2021. Waste water reuse in France–social perception of an unfamiliar practice. Water Supply, 21(5), 1913-1926

References of Table 2

7. Manganyi, B., Karuaihe, S., and Jourdain, D. 2022. Preferences for index-based pasture insurance: a choice experiment in Limpopo Province, South Africa. Paper presented at the AEASA Conference, Swakopmund, Namibia.
8. Mokaddem, A. E., Morardet, S., Lejars, C., Doukkali, M. R., and Benchekroun, F. 2016. Conception d'un paiement pour services environnementaux en pâturages collectifs. Une expérimentation des choix. Économie rurale. *Agricultures, alimentations, territoires* (355), 67-89.
9. Le Coent et al. 2017)
10. Kanyoka, P., Farolfi, S., and Morardet, S. 2008. Households' preferences and willingness to pay for multiple use water services in rural areas of South Africa: An analysis based on choice modelling. *Water Sa, 34*(6), 715-723.
11. Favre, M. 2021. Are Households Willing to Finance the Cost of Individual Water Supply? Case Study in Central Tunisia. *Water Economics and Policy, 07*(04), 2150016. doi:10.1142/s2382624x21500168
12. Hérivaux, C., and Le Coent, P. 2021. Introducing nature into cities or preserving existing peri-urban ecosystems? Analysis of preferences in a rapidly urbanizing catchment. *Sustainability, 13*(2), 587.
13. Hérivaux, C., and Rinaudo, J.-D. 2016. Integrated assessment of economic benefits of groundwater improvement with contingent valuation *Integrated Groundwater Management* (pp. 519-549): Springer, Cham.

14. Jourdain, D., and Vivithkeyoonvong, S. 2017. Valuation of ecosystem services provided by irrigated rice agriculture in Thailand: a choice experiment considering attribute non-attendance. *Agricultural Economics, 48*(5), 655-667. doi:10.1111/agec.12364

15. Vivithkeyoonvong, S., and Jourdain, D. 2017. Willingness to pay for ecosystem services provided by irrigated agriculture in Northeast Thailand. *International Journal of Biodiversity Science, Ecosystem Services and Management, 13*(1), 14-26. doi:10.1080/21513732.2016.1242093

16. Cottet, M., S. Morardet, M. Adam, S. Vukelic, A.L. Collard, L. Coussout, L. Vaudor, A. Rivière-Honegger, S. Février. 2019. ViaRhôna : la valorisation du patrimoine rhodanien à l'épreuve des territoires, des acteurs et des usages. Rapport final du projet RhônaVel'eau, Plan Rhône, Agence de l'eau Rhône-Méditerranée et Corse, EDF, FNADT, Lyon.

References of Table 3

17. Farolfi S., Dubois D., Morardet S., Nouichi I., Marlet S.. 2018. Fourniture d'information et consentement à payer l'eau d'irrigation dans les groupements de développement agricole tunisiens. Une étude par l'économie expérimentale. Cahiers Agricultures, 27 (2) : 10 p.

18. Brugnach M., De Waard S., Dubois D., Farolfi S. 2021. Relational quality and uncertainty in common pool water management: An exploratory lab experiment. Scientific Reports, 11 (1):14 p.

19. Chabé-Ferret, S., Le Coent, P., Reynaud, A., Subervie, J., Lepercq, D., 2019. Can we nudge farmers into saving water? Evidence from a randomised experiment. Eur. Rev. Agric. Econ. 46, 393–416.

References of Table 5

20. Dubois, E., Barreteau, O., Souchère, V., 2013. An agent-based model to explore game setting effects on attitude change during a role playing game session, Journal of artificial societies and social simulation

21. Dubois, E., Bonté, B., Farolfi, S., (in prep.) Pure Nash strategies effects on implicit and explicit attitude change in a common pool resource dilemma.

22. Bonté, B, Farolfi, S, Ferrand, N, Abrami, G, Diallo, M C, Dubois, D, Johannet, A; Gaudi, W A 2019) Building new kinds of meta-models to analyse experimentally (companion) modelling processes in the field of natural resource management Environmental Modelling and Software,120,104486, Elsevier.

23. Girard C., Rinaudo JD, Pulido-Velazquez M, Caballero Y(2015) An interdisciplinary modelling framework for selecting adaptation measures at the river basin scale in a global change scenario, Environmental Modelling and Software, Volume 69, Pages 42-54, ISSN 1364-8152

24. Malard, J. 2020. Méthodes pour la modélisation dynamique des composantes socioéconomiques et biologiques des systèmes agricoles à petite échelle. Thèse, Université McGill.