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ABSTRACT

Although potential benefits and limits of scenarios are well known, few studies verify their impacts on knowledge production and public decision-making in the long term. In this paper, we perform an ex-post evaluation of land-use and land-cover change (LUCC) scenarios produced in 2004 aiming to support water management. The objective is to evaluate to what extent the impacts of those scenarios reflect expectations and to understand which factors influenced the occurrence of impacts. Moreover, we provide insights on the driving forces considered in LUCC modelling that produce plausible scenarios at a watershed level. At the time horizon of scenarios, we used semi structured interviews, combined with a quantitative comparison between observed and simulated LUCC. Results indicate that scenarios fulfilled their original purpose: to support the definition of the local water management strategy. Furthermore, they promoted a multidisciplinary perspective within land managers and facilitated the recognition of challenges and opportunities faced by local farmers. Nevertheless, they failed in creating a shared vision of the future across groups of different actors. The lessons learned from the evaluation are synthesized in guidelines that can be used to enhance impacts of any future scenarios.

1. Introduction

1.1. Classification of scenarios

Since their initial application in the military (Bradfield, Wright, Burt, Cairns, & Van Der Heijden, 2005), scenarios have become a popular tool to explore the range of possible futures in multiple disciplines and contexts (Harries, 2003; Harrison et al., 2019; Reed et al., 2013; Sitas et al., 2019; Varum and Melo, 2010). Nowadays, scenarios are particularly used in environmental management (Oliveira, de Barros, de Carvalho Pereira, Gomes, & da Costa, 2018; Garb, Pulver, & VanDeveer, 2008; Palomo et al., 2001) where they are considered as an important tool for defining land-management policies (Kok et al., 2017; Metzger et al., 2017).

Despite a wide range of definitions (Chermack and Lynham, 2002; Parson, Burkett, Fisher-Vanden, Keith, & Mearns, 2007), scenarios can be considered as "plausible descriptions of how the future may develop, based on a coherent and internally consistent set of assumptions about key relationships and driving forces'' (IPCC, 2000, p.594). The multitude of scenario types, the lack of a consistent classification (Börjeson, Höjer, Dreborg, Ekvall, & Finnveden, 2006) and common terminology can hinder an easy understanding of the methodology and purpose behind a scenario.

One possible classification system divides scenarios into two categories; forecasting and backcasting scenarios, according to the *vantage point* (Van Notten, Rotmans, Van Asselt, & Rothman, 2003). In forecasting scenarios, the developer makes some assumptions on the evolution of key driving forces (i.e, changes in macro-economic factors, changes in human behaviors and preferences…), and

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they explore the potential consequences. In backcasting scenarios, the developer assumes what the future will look like and they explore the conditions needed to reach that state.

When including the concept of desirability, another classification is possible (see Rotmans et al., 2000; Van Notten et al., 2003 for examples) and scenarios can be divided into exploratory (or descriptive) and normative. Exploratory scenarios look at possible futures without stating an order of desirability, but rather building on past and present trends (Durance and Godet, 2010). On the contrary, normative scenarios describe probable or (un-)desirable futures. While the role of exploratory scenarios is well recognized in environmental management, a limited place is reserved to normative ones (Van der Voorn, Quist, Pahl-Wostl, & Haasnoot, 2017; Van der Voorn, Pahl-wostl, & Quist, 2012), such as backcasting scenarios which are normative by nature (Milestad, Svenfelt, & Dreborg, 2014).

Confusion may also arise from the difference between the terms *foresight and forecasting* which, despite their similarity, carry different meanings. The difference between them lies in the space left to uncertainty: while a forecast tries to define the most probable future, foresight rather explores a range of possible futures (Amer, Daim, & Jetter, 2013; Chermack, Lynham, & Ruona, 2001; Wilkinson, 2009, Durance and Godet, 2010). Additional attention must be paid when talking about forecasting scenarios, which as described above, belong to foresight.

When referring to the methodology used to generate scenarios: qualitative, semi-quantitative or quantitative approaches can be followed (Alcamo and Henrichs, 2008; Börjeson et al., 2006; Kok and van Vliet, 2011). When scenarios are applied to geographical systems and land management, quantitative models are often used (Fusco et al., 2017). Geographic systems, modelling and prospective studies are then combined in a so-called geoprospective approach: a type of study that integrates the spatial dimension (i.e. neighbouring effects of land covers and land uses, emerging properties of socio-ecological changes, etc.) as economic, historic or demographic dimensions (Voiron-Canicio, 2012). In this approach, narratives, modelling and participatory methods are combined (Houet and Gourmelon, 2014), creating scenarios particularly suited to support land managers in designing a sustainable development for their territory accounting for population's expectations on the future (Voiron-Canicio, 2006).

1.2. The application of scenarios in the land management

Uses and benefits of scenarios in the public planning sector and land management are commonly explored in literature. Xiang and Clarke (2003) state that scenarios have the powerful quality to bridge different pieces of information and facilitate knowledge sharing and the co-production of knowledge. In addition, scenarios stretch the personal thinking allowing to consider a wider range of possible futures by reconsidering personal beliefs (Xiang and Clarke, 2003). Participatory scenarios are also expected to promote a dialogue, a consensus, and a shared vision of the future between different actors (Baker, Hulse, Gregory, White, & Sickle, 2004; Palomo, Martín-López, López-Santiago, & Montes, 2011). Moreover, they can help to clarify the interactions between different variables (Hagemann et al., 2020; Swart, Raskin, & Robinson, 2004) supporting the definition of land management goals and the identification of management strategies (Xiang and Clarke, 2003). Finally, participatory scenarios can enhance consciousness about territorial issues pushing local actors to take action (empowerment) (Palomo et al., 2011).

Impacts of scenarios can be divided in three categories (Dunlop, 2014; Lumbroso, 2019; Mckenzie et al., 2014):

- *Instrumental impacts* where scenarios serve to inform decision makers and improve policy actions;
- *Conceptual impacts* where scenarios help deepen understanding about a complex phenomenon, shape ways of thinking and allow new beliefs and values to arise. As highlighted by Dunlop (2014), this kind of impact is indirect, and it may arise time after the communication of scientific knowledge;
- *Political impacts* in which scenarios promote the legitimization of a specific group of interest or preference. In this political mode, scenarios can be used to support pre-existing preferences and policy options, or to legitimize action.

However, not all scenarios produce the impacts expected, and many studies address obstacles to implementing scenarios as decision-making tools, such as the balance of power and interests among stakeholders (Commod, 2005; Kothari, 2001; Lumbroso, 2019), the large amount of time needed to develop participatory scenarios (Walz et al., 2007) and cultural barriers between researchers and final users (Bradshaw and Borchers, 2000; Carden, 2004). Due to these obstacles, even salient scenarios can be of little help for decision making (Cairns, Wright, Fairbrother, & Phillips, 2017; Clark, Mitchell, & Cash, 2006).

Amer et al. (2013) propose a literature review of the scenario validation criteria: consistency and plausibility being the most cited. In this paper, special attention will be given to plausibility, defined as the capacity of scenarios to "fall in the limits of what might conceivably happen" (Wilson, 1998, pp.91). To improve scenarios' plausibility, land change science community often combines LUCC models with participatory narratives to evaluate possible quantitative impacts on resources and ecosystems services (Houet, Aguejdad, Doukari, Battaia, & Clarke, 2016; Houet, Marchadier, et al., 2016).

Despite the potential benefits and limits of scenarios are well known, the literature assessing the use of scenarios remains limited, and many authors highlight the need to verify impacts on public decision making empirically (Bowman, MacKay, Masrani, & McKiernan, 2013; European Environment Agency, 2009; Langhammer, Thober, Lange, Frank, & Grimm, 2019; Volkery and Ribeiro, 2009). Few studies (Cairns et al., 2017; Mckenzie et al., 2014; Saritas, 2006; Sitas et al., 2019) have evaluated the influence of scenarios on decision making in the public context, and even fewer have evaluated scenarios years after the end of the project (ex-post evaluations). Oteros-Rozas et al. (2015) performed ex-post evaluation of 23 participatory scenarios and concluded that the scenarios had several indirect benefits, but they stressed the difficulty in producing evidence of a direct impact on management actions. The lack of ex-post evaluation can be a strong barrier to understanding which features of scenarios make them influential on the decision making.

This study aims to address this knowledge gap by assessing spatially explicit scenarios developed to support water management in

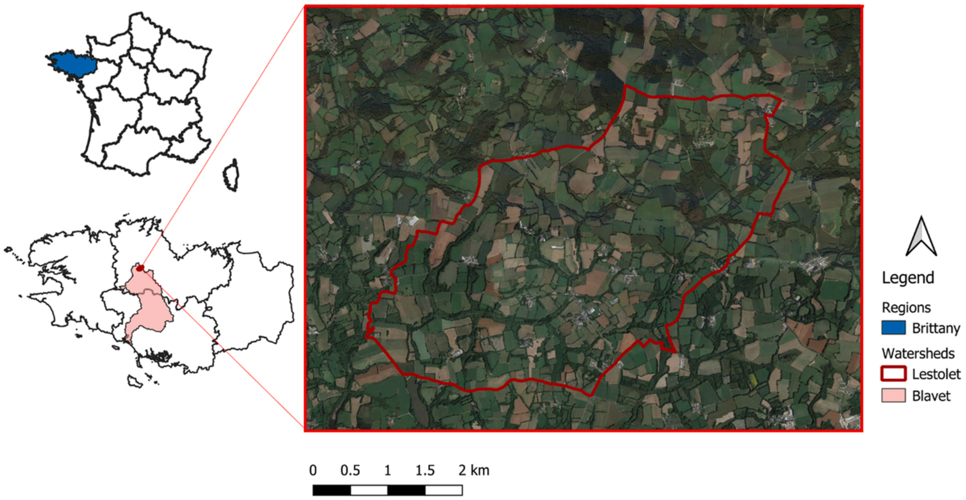

Fig. 1. The Lestolet watershed (red outline) located in central Brittany (France) on the northern edge of the Blavet watershed (reddish area).

Brittany (western France).

We analysed scenarios built in 2004 for the year 2020 published by Houet (2006) and Houet, Hubert-Moy, & Tissot (2008); Houet et al. (2010). Both forecasting and backcasting scenarios were produced and multiple trajectories of LUCC were simulated for 2006-2020 for the Lestolet secondary watershed, an area of 1320 ha in central Brittany. The assessed scenarios were expected to produce instrumental impacts, as a support tool for the definition of the local Water Development and Management Plan[1] (SAGE), a planning tool aiming at the sustainable management of water resources. Moreover, being developed in a context where different actors work together in managing a complex system, the expectations on conceptual and political impacts could reasonably be high.

From a modelling perspective, monitoring landscape and land use/cover changes is essential to identify the driving forces which are needed to produce plausible LUCC modelling (Houet, Verburg, & Loveland, 2010). Comparing observed and simulated LUCC would allow us to identify which driving forces should have been included to improve the model's predictive power, considered as a mean to increase scenarios plausibility. Thus, we deem that an ex-post evaluation is particularly suited to, on one side, verify scenario impacts on public decision making, and, on the other side, to provide useful knowledge for future LUCC modelling.

The objective of this paper is to verify if the contribution of scenarios reflects expectations derived from the literature in terms of impacts and to understand which factors influenced the occurrence of impacts (i.e., the steps followed to co-construct scenarios, the selection of basis hypotheses behind scenarios narratives, the methods used to communicate the results of scenarios results, the institutional and political context in which scenarios were developed.).

Moreover, we aim at giving insights of LUCC driving forces which need to be considered in LUCC modelling to produce plausible scenarios at a watershed level. Being aware that neither backcasting nor forecasting scenarios have a predictive aim, at no point do we want to evaluate the effectiveness of a scenario based on its accuracy. Nevertheless, identifying the main LUCC drivers that were either missing or over-influential can further improve scenarios plausibility.

To meet these goals, we interviewed local actors to understand (1) the impacts of the scenarios; (2) the elements that increased or decreased impacts; and (3) which factors contributed to variations between scenarios and reality. In parallel, we compared the observed LUCC trajectory to those proposed by scenarios and used this analysis to support the interviews. Finally, we synthesized the results from the qualitative and quantitative analysis into practical advice to consider in each step of the creation of participatory scenarios.

2. Materials

2.1. Study site: landscape and institutional description

The study site is the Lestolet secondary watershed (1320 ha), located in the Blavet watershed in the Cotes d'Armor department (Brittany) (Fig. 1), a region historically devoted to agriculture. The case study was selected because scenarios were developed far enough in the past to allow for a long-term ex-post evaluation at the time horizon of scenarios. Regardless of changes in ownership and of responsibility for local land management, we were still able to contact the main actors who had participated in the scenario-building process and other potential end-users.

The Lestolet watershed is defined by its distinctive location on top of a granite massif and the presence of a dense hedgerow network and riparian wetlands. Compared to the northern part of the Blavet watershed, the Lestolet is a highly productive sector in which most

[1] *Schéma d'aménagement et de gestion de l'eau in French*

of the area is dedicated to livestock and dairy production. As a result of the intense agricultural activity, the area has faced water-quality problems since the late 1970s (like everywhere else in Brittany), due mainly to high nitrate concentrations. In 2004 when the scenarios were built, water quality was a major concern on the Lestolet, but its indicators were improving considerably (Agence de l'eau Loire-Bretagne, 2007; Syndacat Mixte du SAGE Blavet, 2011) and other environmental issues and geographic areas started to draw land planners' attention instead.

French water is managed at the watershed level as defined by the Water Act of 3 Jan 1992 (Allain, 2002), which established the creation of the Local Water Commission[2] (CLE) and the SAGE. The CLE is the political body, composed of elected, land-user and public-service representatives, that develops and validates the SAGE and monitors implementation of its directives (Allain, 2002). This water management organization relies on a participatory planning approach, where different local actors are meant to work together to manage all the issues related to water (irrigation, sanitation, drinking water, aquatic environments and flooding) jointly (Allain, 2001; Rinaudo, Marchet, Billault, & Groundwater, 2020).

To define the SAGE, a perspective study is mandatory, and it allows to choose which strategy to adopt in the watershed (Allain, 2002). Once approved, several local programs can translate the directives into practical operations and ultimately meet the goals that have been set (SAGE Blavet, 2013). The jurisdiction of operational organizations reorganized greatly beginning in 2018, when the MAPTAM law (of 27 Jan 2014) came into force, and municipalities (or groups of them) took over watershed management and flood prevention (Barone and Dedieu, 2015), leaving the planification phase unchanged. Thus, water management of the Lestolet changed from the Syndicat mixte Kerné-Uhel (Houet, 2006), to the urban area of Loudeac, with little continuity.

Given the organization of water management, we identified the technicians responsible for managing the water quality of the Blavet watershed (i.e. working for operational organizations), people sitting in representative bodies responsible for land management and water quality (i.e. SAGE Blavet and the CLE) and landowners in the Lestolet and surrounding areas as important stakeholders.

2.2. Spatially explicit scenarios (2006 -2020)

In 2003, the SAGE Blavet asked for a prospective analysis at two scales: (1) local, including secondary watersheds such as the Lestolet), for which simulation of annual LUCC highlighted landscape dynamics and possible water quality evolutions (Houet, 2006 and Houet et al., 2008), and (2) the entire Blavet watershed. The local scenarios were used to integrate local characteristics into the larger scale and improve estimates of potential costs of landscape management actions (e.g. riparian wetlands, hedgerow restoration).

In this context, Houet (2006) developed backcasting and forecasting participatory LUCC scenarios for the Lestolet and for other two secondary watersheds. Local scenarios were subsequently used to feed more global scenarios at the Blavet watershed scale (details in appendix A). For the scope of this article, we will focus on the scenarios developed for the Lestolet. Indeed, backcasting scenarios were developed just for the Lestolet, and contacts with local actors had been particularly developed in that study site.

Two of the backcasting scenarios assumed that water-quality targets were met either by spending large amounts of money or by the disappearance of farms. A third backcasting scenario predicted a strong decrease in water quality (increased nitrate concentration) and a loss of biodiversity due to the transition to agro-energy cropping systems.

The forecasting scenarios considered farmers' coping strategies in response to the 2006 reform of the EU Common Agricultural Policy (CAP). Three potential changes to the CAP and farmers' response to each were defined:

- no drastic changes: farmers do not change their practices, thus maintaining an overall increase in maize at the expense of grassland ("business-as-usual (BAU) strategy")
- favoring grasslands: farmers increase grassland area at the expense of silage maize area ("Greening strategy")
- favoring crops: farmers increase the percentage of wheat area slightly (by 5 percentage points compared to the 2004 reference year) at the expense of grassland ("Cropping strategy").

In addition, three assumptions were made: the same behavior for all farmers, an increase in farm size, and the stability of production systems.

The same group of local stakeholders participated in the co-construction of both backcasting and forecasting scenarios. The final outcomes of both types of scenarios were presented to local actors in a single meeting. Following the analysis framework developed by Lumbroso (2019), the local and watershed-level scenarios were presented to the SAGE with an environmental management objective and whose ultimate aim was to inform a collective decision (i.e. definition of water-management strategies). Conversely, forecasting and backcasting scenarios at the local scale were presented to local actors to return the results to the people who participated in the scenario-building process and to enhance their understanding of the relations among farm practices, landscape elements and water quality.

3. Methods

To meet the objectives of this study, we couple qualitative and quantitative methods. Qualitative analysis firstly allowed us to understand the impacts of scenarios and what enabled or inhibited those impacts. As plausibility is considered one of the main

[2] *Commission locale de l'eau* in French

validation criteria for scenarios, we also aim to understand which driving forces shaped the landscape changes, and to what extent they had been considered in the scenario making. To do so, a quantitative analysis comparing scenarios and observed LUCC is proposed. Results of the quantitative analysis were used as support for interviews to get insights on the main driving forces and on which factors caused discrepancies between simulated LUCC and real world observations. Results from the qualitative and quantitative analysis are combined to develop practical guidelines to enhance plausibility and impacts of scenarios on decision making, qualitative analysis mainly fed guidelines to design realistic and attainable scenarios.

3.1. Qualitative analysis of scenarios impacts and LUCC drivers

Interviews with local actors were crucial for understanding to what extent the spatially explicit scenarios had been used by local actors and to re-construct which elements originated differences between simulated and observed LUCC from 2007 to 2020. Interviewees were selected according to their current profession or to the one they had when scenarios were built. We interviewed eight local actors (LA) among farmers, members of the CLE, SAGE Blavet, Agricultural Council and other local organizations. Participation in the workshops that had been held to develop scenarios in 2005 was not a selection criterion. This choice allowed us to understand if local actors involved in land management who did not attend the workshops were aware of the study. Although the small study area and depth of the interview protocol prevented us from interviewing more actors, we were still able to collect a large amount of consistent data by selecting participants with a deep knowledge of the territory and central roles in local management. Moreover, this type of evaluation exercise commonly has a small number of interviewees (e.g. Mckenzie et al., 2014).

To collect data, we used a semi-structured interview composed of open questions and a “card game” in which LAs had to sort a list of possible impacts based on whether or not they thought that the scenarios had produced these impacts (Harrell and Bradley, 2009). Questions were followed by prompts, according to recommendations presented in Kallio, Pietilä, Johnson, and Kangasniemi (2016) and Turner (2010). Using this structure, interviewees felt free to express their thoughts and to raise what they perceived as the most important themes, while producing comparable data. The protocol (see appendix B) was divided in two main parts: (1) collecting information about the main drivers of LUCC in relation to the results of the quantitative analysis and (2) attempting to understand impacts of scenarios. We analysed the data collected using a thematic analysis (Braun and Clarke, 2006) (see Maguire and Delahunt (2017) for an application and Ronan and Gallagher (2016) for a practical guide). To report results, we adapted the form used by Mckenzie et al. (2014). Due to the COVID-19 health crisis (2020 - 2021), most interviews were performed via videoconference.

3.2. Quantitative analysis: a comparison between the observed LUCC and the simulated ones in scenarios

We compared Land Parcel Identification System (LPIS) data, georeferenced data issued from farmers’ common agricultural policy (CAP) declaration and published yearly, to the LUCC composition and configuration of the proposed forecasting scenarios (Li and Reynolds, 1995).

We first calculated Kappa indices (Kappa, Khist, Kloc, Fuzzy Kappa) from land-cover maps rasterized into 1×1 m cells using the Map Comparison Kit software (Visser and De Nijs, 2006) to compare LUCC at the scenarios’ time horizon (2020). The Kappa indexes are widely used metrics to perform comparison of categorical maps (Cohen, 1960; Pontius, Cornell, & Hall, 2001). Kappa index measures classification accuracy in a single metric, while Kappa location (Kloc) and the Kappa quantity (Khist) consider errors induced by location and quantity separately (Hagen, 2002; Pontius, 2000). In addition, the fuzzy Kappa considers near misses by comparing neighbouring cells around each pixel (Hagen-zanker, 2008; Hagen, 2003).

To limit effects of crop rotations (variations in quantity and location), for each scenario, we calculated mean values and variance of K indexes of all combinations of observed and scenario values for 2017, 2018 and 2019. Pixels whose value did not change in the simulation (e.g. forests, fields whose owner was not identified) were removed from the analysis and an exponential decay function with a radius of 100 pixels was used to calculate the fuzzy Kappa.

To provide insights into drivers of change and to understand what may have caused potential differences between observed and predicted land-cover configuration, we analysed the observed land covers’ trajectories and interviewed local actors. We considered two geographic scales for the LPIS data: (1) the watershed level, which considered only the fields inside the watershed boundaries, and (2) the farm level, which considered all fields that belonged to farms that had at least one field inside the watershed boundaries. Working with data at the farm level allowed us to verify each farmer’s strategy and the assumption of increasing farm size used to build the scenarios. The advantage of using LPIS is that it provides farm’s boundaries allowing an analysis at the farm level. However, LPIS data from 2007-2014 and from 2015-2019 were published with different spatial resolutions. To address this problem, we used the method of Barbottin, Bouty, and Martin (2018).

We visually compared the predicted trajectories of crop percentages to the observed percentages using stack graphs. Once again, to limit effects of crop rotations, we calculated a three-year moving average for observed land cover when considering only the fields inside the watershed (1064 ha in 2007 and 1061 ha in 2019). In the Lestolet, crop rotations follow mainly a five year pattern, and a three year pattern (Martin, Rabenandrasana, Poméon, & Serard, 2021). Since performing a five-year moving average on a thirteen-year time series would leave us with a too short series to be studied, we opted for a three-year moving average.

To identify the farms’ actual production systems, we used the knowledge of a local farmer and a technician. Knowing which farm did or did not change their production system from 2006-2020 allowed us to compare the two groups’ LUCC trajectories. We considered the BAU, Greening and Cropping trajectories mentioned previously. The intensity of each trajectory was classified (with arbitrarily chosen thresholds) as: “in line”, if the increase of the concerned land cover is lower than 7.5% over the period; “strong”, if it increased 7.5-12.5% and “extreme” if it increased more than 12.5%.

4. Results

As stated during the interviews (LA1), the local and watershed-level studies were perceived as a single study by the actors involved in the SAGE. The same applies to the type of scenarios: during the interviews, LAs did not clearly distinguish forecasting and backcasting scenarios, but they rather refer to elements coming from both of them without differentiation. The vision of backcasting and forecasting scenarios as a unique tool impedes understanding which impacts arise from one or the other.

Three main themes emerged from interviews: (1) significant impacts of scenarios, (2) scenarios' related features that influenced their usefulness and (3) external factors that influenced their usefulness. Appendix C provides results of transcript analysis and quotations for each of the themes. Scenario impacts were divided according to the scenario usage (Instrumental, conceptual and political). We then associated with these impacts the scenario and process attributes and the external conditions that influenced each of them.

4.1. Significant impacts of scenarios

4.1.1. Instrumental use

According to LAs who were involved in the definition of SAGE 2007 (n = 3), the scenarios at the watershed level were one of the supporting materials used to choose the environmental management strategy and write technical documents for land planning (the SAGE Blavet 2007), which agrees with the original aim. In combination with other studies, the scenarios helped define priority intervention zones, which are areas where LUCC could decrease water quality below targets.

4.1.2. Conceptual use

All the interviewees who were familiar with the study (n = 6) recognized some conceptual impact of scenarios.

The most cited contribution of scenarios (n = 5) has been to foster a systems analysis approach and to promote a multidisciplinary perspective. In this perspective, scenarios pushed local actors to consider new variables in their everyday work.

> *[We became more aware] of the time that we could devote to landscape management for instance, [...] and all that is wetland restoration. (LA 3)*

> *Personally [looking at the scenarios] it was an electroshock for me. [.] For me, personally, it made me say to myself: you focus too much on agriculture; you need to open your mind to other things. (LA 4)*

Interviewees recognized scenarios as a support tool which enable to get used to new working methods (n = 4, 3 of them part of the Chamber of Agriculture);

> *I don't know to what extent your work has contributed, but I would say that [in our everyday job] the work with cartography was integrated at about the same time [of the scenarios]. [.] Before we were very much focused on agriculture. We used to take the maize, the wheat and to go on like that. From then on, we were much more with a system approach using cartography. […] For me, even if then we focused on another watershed, [.] in terms of methods, in terms of approaches, it [scenarios] could very well have been used to work on neighbouring areas. (LA 6)*

Third, scenarios were recognized to be useful in anticipating new challenges and visualizing middle/long term trajectories of land use development (n = 3).

> *[Scenarios] allowed us to get the support to work in a direction, to go further in the reflection. [It allowed] to say: "this is how it can be tomorrow". It was useful to alert. (LA 4)*

Finally, there was no agreement on the effectiveness of scenarios in creating a shared vision of the future. Nevertheless, the interviewees involved in the SAGE agreed on saying that scenarios contributed to construct a shared vision between people involved in the planning (i.e., members of the CLE), but not with the actors managing the operational phase (i.e., member of the Chamber of Agriculture). To support this statement, interviewees working for operational structures stated that scenarios failed in creating a shared vision of the future. Nevertheless, interviewees who attended the participatory meetings and scenario presentations agreed that the study allowed them to create a space in which LAs could debate even while having conflicting and diverging objectives (farmers *vs.* water managers).

4.1.3. Political use

Local forecasting and backcasting scenarios were presented to individual farmers by a member of the Agricultural Council to analyse factors that could play a major role in social and environmental dynamics of the area. The backcasting scenarios considered the arrival of non-farmer land users (e.g. fishers and hunters) who exploit natural resources for recreational and economic activities. Farmers reacted strongly to these scenarios and recently compared them to the arrival of new land users who exploit woodlands. In this case, scenarios were not only useful in recognizing new challenges (the possibility to exploit marginal land and the arrival of external people making profit on them), but this awareness allowed farmers to reflect on how they can exploit marginal lands. Finally, they proposed creating an Economic and environmental interest group[3] (GIEE) to manage and take advantage of marginal lands. Local

[3] A collective of farmers that develops local projects to reach social, economic and environmental goals. Groupements d'intérêt Économique et Environnemental in French.

farmers thus recognized the local scenarios as an awareness-raising tool, which increased consciousness about their role in landscape and environmental management and legitimized their actions in non-agricultural domains.

> *We talked about it again [with reference to the scenarios] at the creation of the GIEE, where we said: you see, at the time we were already talking about hunting companies coming [.] and today it's the start-ups that are valorising our wood. They manage to live with it and we don't do anything with this land. Maybe we need to take a new look at these surfaces. (LA 4)*

4.2. Features influencing the use of scenarios

LAs identified scenarios and process-related features that enhanced or prevented scenario impacts on decision making (Table 1).

As widely discussed in the literature (Commod, 2005), the participatory method used to build the scenarios is acknowledged as being useful for multiple aspects, as well as presenting results to LAs using different supports (i.e., maps, narratives, LUCC indicators measuring LUCC's impact on environmental variables). Analysing management implications of the study with final users has also been identified as a useful and well-established practice to improve instrumental use.

Presenting narratives that address all aspects of territorial development allows a dialogue to be established between people who represent different issues. Indeed, technicians explained they refer to economic, social and environmental data to draft land management documents.

Moreover, the fact that scenarios presented multiple alternatives and not few caricatural scenarios which only differ for the level of ambition is recognized as crucial for establishing dialogue.

> *In other studies, three scenarios were proposed: a not very ambitious one that doesn't cost much; [.] a second, moderately ambitious scenario that costs more, but that was still affordable; a third one, very ambitious that costs a lot and it was known that the communities would not have the budget to implement it. And so, there are three caricatured scenarios [.] and we basically chose the middle one. (LA 1)*

Although technicians used scenario predictions in an instrumental way, the functioning of institutions, the discontinuity of political representation and landowners' priorities represented the main barriers to the impact of scenarios on local land management.

A member of SAGE highlighted how the land-management documents written with the contribution of the scenarios have never been translated into practical actions because of a change in political representatives and political will.

> *In 2014, we had municipal elections with a complete renewal of the CLE. [.] thus we had a CLE with elected representatives who did not necessarily want the provisions of the SAGE to be implemented. The environmental field [.] is extremely dependent on the public policies that are set up and on the will of local representatives. (LA1)*

Regarding the functioning of institutions, a technician stressed the need to wisely choose the moment to present scenarios. poor communication between different water management structures paired with poor timing in the presentation of scenarios, hindered other instrumental uses of scenarios besides the definition of the SAGE.

4.3. Comparison of scenario projections with observed changes

Through a quantitative analysis, we identified the driving forces of LUCC. Although plausibility of scenarios is the result of different key factors (such as the internal structure of scenarios, the presentation of scenarios, the correspondence with users' worldviews), precision of scientific knowledge can enhance credibility of science for policy (Maxim and van der Sluijs, 2011; Schmidt-Scheele, 2020). We performed a quantitative comparison between the observed LUCC and the one proposed by scenarios to identify crucial variables to produce plausible LUCC modelling for land use management at a watershed level.

4.3.1. Comparison of projected and observed trajectories of crop percentages

In terms of landscape similarity, the Kappa index ranged from 0.097-0.135 (0.090 – 0.143 for Fuzzy K) which indicates slight strength of agreement according to Landis and Koch, 1977. In terms of quantitative similarity, the BAU and cropping scenarios differed slightly less from the observed (LPIS) data than the greening scenario did. Appendix D provides details of K indexes.

When comparing scenarios and observed trajectories, all scenarios underestimated the presence of grassland during the entire period, while cereals and oilseeds were generally overestimated (Fig. 2). For the farms that had at least one field inside the Lestolet watershed (farm level), grasslands increased continuously from 2007-2019 (by 10%). Conversely, for only the fields inside the watershed (watershed level), grassland increased drastically from 2008 to 2011 and then dropped (by 14%) from 2014-2015 and continued to decrease. This suggests that the overall increase in grassland observed when considering the farm level occurred mainly on fields outside the watershed from 2015. At the farm level, the cereals and oilseeds percentage continuously increased from 2008-2014 (by 25%) and decreased from 2014-2019 (by 8%), suggesting that certain forces favoured grasslands at the expense of cereals beginning in 2015. Maize decreased continuously from 22% of the UAA in 2007 to 17% in 2019.

Moreover, the observed trajectories appeared to be more similar to the one resulting from exploratory scenarios when considering farms that had at least one field inside the Lestolet watershed (Details on trajectories of crop percentages in Appendix E).

According to the local actors and consistent with LPIS data, crop percentages did not change greatly. The small increase in grasslands, was likely due to EU Agri-Environment and Climatic Measures[4], a regulatory mechanism that began in 2015 available in

[4] Mesures agroenvironnementales et climatiques (MAEC), in french

Table 1
Scenario impacts and factors that influence scenario use. Scenario attributes and process attributes influence the related impacts in a positive way. External conditions can have a positive (+) or negative (-) influence on scenario impact.

Mode of scenario use	Impacts of scenarios	Attributes of the scenarios that influenced impacts	Attributes of the process that influenced impacts	External conditions that influenced impacts
Instrumental	Help choose the environmental management strategy and write technical documents for land planning (SAGE Blavet 2007). Define priority zones where land use was incongruent with water-quality targets.	Results presented with metrics familiar and useful to technicians. Scenarios were perceived as realistic and attainable. The spatial scale was consistent with the planning scale.	Technicians and researchers shared with each other the raw data used to build scenarios. The scenario-building process helped technicians trust the researchers. The scenario-building process created a space for negotiation framed by technical/scientific elements. Scientists worked with politicians on political implications of the study.	Change in political representatives and political will prevented translation of technical documents into action (-). Improvement in water-quality indicators and change in priority areas (-). Change in jurisdictions among organizations: municipalities and their urban areas become responsible for managing watersheds (MAPTAM) law 2014-58 of 27 Jan 2014). Change in jurisdictions added workload and prevented organizations that did not explicitly ask for the scenarios from looking at scientific studies (-). Scenarios were presented to technicians responsible for water management during the implementation phase, while they look at perspective studies mainly in the planification phase recurring every 5 years (-)
Conceptual	Help build a systems approach. Stakeholders gained a deeper understanding of relations among farm practices, landscape elements and water quality, while technicians became used to new methods and the idea of working in multidisciplinary teams. Anticipate possible future challenges. Push farmers and technicians to consider more variables in their everyday work: farmers became more aware of the time they could spend on landscape management. Members of the Chamber of Agriculture recognized that they were too focused on agricultural issues.	Scenarios assess multiple (economic, environmental, social) aspects. Presence of novel elements that break codes of thinking. (e.g. introducing new external factors that influence LUCC, introducing new working methods such as a multidisciplinary approach).		Overall change in the land-management approach during the period when scenarios were developed. Technicians were changing how they analyzed problems from a field approach to a systems approach (-). Presence of a dynamic social environment in which farmers are generally actively engaged in managing environmental issues (+).
Political	Scenarios were an empowerment tool for farmers. Scenarios were used as support materials to discuss stakeholders' interests.	Scenario narratives reported the local actors' discussions. Stakeholder groups could recognize their role in the scenarios narratives. Presenting spatially explicit scenarios allowed the issue to be visualized and perceived more concretely. Scenarios assessed multiple (economic, environmental, social) aspects.	Scenario results were disseminated to a wide range of stakeholders, even those not directly involved in the research. Results were communicated in accordance with the positions of stakeholder groups. (e.g. avoiding to present scenarios to farmers in terms of environmental issues connected to agricultural practices to not make them feel accused).	Poor communication between planning and operational organizations is a challenge. The study was not disseminated by the requesting organization to other organizations/actors involved in landscape management. Communication to different stakeholder groups was crucial to overcome this issue (-). Generally low level of interest in scientific research. At the farm level, decisions are made mainly according to economic and workload constraints. Environmental constraints are known, but secondary (-).

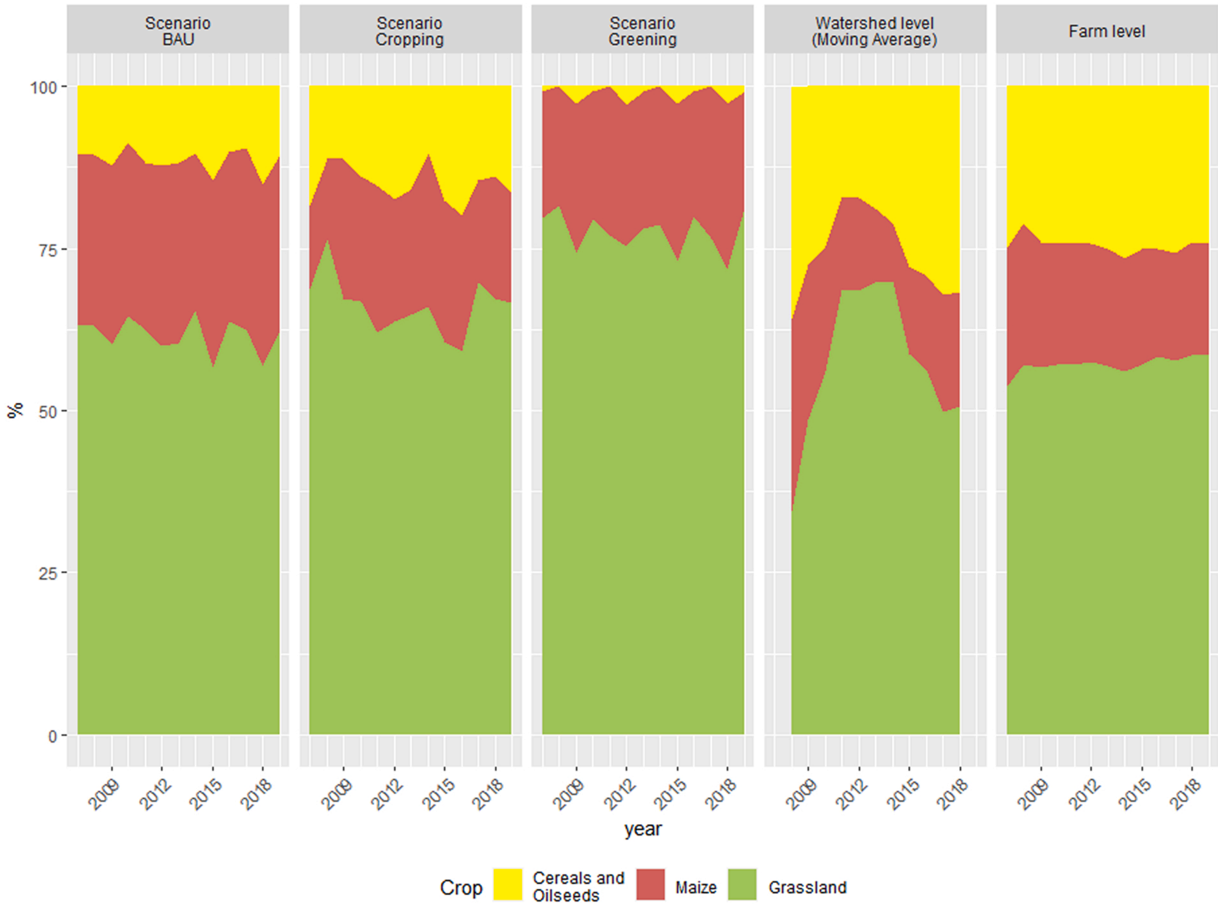

Fig. 2. Trajectories of crop percentages resulting from each scenario compared to those observed inside the Lestolet watershed ("Watershed level") and for all farms that had at least one field inside the Lestolet watershed ("Farm level"). Scenarios: "business-as-usual" (BAU) (increase in maize at the expense of grassland), Greening (increase in grassland at the expense of maize) and Cropping (increase in wheat at the expense of grassland).

Brittany, which pays farms based on their grassland percentage. Due to this mechanism, the grassland percentage of farms with at least one field in the watershed increased slightly, unlike the regional trend (Chambre d'agriculture de Bretagne, 2019). The local format of regulatory framework and the farmers' adaptation strategies to economic incentives is therefore a crucial variable to consider in LUCC scenarios. Although scenarios did not consider a change to the regulatory system in 2015, it did consider adaptation strategies to the CAP reform as discussed in Section 2.2.

4.3.2. Comparison of projected and observed farm size and production system

The mean size of farms increased from 75.0 ha in 2007 to 98.5 ha in 2019 (in agreement with the scenarios' assumptions) and the number of farms decreased (from 37 to 35, i.e. 5%), but by less than the percentage predicted by the scenarios (55% from 1998-2020) or by the mean percentage for Brittany (14% from 2010-2018) (Chambre d'agriculture de Bretagne, 2019). As highlighted in the interviews (LA4), the Lestolet watershed remains an attractive area for its soil characteristics and social context.

The mean ratio of the area inside and outside the watershed per farm decreased from 43.9 to 36.7, while the mean distance between fields of the same farm increased from 1.8 to 2.0 km. The increased farm size combined with farm fragmentation likely caused grasslands to concentrate around the farms to reduce herd movement. This phenomenon might explain the differing trajectories of grassland inside and outside the watershed. Moreover, the increased farm size may have increased workload, changing the organization of work and distribution of crops, as explained by interviewees. Thus, the assumption of an increase in farm size was partly verified and the structure of farms influenced LUCC.

With LA, we reconstructed the farms' current production systems on the study site. the production systems did not change drastically, and milk production remains the dominant production system (Fig. 3). Nonetheless, according to the farmer and technician, livestock farmers took their production systems in three main directions in the past 5-6 years – intensification, a mixed system (with some grazing) and organic – which diversified the dairy production systems. Moreover, the diversity of production systems increased at the expense of cattle-only farms.

Although land cover did not change drastically at the watershed level, it did at the farm level. Changing the production system

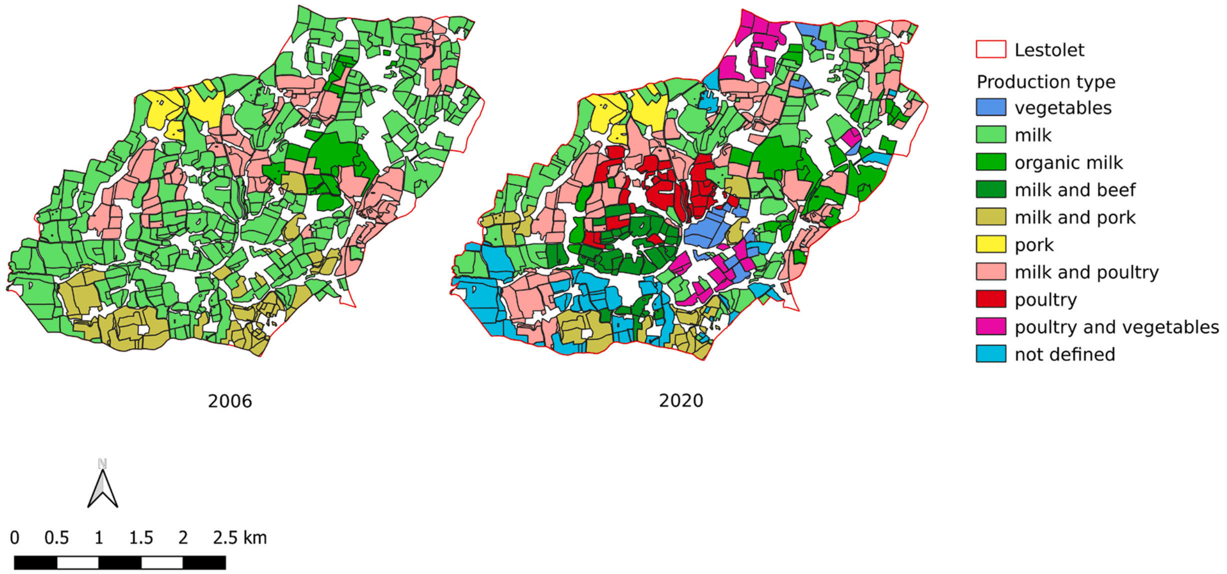

Fig. 3. Observed distribution of farm production systems in 2006 and 2020 in the Lestolet watershed.

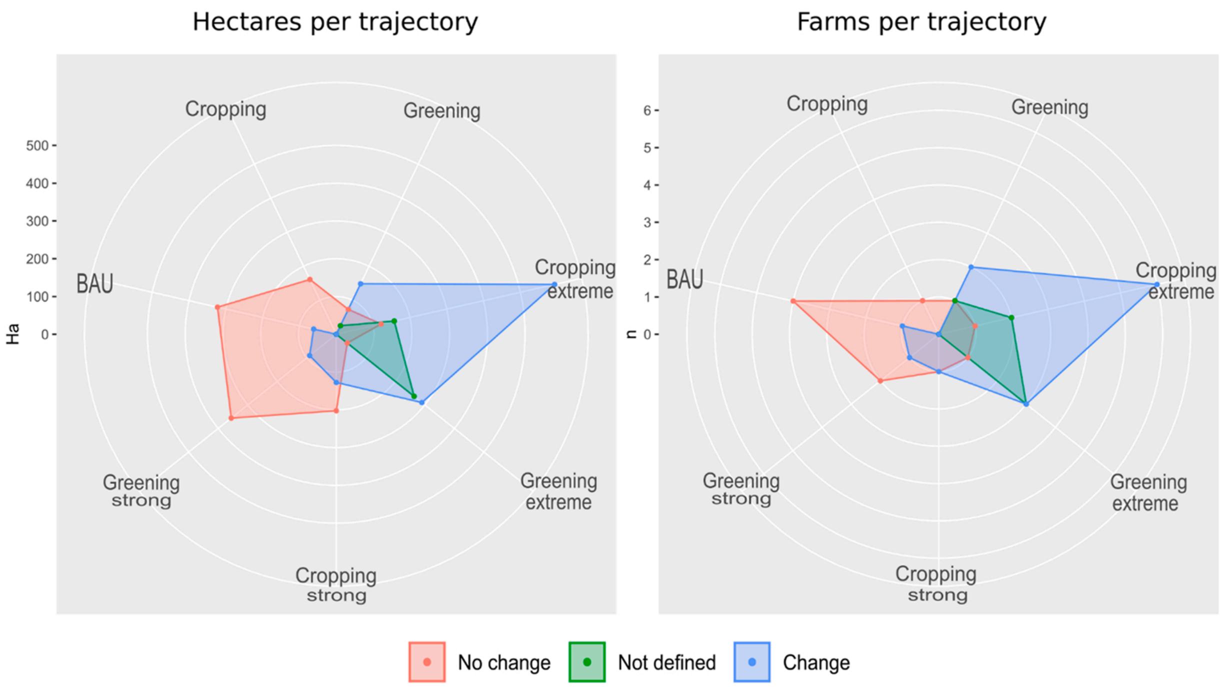

Fig. 4. Observed distribution of farm production systems in 2006 and 2020 in the Lestolet watershed.

could influence the strategy adopted: the farmers who maintained the same production system tended to have less drastic LUCC than those who did change and to follow mainly a greening trajectory (Fig. 4). Conversely, the farmers who did change their production system reported more drastic LUCC, mainly in the cropping direction (see Appendix F for more details). Thus, the fact that land cover did not change drastically at the watershed level seemed to result from two contrasting trends: (1) greening, followed mainly by farmers who did not change their production system, and (2) cropping, followed mainly by farmers who did change their production system. As observed in previous studies (Ronfort, 2010), the basic assumptions of the stability of production systems and homogeneous behaviour of farmers were shown to be incorrect by this study. Change in the production system and heterogeneous behaviour of farmers should then be considered to produce plausible LUCC scenarios.

Table 2
Elements to consider during the stages of the scenario-building process to enhance scenario impacts.

Stage of scenario-building process	Objective	Action	Mode of scenario use
Planning	Design realistic and attainable scenarios	Define an appropriate spatial scale that matches expected results • Consider the land-planning scale • Consider the spatial scale at which variables impact landscape dynamics	Instrumental
		Allow different agents' behaviours	CognitiveInstrumental
	Maximize result dissemination	Define a communication strategy • Select the interested stakeholders and the most appropriate moment for them to receive scenarios • Identify key actors who can disseminate scenario results further	InstrumentalCognitive
Scenario co-construction	Create trust between researchers and final users	Use raw data explicitly to build scenarios	Instrumental
		Define indicators and metrics to present scenario impacts	InstrumentalConceptual
	Allow a change in the way of thinking	Allow multiple aspects (social, economic, environmental) to arise and include them in narratives	Conceptual Political
		Identify elements of originality to include in narratives	ConceptualPolitical
Result dissemination	Maximize communication impact	Stress the elements that break codes of thinking	Conceptual
		Use different communication materials, such as maps and narratives	Conceptual
		Tailor communication to stakeholder groups	Conceptual
		• For farmers, avoid talking directly about environmental issues • For technicians, stress the impacts on indicators	Instrumental
		Disseminate to the largest number of stakeholders possible	Conceptual Political
		Analyse management implications of the study along with the final users	Instrumental

4.4. Improving scenarios impacts: recommendations

Merging results from the qualitative and quantitative analysis, we developed practical guidelines for researchers to enhance impacts of scenarios on decision making (Table 2). The table suggests actions to take during the different stages of the scenario-building process, to attain specific objectives and improve Instrumental, cognitive, or political use of scenarios. While it is not an exhaustive list, these guidelines summarize the lessons learned from our study. Moreover, even though the results are based on a specific case study, we believe that they can be used for studies that aim to influence decision making using spatially explicit scenarios.

5. Discussion

5.1. Contributions and limitations of scenarios: What is needed to improve their usefulness?

In this paper we adopted a mix of qualitative and quantitative methods to evaluate the contributions of local LUCC spatially explicit scenarios for water management. Although expectations driven from literature on scenario impacts had been partly met, some context related factors and some scenarios characteristics hindered the visibility of the research in the local community and its impact on local water management.

Knowing the political and institutional context is crucial in developing a strategy to effectively diffuse study results in a timely manner. In our study context, poor communication among land-management organizations had been widely recognized. Nevertheless, the results of scenarios had been disseminated to local farmers by a member of the Agricultural Council. Targeting the different institutions for communicating the results of scenarios and identifying the people who can disseminate the study results further to their networks is vital in overcoming a potential lack of information flow due to how administrative and operational organizations operate.

The essential character of 'novelty' in scenarios is also worth discussion. Interviewees indicated the presence of elements that diverge from typical thinking as essential to increase the cognitive use of scenarios. Moreover, they referred to "caricatural scenarios" as scenarios that missed novelty, but they are rather extensions of current trends with different levels of ambitions for environmental targets. On the other end, scenarios must be plausible to evaluate alternative management options that lie within the reach of stakeholders to increase instrumental use. The elements of rupture included in the narratives should thus be anchored in reality (Xiang and Clarke, 2003). In the scenarios evaluated, envisioning fishers and hunters coming to the Lestolet watershed was considered an element of rupture; the fact that they were already coming to nearby areas added credibility.

While scenarios contributed to create a collective vision of the future within homogeneous groups of actors (i.e., within technicians working on water management), they failed to create a shared vision across groups. The different perspectives on the territory and the past experiences can anchor people to a predetermined vision of the future. Using scenarios built on present situations and past trends could hence prevent the arousal of a common vision (Van der Voorn et al., 2012). Even though creating a shared vision of the future was not the original aim of scenarios, enhancing the heterogeneity of stakeholders contributing to scenario making (Voinov and Bousquet, 2010) and giving more space to backcasting (Van der Voorn et al., 2012) scenarios might have been possible ways to encourage the emergence of a common vision.

Finally, we want to stress the need to clearly define the scope of the study at the beginning of the scenario making process. Even though this can be perceived as an obvious approach, many studies highlight the benefits of this (see Edwards and Kok (2021) as an example) and we believe that scenarios originally developed for an instrumental scope can overlook the whole spectrum of benefits they can provide. The scenarios we evaluated had been originally commissioned to support the definition of the SAGE, so that the only impact that was clearly expected was an instrumental one. Being aware of the different impacts that may arise from scenarios can help to set up a scenario-building process that also maximizes cognitive and, eventually, political impacts without harming the instrumental one.

5.2. Predictive ability and scenarios impact

Although some main drivers were considered when building the scenarios (i.e. reform of economic incentives, the farmers' associated coping strategies, increase in mean farm size), some assumptions were found to be too restrictive (i.e. no change in production systems and homogeneous farmer behaviour). In agreement with the results of Houet and Verburg (In press), integrating the farm level into landscape scenarios appeared to be crucial to produce plausible LUCC simulations. When building scenarios, choosing a spatial scale that matches the scale at which the drivers of LUCC produce their effects seems crucial to produce plausible estimates of LUCC. Nonetheless, limited data availability (e.g. LPIS data protection, high costs) and the fact that land tenure data do not exist over the long term (i.e. at least 20 years) remains a strong limit to understanding the influence of land tenure on landscape changes.

Moreover, individual choices at the farm scale influence the landscape and LUCC strongly, suggesting the need to consider diversifying actors' strategies, which are influenced by the social and demographic systems. This result is in line with the importance of incorporating farmers' decision-making in land-use change models emphasized by Agarwal, Green, Grove, Evans, and Schweik (2002), Martel et al. (2019) and Truong et al. (2015).

Defining the appropriate scale was an issue raised during the interviews. As reported in the literature (Biggs et al., 2007), our results confirm the importance of selecting the spatial scale according to the goals. In our study, scenarios at the primary watershed-level were used in an instrumental mode, while finer scale (secondary watershed-level) scenarios provided a more cognitive impact by making interactions among variables explicit and contributing to building a more systematic approach.

This study indicates that even though the scenarios failed to predict the range of developments observed in the recent past, they succeeded in triggering some instrumental, conceptual and political impacts on local actors and local land-management. This strengthens the generally agreed idea that scenarios are not meant to predict territorial changes, but instead to suggest different possible trajectories to support policy makers and stakeholders in their management decisions and in the change in their knowledge and ways of thinking. Nevertheless, the spatial rendering of narratives reinforced the perceived plausibility of scenarios reinforcing the interest of combining narratives and LUCC models. In this context, improving the predictive power of LUCC models appears to be crucial even for scenarios that do not have a predictive aim.

5.3. Theoretical and practical limitations

Our results provide evidence of impacts of scenarios in the context of local water management. However, some limitations are worth noting. The number of interviewees was limited due to the few stakeholders involved in the process and the difficulty in reaching people involved in a process that occurred more than 10 years in the past. Although we were able to collect a large amount of consistent data, scarcity in interviewees hindered us from understanding how the interviewees' personal point of views fit into the opinion of a wider stakeholder group. The context-dependency of the study represents a second limitation. The specific contributions of scenarios and related influencing factors are dependent on different scenarios application and/or institutional, environmental, and social context. For example, in a context of fluid communication among land-management organizations, issues such as distortion of information or manipulation of results that we did not find in our case study may arise. In addition, farmers with a long-term vision of the territory created the GIEE as they perceived external people exploiting the land as a challenge. Local actors might not have reacted if farmers' decrease and new residents' arrival in the area were more consistent than observed. Nevertheless, the participatory method used in the scenario-building process ensures that the context and values belonging to the stakeholders are considered to produce case-specific instrumental, cognitive, and political use.

Moreover, conceptual impacts, such as the promotion of a multidisciplinary approach, are heavily dependent on a larger cultural change. While interviewees referred to scenarios, quantifying the contribution of the individual study in a changing environment is impossible.

Repeating the analysis for other case studies would be useful to generate a more comprehensive picture of the elements to consider during scenario building to enhance scenario impacts. The data used for the quantitative analysis are freely available for several European countries and the interview protocol is easily reproducible, making our procedure applicable to other case studies.

6. Conclusion

We found that scenarios supported water managers in the definition of land management policies and produced several conceptual and political impacts but failed to create a common vision of the future for the local actors. Nonetheless, our analysis showed that there is room to improve scenarios as decision-making tools, both in the modelling and in the participatory process. To address this issue, we provided practical guidelines to consider in the stages of the scenario-building process. For example, we suggest defining the expected impacts of scenarios beforehand, without limiting them to the institutional ones, selecting the spatial scale that best fits the expected results (land-planning scale or the scale at which variables impact landscape dynamics), adapting the communication strategy to the political and institutional context, and stressing the element of novelty in scenarios narratives. Even though the guidelines we propose are not exhaustive, they summarize the lessons learned from our study and are based on empirical evidence. Additional assessments with a wider variety of case studies are needed to verify the usefulness of scenarios in the long term; nonetheless, this study can be considered a step forward in understanding how to enhance scenario impacts on decision making.

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Declaration of Competing Interest

None

Appendix A. Details on spatially explicit scenarios

Scenarios were developed to support the definition of the SAGE of the Blavet watershed (2000 Km^2) in 2003 by: (1) clarifying the processes and main factors of LUCC and their interactions; (2) delineating the range of possible futures changes to help evaluate water management options.

The authors realized forecasting scenarios at a fine scale on three small sites inside the Blavet: le Lestolet (Côtes d'Armor), le Coët-Dan et le Stang Varric (Morbihan), each one of approximately 1400 ha. Backasting scenario had been developed for one site (the Lestolet). Three small watersheds were chosen in partnership with the SAGE Blavet as representative of the landscape diversity and the different water quality management issues of the entire watershed.

The fine scale scenarios feed into more global scenarios (at the Blavet scale) concerning water management issues. The scenario at the Blavet scale has been developed by the consulting firm ASca.

The process of scenario development includes four steps both for backcasting and forecasting scenarios: the construction of the base, the construction of the scenarios, the spatial dimension of the scenarios and their evaluation.

The construction of the "base" consists in understanding the functioning of the agricultural system and it is based on two successive phases: (1) the reconstruction of the LUCC trajectories using remote sensing data and the identification of the processes that determine land cover evolution throughout participatory meetings with a group of local stakeholders and experts; (2) the identification and prioritization of the explanatory factors for the current and future changes highlighted using a systemic analysis and a geostatistical study.

The evolution of the agricultural landscape is explained by the following factors:

- The dynamics of land structures (farm takeovers, enlargement of land parcels);
- The change in land use (change in the average crop rotation associated to a type of production, crop successions);
- The change in use of valley bottom wetlands (change in land use following abandonment, reduction by drainage or extension);
- The change in the extension of the bocage (creation and/or leveling of hedges).

Moreover, the evolution of the agricultural context (market variations, reform of agricultural and environmental policies, etc.) forces the farmer to adapt his activities, and contributes to change the composition and organization of the landscape in a context strongly affected by the decrease in the number of farmers.

This first step allowed us to identify the main variable to consider in the scenario construction and to define scenario's focus: assess the potential impact of the 2006 Common Agricultural Policy and farm expansion on the medium-term evolution of land use patterns. The adaptation strategies of farms in the Blavet to the 2006 CAP and their impacts on land use types, bocage and wetlands were defined during a participatory meeting in 2005.

Both backcasting and forecasting scenarios consist of narratives and cartographies. The construction of narratives and the spatial dimension, depends on the type of scenario.

Forecasting scenario

The time horizon of the forecasting scenario is 2020

The forecasting scenarios were produced by crossing two variables: the adaptation to the CAP 2006 reform and the expansion of farms.

Regarding the reform of the CAP, three hypotheses were formulated: The CAP continues without major changes, the CAP becomes more favorable to grass, the CAP becomes more favorable to crops.

Regarding the enlargement of farms, scenarios were developed both by considering or not the enlargement of farms. In this paper we limit our quantitative analysis to the scenarios who consider the enlargement.

Three potential farmers' coping strategies in response to the 2006 reform were defined:

- In the first case (no drastic changes of the CAP): farmers do not change their practices maintaining an overall increase in maize at the expense of grassland ("business-as-usual (BAU) strategy")
- In the second case (CAP favoring grasslands): farmers increase grassland area at the expense of silage maize area, all cereals and oilseeds are converted to grass ("Greening strategy").
- In the third case (CAP favoring crops): farmers increase the percentage of cereals (by 5% compared to the 2004 reference year) at the expense of grassland ("Cropping strategy")

The choice of a particular strategy depends on the structure of the farm and the farmer. Thus, the influence of the 2006 CAP on land use patterns can vary from one farmer to another. Further assumptions are that farmers do not change production systems and all farmers assume the same coping strategies.

Regarding farms' takeover and enlargement, farms can be either taken over entirely by a young farmer or by a neighboring farm chosen randomly or according to other criteria (economic size, buildings already brought up to standard, age of the buyer.). Due to data scarcity, only the Lestolet watershed scenarios consider farm enlargement. For the Lestolet case study, it was estimated that 17 of the 31 farms existing in 1998 would cease operations by 2020. Of these 17 closures, 6 farms are taken over by a young farmer and the other 11 by neighboring farms.

The evolution of the percentage of crops and grassland, their spatial distribution, and the extension of the bocage and wetlands has been calculated for each scenario using the L1 platform: a dynamic and spatially explicit modeling platform that produces an annual mapping of the types of occupation and land use.

Backasting scenario

The time horizon of the backasting scenario is 2027.

Three contrasting hypotheses were made for the evolution of each of the landscape components (PAC evolution and land use, bocage, wetlands) during the participatory meeting in 2005 previously mentioned. By crossing the hypothesis on different components, and by checking for internal consistency, three backcasting scenarios were developed for the Lestolet watershed:

- The first scenario assumed that water-quality targets were met by spending large amounts of money and by a consistent engagement of local actors in maintaining landscape elements (bocage, hedgerows) and to keep wetlands open;
- The second assumed that water-quality targets were met by the disappearance of farms due to difficult economic conditions;
- The third predicted a strong decrease in water quality (increased nitrate concentration) and a loss of biodiversity due to the transition to agro-energy cropping systems. Wetlands are dedicated to hunting.

The spatial dimension of the scenarios has been built with a GIS.

A final participatory meeting with local stakeholders was organized in 2006 to present the scenarios and to evaluate the results.

Once the scenario-making process was finished, scenarios were used by the consultancy firm ASCA to quantify the socio-economic impacts of scenarios. The consultancy firm worked together with the SAGE and the CLE and results were presented to the members of the two organizations.

Appendix B. Interview protocol

See Table B1

Table B1
Interview protocol.

Section	Subsection	To	Script
Introduction (10 min)	Presentation	All	Personal presentation; Project presentation
	Interview process	All	Aim of the interview; Profile of the interviewees; Structure of the interview; Recording.
	Data utilization	All	Expected use and stack of data; Sign the terms of confidentiality
	Further questions	All	Do you have any questions before we get started with the interview?
Landscape change (30 min)	Landscape change	All	**The study we are evaluating presented few possible trajectory of change of the Lestolet between 2006 and 2020. Can you describe which were the major changes in the territory during this period?** • So we said that……….. Which were the drivers of such changes? • The scenarios considered changes in terms of type of crops, in terms of exploitation number and dimensions and exploitation type (pork, lait…). How do you think the Lestolet changed regarding these variables? • The scenarios considered the CAP and the agricultural exploitation expansion as main drivers. How would you say these variables impacted the territory?
		All	**Showing the preliminary data analysis. To what extent do you think the graphs well represent what happened in the Lestolet?** • If they are (not) coherent, which are the (in)congruences?
		Transition to the second part	
Scenarios usefulness (50 min)	Instrumental use of scenarios	No workshops participation	**Have you ever heard about Author's study before I contacted you for the interview?** • If yes, on which occasion? • How did you get to know about the study? **(If not, go to the next one)**
		All	How often do you refer to academic studies in your everyday work?
		All	How often do you refer to scenarios in your everyday work?
		All	What kind of scenarios had you already considered for your everyday work? **(if they have never heard about the study go to the closure part)**
		heard about the study	**Do you think this study had some kind of impact?** **Have you ever referred to Author' study results as a base for your everyday work?** If not, can you identify some elements that prevent you from referring to the study in your everyday work?
	Indirect use of scenarios	heard about the study	**I will now give you a list of possible indirect impacts of a scientific study, can you please tell me which of them resulted from the study in your opinion? The questions may seem very general, but we will go deeper afterwards.** This study was useful to Improve your knowledge This study allowed you to change point of view on some prior ideas you had This study allowed you to consider more variables/notions in your job that you were not used to thinking about before Did this research allow you to create a new network of people working on similar themes? Did this research allow you to strengthen links between people belonging to pre-existent networks? Did this research allow you to create a collective vision of the future? Did this research allow you to create a collective understanding of the current situation of water quality and land use in Lestolet? Did this research allow you to create a collective understanding of future challenges for water quality and land use in the Lestolet? Did this research allow you to bring to light some inadequacy of the land-management system? **So, we said that Author's research had an impact on……., but not on………. To be a bit more specific:** Acquisition of knowledge Can you tell me what the study brought you in terms of acquisition of knowledge? Was the knowledge you acquired from the study useful in your everyday work afterwards? Why do you think it did not improve your knowledge?

(*continued on next page*)

Table B1 (*continued*)

Section	Subsection	To	Script
			Prior ideas
			Can you give me any example of ideas you changed thanks to Author's study? Why do you think it did not change any prior ideas?
			Considering other variables
			Can you give me an example of variables/notions you the study helped you to consider? Why do you think it did not help you to consider more variables?
			Creation of networks
			Could you tell me a bit more about the links that were created thanks to this project? Why do you think this study did not help you to create new links?
			Collective understanding of the situation
			Do you think the understanding of the situation was homogeneous between the technicians before the project started? In which way do they differ?
			Collective vision of the future/ future challenges
			Do you think the vision of the future/ was homogeneous between the technicians and farmers before the project started? If there was a creation of a collective vision: was this collective vision facilitating decision making afterwards? If there was not: can you tell me why do you think the study failed to create a collective vision of the future?
			Inadequacy of the land-management system
			Could you tell me a bit more about it?
		Heard about the study	**Are there any other impacts that we haven't touched upon that you would like to bring to light?**
	Influence of participation	Participation in workshop	**To what extent do you think that participating in the workshops influenced the perceived usefulness of the study?**
		Participation in workshop	In which way do you think preparatory workshops were useful?
		Participation in workshop	Would you say that the study had an impact only on people who participated in the workshops?
		We can now pass to the questions related to the barriers to the study usefulness.	
	Barriers to the use of scenarios	Heard about the study	**You previously told me that ……………. (ie you never used the study in a direct way to produce technical documents), could you tell me in your opinion what impeded its utilization?**
		Participation in workshop	• What about the relation between land-planners and researchers at the time of the workshops/ when you first heard about the study?
		Heard about the study	Were you used to collaborating? Was there an already well-established communication?
		Heard about the study	• Was water quality a relevant topic for you in the moment of the workshops/ when you first heard about the study?
		Participation in workshop	Did you work on land cover related issues?
		Participation in workshop	• What about research quality? Do you think that was a barrier? Did you believe the researcher was able to effectively conduct the research?
		Participation in workshop	Did you perceive the research as well rooted in the local reality? Do you think that all the relevant variables affecting land use change were considered? If not, which one should be considered?
		Participation in workshop	• What about results? Do you think the understanding of results could have been a barrier?
		Participation in workshop	At which point did you find results comprehensible? If not completely, which was the reason? was it due to a lack of knowledge? Which part of the results was difficult to understand? (Maps, text format, graphs, impact

(*continued on next page*)

Table B1 (*continued*)

Section	Subsection	To	Script
			on water quality) Were results different from what you expected? Did they contradict some previous knowledge? • To what extent do you think it would have been useful to take a step forward and discuss policy options together with researchers? • Were the policy options related to the study too challenging to implement? Do you think that contrasting the envisioned futures would have gone against the interest of important players? Can you give me some examples? Do you think that contrasting the envisioned futures meant making major changes in institutional arrangements? In which way? • What about results communication? Were the results of the project well diffused to the land-planners? Did they reach people who did not participate to workshops? • Could the study have been more effective if land-planners could directly influence the variables considered? What about participants' influence on decision-making? Did people at the workshop have enough influence on decision-making?
Closure (5 min)		All	Acknowledgments Would you like to revise notes before we start data treatment? Do you want me to send you the final article when ready? Please feel free to contact me anytime if there is something you want to share that didn't come to your mind today.

- Date:
- Location of the interview:
- Interviewee:
- Interviewee organization:
- Interviewee participation in 2005 workshops:

Appendix C. Interview transcript extracts and themes

See Table C1

Table C1
Interview themes and extracts.

Scenario impacts			
Mode of scenario use	**Impact**	**Citation**	**Local actor**
Instrumental	Help choose the environmental management strategy and define priority zones	Author' work made it possible to pinpoint the places where there was an incoherence between land use and aquatic environments [.]. It was just a matter of being able to locate certain things. Author's study regarded much more general themes; it was one element among others.	LA1
Political	Empowerment tool for farmers	[Scenarios] are also a development tool [.]. Presenting the scenarios opened up the farmers' vision at that time. Because they strongly reacted when they saw such a scenario. We talked about it again [with reference to the scenarios] at the creation of the Economic and Environmental Interest Grouping (GIEE), where we said: you see, at the time we were already talking about hunting companies coming [.] and today it's the start-ups that are valorising our wood. But wait.they manage to live with it and we don't do anything with this land. Maybe we need to take a new look at these areas.	LA4
	Create a space for stakeholders to discuss different interests	[Scenarios] allow the dialogue to be constrained in a space where the word can be openly spoken and for solutions to be found together within that space. [.] Author's work has done its job; it has allowed this dialogue [.].	LA5
Conceptual	Disseminate a new working method	I don't know to what extent your work has contributed, but I would say that [in our everyday job] the work with cartography was integrated at about the same time [of the scenarios]. [.] Before we were very much focused on agriculture. We used to take the maize, the wheat and to go on like that. From then on, we were much more with a system approach and using cartography. […] For me, even if then we focused on another	LA6

(*continued on next page*)

Table C1 (*continued*)

Scenario impacts			
Mode of scenario use	**Impact**	**Citation**	**Local actor**
		watershed, [.] in terms of methods, in terms of approaches, it [Thomas' study] could very well have been used to work on neighboring areas.	
		We must break the codes, open our mind and work in a more multidisciplinary perspective. That's what I learned from what you [Author] had done.	LA4
	Help building a systems analysis approach and help to consider more variables	We used to be extremely focused on crops […]. From that moment on [when scenarios were proposed] we used a systems approach and cartographic elements much more frequently.	LA6
		Personally [looking at the scenarios] it was an electroshock for me. [.] For me, personally, it made me say to myself: you focus too much on agriculture; you need to open your mind to other things.	LA4
		I'm sure that they [the scenarios] open up a Pandora's box of variables which we are not aware of a priori, but which […] the participatory workshop will bring to light.	LA5
		[We became more aware] of the time that we could devote to landscape management for instance, [.] and all that is wetland restoration.	LA3
	anticipating new challenges	Scenarios] allowed us to get the support to work in a direction, to go further in the reflection. [It allowed] to say: "this is how it can be tomorrow". It was useful to alert.	LA4
	Create a shared vision of future	I would say: [the scenarios were used] to write the strategy of the SAGE, which is ultimately validated by the CLE. So, they bring a collective vision, a kind of vote saying: this is where we want to go. They [the scenarios] obviously served this purpose. Anyway, we are in the planning phase and then there is the operational phase [.]. The next level of implementation didn't take place.	LA2

Related features of scenarios that influence scenario impacts		
Features	**Citation**	**Local actor**
Definition of a consistent spatial scale	[…] I think that the scenario approach at a larger scale than the operational one is important.	LA5
Scenarios are perceived as realistic and attainable. Caricatural scenarios were avoided.	Being too much in the caricature, it makes you lose credibility sometimes. [Talking about another study] There were three scenarios: one that was an extension of what has been done until today; one with some modifications; and the two others were break-up scenarios very caricatured. And then you ask yourself: what are we looking for? Are we trying to challenge people through these scenarios, are we trying to create discussion and a political debate or. I don't know. [.]. having overly exaggerated scenarios is not so useful in the end. In other studies, three scenarios were proposed: a not very ambitious one that doesn't cost much; [.] a second, moderately ambitious scenario that costs more, but that was still affordable; a third one, very ambitious that costs a lot and it was known that the communities would not have the budget to implement it. And so there are three caricatured scenarios [.] and we basically chose the middle one. (LA 1)	LA6LA1
The presence of elements of innovation attracted interest	I think the work was original compared to what used to be done elsewhere in other SAGEs. [.] This meant that, as soon as an original work was done, the technicians were interested, and this made it possible to create links between them.	LA1
Narratives that contain elements that break codes of thinking	[Talking about] fishing and hunting companies coming in was an electroshock. It was out of the agricultural perspective. [.] And I did some research, it was beginning to happen on the Lorient.	LA4
	Breaking codes is good, it's disturbing, but. When you told me about the scenarios, I came straight away, because it was something useful for me.	LA4
Addressing multiple aspects allowed communication between different interests	It [the combination of the scenario and other studies] was interesting because it allowed us to have a description of the territory not only in terms of environmental protection, but also in terms of economic development, and social development [.]. In the decision-making bodies, we shouldn't hide it, there are also power dynamics with someone who wants to defend a position, others support other positions, and consensus is not always reached. Sometimes it's a bit of a struggle, and I think that this [these studies] could have prevented this frustration in the beginning. I found that it [these studies] brought information and that it could also bring another perspective for collective reflection.	LA2
Results presented in different ways	Because the narrative is the mirror of the actors' discourses. And therefore, people recognize themselves in it or not.	LA5
	[Cartography] made things visible and to get away from the concept. That is to say. a farmer needs to see. We have materialized something that was simply a reflection.	LA6
Communication enhances impacts	This little work of dissemination which was done right at the end of the work.well, I think it was extremely useful.	LA6
Result communication tailored to each stakeholder group	We were only receptive to water quality at the beginning. [.] So the first action was that: [to look] at the maps and the water quality. And then, when we saw the social thing, we said: oops.[.] If it hadn't been for that indicator.	LA4
	If we wanted to assist farmers in the evolution of their practices, we should not talk about water quality. Because it was a halt, and the dialogue was interrupted. They felt accused and singled out.	LA5
Participatory methods are crucial to build trust between researchers and final users	If I hadn't worked with him, I would have never presented the scenarios [to the farmers]. I think that a relationship of trust can be created.	LA4
Researchers' opinions on implications of the study		LA1

(*continued on next page*)

Table C1 (*continued*)

Related features of scenarios that influence scenario impacts		
Features	**Citation**	**Local actor**
	In general, when we ask for a study there is not only the inventory and the assessment, but we ask: "and then according to you, as an expert in this field, what should we do"? Usually we get to that point. So the researcher, or the consultancy firm, is involved in the proposal.	

External features that influence scenario impacts		
Features	**Citation**	**Local actor**
Change in political will	In 2014 we had municipal elections with a total renewal of the CLE. [.] We had a majority of the elected representatives who had rather voted against the SAGE, who had given an unfavourable opinion. [.] The environment field is extremely dependent on the public policies that are put in place and on the will of local representatives.	LA1
	The SAGE sets priorities in different areas. If afterwards, at local level - in the watershed unions, at the level of the municipalities - there is no political will or there is a message that says: "That's nice, but all that is costly, and we won't make money available". The next level, the implementation one, will not be done.	LA2
Change in priority areas	[In 2006] It's true that the Lestolet was still in orange, but overall, we thought we had reached our objective. [.] Which meant that in 2007 we were already starting some actions on the Sulon watershed, right next to the Lestolet.	LA6
Change in organizations' jurisdictions	I was so caught up in the agricultural actions that I didn't have much time to take a step back and look at the bigger picture. [.] And the person who might have had time to do that was the director of the union, but she was busy the whole time with this story of governance, the change of status, the reform of the union.	LA8
Organization of operational organizations	In fact, during the operational phase, we committed for 5 years to implement actions to the water agency, to the department, to the region. Well, for five years we're going to set up actions and we're not stopping to look at scenarios, forecasts, etc. We're in the practice and we're not too much in the reflection. Then every 5 years we take the time, we take a step aside and it's time to take stock. [.] Is it necessary to reorient? What is the state of aquatic environments? And there is often a need for the territories to rely on studies or on important data like that [referring to scenarios].	LA8
Overall change in the land-management approach	I don't know to what extent your passage and your work has contributed, but I would say that [in our everyday job] the work with cartography was integrated at about the same time [of the scenarios].	LA6
General social environment	The Blavet Pond was completely invaded, and, with some colleagues, we said: we can't leave it like that and so in 2013 we ditched the soil [.] this is part of the actions that are interesting to carry out.	LA3
	[Le Lestolet] was an area where farmers were active, that had bonds between them.people were talking to each other, working together.it changed a lot. So quite recently, about a year and a half ago, we knew that we were going to have less action handled in the watershed, and a little less funding, because the indicators are gradually improving.	LA6
Poor communication between planning and operational structures	This work has been done a lot in connection with the SAGE [.], there are some difficulties of work between the SAGE and the operational structures [.], very very little information circulates between the SAGE and us. It's true that when a study is carried out within the framework of the SAGE, we use it essentially for our work, for our needs, and it's true that we don't really disseminate it.	LA8
Landowners' low interest in scientific research	I sit on the SAGE Blavet, so we are required to take an interest [in scientific studies]. But the farmers on their farm.it's more about economic factors and workload, these two constraints in fact.	LA7

Appendix D. Kappa indexes

See Table D1

Table D1
Similarity indexes between observed and scenario-predicted land-use cover (means of 2018, 2019 and 2020).

Scenario	Kappa		Khist		Kloc		FuzzyK	
	mean	variance	mean	variance	mean	variance	mean	variance
BAU	0.135	0.001	0.634	0.002	0.214	0.003	0.140	0.001
Greening	0.097	0.001	0.432	0.002	0.221	0.002	0.090	0.001
Cropping	0.123	0.001	0.622	0.002	0.197	0.001	0.143	0.001

Appendix E. Evolution of crops trajectories

See Appendix Fig. E1

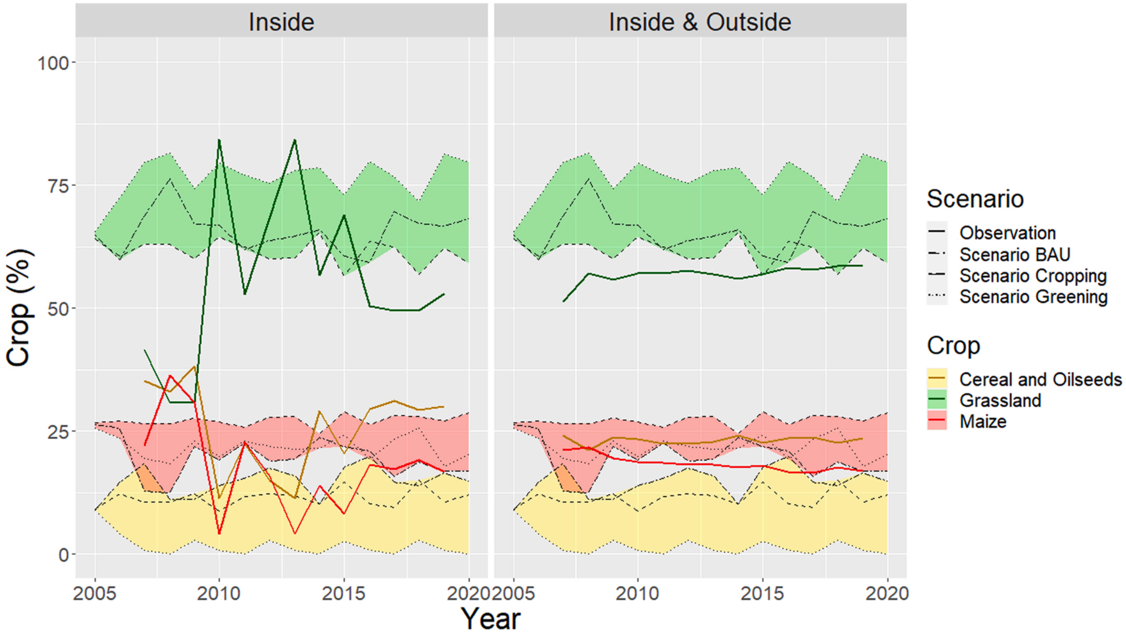

Fig. E1. Comparison of observed (LPIS data, solid lines) and predicted (scenarios, dotted lines) trajectories of crop percentages for the parcels inside the Lestolet watershed ("Inside") and for all farms that had at least one field inside the Lestolet watershed ("Inside") and for all farms that had at least one field inside the Lestolet watershed ("Inside & Outside"). Ribbons highlight the ranges of variation predicted by scenarios. Scenarios: "business-as-usual" (BAU) (increase in maize at the expense of grassland), Greening (increase in grassland at the expense of maize) and Cropping (increase in wheat at the expense of grassland).

Appendix F. Strategies followed by farms

See Table F1

Table F1
Number of hectares (Ha) and farms (n) that followed a land use strategy.

				Land use strategies							
				BAU	Greening			Cropping			Not defined
				In line	In line	Strong	Extreme	In line	Strong	Extreme	
Production system	No change	Pork	Ha	85.92							
			n	1							
		Dairy and pork	Ha		73.36			157.96			
			n		1			1			
		Dairy and poultry	Ha	93.07		159.19				118.78	73.50
			n	1		1				1	1
		Dairy	Ha	142.31		106.76			42.32		163.83
			n	2		1			1		2
		Dairy bio	Ha				62.14				
			n				1				
		Total	Ha		73.36	265.95	62.14	157.96	42.32	118.78	
			n		1	2	1	1	1	1	
			Ha	321.30	401.45			319.06			237.33
			n	4	4			3			3
	Change	Specialization & bio	Ha			80.35	155.50			147.60	
			n			1	2			1	
		Diversification	Ha	58.08	130.04		34.13			227.95	

(continued on next page)

Table F1 (*continued*)

			Land use strategies							
			BAU	Greening			Cropping			Not defined
			In line	In line	Strong	Extreme	In line	Strong	Extreme	
		n	1	2		1			5	
	Others	Ha						119.97		
		n						1		
	Total	Ha		130.04	80.35	189.63	0	119.97	375.55	
		n		2	1	3	0	1	6	
		Ha	58.08	400.02			495.52			0
		n	1	6			7			0
		Ha		203.40	346.30	251.77	157.96	162.29	494.33	
		n		3	3	4	1	2	7	
		Ha	379.38	464.83			415.62			237.33
		n	5	13			13			3

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