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Roberta Rigo

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THESE DE DOCTORAT DE

L'UNIVERSITE RENNES 2

ECOLE DOCTORALE N° 645
Espaces, Sociétés, Civilisations
Spécialité : *Géographie*

Par

Roberta Rigo

**Outcomes of fine scales land use and land cover change scenarios:
a temporal assessment applied to water and environmental management**

Thèse présentée et soutenue à Rennes, le 25 Mai 2023

Unité de recherche : **UMR 6554 LETG (Littoral, Environnement, Géomatique, Télédétection)**

Rapporteuses avant soutenance :

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SUMMARY

Introduction	1
1 Program evaluation in sustainable studies	2
2 The (LUCC) scenarios as a tool for sustainable studies?	16
3 Applying evaluation frameworks to LUCC scenarios	25
4 The need for transformative science	30
5 The national context	32
6 Partial conclusions	34
7 Objectives and structure of the thesis	36
Materials	43
1 Scenarios for the Couesnon study area	46
2 Scenarios for the Lestolet study area	57
3 Partial conclusion	65
Chapter 1 Outcomes of scenarios in the short term	67
1 Introduction: dissemination pathways as multipliers of outcomes	68
2 Article: Evaluating and maximising the outcomes of LUCC scenarios: strategies for an effective dissemination	70
3 Additional results and conclusion of Chapter 1	96
Chapter 2 Outcomes of scenarios in the mid-term	99
1 Introduction: scenarios as boundary objects?	100
2 Article: Do land use and land cover scenarios support more integrated land-use management?	102
3 Additional results and conclusion of Chapter 2	126
Chapter 3 Outcomes of scenarios in the long term	131
1 Introduction: reconstructing the past	132
2 Article: Contributions of local LUCC spatially explicit scenarios for water management: lessons learned from an ex-post evaluation	133

SUMMARY

3	Additional results and conclusion of Chapter 3	157
General Conclusions		161
1	Theoretical contribution	162
2	Limits of the study and scientific perspectives for LUCC scenarios	170
3	Contributions and perspectives for sustainable studies	174
Bibliography		177
Appendices		221
1	Appendix Materials	221
2	Appendix Chapter 1	268
3	Appendix Chapter 2	277
4	Appendix Chapter 3	285
5	Other contributions	298
Résumé étendu		299
Table of Content		325
List of Figures		329
List of Tables		331

GLOSSARY

BAU Business As Usual.

BGINS Blue and Green Infrastructures.

BZH Brittany.

CAP Common Agricultural Policy.

CLE Commission Locale de l'eau.

CNRS Centre Nationale de la Recherche Scientifique.

DHC Descending Hierarchical Classification.

DREAL Direction Régionale de l'Environnement, de l'Aménagement et du Logement.

EPCI Établissements publics de coopération intercommunale.

FCA Factorial Correspondence Analysis.

GIEE Groupements d'Intérêt Économique et Environnemental.

INEE Institut Écologie et Environnement.

ITN International Training Network.

LTER Long Term Ecological Research.

LUCC Land Use Land Cover Change.

MAEC Mesures agroenvironnementales et Climatiques.

ONIC Office National Interprofessionnel des Céréales.

RPG Registre Parcellaire Graphique.

SAGE Schéma d'Aménagement et de Gestion de l'Eau.

SAS Storylines And Simulation.

SCOT Schéma de Cohérence territoriale.

SDAGE Schéma Directeur d'Aménagement et de Gestion des Eaux.

SES Socio-ecosystems.

UAA Utilised Agricultural Area.

WS Watershed.

ZA Zone Atelier.

INTRODUCTION

1 Program evaluation in sustainable studies

Although science has long warned about the limits of growth (Meadows et al., 1972) and settled evidence of the cost of political inaction, it fails to support social, ecological and environmental transitions at a large scale (Glavovic et al., 2021). In this context, evaluating research outcomes becomes crucial to maximizing the societal benefits of research aiming to support the comprehension and management of socio-economic and environmental problems (Penfield et al., 2014).

To effectively tackle socio-economic and environmental problems, environmental science has to deal with the many feedback between physical and social factors that make the framing of such problems extremely complex. This complexity and a high degree of uncertainty leads to the non-existence of a unique optimal solution (Head and Alford, 2015; Jahn et al., 2012; Rittel and Webber, 1973) and complicate the management of environmental-related problems which are often defined as wicked. Recognising the interactions and co-evolution of social and ecological components and the intrinsic complexity of environmental issues implies recognising the need to tackle them with integrative strategies based on multi-, inter- (Haberl et al., 2019) and transdisciplinary approaches (Dick et al., 2018; Hage et al., 2010). In this first part of the introduction, we will expose the central concept of the two fields of study that deal with the complexity of framing and tackling environmental problems and in which this thesis is anchored: sustainable studies and outcomes evaluation. We will start by briefly retracing the development of sustainable studies as a research field that acknowledges the intricate nature of environmental issues and the close interdependence between social and ecological systems. Then we will look into the main concepts of modern outcome evaluation, including the difference between outputs and outcomes and the idea of research impact pathways.

1.1 A brief history of science and socio-ecological issues: from multidisciplinary approaches to sustainable studies

In the last decades, our vulnerability to natural hazards has increased (Yigitcanlar et al., 2022), and the ecosystems' general degradation is leading to biodiversity erosion (Almond et al., 2022) and threatening ecosystem services' provision (Maes et al., 2021). In parallel to the increasing sustainability challenges that characterise the Anthropocene (Lewis and Maslin, 2015), public concerns around the environment and climate are rising.

For example, between 2010 and 2020, the share of people considering climate change a severe problem passed from 46% to 74% (Funk et al., 2023) and nowadays, more than half of French people consider climate change somehow affecting their living area. In this general increase in vulnerability and concern, science's role in tackling environmental pressures evolved.

During the 60s, environmental studies were formally structured to study human-environment relations (Montello and Sutton, 2012). Due to its intrinsically multidisciplinary focus, environmental studies transcend the boundaries of disciplines addressing biophysical processes and include principles from economics, social sciences and humanities (Emmett and Zelko, 2014; Mishra, 2008). Scientific research belonging to this branch has studied the environmental and social risks associated with well-established practices. For example, Rachel Carson (1962) documented the harmful consequences of the massive use of pesticides on the environment and her book *Silent Spring* is often considered the publication marking the beginning of the modern environmental movement. Moreover, in the 70s, scientists started to warn against the disruptive consequences of the exponential rise of greenhouse gases (IPCC, 1990; Meadows et al., 1972). These two examples show that environmental advocacy has been part of environmental studies since its inception (Montello and Sutton, 2012). Nevertheless, during the 90s, we assisted in an increasing debate on global environmental problems, and the apparent need for rapid and substantial changes in the socio-ecological systems impulsed a reorganisation of part of scientific production aiming at providing actionable research.

Following the definition of Dilling and Lemos (2011, p. 681), then retaken and completed by Pearman and Cravens (2022), actionable science can be defined as science “produced to contribute directly to the design of policy or the solution of a [real-world] problem”. Research funding mechanisms also reflect and drive this shift towards goal-oriented research, and public funders design grants to promote environmental-related research projects producing applied solutions and fostering sustainability (Arnott et al., 2020; ESRC, 2022). For example, between 2014 and 2020, the European research and innovation funding programme Horizon 2020 reserved at least 35% to climate action (European Commission, 2014). In this movement towards the production of action-oriented science, we assisted a diversification of actors involved in producing knowledge (Funtowicz and Ravetz, 1993; Skarlatidou and Haklay, 2021; Weichselgartner and Truffer, 2015).

Scientists, institutions and civil society started to cooperate regularly to produce transdisciplinary research that can be defined as a research approach based on the co-production of knowledge crossing academic, disciplinary and epistemic boundaries (Thompson et al., 2017). A common attribute of this type of research is a methodology based on participatory approaches and the willingness to “understand the real world” (Holzer et al., 2018, p. 812). While the aim of participatory approaches can drastically differ, ranging from extractive to co-management purposes (Lynam et al., 2007; Norström et al., 2020), the transdisciplinary approach can align the aim of scientific research to local actors’ needs and expectations and produce actionable science.

In a context where the scientific recognition of transdisciplinary and actionable science flourished, the discipline now called under the name of sustainable studies was structured. Besides a registered bias towards environmental variables, sustainable studies were born as a distinct field (Kates, 2011) that “builds toward an understanding of the human–environment condition with the dual objectives of meeting the needs of society while sustaining the life support systems of the planet” (Turner et al., 2003, p. 8075). Then, Fang et al. (2018, p. 12) recently added to the definition the “place-based, multi-scale, and transdisciplinary approach” on which sustainable studies are based. Between 2006 and 2015, sustainable studies experienced exponential popularity, and several specific peer-reviewed journals were funded, marking the establishment of this scientific field (Fang et al., 2018; Miller, 2013).

1.2 Evaluating societal impacts

As presented in the previous section, sustainable studies aim to produce actionable knowledge. However, is actionable science effectively usable and used by actors outside the academic world? To answer this question, different authors started to apply previous works developed in the field of program evaluation to sustainable studies (Madaus et al., 1983), discussing and elaborating on criteria to determine the success of sustainable studies.

Evaluation studies flourished during the mid-70s and 80s in what is called “the golden age” of the research on evaluation (Henry and Mark, 2003, p. 294). If during the preceding decades, the contribution of science to society was mainly evaluated in terms of contribution to innovation (Marjanovic et al., 2009), during the golden age, the focus

turned towards the influence on policy-making. In the same period, scholars studied and schematised not only the possible outcomes of research on public decision-making but also the processes through which science could influence policy and foster evidence-based policy-making (Dunlop, 2014). During this time, frameworks were primarily developed under the so-called “Two-community” approach, whose fundamental idea is that researchers and policymakers belong to two distinct and poorly related groups, and the non-utilisation of scientific knowledge depends on different constraints, incentives structures, languages, interest and obligations between two groups (Caplan, 1979; Cherney et al., 2012).

The two-community theory was then challenged and defined as reductive, and boundaries between science and research started to be perceived as more blurry (Hage et al., 2010). Moreover, with the rise of sustainable studies and its new way of doing science, civil society has been increasingly involved in scientific activities and practices, for example, via citizens’juries, consensus conferences, public meetings and science festivals (Skarlatidou and Haklay, 2021). Simultaneously, evaluation practices adapted to this changing science by acknowledging more personal cognitive outcomes registered beyond the public policy-making arena (Bauer, 2009). In this shift, the historical ‘social contract’ according to which science produces knowledge that decision-makers directly implement in policies was overcome. Instead, a new paradigm arose valuing the “shared responsibility between science, policy and society, where public policy is based on evidence and underpinned by a ‘new social contract’ between science and society that emphasises responsibility for action as well as freedom of thought” (European Commission, 2009, p. 7). With this new concept, the added value of science became more nuanced than the direct contribution to policy-making, including cognitive impacts on society.

The distinction between output and outcomes¹ is central in evaluating the whole spectrum of societal impacts of scientific evidence. Research outputs are quantifiable products of the research, such as articles, workshops, training or factsheets presenting

1. The terms outcomes and impacts are often used interchangeably. Nevertheless, there is little consensus on the precise meaning of impact (Brewer, 2011), and some frameworks differentiate outcomes and impacts in a non-unique way. For example, Holzer et al. (2018, p. 812) identify outcomes as “concrete changes in policy or facts on the ground” and define ecological and social impacts as outcomes. Similarly, Walter et al. (2007) define outcomes as societal effects (e.g., increased decision-making capacity) and impacts as intermediate effects (such as network building and the availability and use of knowledge) that ultimately lead to outcomes. Other authors, such as Mitchell (2019, p. 822), differentiate outcomes and impacts based on timescales. They identify outcomes as “short-term changes in stakeholders’thinking or behavioural” and impacts as “long-term overall accumulation of all outcomes”.

research findings. Outcomes are instead intended as “changes in values, attitudes and behaviour in the world beyond the walls of the research institute” (Matthews et al., 2011, p. 247) and occupy a central role in the sustainable studies evaluation frameworks (Ewart and Ames, 2020). Other central aspects of evaluation frameworks applied to sustainable studies are 1) the analysis of intrinsic characteristics of a study necessary to produce outcomes; 2) the registered outcomes and their classification, and 3) the process and context-related features that influence them.

The rest of Section 1.2 is dedicated to insights derived from literature on these three central points of sustainable studies evaluation frameworks.

1.2.1 Usability of scientific knowledge

There is a significant consensus on the essential characteristics of usable scientific knowledge intended as a piece of knowledge with the potential to create outcomes through its use. Indeed, many scholars agree that **credibility, legitimacy and saliency are necessary characteristics to create outcomes** (Bauler, 2012; Cash et al., 2002; Dilling, 2007; Van Voorn et al., 2016). Credible knowledge meets expected quality standards, “scientific plausibility and technical adequacy” (Cash et al., 2003, p. 4). Legitimate knowledge is transparent, understandable and conforms to stakeholders’ values. Finally, salient knowledge is relevant to users and coherent with the context they experience. Besides these three pillars of knowledge usability, a substantial part of the literature adds *timely* to the characteristics of usable science (Lemos et al., 2012; Orlove et al., 2004), while some consider it part of saliency (i.e., Hamilton et al., 2019).

Participatory approaches have been recognised as valuable in increasing the usability of scientific studies (Hage et al., 2010; Lemos et al., 2012; Mehryar, 2019; Van Den Hove, 2000; Waylen et al., 2015) at the point that co-production has become the mainstream approach for sustainable studies (Nature Editorial, 2018). Consequently, extensive literature explores how to develop productive interaction with stakeholders (Ferguson et al., 2014; Reed et al., 2014), going beyond the purpose of extracting information. Indeed, to increase scientific knowledge usability, co-production must 1) clearly define shared and meaningful goals directly related to operational challenges (goal-oriented); 2) it must recognise the different types of knowledge and practises shared by local actors (pluralistic); 3) situate the process in a specific context, place or issue (Context-based);

and 4) facilitate active engagement, learning and interaction between local actors (interactive) (Norström et al., 2020).

1.2.2 Expected outcomes of scientific knowledge

Although necessary, the usability of scientific knowledge is not sufficient to produce outcomes. Instead, to let outcomes arise, stakeholders must use it (Reed et al., 2021). The French current of the *sociologie des usages* (Proulx, 2015) helps us understand the concept of use by differentiating between the terms utilisation, usage and practice. For this field, utilisation (*utilisation* in french) of scientific information refers to the use of a tool by an individual or a group. The usage (*usage* in french) refers not only to its use but also to the relation between the user and the tool (e.g., the user's representation of the tool and the needs fulfilled by the tool with respect to his/her expertise) (Noucher, 2009; Paganelli, 2012). Finally, the practice (*pratique* in french) refers to repeated usage (Bazin, 2009). While in the context of this thesis, we will refer to the general term use, acknowledging the different implications of the term allows us to drive attention to the context in which the creation, communication and use of scientific knowledge arise and to the users' representations and background.

Already in 1979, Carol Weiss, in his reference text *The Many Meanings of Research Utilization* (Weiss, 1979), developed a framework that identifies seven knowledge processes through which research is used to formulate policies or guide decision-making. While the processes through which research leads to outcomes will be addressed in detail in the next section, we anticipate Weiss classification as it allows us to identify corresponding outcomes. Indeed, his classification has been reduced to three approaches and largely retaken to schematise the outcomes deriving from the different uses of knowledge. The **rational** approach assumes direct use of research into practical actions; the **strategic** one states that science supports pre-existing ideas or increases agencies' reputation; and the **enlightenment** approach is grounded in the idea that a specific study cannot directly impact decision-making, but rather scientific knowledge offers support to understand complex issues and influences the way of thinking that ultimately impact decision-making. More recently Weiss et al. (2005, p. 25) added the **imposed** use of knowledge to the classification that happens when "a higher level of government with funds to disburse demands specific action on lower operating levels, based on evidence".

Different outcomes, i.e. instrumental, political and conceptual outcomes can be associated with the different uses of knowledge (Beyer, 1997; Dunlop, 2014; McKenzie et al., 2014). These large categories of knowledge use are handy as they are simultaneously flexible enough to apply to any sustainable study and detailed enough to give an insight into the complexity of the outcomes of scientific production. Indeed, the idea of a linear model of knowledge production and direct use to inform decision-making by defining goals (instrumental outcome) is coupled with the support of scientific knowledge in the conceptualisation of a problem i.e by triggering new ideas and shaping the way of thinking (conceptual outcome, also called cognitive outcome). In addition, political outcomes (also called strategic or symbolic outcomes) arise when scientific knowledge is used to support preconceived positions and can be seen as a particular conceptual outcome.

While classifying outcomes is essential to recognise them, outcomes should not be seen as fixed and immutable but rather as an evolving continuum. I.e. conceptual outcomes have been recognised to unexpectedly influence institutional or private decision-making (Court and Young, 2003). Nevertheless, despite acknowledging cognitive and political outcomes as expected and desirable, a consistent part of knowledge exchange initiatives aim to support direct use of knowledge in policies or management (Karcher et al., 2021). This aim reflects the final ambition for action-oriented scientific knowledge to enter into an institutionalised decision-making process.

When discussing instrumental outcomes, the concepts of decision-making and public policy-making are often mentioned, making it necessary to clarify the terms. Despite a lack of consensus on what policy-making is (European Commission, 2017), we can consider it a cyclical process involving both technical and political processes by which actors translate their political vision, goals and means into programmes and actions (European Commission, 2017; Howlett and Cashore, 2014; Northern Ireland Executive, 2016). Following this definition, Newman et al. (2016) use some Australian case studies to point out that the policy community should not be seen as a homogeneous group. Instead we should distinguish between technicians and politicians because of their different use of scientific knowledge in policy-making. Moreover, Howlett and Cashore (2014), basing their analysis on previous literature, highlight how agreed principles of public policy-making are: the public character of agents involved in the process (governments), the presence of making a

conscious choice, the explicit mention of goals and means that lead to the decision. On the other side, decision-making has a broader scope and can be considered as any process that leads to selecting the best option through screening a set of alternatives (Beach, 1993). Considering instrumental outcomes on decision-making allows us to analyse processes and decisions taken outside governmental frames and consider a larger panel of stakeholders.

Finally, the concept of *learning* is central in this thesis as it can be found at the origin of the three types of outcomes. According to Mezirow (1990), learning can occur at three different levels: the *instrumental* one, which is the acquisition of new knowledge or skills, the *communicative* one, which is the understanding and the reinterpretation of previous knowledge and the *transformative* one that leads to a change in attitude, behaviours and social norms. This distinction allows us to see that learning does not automatically lead to a change in behaviour, attitudes and building of trust (Reed et al., 2010). Following this premise, we introduce the concept of *social learning* presented by Reed et al. (2010, p. 6) as “a change in understanding that goes beyond the individual to become situated within wider social units or communities of practice through social interactions between actors within social networks.” This concept is deeply embedded in complementary works on how collaboration and communication shape knowledge, such as the theory of situated learning of Lave and Wenger (1991) and the work on the community of practices (Wenger, 1998). Moreover, it allows us to see that *outcomes can overcome the personal level to reach group (and eventually system) levels* (Hamilton et al., 2019). In the context of environmental-related problems the possibility to reach group level outcomes is essential. Indeed, the solutions of wicked problems are not unique but “depend on the capacity of different actors and groups to communicate, negotiate and reach collective decisions” (Muro and Jeffrey, 2008, p. 329) and require changes in social practices. For this reason the concept of social learning has been previously applied to natural resources management (Pahl-Wostl and Hare, 2004).

The simple outcomes classification that we presented in this chapter can be further detailed and nuanced according to the context in which the impact of scientific knowledge is analysed. For example, Tonn et al. (2000) propose a framework describing the use of scientific information in a decision-making process in which the conceptual and instrumental use can be disentangled in issue familiarisation, criteria setting, option construction, options assessment, and reaching a decision. Detailed outcomes belonging to each of the

three categories of outcomes will be detailed in Section 3, applied to the outcomes of LUCC scenarios.

To conclude this section we summarise in Table 1 the concepts that have been mobilised so far.

1.2.3 Impact pathways and context-related features influencing outcomes

In the previous sections, we defined the characteristics of usable knowledge and the range of possible connected outcomes. Nevertheless, although necessary, the usability of scientific knowledge is not sufficient to produce outcomes. Indeed, local actors must use the (co-)produced information to let outcomes emerge.

Despite a large availability of scientific information (Newman et al., 2016) and the widespread ambition of researchers for instrumental use (Karcher et al., 2021), evidence shows that even usable co-produced studies can result in little instrumental outcomes (Posner and Cvitanovic, 2019), and functional, structural, and social barriers to the use of knowledge (Weichselgartner and Kasperson, 2010) have been extensively discussed. Indeed, individual beliefs and values, political pressures, cultural and linguistic barriers between researchers and stakeholders, along with differences in risk acceptance and considered time horizons, can result in what is known as a **usability gap** (see in example Bowen and Zwi, 2005; Bradshaw and Borchers, 2000; Briggs, 2006; Carden, 2004; Newman et al., 2016; ODI, 2004; Rose et al., 2018; Ruckelshaus et al., 2015; Trostle et al., 1999; Weiss et al., 2008). Moreover, even when research use is detected, a widespread mismatch between expected outcomes and scientific project design has been identified (Carden, 2004). In this regard, even if the black-and-white conceptualisation of knowledge use has been criticised, many projects follow an ideal linear process of knowledge creation and implementation which hardly ever fits the ambition for instrumental uses (Floor et al., 2019).

To reduce the usability gap, the mechanisms of knowledge creation and exchange must align with the expected outcomes (Benneworth et al., 2018; Fazey et al., 2014). Consequently, outcomes evaluation cannot focus solely on detected outcomes but must address how they are embedded in the complex interaction process between science, policy and society. At this scope, we introduce the concept of **impact pathway, intended as mechanisms by which research leads to societal impacts** (Muhonen et al., 2020)

Concept	Definition	Reference
Actionable science	Scientific knowledge “produced to contribute directly to the design of policy or the solution of a [real-world] problem”.	Dilling and Lemos (2011, p. 681)
Transdisciplinary research	Research approach based on the co-production of knowledge crossing academic, disciplinary, and epistemic boundaries.	Thompson et al. (2017)
Sustainable studies	Field of study that “builds toward an understanding of the human–environment condition with the dual objectives of meeting the needs of society while sustaining the life support systems of the planet” based on “place-based, multi-scale, and transdisciplinary approaches.”	Turner et al. (2003, p. 8075) Fang et al. (2019, p.12)
Outputs vs outcomes	Research outputs are quantifiable products of the research. Research outcomes are “changes in values, attitudes and behaviour in the world beyond the walls of the research institute”.	Matthews et al. (2011, p.247)
Usable knowledge	Credible, legitim and salient knowledge that can produce outcomes throughout its use.	Cash et al. (2002)
Types of outcomes	Conceptual (or cognitive) outcomes: contribution of scientific knowledge in the conceptualisation of a problem and the emergence of new ideas; Political (or strategic, symbolic) outcomes: support of pre-conceived positions; Instrumental outcomes: direct information for decision-making.	Beyer (1997)
Levels of outcomes	Outcomes can arise at the personal, group, and system level.	Hamilton et al. (2019)
levels of learning	Instrumental learning is the acquisition of new knowledge or skills; Communicative learning is the understanding and reinterpretation of previous knowledge; Transformative learning is a change in attitudes, behaviours, and social norms.	Mezirow (1990)
Social learning	“A change in understanding that goes beyond the individual to become situated within wider social units or communities of practice through social interactions between actors within social networks.”	Reed et al. (2010, p. 6)

Table 1 – Summary of concepts and associated references.

by linking the demand and supply of science. In analysing the role of actors implied in knowledge production and exchange, Sarewitz and Pielke (2007) identify, on the demand side, the knowledge users: “people or organisations that use the results of research to better inform decisions and influence outcomes“ (McNie et al., 2016, p. 886). On the

supply side, a broad panel of actors can be found, ranging from purely academic to hybrid organisations that have been taking more and more space in the **supply-demand interface** in the last few years (Hellström and Jacob, 2003). For instance, information brokers, collaborative group processes, boundary organisations and knowledge networks have been created to reconcile the demand and supply of knowledge and create a space where suppliers and users can co-create useful knowledge (Gustafsson and Lidskog, 2018; Safford et al., 2017).

Then **production modes define how information is exchanged between knowledge users and producers** (McNie, 2007), and following the “Pull-Push” model, Dilling and Lemos (2011) divide them into *science-push, demand-pull and co-production*. In the first model, evidence is developed for seeking knowledge, and its application is desirable but not necessary. In the second model, evidence is commissioned by external stakeholders, and it is shaped so that the usability of scientific evidence is straightforward (Šucha and Sienkiewicz, 2020). The third model of “Co-production” combines the first two by merging users and producers in an iterative process to define the research agenda. Hoppe (2005) presents a classification of interaction modes between research and policy, dividing them according to which of the two sides has primacy and the degree of convergence, intended as serving “the same societal function” (Figure 1) (Hoppe, 2005, p. 208).

Hoppe’s models can be read via the Pull-Push prism and applied more broadly to the science-society interface. Some of the merits of this classification are to schematise the different forms of interconnections between decision-making and research and acknowledge the role of interest groups, including citizens. Between the models based on the primacy of science, we can find the *enlightenment model* and the *technocracy* one. As already cited in the previous chapter, the enlightenment model was originally structured by (Weiss, 1977), and it is based on the idea that scientific knowledge, which is naturally slowly transmitted to policymakers, produces a change in ideas and way of thinking, leading ultimately to progress; according to the *technocracy model* scientific knowledge is at the base of decision making, and experts strongly influence decision-makers de facto holding the control over decisions. Between the models based on the primacy of politics, we can find: the *bureaucratic model*, based on the idea that science is used to bring knowledge to the political power by a board of experts which intervene in the administration, and the *engineering model*, which, similarly to the bureaucratic one, states that science is used

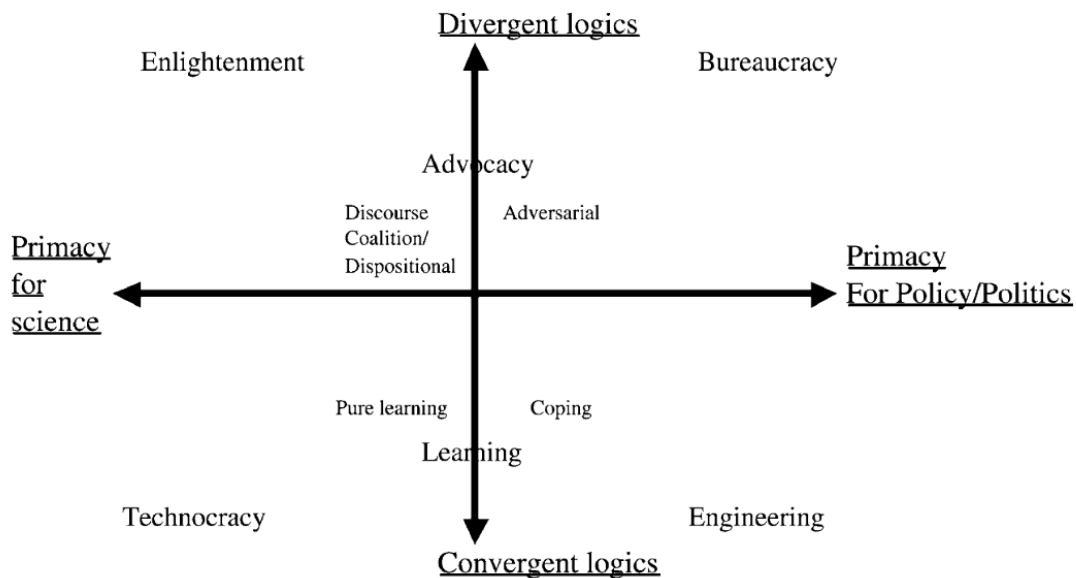


Figure 1 – interaction models between research and policy according to primacy and convergence. Source Hoppe (2005), p.208.

to inform politicians, but experts are not supposed to be part of political institutions. Other models do not presuppose the supremacy of one of the two parties but rather a dialogue between equal institutions. Within those, the *advocacy model* considers science as “one among multiple political voices that enable political debate, judgement and decision”. Lastly, the *learning model* sees “all actors [...] as ‘inquirers’ engaged in a process of social learning through social debate” (Hoppe, 2005, p. 211). More recently, Muhonen et al. (2020) synthesised 13 forms of interaction between science and society adapted to the structural change in knowledge production that happened in the last decades (pipeline pathways). The 13 forms of interactions are grounded in 60 Social Sciences and Humanities projects and grouped into four groups reflecting ideal ways in which outcomes are generated, namely: *dissemination*, *co-creation*, *reacting to societal change*, and *driving societal change*. While schematising interfaces allow one to visualise mechanisms leading to outcomes, the authors warn that rather than reflecting actual pathways of scientific projects, they are archetypes that can be simultaneously or subsequently taken in a single project.

Besides the impact pathways, other factors conditioning research outcomes are the evaluation timing and other external uncontrollable events. Regarding time, the **evalu-**

ation moment and the time-lag between the scientific project and evaluation significantly impact registered outcomes (Brewer, 2011; Mayne, 2004; Penfield et al., 2014). For this reason, Hamilton et al. (2019) suggest seeing evaluation as an ongoing process rather than a moment in time, and they link personal, group and system outcomes to an increasing time-lag between the knowledge creation and the arising of outcomes. In the same perspective, Rossi et al. (2018) distinguish between the immediate effects of programs intended as direct results of the interventions on the participants, and the final goals which need time to be indirectly reached. Similarly, several evaluation frameworks include the notion of time and link cognitive and personal impacts to a short time frame and instrumental outcomes to a longer one considering that the conceptual use of knowledge can need a longer time to produce tangible effects (Ruckelshaus et al., 2015; Saritas, 2006). Furthermore, external elements influencing values, beliefs and opinions (such as changing geopolitical conditions or institutional context) can occur at any time, making it impossible to set a universally appropriate time frame for evaluation (Hamilton et al., 2019; Walter et al., 2007). Instead, several evaluation timings can be appropriate for evaluating different outcomes. Indeed while outcomes can appear long-time after the project (Morris et al., 2011), the impression of scientific knowledge and process are vivid in the short term (Karcher et al., 2021). Consequently, depending on the moment when the evaluation is done, scenarios can be evaluated according to their usability (at the moment of results communication/project development) and short to long-term outcomes (ex-post evaluation) (Ghazinoory et al., 2015).

In conclusion, the intangibility of cognitive and political outcomes, the indirect causal relation between scientific research and outcomes, and the resulting time-lags are considerable barriers to research evaluation. Moreover, while impact pathways play an essential role in outcomes, multiple and uncontrollable external influences can arise, with effects on cognitive, political and instrumental outcomes that are difficult, if not impossible, to disentangle from the ones caused by the creation of scientific knowledge.

1.3 Partial Conclusion

Over the past decades, the way of studying wicked environmental problems evolved significantly. First, in the 60s and 70s, environmental scientists advocated for sustainable development based on multidisciplinary studies (Montello and Sutton, 2012). Then, in line with the urgent need to tackle climate change and biodiversity loss during the 90s,

part of environmental studies transformed the way of doing science, shifting toward a more action-oriented transdisciplinary approach (Funtowicz and Ravetz, 1993). In this movement, the field of sustainable studies started to structure itself until its establishment as an alone-standing field characterised by the ambition to produce action-oriented science that helps to understand socio-ecological systems using locally based and transdisciplinary approaches (Fang et al., 2018).

Together with the establishment of sustainable studies, the question of how to verify whether local stakeholders were effectively using the produced knowledge arose. The works on program evaluation were then mobilised to assess the outcomes of sustainable studies, intended as “changes in values, attitudes and behaviour in the world beyond the walls of the research institute” (Matthews et al., 2011, p. 247). This extensive definition of outcomes fits with the restructuring of the social contract between science and society that happened in the same decades. Indeed, if historically the social contract was based on the idea of a linear and direct application of science in the policy arena, with the increased place of transdisciplinary research, the contribution of science to society started to be perceived as more nuanced and indirect and the role of science more based on emphasising responsibility for action and freedom of thought (European Commission, 2009).

Overcoming the idea of science produced by scientists and directly applied in policy-making goes hand-in-hand with full recognition of political and cognitive outcomes at a personal and group level together with the instrumental ones. The outcomes of scientific knowledge production can indeed be classified into the following (Dunlop, 2014):

1. **conceptual (or cognitive) outcomes** intended as the support in the conceptualisation of a problem and triggering new ideas;
2. **political (or strategic, symbolic) outcomes** that arise when scientific knowledge is used to support preconceived positions;
3. and **instrumental outcomes** intended as the direct use of knowledge to inform decision-making.

Besides the impacts of scientific knowledge, sustainable studies evaluation frameworks also focus on the intrinsic characteristics of a study necessary to be usable and potentially produce outcomes through its use, as well as the process and context-related features influencing outcomes. In this regard, a **credible, legitimate and salient** study is considered usable (Dilling, 2007), and participatory methods of co-production of knowledge

have been broadly recognised as effective strategies to increase usability (Nature Editorial, 2018). Nevertheless, producing usable knowledge is insufficient to assure the emergence of outcomes as functional, structural and social barriers can impede its use (see in example Briggs, 2006).

To reduce the usability gap, aligning scientific project design with expected outcomes is considered effective (Benneworth et al., 2018; Fazey et al., 2014), and the mechanisms through which knowledge is created and diffused become crucial aspects of the outcomes evaluation frameworks. Furthermore, different impact pathways have been recognised and categorised in **science push, demand pull and co-production modes** (Sarewitz and Pielke, 2007) according to which side of the knowledge users and producers interface has supremacy in the process of knowledge creation, and that can be further detailed in multiple forms of interaction between science and society. Finally, besides the impact pathway and the intrinsic usability of knowledge, the time-lag between knowledge production and evaluation and the **evaluation time** significantly determines the detected outcomes (Mayne, 2004). Indeed, outcomes continuously evolve and can be indirectly linked with knowledge production. Moreover, external, uncontrollable events, such as changing geopolitical conditions and institutional context, can happen anytime, hindering or fostering outcomes.

2 The (LUCC) scenarios as a tool for sustainable studies?

The practices, outputs and methodologies associated with sustainable studies are the most diverse (Salas-Zapata et al., 2017; Spangenberg, 2011). Inscribed in the context of sustainable studies, we can find ***futures studies*** and ***foresight*** that, even if often used interchangeably, represent distinct concepts (Sardar, 2010). Indeed, the first is a field of study that, based on the postulate of the intrinsic uncertainty of the future, explores possible different futures instead of trying to make predictions (Rohrbeck and Bade, 2012). With the term foresight, scholars refer instead to “the ability to create and maintain a high-quality, coherent and functional forward view, and to use the insights arising in useful organizational ways [...]. It represents a fusion of futures methods with those of strategic management” (Slaughter, 1997, p. 1). Instead of a field of study, foresight is a practice, it is the application of future studies to a specific management problem im-

plying that the actions taken in the present shape the future (Sardar, 2010; UNDP, 2018).

Specific tools that can be applied in the foresight process are **scenarios** (Voros, 2001) **which are defined 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). For their support in developing long-term strategies, scenarios become an increasingly popular tool both in private and public decision-making (Biggs et al., 2007; Kok et al., 2011; Peterson et al., 2003). For instance, the OECD has an entire foresight division, and recently the European Commission has inscribed foresight in its priorities (Šucha and Sienkiewicz, 2020) and publishes an annual report on macro trends, challenges and opportunities (Cagnin et al., 2021). In addition, scenarios have been recognised as valuable tools in tackling central questions posed by sustainable studies (Fang et al., 2018; Swart et al., 2004) when assumptions underpinning scenarios storylines regard the “co-evolutionary pathways of combined human and environmental systems” (Swart et al., 2004, p. 139). Indeed, in an uncertain context characterised by fast-changing conditions, foresight can support the long-term resilience of socio-ecological systems by structuring reflections on the co-evolution of socio-economic and environmental variables and related management challenges (Swart et al., 2004).

After this brief introduction to scenarios, we will first focus on different scenario-making approaches and scenarios types; then, we will present the specific features of land use land cover change (LUCC) scenarios for intensive agricultural landscapes.

2.1 Different approaches and categorisation of scenarios

Two geographical centres marked the history of scenario-making: the **USA and France**. Different approaches to scenario-making arose in the two centres, differing mainly on the scale of the considered drivers of change and the applied methodology. Indeed, in the USA, scenario-makers mainly focused on analysing global trends' impacts on American firms and policies, while in France, scenarios were more based on national drivers. Moreover, while the USA methodologies are mainly intuitive and open, the French school is more based on structured probabilistic and mechanical processes and most often recur to participative methods to determine future events and their relative probability of occurrence (Bradfield et al., 2005).

In the American school, two approaches arose: the *Intuitive Logic* and the *Probabilistic Modified Trends*. The first one was rooted in a scenario experiment carried on in the Shell company at the beginning of the 70s and is based on qualitative analysis identifying the main uncertainties in the macro-environment and their implication on the object of study. In the same period, more mathematical approaches were developed by the probabilistic modified trends approaches that estimate the probabilities of the occurrence of singles or pairs of future events modifying past trends and leading to alternative futures (Bradfield et al., 2005). Originally anchored at the RAND Corporation and in the works of Gordon (Gordon, 1994), this approach was first applied to USA defence management.

On the other side of the ocean, in France, scenarios had been developed since the 50s following an approach called *la prospective*. In particular, French methods for scenario-making were based on the works of Gaston Berger (1957, 1964) and Jouvenel (1964) and originally applied to public policy and planning. This french approach is rooted in the idea that images of the future can be created to guide policy makers towards desirable futures. In a second moment, the work of Godet (1986) largely influenced the French school consolidating the computer-based and mathematical approach to scenarios.

Nowadays, scenario-making often combines **storylines (narratives) and visual representations** that can eventually be produced using spatially explicit mathematical models. The complementarity between narratives and models lies in the fact that narratives qualitatively describe future conditions by making explicit assumptions about the drivers of change. In contrast, models give quantitative outputs based on the narratives'assumptions (Houet and Verburg, 2022). When using spatially explicit models, the resulting maps help to visualise the impacts of selected hypotheses on the landscape at different time steps (Castellazzi et al., 2010). The methodologies to combine narratives and modelling are based on two main approaches (Houet and Verburg, 2022): the *Storyline and simulation* (SAS), which is based on storyline primacy (Alcamo and Henrichs, 2008), and the model-driven approach, based on model primacy. Indeed, in the SAS approaches, storylines are first generated, and scenario-makers extract the parameters to feed modelling from them. In reverse, the model-driven approach produces simulations of futures by modifying model parameters coherently, and storylines are developed based on the models'outputs. Regarding the originality of imagined futures, SAS approaches can produce a broader range of possible futures. Indeed, while human imagination benefits

from great freedom, models are subject to technical restrictions that limit the simulations. Moreover, the two approaches can also differ in the level of stakeholders involvement as, while models are usually developed, calibrated and adjusted for a specific application by scenario-makers experts, the construction of narratives can be based on a variety of experts and participatory approaches (Houet and Verburg, 2022).

Different scenarios classifications have been produced. For example, the starting moment from which scenarios are developed (vantage point) can be used to classify scenarios. Following this criterion, scenarios can be divided into **forecasting and backcasting scenarios** (Van Notten et al., 2003). In forecasting scenarios, the scenario makers develop assumptions on the evolution of fundamental driving forces (e.g. changes in macroeconomic factors, changes in human behaviours and preferences), and they explore the potential consequences. In backcasting scenarios, the developers assume what the future will look like and explore the conditions needed to reach that state. When including the concept of *desirability*, a division of scenarios into **exploratory (or descriptive)** and **normative (or target seeking)** is possible (see Rotmans et al., 2000; Van Notten et al., 2003 for examples). Indeed, exploratory scenarios look at possible futures without stating an order of desirability but 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 recognised in environmental management, a limited place is reserved for normative ones (Van der Voorn et al., 2012; Van der Voorn et al., 2017), such as backcasting scenarios which are normative by nature (Milestad et al., 2014).

As we have seen precedently, scenarios are often applied in foresight to reflect on a management/policy problem. In this regard, the IPBS proposes a **division of the scenario types according to the moment of the policy agenda** in which they play a significant role (Figure 2) (Ferrier et al., 2016). In particular, they connect exploratory scenarios' main contribution to the initial phase of the policy agenda. Indeed, by presenting a broad panel of possible futures and key drivers' trajectories, they can support the definition of the problem and the agenda-setting. On the other hand, normative scenarios' main contribution is highlighting what needs to be changed to reach a targeted goal which belongs to policy design (Cinq-Mars and Wiken, 2002).

Finally, scenarios can differ, not only by structures and objectives but by many other

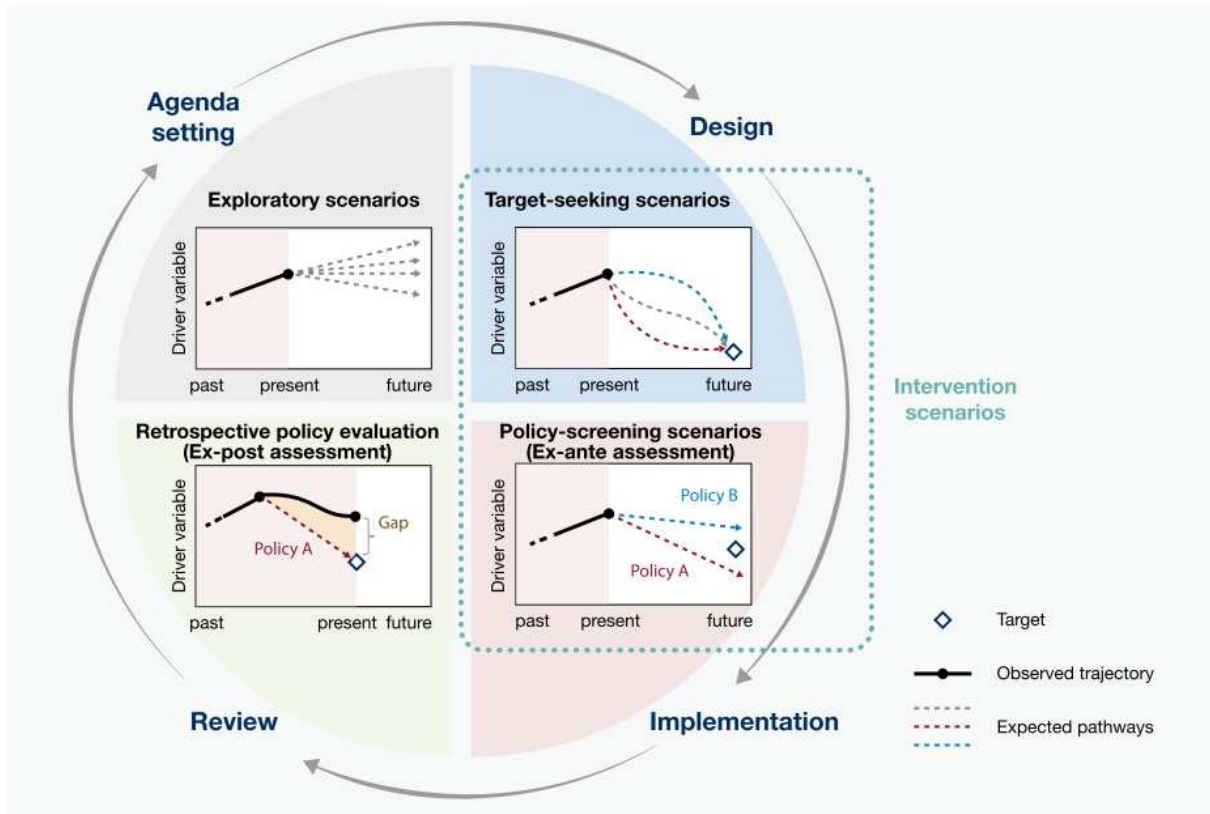


Figure 2 – Building scenarios within the policy cycle context. Source: Ferrier et al., 2016, p.94.

dimensions (Biggs et al., 2007; Van Vuuren et al., 2012), including the outputs they produce. Indeed, besides narratives, the outputs of scenarios can take many forms, such as spatially explicit maps, video clips and movement effects (Ferrier et al., 2016), and projections of quantitative variables values in graphical and tabular formats (Parson et al., 2007). Furthermore, since the way through which scenarios are presented can influence the impact on decision-makers (Von Wirth et al., 2014), defining a suitable output format is crucial to diffuse the scientific information effectively and to facilitate the identification of challenges and opportunities affecting the study area (Ferrier et al., 2016).

2.2 Case of LUCC scenarios in intensive agricultural landscapes: practice at the crossing of multiple disciplines and methods

In the last decades, scenarios have been applied to different domains (Palomo et al., 2011; Varum and Melo, 2010), of which environmental management is one of the most recurrent (Garb et al., 2008). Indeed, modelling landscape dynamics can support management decisions by unravelling interactions between social and ecological processes. To emphasise this intrinsic interrelation between ecological and social dimensions, Redman et al. (2004, p. 163) formalised the **concept of socio-ecosystems** (SES) as “1) a coherent system of biophysical and social factors that regularly interact in a resilient, sustained manner; 2) a system that is defined at several spatial, temporal, and organizational scales, which may be hierarchically linked; 3) a set of critical resources (natural, socio-economic, and cultural) whose flow and use are regulated by a combination of ecological and social systems; and 4) a perpetually dynamic, complex system with continuous adaptation.” When recognising the SES as a singular more than two separated system (Kinzig, 2001), it becomes clear that resource management based purely on the social or biophysical dimension may result in biased and unsustainable decisions and unexpected outcomes. To highlight the links between core items (i.e. goods, values, benefits, collective action, resources and practices) that are set and operate in a given landscape, Bretagnolle et al. (2019) proposed to frame SES as the combination of adaptive management and ecosystem services. Despite the controversy around the concept of ecosystem services (Borie and Hulme, 2015; Chan et al., 2016), the framework allows highlighting the components that directly impact the SES and conceptualising the landscape both as the context and the result of social and ecological variables. The emergence of the SES concept and the recognition of the strong interconnection between social and ecological elements resulted in a call for an integrated approach to defining research questions, policies and management approaches (Mehring et al., 2017).

In intensive agricultural landscapes, land management and agricultural practices strongly influence trade-offs between the different components of SES, e.g., the decision to use more or fewer fertilisers can be favoured or hampered by the legal and economic framework and impact both water quality and crop yield (Mehring et al., 2017). Consequently, agriculture is torn between multiple challenges including producing food and energy for an increasing population, limiting environmental damages due to modern agriculture and promot-

ing carbon sequestration while maintaining an adequate standard of living for farmers (Bretagnolle et al., 2018). Moreover, socio-ecological systems are impacted by drivers of change that overcome the landscape extent (e.g. continental regulations), causing spatial mismatches between social and ecological processes (Cumming et al., 2013). Therefore, to attain balanced outcomes and landscapes resilience implies knowing and considering the socio-ecosystem interactions in their complexity and managing landscapes with an integrated approach.

As we have seen in the previous paragraph, land use land cover change (LUCC) scenarios allow us to consider the co-evolution of multiple socio-ecosystem components with different scale patterns as drivers of change (in narratives) and model their impacts on social and ecological factors. For this reason, LUCC scenarios are often developed as a management support tool and deal with the complexity of modelling crop rotations determined by interactions between different social and ecological factors taking place in nested scales and with nonlinear causal effects (Gomes et al., 2019).

In a recent publication, Houet and Verburg (2022) describe specificities of land use land cover change (LUCC) scenarios in agricultural landscapes. Considerable challenges are represented by the interactions between different factors taking place in nested scales and with nonlinear causal effects on crop rotations (Gomes et al., 2019). Indeed, in agricultural landscapes, the main factors determining the LUCC are **personal decisions taken at the farm level** that can be driven by personal preferences for specific farming approaches but also by **pressures operating at larger scales**, such as biochemical limits of the soil, climate pressures, and economic and financial mechanisms (Houet and Verburg, 2022). Besides the difficulties in combining internal and external drivers of LUCC, the sum of different agricultural practices compose landscape **patterns that vary according to the considered scale**, and personal management decisions impact natural resources beyond the farm's boundaries.

To catch the complexity of drivers and effects of a LUCC, **large to fine-scale models** are used for different goals and submitted to different pros and cons. On the one hand, fine-scale models are developed at watersheds to a regional extent and can use fields as elementary units. Moreover, fine-scale scenarios are particularly developed in sustainable studies and can contribute to agricultural landscape management in several ways. For

example, fine-scale models can estimate the biochemical impacts of LUCC on physical elements such as water quality or quantity or biodiversity over a restricted area; they can provide the allocations of crops that meet pre-defined constraints or simulate biomass production under specific conditions, and they can identify agricultural practices that meet policy restrictions or resource availability (e.g. future water availability or water quality imposed by legal norms). On the other hand, large-scale models cover continental and global surfaces with a spatial resolution of hundreds of metres to multiple tens of kilometres. Applied to agricultural landscapes, large-scale models can instead give insights into regional responses to large-scale pressures and into how regional responses can indirectly impact other areas. Nevertheless, including the agronomy principle in large-scale models is difficult because simulations are produced for units (e.g. pixel) with lower resolution than spatial structures on which agricultural practices are defined (farms) (Houet and Verburg, 2022).

When scenarios are applied to geographical systems and land management, LUCC models are often used (Fusco et al., 2017). **Geographic systems, modelling and prospective studies are then combined in a so-called geopropective approach** integrating the spatial dimension (i.e. neighbouring effects of land covers and land uses, emerging properties of socio-ecological changes) of economic, historical or demographic dimensions (Gourmelon et al., 2012; 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 the local actors' expectations (Voiron-Canicio, 2006).

As evoked throughout this introduction, LUCC scenarios collect insights from multiple disciplines (Figure 3). Indeed, multiple socio-economic and environmental factors are considered as drivers of change and, in return, impacts are calculated on multiple aspects of the socio-ecosystem. Moreover, the applied methodologies range from computer-based models to participatory methods, often chaired by researchers, to include stakeholders' perspectives and values in narratives (Oteros-Rozas et al., 2015).

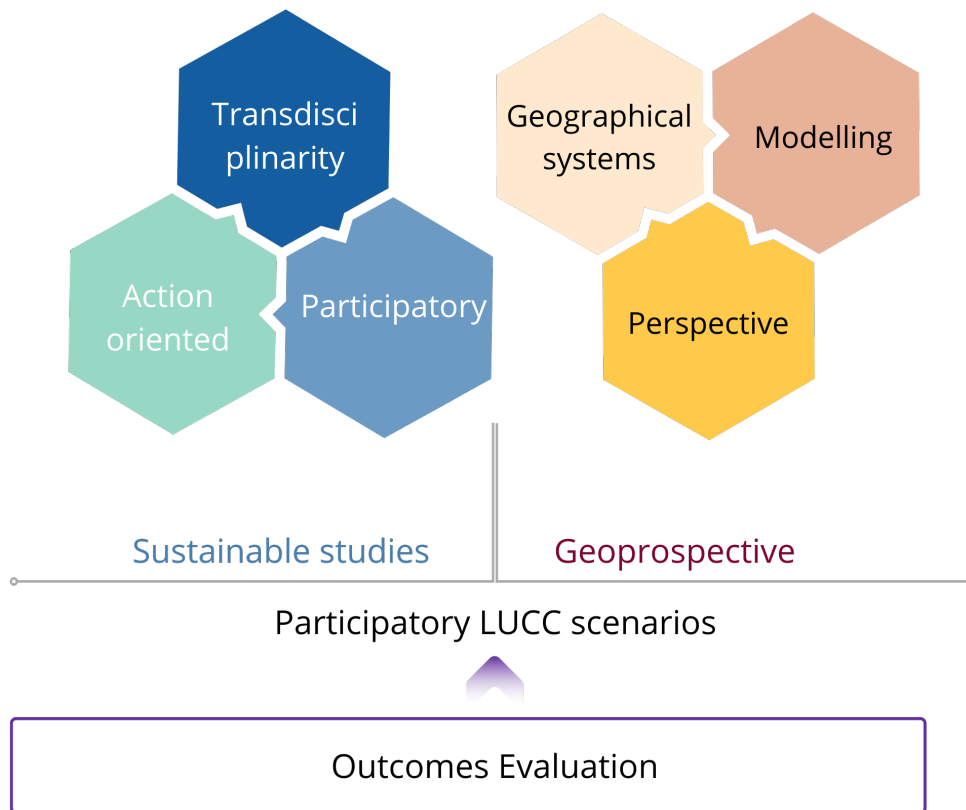


Figure 3 – Participatory Lucc scenarios belong in the same time to sustainable studies and to the geoprospective approach and are characterised by the methodologies and topics specific to these approaches. In this thesis, insights from outcomes evaluation will be applied to Lucc scenarios.

2.3 Partial Conclusion

Scenarios are “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). Consistently used in the foresight practice, scenarios have been **recognised as valuable tools for sustainable studies** for their support in developing long-term visions of the future. Indeed, reflecting on the co-evolution of social, economic and natural systems (Swart et al., 2004) is essential for the long-term resilience of socio-ecological systems.

In the history of scenarios, the USA and France are the leading geographical centres in which scholars developed different approaches to scenarios and foresight. While

some differences can be found between the different approaches to scenario-making, one common feature is the **combination of storylines** describing the evolutions of future trends and their **visual representations** (e.g. in the form of maps, videos, 3D pictures, and drawings). In developing storylines, scenario-makers often appeal to local experts and participatory approaches. On the other hand, **spatially explicit representations** are often produced by scenario-makers eventually through mathematical models that help to evaluate and visualise the impacts of hypotheses on the landscape at different time steps. While this thesis will focus on **fine-scale participatory scenarios**, fine to large-scale models can support understanding the complex interconnection between driving forces and responses.

If we focus on the agricultural context, decisions are taken at the farm level and are determined by personal preferences and broader scale forces such as biochemical limits of the soil, climate pressures, and economic and financial mechanisms. Moreover, agricultural practices determine patterns at different spatial scales and impact natural resources beyond the farm's boundaries. While fine-scale models are usually developed for restricted spatial extents, one main advantage is using the field as an elementary unit. Producing modelling outputs at the fine scale allows finely estimating impacts of agricultural management decisions on environmental variables such as water quality and quantity or biodiversity, giving insights for land management.

Finally, scenarios can be distinguished between **forecasting and backcasting scenarios** (based on the vantage point) and **normative and exploratory** ones (based on the presence/absence of the notion of desirability).

3 Applying evaluation frameworks to LUC C scenarios

Despite the ambition of scenarios in supporting decision-making (Harrison et al., 2019), verifying the effective outcomes is still far from standard practice (Oteros-Rozas et al., 2015; Von Wirth et al., 2014), and knowledge coming from the program evaluation is not yet wholly explored in its application to scenarios. However, some scenarios evaluation have been previously done (e.g. Baker et al., 2004; Oteros-Rozas et al., 2015; Palomo et al., 2011), allowing to develop guidelines for the production of outcomes-oriented scenar-

ios (e.g. Eriksson and Weber, 2008; Hagemann et al., 2020; Henrichs et al., 2010; Priess and Hauck, 2014; Therond et al., 2009). Moreover, some studies clarified the panel of potential outcomes of scenarios (e.g. Millenium Ecosystem Assessment (MA), 2005; Sitas et al., 2019) and produced some frameworks to evaluate them (Swart et al., 2004; Xiang and Clarke, 2003, see also Hamilton et al., 2019; Matthews et al., 2011; Yeeun Lee et al., 2022 for environmental models evaluation frameworks).

Driving from this literature and a larger panel of studies in spatial decision support systems, we put together the insights from Chapters 1 and 2 by analysing **how the concepts developed in program evaluation apply to sustainable studies scenarios.**

Salient	Credible	Legitimate
Goal oriented scenarios Clearly deduce challenges from storylines	Plausible unexpectedness Storylines that start from or reach a recognisable present Plausible visions of the future Novelty	Transparency of results, conclusions and methods (including models)
innovative transdisciplinary insights	Internally consistent storylines	Ergonomic design Appropriate number of themes, hypothesis, scenarios and appropriate time horizon
Timely	Locally based storylines consistent with wider hypothesis	Simple presentation Contrasted storylines Integration of different stakeholders' views, needs, values Informational vividness

Table 2 – Characteristics of usable scenarios.

As highlighted in Chapter 1.2.1, *usability* results from a salient, credible and legitimate study and those three characteristics take some particular nuances in the context of scenarios. A credible scenario reports plausible visions of the future with storylines that

start or reach a recognisable present (Mitter et al., 2019). At the same time, a consistent degree of novelty must be present, considering events that create unexpected shifts from the present trend and challenge expectations (Wilson, 1998). Xiang and Clarke (2003) call this connivance of plausible futures and surprising elements as *plausible unexpectedness*. Moreover, the hypothesis underpinning storylines must be internally consistent, and storylines adapted to a small area must be consistent with larger scale ones. On the legitimacy side, transparency on the results, conclusions, and methods used, including the model accessibility, is crucial (Durance and Godet, 2010; Hamilton et al., 2019). Furthermore, an ergonomic design of a scenario intended as an appropriate number of themes, hypotheses, and scenarios, as well as an appropriate time horizon, a simple presentation and well-contrasted storylines impact the legitimacy (Amer et al., 2013; Sieber et al., 2018; Wilson, 1998; Xiang and Clarke, 2003). Legitimacy also depends on integrating different stakeholders' views and the capacity of scenarios to represent the futures vividly, stimulating stakeholders' emotions and reflecting their needs, desires, motives and values (Mitter et al., 2019; Xiang and Clarke, 2003). This *informational vividness* (Xiang and Clarke, 2003) is also stimulated by considering relevant space and time for stakeholders and producing concrete visions of the future. Lastly, saliency represents the pertinence and importance of scenarios. A salient scenario is a goal-oriented scenario that, if the goal is supporting decision-making, gives specific insights to support a decision informing the duties of stakeholders (Mitter et al., 2019; Wilson, 1998). In this regard, storylines must allow stakeholders to deduce associated adaptation and mitigation challenges (Mitter et al., 2019) and allow for spatial specification, adding relevant information when applied at smaller scales. Storylines must give innovative, transdisciplinary insights, considering socio-economic, environmental and technological drivers and effects (Mitter et al., 2019; Sieber et al., 2018) and must be developed in a timely manner.

When scenarios are perceived as usable, envisioning different futures triggered by unprecedented events potentially engenders several direct and indirect outcomes emerging from the short to the long term (Saritas, 2006) at the individual, group and system level.

On the **cognitive side**, scenarios can stimulate learning in its instrumental and cognitive sense through the contribution of new information and the support in structuring already acquired one. Xiang and Clarke (2003) refer to this double cognitive outcome of scenarios as a *bridging and stretching function*. On the bridging side, scenarios

couple multiple little pieces of information and structure them into a systemic and coherent vision supporting a more comprehensive understanding of a complex system. On the stretching side, scenarios can widen the range of elements, drivers of change and possible futures considered. In this sense, scenarios can help to consider uncertainties in the reflection (Cook et al., 2014; Pereira et al., 2019), detect key variables of change (Godet and Lesourne, 1977) and anticipate management challenges (Van der Voorn et al., 2012). Stimulating causal thinking (Priess and Hauck, 2014) is also considered as a result of the stretching function of scenarios, including support in the identification of trade-offs (Palomo et al., 2011), of the effects of today's choices on different socio-ecological factors (Swart et al., 2004) and of patterns of change (Mas et al., 2012). Cognitive changes can also be reflected in group dynamics by introducing new information in collective discussions and promoting knowledge sharing, creative thinking and shared understanding of socio-ecological dynamics (Butler et al., 2015; Priess and Hauck, 2014), or by supporting the detection of issues in the established reasoning/management (Da Costa et al., 2008).

From the **political side**, scenarios can be used to promote personal and group preferences regarding desirable futures. Finally, on the **instrumental side**, substantial changes can happen in personal behaviours through transformative learning leading to private management decisions and change in openness towards other stakeholders. At the group level, instrumental outcomes regard instead the direct use of scenarios in selecting policy options and developing consensual intervention strategies. Scenarios can also be used instrumentally to improve management mechanisms, like creating structured collaborations or modifying management tools to overcome institutional incompatibilities (Hauck et al., 2019; Lumbroso, 2019; Ruckelshaus et al., 2015; Wimmer et al., 2012).

Finally, system outcomes arise indirectly in the long term and regroup shifts in the general understanding of a problem and in the way of thinking, priorities and functioning of a system (Hamilton et al., 2019). Table 3 resumes the potential outcomes of scenarios, which should be seen as continuously evolving impacts so that cognitive outcomes can lead to political and instrumental ones, and personal outcomes can support group ones, ultimately contributing to system outcomes (Ghazinoory et al., 2015).

Limitations and obstacles to the emergence of the outcomes of scenarios are also well documented. When facing complex systems and problems, scenarios must provide

	Individual	Group	System
Cognitive	Acquire new information (instrumental learning) Consider uncertainty; Detect key variables; Anticipate challenges	Consider new information in collective discussions Knowledge sharing; Shared understanding of socio-economic systems and dynamics; Create shared values; Creative thinking	Shift in community understanding
	Reinterpret previous information (Communicative learning) Stimulate causal thinking about effects of today's choices, trade offs, small/large scale drivers and effects; Highlight pattern of changes	Identify issues in established reasoning/management Detect institutional incompatibilities	
Political	Reinforce personal political opinion/preference	Support group political opinion/preference Mediate conflicts	Shift in community priorities
Instrumental	Change in personal behaviour (transformative learning) Change in private management; Change in attitudes towards other stakeholders	Develop of new policies Develop of management strategies; Support choices between options	Shift in community practices
		Modify management mechanisms Improve collaboration mechanisms between institutions/groups; Improve management tools	

Table 3 – Expected outcomes of scenarios according to the individual, group and system level and to the type of outcome.

a broad overview of possible futures to favour their stretching function (Sutherland and Woodroof, 2009). Nevertheless, the variables considered in scenario-making are limited

first because the system complexity and the lack of information prevent addressing them all, and second because reducing the system's complexity is crucial to produce cognitive outcomes. While usable scenarios must select a limited number of variables, the assumptions made to limit complexity are often non-explicit, creating a lack of transparency and biased decisions (Reed et al., 2013). Moreover, in selecting the variables included in the system, there is often a bias towards environmental variables (Winkler et al., 2018), possibly hindering relevance for decision-makers who base decisions mainly on social ones.

Moreover, while the benefits of participatory processes on the usability of scenarios are acknowledged (Reed et al., 2013), the involvement of local actors in storylines development can also introduce significant biases that must be recognised to increase the transparency of scenarios and reduce the emergence of biased ideas and decisions. Indeed participatory scenarios are based on local actors'expertise, values and opinions, and could reflect the voice of the most influential actors (Butler et al., 2015). As highlighted in program evaluation, assessing the outcomes of scenarios and categorising a scenario as successful is not easy, and several authors **associate success with the concordance with a pre-defined purpose** (Hamilton et al., 2019; Voinov et al., 2018). In particular, scenarios can be developed as decision-support, participatory, and research tools (Hamilton et al., 2019) reflecting the ability of scenarios to 1) support decisions, 2) support social learning and communication and 3) support a better understanding of the system.

4 The need for transformative science

In the context of a growing population and an exacerbated social and environmental crisis, the call for a radical transformation of economic and societal development is becoming increasingly frequent (McCrory et al., 2020; Schneidewind, Singer-Brodowski, Mandy Augenstein, et al., 2016). In this general call for profound transformation, researchers and practitioners implied in sustainable studies are pledging for a transformative science intended as “a specific type of science that does not only observe and describe societal transformation processes, but rather initiates and catalyzes them” (Schneidewind, Singer-Brodowski, Mandy Augenstein, et al., 2016, p. 6). More than a separate field, a transformative science approach can nourish sustainable studies (Horlings et al., 2020) by focusing on human-environment interactions in transformation contexts and giving a methodological framework to a field of study mainly constructed around a type of question.

In transformative science, science and society overlap, and the usability of science-produced knowledge is not the result of a negotiation between knowledge producers and users (Schneidewind, Singer-Brodowski, Mandy Augenstein, et al., 2016) but instead arises from a process in which researchers are one between multiple knowledge providers helping to understand and facilitate transferability of solutions. In this understanding and transfer process, people who confront and address a concrete problem (frontrunners) are seen as “having a sense of problem ownership”, overcoming the knowledge-first approaches that see society as the problem owner and science as a problem solver that shapes and answers research questions (Wittmayer and Schöpke, 2014, p. 485; Miller, 2013).

As for transdisciplinary research, the processes of developing transformative research vary significantly (Hilger et al., 2021). Nevertheless, real-world lab experiments are the primary context for carrying out transformative research. Indeed, anchored in the idea that experimenting with on-ground experiences leads to a better understanding of transformations, real-world experiments want to capacitate and create change (Kok et al., 2023) by testing and producing acceptable solutions for concrete problems and transfer them beyond the limits of the labs (McCrory et al., 2020; Parodi et al., 2018). While in natural science experiments, the environment is controlled, in real-world labs, the environment is constituted by society, with frontrunners initiating transformative experiments as main actors (Sengers et al., 2019). Moreover, embedding scientific knowledge in transformation processes implies rejecting the vision of researchers as knowledge providers and recognising a multiplicity of researchers’ roles in sustainability transitions (Wittmayer and Schöpke, 2014). Indeed, in transformative science, scientific knowledge and scholars are an active part of the societal transformation, frontally denying the concept of neutral science and embracing the idea of a science rooted in social progress that cannot exist outside politics (Racimo et al., 2022; Turnhout and Lahsen, 2022). In this perspective, advocacy is not seen as an activity harming scientific production (Kotcher et al., 2017; Nelson and Vucetich, 2009) but as part of the scientific activity. Moreover, advocacy can be expressed not only by engaging beyond academic context but also by asking action-oriented questions and by explicitly stating implications and actions suggested by finding (Green, 2020). Nevertheless, while several initiatives arise to create an academic environment favourable to research engagement into societal problems (e.g. the DORA Declaration; Kraas et al., 2016; NWO, 2019), transformative science requires a profound transformation of academia

escaping the “forces of metric fixation, competition, and commercialization” and leaving time and space for action (Urai and Kelly, 2023, p. 6).

This thesis focuses on the societal outcomes of science-pushed scenarios aiming for transformative change. In this context, while advocacy could occur in the scenarios’ results presentation phase, it is restricted in scenario-making. Indeed, in scenario-making, researchers collect participants’ visions on territorial evolutions, and legitimacy rests on including those visions in scenarios’ narratives without imposing the researcher’s one.

5 The national context

5.1 The Zone Atelier research network: A french socio-ecological initiative

In a recent article, Arpin et al. (2022) retraces the history of the french interdisciplinary research for the environment, which, even if not yet clearly constituted in a scientific field with standardised methodologies, can be assimilated with the international field of sustainable studies. Indeed, this French branch of scientific research shares with sustainable studies the interdisciplinary methods and a locally based problem-solving approach aiming to understand local realities and the socio-ecosystem interactions. With the increasing visibility of environmental problems, and in accordance with the international context, fighting against environmental deterioration became a stated priority in the French scientific and governmental sphere from the 90s. In that period, national scientific structures started to value interdisciplinary environmental research, and only in 2006 a transversal department of the National Center for Scientific Research (CNRS) addressing environmental issues (now called the Ecology and Environment National Institute - INEE) was created. In parallel, several structures allowing long-term locally based research had been structured. In particular, the Zones Atelier (ZA) are experimental sites equipped with research instruments for studying the complexity of socio-ecological systems in the long term from the prism of multiple disciplines, including social sciences. Depending on the INEE, the 14 national ZA are linked throughout a national network and, together with other similar structures (e.g. the Observatories Hommes Milieux and the European LTER platform), considerably support the national development of sustainable studies and transformative science. Moreover, the real-world lab approaches are declined nationally via the

experiences of the territoires-ecoles (Cayre et al., 2021).

5.2 The water management: a regulatory context requiring foresight studies

Besides the scientific structures facilitating the application of goal-oriented interdisciplinary research, some institutional mechanisms favour the convergence between public managers, technicians and research tools. In particular, the integrated approach characterising French water management (Biswas, 2004; Hassin et al., 2009) implies cross-cutting management decisions (Daudin et al., 2021), making the water sector a breeding ground for sustainability studies. Even if the implementation of integrated management practices is still limited, interactions between water agencies, researchers and technicians are promoted (Bouleau, 2014; Daudin et al., 2021). For example, the **French water management system requires a prospective phase** to support the choice of the management strategy to adopt (Allain, 2002). Although consultancy firms rather than public research institutes are commonly in charge of this prospective phase, the obligation to include foresight studies in the policy-making process shows some level of anticipatory governance (Quay, 2010).

As defined by the Water Act of 3 Jan 1992 (Allain, 2002), which established the creation of the Local Water Commission² (CLE) and the Water Development and Management Plan³(SAGE), water in France is managed at the watershed level. The CLE is the political body, composed of local authorities, users and State representatives, that proposes the SAGE consistently with the broader scale Water Development and Management Directive Plan⁴ (SDAGE) and approves it after a public consultation. Once the SAGE is approved, a technical structure manages and monitors the implementation of its directives on the ground, and several local programs can translate them into practical operations (Allain, 2002; SAGE Blavet, 2013). This water management organisation relies on a participatory planning approach, where different local actors are meant to jointly manage the ensemble of water-related issues such as irrigation, sanitation, drinking water, aquatic environments and flooding (Allain, 2001; Rinaudo et al., 2020). The jurisdiction of operational organisations reorganised significantly beginning in 2018, when the MAP-

2. Commission locale de l'eau in French.

3. Schéma d'aménagement et de gestion de l'eau in French.

4. schémas directeurs d'aménagement et de gestion des eaux.

TAM 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 planning phase unchanged.

On the land-planning side, the reference documents are the Territorial Coherence Schemes⁵ (SCoT), which must be consistent with the objectives imposed by the SAGE but developed for a different administrative unit not based on geographical boundaries but rather on administrative ones.

6 Partial conclusions

The field of sustainable studies is characterised by the ambition to produce action-oriented knowledge. To verify if this clear goal of sustainable studies is reached, scholars mobilised the precedent works that flourished in the field of program evaluation to assess the continuing evolving conceptual, political, and instrumental outcomes linked with sustainable studies. Together with outcomes, works analysing the usability, the impact pathways and the biases induced by the evaluation time have been produced. **In this thesis, we focus on the outcomes of scenarios**, a tool used in sustainable studies and particularly in foresight. While the lessons learned from program evaluation had not yet been thoroughly explored in its application to scenarios, some studies allow to clarify the specificity of the term *usable* and the panel of potential outcomes applied to scenarios. Driving from this literature, some of the main characteristics of a usable scenario are a timely goal-oriented scenario in which socio-environmental challenges can be deduced from simply-presented and internally consistent storylines. Moreover, storylines must be in an appropriate number and with an appropriate time horizon, contrasted, simultaneously plausible and including novelty, and they must integrate different stakeholders' views.

On the outcomes side, scenarios can produce cognitive, political and instrumental outcomes. At the **individual level**, cognitive outcomes include acquiring new knowledge and competencies, such as considering uncertainty and anticipating challenges or reinterpreting previously acquired information. Also, political and instrumental individual outcomes can appear. E.g. scenarios can reinforce personal political preferences and support a change in personal management or attitude towards other stakeholders. **Group**

5. Schéma de cohérence territoriale

outcomes include group effects of social learning, such as a shared understanding of socio-economic systems and the identification of institutional incompatibilities with collective goals/views. On the group instrumental side, scenarios can support the development of new policies and the modification of sub-optimal management mechanisms. Finally, a shift in community understanding, priority and practice can happen indirectly in the long term.

While scenarios have been applied to a multiplicity of domains, this thesis will focus on scenarios developed for local French agricultural contexts using a geopropective approach that combines narratives, participatory methods and (fine-scale) modelling. A structured scientific field corresponding to sustainable studies is not yet constituted in France. Nevertheless, several national structures allow long-term, locally-based transdisciplinary research to study socio-ecosystems and fostering transformation. Moreover, some institutional mechanisms favour transdisciplinary research. In particular, the integrated approach characterising French water management implies cross-cutting preoccupation and management decisions, making the water sector a breeding ground for sustainability studies. In addition, the water management system requires a prospective phase and is entangled with agricultural and urban management through financial and legal mechanisms. This presence of some level of anticipatory governance and interconnections between different environmental management sectors makes French water management a rich context to study the outcomes of fine-scale scenarios, with converging methodological scientific interests.

7 Objectives and structure of the thesis

7.1 Identifying the knowledge gap

While in the private sector, some scenarios evaluation has been produced (Chermack et al., 2006; Ghazinoory et al., 2015; Haeffner et al., 2012; Phelps et al., 2001), and the capacity of scenarios to positively affect decision-making has been proved (Meissner and Wulf, 2013), evaluation on the broad spectrum of outcomes of scenarios in the public context is still confronted by numerous barriers (Volkery and Ribeiro, 2009). Indeed, while scenarios can benefit from monitoring accordance between original purpose, impact pathways and outcomes (Arnott et al., 2020; Karcher et al., 2021), evaluations are often overlooked because of a lack of time and resources, pressures and bias on researchers, a lack of recognition of evaluation benefits, and a lack of standardised evaluation procedures and expertise (Hamilton et al., 2019).

Recently Hedelin et al. (2021) conducted a literature review of 60 participatory modelling projects finding that over 60% did not report any evaluation and 90% lacked a description of evaluation criteria, methods of data collection and analysis. Similarly, Karcher et al. (2021) analysed a panel of studies based on knowledge exchange processes and found that scholars often claim outcomes more than reporting evidence. Moreover, despite the general agreement on looking at outcomes as evolutive processes that change over time, the temporal dimension of outcomes has rarely been addressed (Reed et al., 2021) and lessons learned in engaging different stakeholders in scientific programs are rare (Skarlatidou and Haklay, 2021).

To address this knowledge gap, Arnott et al. (2020, p. 41) suggest developing and applying an “interactive, iterative, and evaluation-centred approach that learns by doing”, implying a structured dialogue between knowledge funders, users and producers and those studying science-societal interactions. While some studies have been conducted, to our knowledge, there is no study assessing the outcomes of spatially explicit scenarios considering various stakeholders’ perceptions, the evaluation moment and impact pathways at once.

7.2 Defining the research questions

This thesis evaluates the personal and group outcomes of two LUCC participatory scenarios studies, which can be attributed to sustainable studies, arising at different time frames and from different impact pathways.

According to the well-recognised need for social learning to tackle environmental problems, we wanted this thesis to be a way to foster outcomes more than purely evaluate them. For this reason, we privileged the analysis of different impact pathways and organised a dissemination activity allowing us to present scenarios and debate them with a broad audience. Moreover, this approach allowed us to introduce a supplementary variable in our analysis (besides timing and impact pathway): the respondent's profile in terms of professional activity. Nevertheless, this choice prevented us from analysing more case studies, for example, introducing some policy-pulled scenarios.

Following Muhonen et al. (2020), the impact pathways we analyse are the collaboration and the interactive dissemination pathway. The first was followed by the local actors involved in the transdisciplinary co-creation of scenarios in which researchers and stakeholders collaborated on several occasions along the project. The second was followed by the local actors who got to know the LUCC scenarios and their results via the dissemination workshops. As highlighted in the introduction, evaluation time is crucial in detecting outcomes. We hence decided to structure the thesis around this variable. Short-term, mid-term and long-term evaluations are then proposed.

The research questions that guide our work are the following:

1 What are the outcomes of LUCC scenarios over time?

1a) How do science-push scenarios modify how territorial dynamics are understood outside the land-management decision-making process?

1b) Do science-pushed scenarios enter into the land-management decision-making process? In which way?

2 What are the main factors influencing outcomes?

2a) The effect of time: do local actors' perceptions of outcomes change over time? For which type of actors and for which type of outcomes?

2b) Complementarity between impact pathways: what is the contribution of (less)more time-consuming pathways on outcomes?

2c) Are there any other influential factors besides time and impact pathways?

In addition, this introduction showed how sustainable studies is expected to produce actionable science that directly contributes to finding solutions to concrete problems (Dilling and Lemos, 2011; Pearman and Cravens, 2022). Nevertheless, program evaluation studies show that direct research use in decision-making is seldom registered. By analysing the mechanisms through which LUCC scenarios can lead to cognitive, political and instrumental outcomes, we will give some insights into this apparent paradox which may depict action-oriented research as a utopia.

7.3 Thesis structure

The rest of the thesis is structured as follows: the next chapter presents the two fine-scale LUCC scenarios studies (ALICE and Lestolet scenarios) evaluated in this thesis; Chapters 1 and 2 evaluate ALICE scenarios in the short and mid-term, while Chapter 3 proposes a long-term evaluation of Lestolet scenarios. Finally, the last chapter draws some general conclusions.

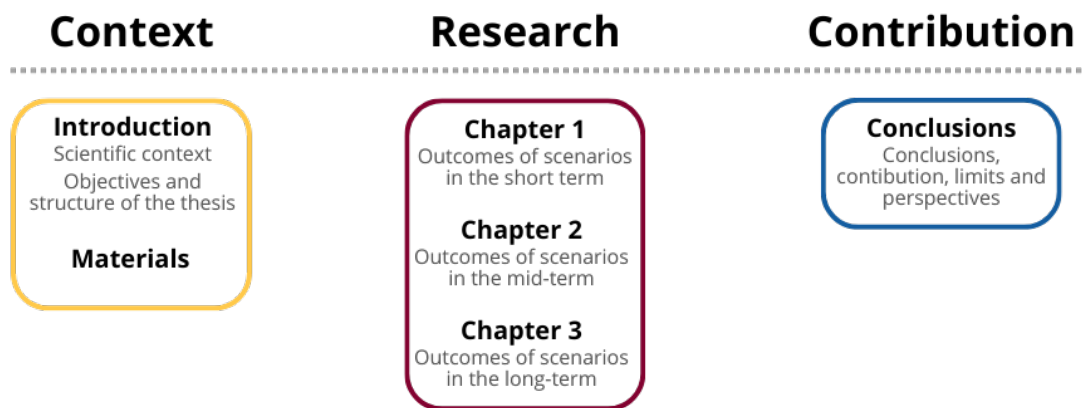


Figure 4 – Thesis structure scheme.

The research-based part comprises three chapters, each containing a research paper submitted or published in a scientific journal (see Figure 4). Each paper is briefly introduced by a chapter re-situating its contribution to the thesis and is followed by a partial conclusion chapter. The partial conclusions presented in Chapters 1, 2 and 3 have a dual scope. On one side, they report the results that go beyond the paper’s scope or over which

we were not able to construct a solid methodological analysis but that are useful in the larger framework of the thesis; on the other side, they resume the take-home messages of the chapter.

The structure of the thesis and the choice of case studies reflect the willingness to study outcomes of different impact pathways over time. Indeed the first scenario was developed for the Couesnon watershed in the ALICE Interreg project (2016-2022), and the second was developed for the Lestolet watershed in the framework of Thomas Houet's PhD thesis (2003-2006). When this thesis started, the ALICE project entered its last semester, allowing us to investigate its short- and medium-term outcomes. On the other hand, with the Lestolet project, we evaluate the long-term outcomes of scenarios produced more than 15 years ago. Besides the evaluation-time effect, the thesis structure captures the effect of different impact pathways strategies. Indeed, the ALICE scenarios were produced and diffused following two distinct impact pathways.

Figure 5 represents the time evaluation and impact pathways covered by articles in Chapters 1, 2 and 3 and an overview of the specific research questions assessed in each paper. As a general overview, in Chapter 1, we investigate if disseminating scenarios previously co-created with a restricted pool of actors to an external audience can enhance outcomes. We presented Alice LUCC scenarios in 12 workshops and collected feedback from 147 local actors, including representatives, water management technicians, farmers and students. The protocol we followed permits us to verify whether local actors perceive scenarios as usable and detect cognitive outcomes. Data were collected through an interactive survey, and the aggregated results were shown in real-time to the assembly to support group discussions. Comprehensive notes of the debates were taken for each session and re-examined. Differences between stakeholders groups answers were analysed with statistical methods. The same protocol was used with people participating in the co-production phase, but answers were not used in the analysis for statistical reasons.

Chapter 2 reports the results of interviews with 20 people who participated in the previously mentioned workshops or the co-creation phase aiming to evaluate tangible outcomes of scenarios. Interviews were composed of semi-structured, reactivation and framing parts, and the collected data were analysed using a lexicometric and thematic analysis.

Chapter 3 presents an ex-post evaluation of LUCC scenarios produced in 2004 based on semi-structured interviews and a quantitative comparison between observed and simulated LUCC. The objectives were to evaluate to what extent the long-term outcomes of scenarios reflect expectations found in the literature and to understand which factors influenced their occurrence. Moreover, we provide insights into the LUCC driving forces to consider in producing plausible fine-scale scenarios.

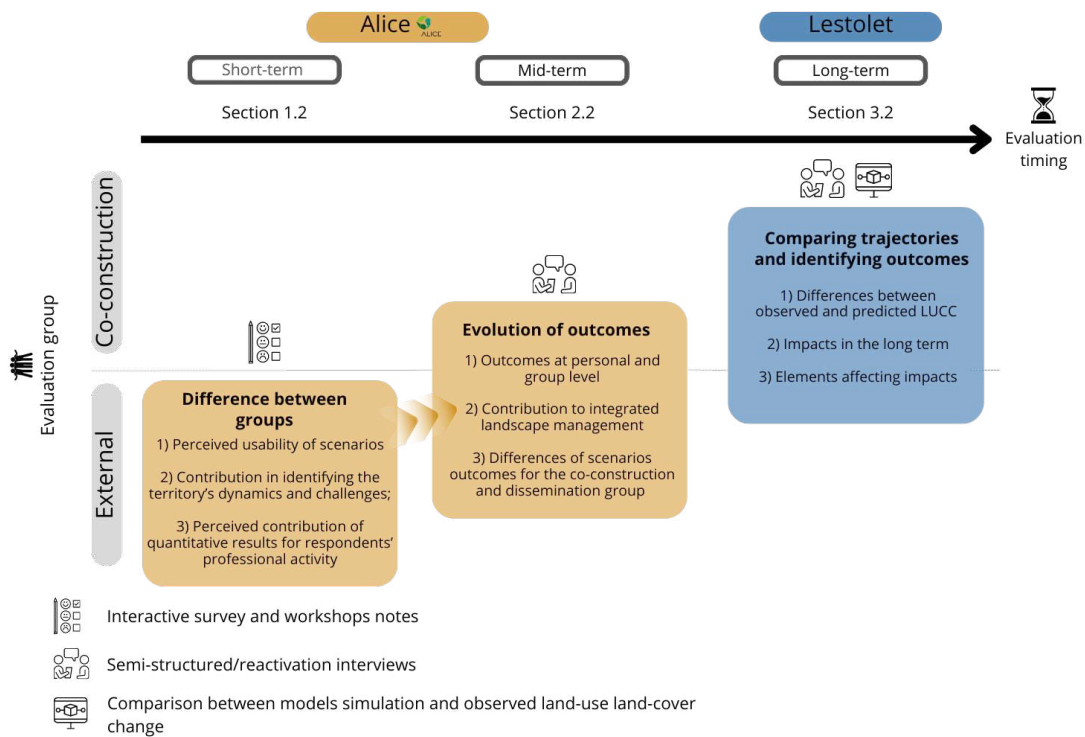


Figure 5 – Scheme of the three articles (corresponding to Section 2 of chapter 1, Section 2 of Chapter 2, Section 2 of Chapter 3) according to stakeholders included in the study and the evaluation time.

While each paper has its own research questions, we address the general thesis questions by compiling and comparing their results, as shown in Figure 6.

In terms of data collection and analysis, this thesis combines quantitative, qualitative and mixed methods design. Indeed, while face-to-face interviews took an important place in this thesis, we also used quantitative data from surveys and land use cover maps.

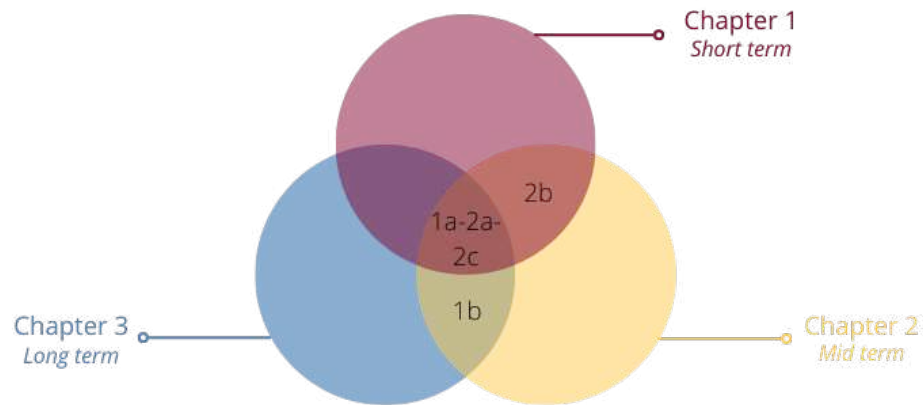


Figure 6 – Contribution of the central thesis’ chapters in answering the thesis questions listed in Section 7.2.

Finally, as this thesis reflects on the research’s impacts on society, I consider it necessary to acknowledge my background. Indeed, my positioning as an Italian, white, middle-class, able young woman with access to high-standard education undoubtedly influences the vision of society and what is to be considered a benefit that underpins this work.

This research work was carried out within the framework of Terranova International Training Network (ITN), the European Landscape Learning Initiative, which has received funding from the European Union’s Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie [grant agreement No 813904]. The output reflects the views only of the authors, and the European Union cannot be held responsible for any use which may be made of the information contained therein. Terranova is the European Landscape Learning Initiative that trains 15 PhD candidates to look at climate change, human-environment interactions, and environmental policies in Europe by integrating research questions and methods across natural, humanities and social sciences. The Terranova ITN is rooted in the scientific agreement of the unprecedented intensity and impact of land management on natural systems and the consequent need for landscape

management supporting the transition to a low-carbon society. The idea underpinning the project is that learning about long-term past landscape management strategies can support a new generation of models and scenarios promoting sustainable land use in the future. Therefore, the three main research objectives of this ITN are: 1) to **reconstruct** the deep history of Europe's cultural landscapes and corresponding changes in coupled human-nature interactions, 2) to **rethink** the outcomes of human-environmental interactions over the past three energy regimes on the present-day landscape in Europe, 3) and to **redesign** landscape management strategies. My contribution to the overall projects is embedded in this third objective. More specifically, this thesis aims to understand how scientific knowledge integrating insights of past landscape evolution with envisioned futures must be co-created and diffused to land managers and practitioners to impulse innovative and integrated land management strategies (Fayet et al., 2021; Lindholm et al., 2020). This work was based at the laboratory LETG-UMR6554 (Littoral Télédétection Environnement Géomatique) of the University of Rennes 2 (France).

MATERIALS

This thesis evaluates the outcomes of two science-pushed LUCC scenarios studies developed for two watersheds in Brittany (western France) (see Figure 7). The selection criteria were the fine-scale and the focus of scenarios on environmental issues. In addition, access to raw materials and contacts with stakeholders who participated in the scenarios'elaboration and with people to mobilise in the dissemination workshops was also a criterion. The selected scenarios are developed for the Couesnon (1130 km²) and Lestolet (1320 ha) watersheds and focus on agricultural land use changes and their influence on water management and/or biodiversity. The Couesnon case study comprises forecasting scenarios, while backcasting scenarios are also represented for the Lestolet. The most prominent space given to exploratory scenarios is due to the role they have in the decision-making process. Being recognised as particularly suited for the definition of the problem and the agenda setting, they are expected to produce not just instrumental outcomes in an institutional context but also cognitive outcomes that can eventually produce action in the long term.

The selected scenarios differ in type and the spatial extent and have been developed 15 years apart. Even if I did not contribute to developing these scenarios, we dedicate this chapter to their production process and results. Indeed it facilitates understanding the materials I worked with and what had been presented to local actors during the restitution and dissemination workshops. The presentation of the study sites and their socio-demographic and geographical context are presented in appendix 1.1 and 1.2 as part of previous studies.

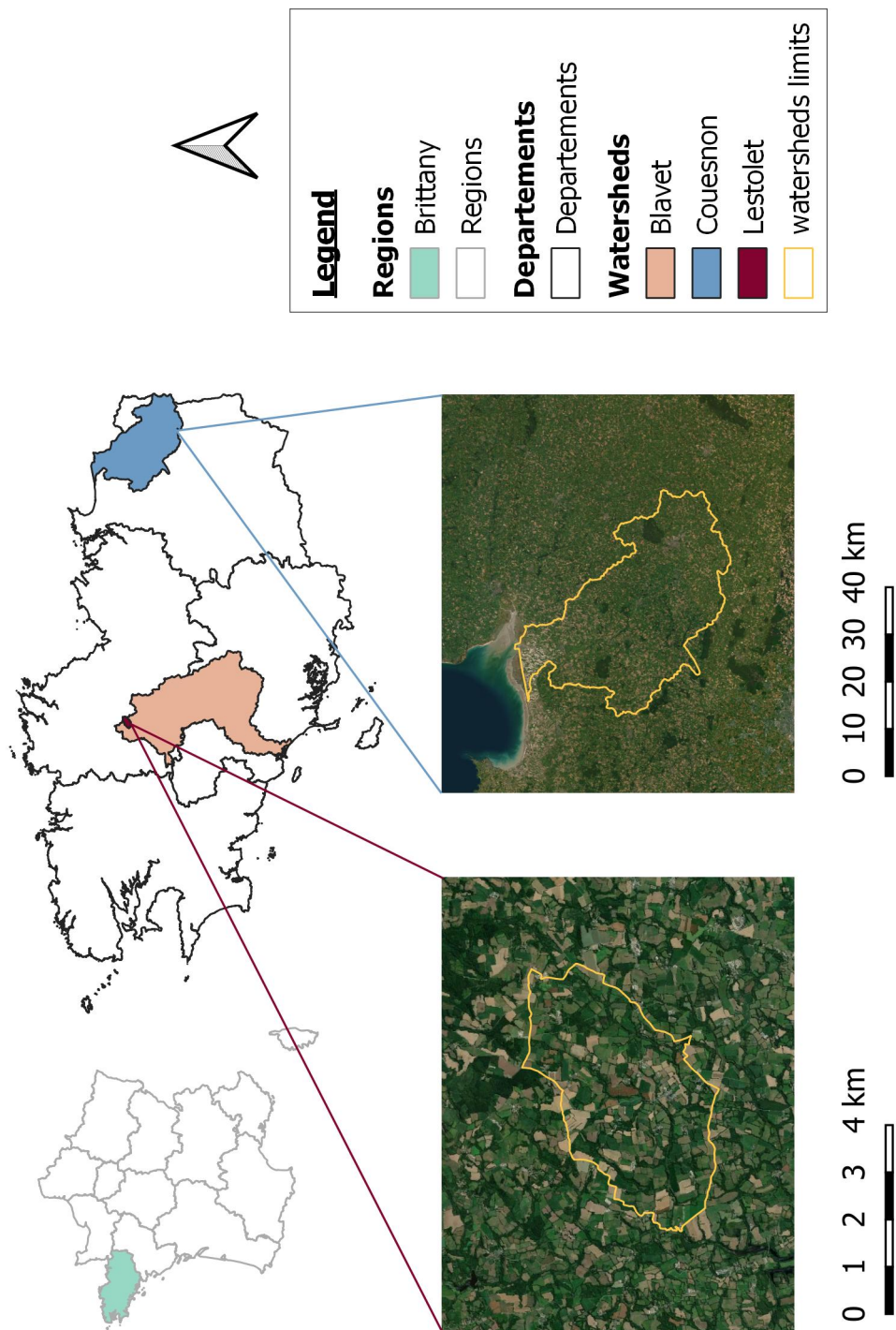


Figure 7 – Location of the two study sites (yellow lines). The Lestolet watershed (red area) is located in central Brittany (France) on the northern edge of the Blavet watershed (reddish area). The Couesnon watershed (blueish area) is located in North West Brittany.

1 Scenarios for the Couesnon study area

The Couesnon scenarios (hereafter Alice scenarios) were developed as part of the ALICE Interreg project⁶ (2016-2022). Scenarios are described in Houet et al. (2022), in which I collaborated principally for the discussion. Here, we report some extracts to expose the material used for Chapters 1 and 2 of the thesis and reintegrate it with the impacts of LUCC on water quality and quantity that are not presented in the paper but that were discussed with the local actors.

1.1 Overview of the methodology

ALICE scenarios evaluated the potential effectiveness of designing Blue and Green Infrastructure Networks (BGIN) strategies by exploring the influence of multiple and contrasting pathways of land-use intensification for the Couesnon watershed at a fine scale.

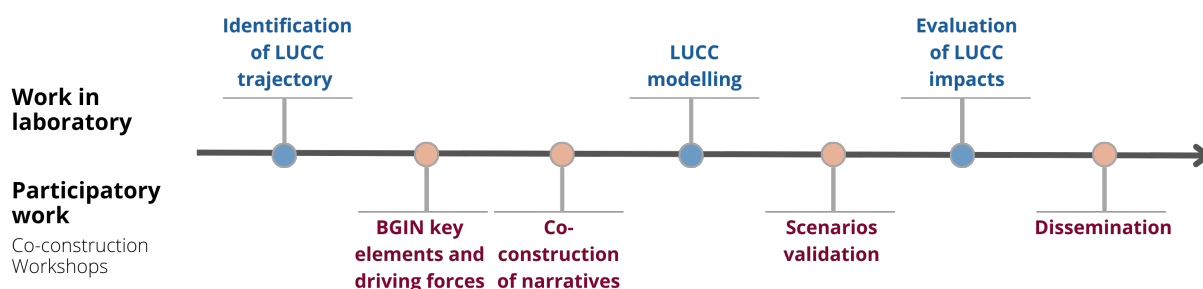


Figure 8 – Overview of the overall method used to develop Couesnon scenarios combining studies carried out in laboratory (in blue) and participatory steps (in red).

Figure 8 represents the overall workflow of scenarios: 1) First, scenario-makers characterised the site's land-use and cover change (LUCC) trajectory; 2) second, they organised two participatory meetings that helped collect the information required to build narratives; 3) third, they developed the FORESCEM modelling framework and used it to simulate future LUCC based on the narratives; 4) fourth, they presented to local stakeholders the combination of LUCC simulations and narratives for validation; 5) once validated, the scenarios provided inputs for the estimation of future LUCC impacts on biodiversity through the lens of landscape connectivity. In addition, impacts on water quality and

6. Alice Interreg project's website (accessed the 12.01.2023) : <https://project-alice.com/alice-project/>

quantity were calculated; 6) finally, results were analysed and disseminated to a broader audience in the framework of this thesis.

1.2 Study area and LUC trajectory

The case study focused on the Couesnon river watershed in the Armorican massif in North West France flowing into Mont-Saint-Michel bay (a UNESCO World Heritage Site). It contains mainly intensive agriculture with mixed dairy/livestock production upstream, while vegetables/cropping systems dominate in the polders next to the sea. The agricultural landscape is dominated by grasslands (temporary and permanent), maize and other cereals/oilseeds (wheat/rapeseed/barley). The landscape has a hedgerow network of variable density and connectivity. Except for two extensive forests, wooded patches are quite small in the agricultural matrix. A Natura 2000 floodplain, the Sougéal marsh, lies near the estuary and is a hotspot of bird biodiversity close to one of the most important and complex bays worldwide.

The area's agriculture intensified greatly after 1945, with the utilised agricultural area (UAA) shifting predominantly to maize (+39 964 ha) since the early 90s, which has decreased the area of grasslands by 43% (Figure 9).

Along with the loss of grasslands, agricultural fields have been abandoned due to problems of accessibility, size, forage production and flooding, especially in valley bottoms, which transitioned to shrublands and then forest, reaching 7 791 ha in 2018. During this period, urban land also increased due to urban sprawl and the construction of the A84 highway (+5 951 ha). The two main ecological concerns in the area are water quality and quantity, which are impacted by agricultural practices. Indeed, agricultural practices emit large nutrient loads into the Couesnon River, the primary drinking water source for local populations, including the Rennes metropolitan area. Overall, 30% of the water pumped is exported and consumed outside the watershed. Furthermore, in the last decades, agricultural intensification, land abandonment in valley bottoms, urbanisation, and soil sealing caused a simplification of the landscape matrix, decreased landscape connectivity and generated biodiversity losses (Kazemi et al., 2018). Lastly, a ZA covers a small portion of the area of interest but facilitates exchanges between researchers and inhabitants.

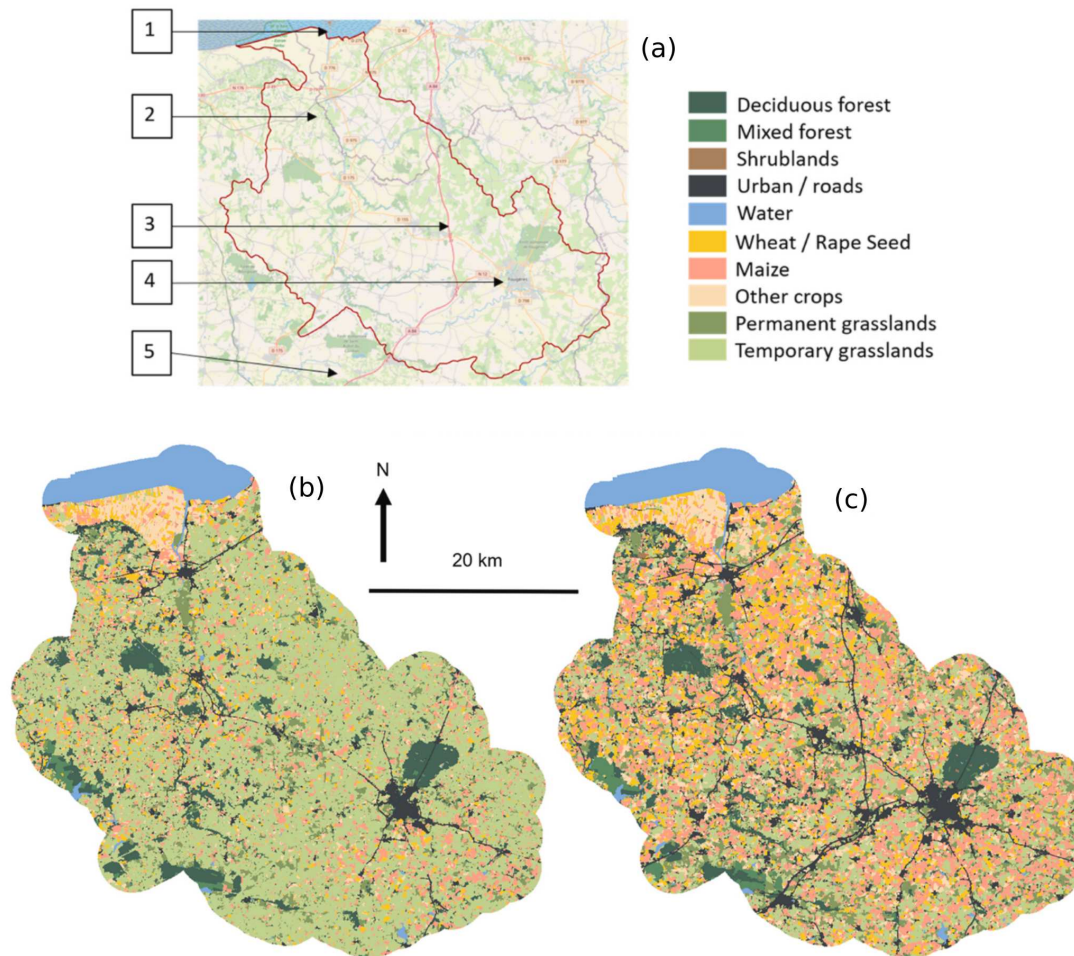


Figure 9 – (a) Couesnon watershed (red outline) and key geographical features: 1 - Mont Saint Michel, 2 - Sougéal marsh Natura 2000 site, 3 - A84 highway, 4 - Fougères metropolitan area, and 5 - Rennes metropolitan area, 40 km from Fougères; land-cover maps in (b) 1990 and (c) 2018.

1.3 Scenario assumptions

The Couesnon scenarios consist of contrasting narratives illustrated by LULC maps. Narratives were defined by combining three independent and contrasting assumptions for agriculture and territorial development (Table 4).

		Territorial development		
		<i>Business-as-usual</i>	<i>Energy transition</i>	<i>Ecological citizen</i>
Agricultural development	<i>Cerealization</i>	DESERT OF CEREALS	ENERGY PERFORMANCE	CONFLICTS
	<i>Dairy intensification</i>	BUSINESS-AS-USUAL	DIVERSIFIED BIOMASS	DOUBLE PERFORMANCE
	<i>Greening</i>	Ø	OPTIMIZED BGINs	GREEN ATTRACTIVENESS

Table 4 – Combination of territorial and agricultural development assumptions. The five most contrasting scenarios (in bold) were selected to explore the widest diversity of possible futures.

Given a temporal horizon of 2050, agriculture could evolve in three directions:

- The first is the “cerealisation” assumption, which favours producing cereals as biomass or biofuel. This is due to a decrease in dairy and livestock production in Brittany in response to the dairy production increase in eastern and central European countries. Locally, less favourable agricultural lands (riparian meadows) are abandoned.
- The second is the “dairy intensification” assumption. The Common Agricultural Policy (CAP) reform creates subsidies per ha that favour the intensification of local dairy/livestock production. Excessive nutrient flows are treated in small biogas plants while fertilisation practices improve.
- The third direction is the “greening” assumption: the CAP will be transformed in 2025 to promote an agroecological transition and agrifood protection. Dairy and livestock production diversify and are based mainly on grassland forage, organic farms increase in total area, and agricultural products are dedicated to local markets.

Territorial development respects local urban-management plans set at the municipal level. It is also driven by the social demand from inhabitants for certain types and locations of housing. It could evolve in three directions. Territorial development respects local urban-management plans set at the municipal level. It is also driven by the social demand from inhabitants for certain types and locations of housing. It could evolve in three directions.

- The first is the “business-as-usual”: inhabitants prefer single-family houses with a small yard, and municipalities compete to attract future inhabitants (+31 600 in 2050; AUDIAR, 2018; INSEE Bretagne, 2019a, 2019b). The objective of *zero urbanisation* (France Stratégie, 2019) cannot be attained in 2040, although the main BGINs are protected from urban sprawl.
- The second direction is the “energy transition”: first, commuting decreases due to the development of teleworking, and the high-energy performance of new and renovated houses is the norm. The energy-oriented economy makes the Couesnon watershed attractive for people (+38 800 inhabitants). Urban sprawl is controlled and concentrated in the main urban areas. The zero-urbanisation objective will be met by 2045, and BGINs will be strongly preserved.
- The third direction is the “ecological citizen”: development is driven by citizens’ preferences for a better quality of life and food independence. The area is more attractive than other areas in Brittany (+35 900 inhabitants), and the zero urbanisation objective is not met. However, BGINs are strictly preserved, and local authorities favour ecological preservation and restoration.

Combining these 3×3 assumptions creates eight internally consistent scenarios (one combination is inconsistent). The five most contrasting scenarios (bold in figure 4) were selected to explore the widest diversity of possible future landscape changes. These assumptions were presented to, refined, and completed with stakeholders during the first participatory meeting. The second participatory meeting helped to specify them by considering local characteristics through narratives and participatory mapping. Researchers then refined and quantitatively illustrated Narratives using the FORecasting landscapE SCEnarios Model (FORESCEM) model and calculated the impacts of simulated Lucc on biodiversity and water resources.

1.4 LUCC and Landscape connectivity model

The FORCEM model (Palka et al., n.d.) allows to allocate the LUCC corresponding to the narratives. It was used to simulate LUCC from 2018 to 2050 at a fine scale while preserving landscape patterns (fields). LUCCs are defined as natural vegetation dynamics (e.g. from grassland to forest states) and agricultural or forest cover successions (e.g., crop rotations, maturing forest). LUCCs are also associated with any change due to human decisions such as urban planning or land abandonment. A regulatory map of the BGINs, designed in the SCoT, can be considered as areas protected from future urbanisation.

The simulated land-cover maps for each of the five scenarios were used as input for a landscape-metrics spatially explicit model that estimated landscape connectivity and a model estimating water quality and quantity. For estimating landscape connectivity, the researchers selected an indicator specie for woodland, grassland and wetland and estimated connectivities using CHLOE landscape metrics software (Boussard et al., 2020). Three steps are followed to obtain connectivity maps: (1) first, researchers spatially characterise potential habitats for each indicator species, (2) then they create a permeability map that describes the species'ability to move through patches (3) last, they create a connectivity map that illustrates the areas that can be reached by the species from their potential habitats to a maximum dispersal distance considering permeability. Raster maps had a resolution of 10 m. To estimate the impacts of future LUCC on biodiversity in the Couesnon watershed, researchers used two indicators of landscape connectivity as proxies: extent and quality. The extent equalled the total area of connected habitats in the landscape (i.e. with positive mean landscape connectivity, which was defined as the mean of the three types of connectivity per pixel). Quality equalled the total connectivity values over the study area for each species. Connectivity indicators were ultimately evaluated by comparing current (2018) indicators to those for the scenarios (2050).

For determining water quality in terms of pollutant concentration, researchers coupled a model estimating the flux of nitrates and phosphates with a hydrological model estimating the water quantity (see Álvarez-Cabria et al., 2016 for more details). To estimate the flux of nitrates and phosphates, researchers used a model that integrates several explicative variables such as land use, the percentage of crops and forests and the landscape mosaic. Initially developed for mountainous regions, some peculiar explicative variables adapted to the Brittany context were added (i.e. the percentage of grassland, maize and

other cereals). Subsequently, the effects of the different predictors on the response variables were calibrated for the Couesnon on the base of in-situ historical measures. The hydrological model estimating water quantity was calibrated on data collected in one station situated in the Couesnon watershed (Romazy station) between 1980 and 2018. It considers variables such as altitude, soil type, precipitation, and temperature. The water quantity and the concentration of nitrates and phosphorus had then been estimated for the LUCC envisioned in the scenarios, and a temperature rise corresponding to the 8.5 IPCC scenario on climate change for the upstream area of the catchment.

1.5 Scenarios results

Scenarios results were published in the cited scientific article (Houet et al., 2022), and a booklet was printed and published in french on the Alice webpage and the Syndicat du Bassin Versant Couesnon webpage⁷.

Refined narratives (see Box 1 for an example of a narrative taken from the booklet) were developed for the five scenarios and presented as storylines. Moreover, LUCC changes were presented as maps (from 2018 to 2050) and stacked graphics showing changes in crop surface, urban areas, and km of hedgerow (Figure 10 and Figure 11). The areas characterised as “intensive agriculture areas” are identified by counting the occurrences of a plot covered by maize and wheat over 2018-2050 for the most intensive scenarios. The agricultural intensification mainly concerns the area surrounding the Sougéal marsh and the area south and east of Fougères.

Connectivity changes were also presented as maps and tables for the five scenarios (Figure 12 and Table 5).

7. Syndicat bassin versant Couesnon webpage (consulted the 09.01.2023): <https://bassin-couesnon.fr/bassin-couesnon/les-actions/les-etudes/>

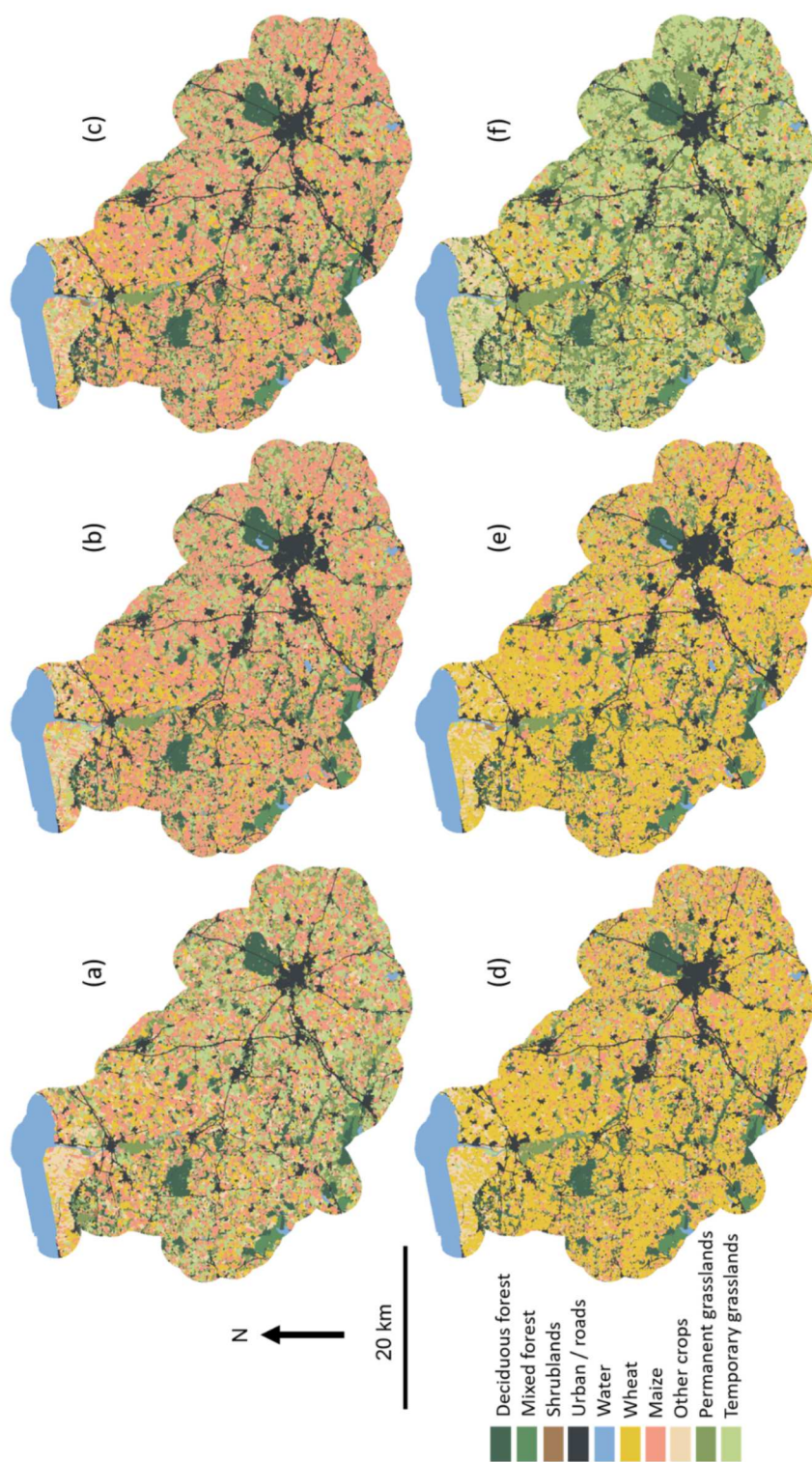


Figure 10 – Land-cover maps for the Couesnon watershed in 2050 and predicted in 2050 with the FORESCEM framework for the (b) Business as usual (c) Double performance, (d) Energy performance, (e) Desert of cereals, (f) Green attractiveness.

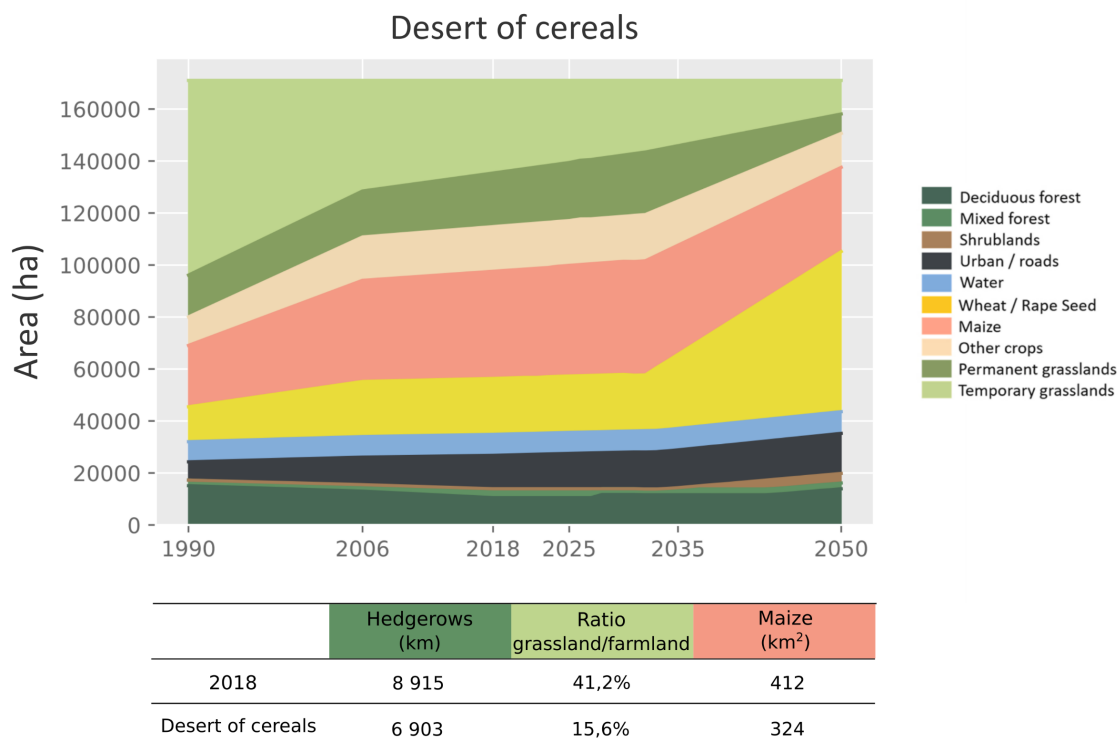


Figure 11 – Evolution of crops and landscape elements for the Desert of cereals scenario.

Box 1: Energetic Performance narrative

Territorial development continues the current logic of competition between territories and the urbanisation of peri-urban areas, coupled with the cerealisation of the territory. The agricultural identity based on cereal and energy production represents a change in the territory’s identity, but it’s based on the seeds of change already at work in 2018 in Brittany. Cereal crops (wheat, rapeseed, maize) are developing massively everywhere. They feed the methanisation plants set up in the catchment area. Livestock farming, which is now very limited, is no longer predominant in the landscape: only a few meadows remain visible at the bottom of the valleys and in the protected sensitive natural areas. Similarly, a few isolated trees dot the plateaus. Moreover, hedges have almost disappeared from the agricultural land (-2012 km): they can only be found on the edges of housing estates built around historic towns, along roadsides or at the edge of farms. In urbanisation, the villages are expanding due to individual housing construction, and the limited urban renewal transforms a few agricultural buildings into residential houses. In parallel, economic zones continue to develop along the A84 motorway. The most significant change is the creation of reservoirs and hillside reservoirs financed by the Rennes metropolitan area. Indeed, accentuated by the effects of climate change, tensions on water resources are increasing due to the cerealisation of agriculture in the catchment area and the demographic growth of the Rennes area.

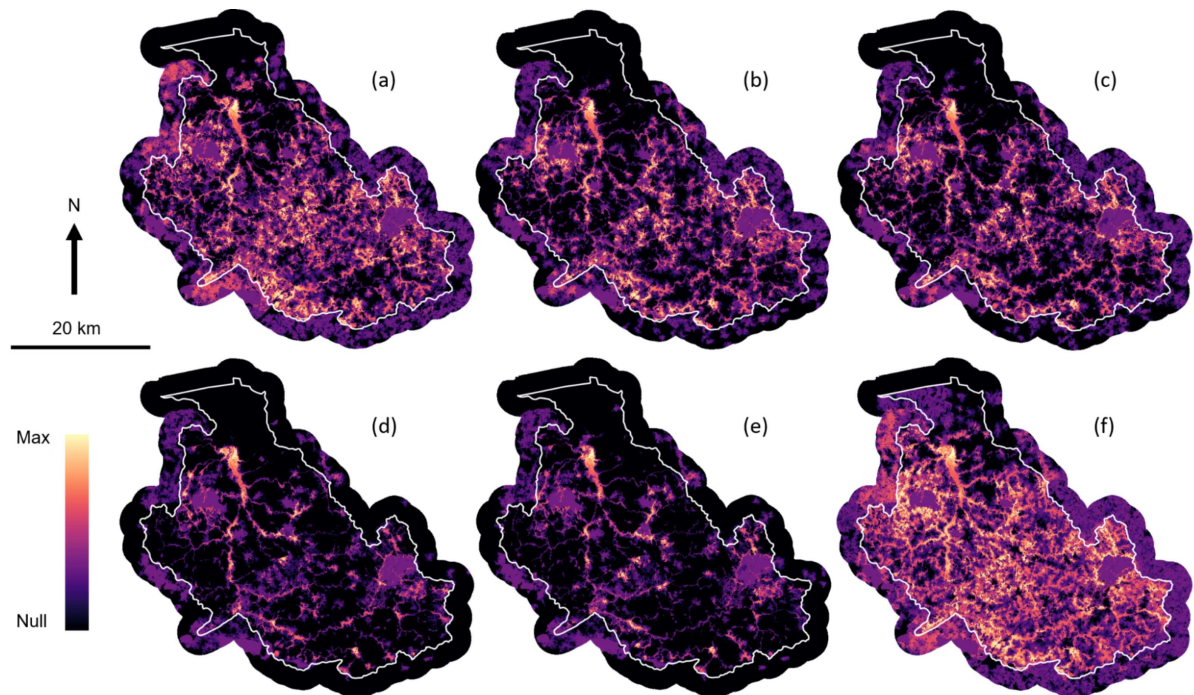


Figure 12 – Mean landscape connectivity (mean of wetland, woodland and grassland connectivities – normalized in %) for the Couesnon watershed (a) in 2018 and for the (b) Business as usual (c) Double performance, (d) Energy performance, (e) Desert of cereals, (f) Green attractiveness.

Urbanisation changes were presented via a map showing the most likely urbanised areas in the future. The probability of urbanisation is calculated as the occurrence of urban sprawl across scenarios at the plot level. Impacts on water quantity in the summer period and water quality (in terms of concentration of Nitrates and phosphorus) are presented as mean values over the entire watershed, as shown in Table 6. Finally, the effectiveness of the BGIN strategy considered in the scenarios was assessed by comparing urbanisation in the Desert of cereals against the Energy performance scenarios. Indeed the first assumed that only the most important corridors would be preserved (connectivity = 100), while the latter assumed optimal preservation of BGINs against urbanisation (connectivity > 50) in the regulatory BGIN map. Nonetheless, the extent and quality of all types of connectivity differed by less than 2%, showing a limited influence of BGINs preservation policies on landscape connectivity. While effectively limiting the development of grey infrastructure, BGINs mainly depended on agricultural land uses.

	Mean landscape connectivity	
	Extent	Quality
2018	87 461.1	31 240.1
Business-as-usual	-13 407.1 (-15.3%)	-7 105.1 (-24.3%)
Double performance	-12 851.3 (-14.7%)	-6 891.2 (-23.6%)
Energy performance	-41 002.4 (-46.9%)	-17 350.5 (-59.4%)
Desert of cereals	-42 758.94 (-48.9%)	-17 782.9 (-60.9%)
Green attractiveness	+ 15 902.6 (+18.2%)	12 555.9 (+43%)

Table 5 – Change in the area (ha) and quality of landscape connectivity from 2018 (present) to 2050 for the five scenarios.

	Summer flow (m ³ /s)	Winter flow (m ³ /s)	T	Station Couesnon - Antrain	Nitrates (mg/L)		Phosphorus (mg/L)	
					Obs.	Sim.	Obs.	Sim.
2018	3,01	10,9	16,5° C	2018	34	24	0,11	0,07
Business as usual	1,68	11,4	17,6° C	Business as usual	79		0,23 ± 0,5	
Double performance				Double performance				
Green attractiveness	1,70	12,73	17,6° C	Green attractiveness	47		0,12 ± 0,3	
Energy performance	Not calculated for this scenario			Energy performance	47		0,30 ± 0,7	
Desert of cereals				Desert of cereals				

a)

b)

Table 6 – Observed (2018) and estimated (2050) water quantity a) and quality b). Water quantity values are calculated for the summer period at the estuary. Values of nitrates and phosphorus concentration are calculated for the summer period for the upstream Antrain station.

2 Scenarios for the Lestolet study area

This section exposes the material used for Chapter 3 of the thesis. The Lestolet forecasting and backcasting scenarios were developed in the framework of Thomas Houet's PhD thesis (Houet, 2006) conducted from 2003 to 2006. Forecasting LUCC scenarios were developed for three sub-catchments in the Blavet watershed: the Lestolet (Côtes d'Armor), the Coët Dan and the Stang Varric (Morbihan), each one of approximately 1400 ha. In addition, backcasting scenarios had been developed just for the Lestolet. This more extensive work allowed scenario-makers to build more solid relations with local stakeholders active on the Lestolet than on the other watersheds. Furthermore, the ensemble of scenarios had been retaken by the consulting firm ASca to feed more global policy-pulled scenarios (at the Blavet scale). Chapter 3 of this thesis focuses mainly on the Lestolet scenarios. For this specific watershed, we reconstructed the LUCC using remote sensing and interviewed local stakeholders to understand LUCC drivers and the outcomes of scenarios. Nevertheless, as 14 years passed between the end of the Blavet scenarios project and this evaluation, local stakeholders could not distinguish between the outcomes related to forecasting and backcasting scenarios and the sub-catchment or Blavet watershed scenarios.

2.1 Overview of the methodology

In partnership with the SAGE Blavet, scenario-makers selected three sub-catchments representative of the landscape diversity and the water quality management issues of the entire watershed. Figure 13 schematises the overall workflow used to develop scenarios.

The scenario development process includes four steps for backcasting and forecasting scenarios (Houet, Verburg, and Loveland, 2010): the knowledge base construction, the scenarios construction, the spatial dimension of the scenarios and their evaluation.

1. The construction of the knowledge "base" follows three successive phases. The first one is the reconstruction of the LUCC trajectories using remote sensing. The second is the identification of the processes that determine land cover evolutions. The last is the prioritisation of explanatory factors for current and future changes. The first phase was carried out in the laboratory, while the second and third phases were carried out in the first participatory meeting.
2. The narratives were constructed during the second participatory meeting and re-

fined by scenario-makers. Exploratory and forecasting scenarios followed different narrative construction processes. Indeed, exploratory scenarios assume different evolution of the LUCC’s main explanatory factors (2006 CAP reform, the enlargement of farms and the evolution of land parcels) and explore their impact on the agricultural landscape. In contrast, the backcasting scenarios assume highly contrasting landscape futures (in terms of land use, hedgerows networks, and wetlands) and trace the necessary conditions to reach those futures.

3. Scenario-makers then translated the narratives into spatially explicit representations. For the exploratory scenarios, the spatialisation was done using the L1 platform (Gaucherel et al., 2006), while backcasting scenarios were spatialised via a GIS. Subsequently, scenario makers identified future challenges for water management (risk of nitrates transfers in the surface and sub-surface flow system and changes in water flows quantity).
4. Finally, a last participatory meeting with local stakeholders was organised in 2006 to present the scenarios and to evaluate the results.

Besides the four steps to developing secondary watershed scenarios, a consultancy firm worked with the SAGE and the CLE on scenarios at the Blavet scale. The fine-scale scenarios developed by Houet (2006) then feed into more global scenarios concerning water management and socio-economic-related impacts.

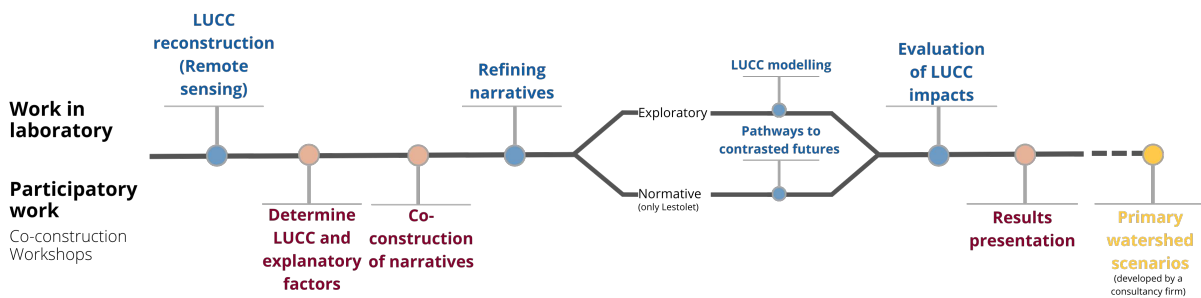


Figure 13 – Overview of the overall method used to develop Lestolet exploratory and normative scenarios combining studies carried out in laboratory (in blue) and participatory steps (in red). The scenarios were then retaken by a consultancy firm to develop more comprehensive scenarios at the Blavet scale (in yellow).

2.2 Study area and LUCC trajectory

At the time of scenario development, the Blavet watershed (2130 km²) was characterised by dairy/livestock farming, representing one-third of the farms (SAGE Blavet, 2005), and water quality was a long-lasting concern with variable agriculture intensity within the catchment area. The Lestolet catchment, on which scenarios are focused, is a 1320 ha area located upstream of the Blavet (Côtes d'Armor department). The Lestolet's topography is rather hilly, and a high presence of the bocage (a dense hedgerow and small forest patched network) historically characterises it. Between the 50s and the end of the century, the hedgerow network and wetlands progressively decreased in the Lestolet. In parallel, the average farm plot size doubled between 1952 and 1999. Moreover, land use changed considerably over time. Indeed, while cultures predominated until the mid-60s, between 66 and 1981, the crop area dropped to 27%, and grassland covered 53% of the surface. In the 80 and 90s, the CAP reform caused a trend reversal: grasslands decreased by 10% while cropping surfaces augmented slightly. In the same period, shrublands previously dispatched in the whole area were concentrated in the valley bottoms. This intensification of agriculture caused a degradation in water quality, and consequently, several regulatory measures have been put in place to restore it.

2.3 Scenario assumptions

As for the Couesnon case study, the Lestolet exploratory and backcasting scenarios consist of contrasting narratives illustrated by LULC maps. Exploratory scenarios were developed at the temporal horizon of 2020. Their narratives had been defined by combining: 1) three independent and contrasting assumptions about the farmer's coping strategies in response to the next-coming 2006 CAP reform; 2) and two hypotheses on the dynamics of land structures represented by farm takeovers and the enlargement of land parcels (exclusively for the Lestolet watershed).

The three contrasted hypotheses about the 2006 CAP reform are the following:

- The first assumes no drastic changes in the CAP. Following this hypothesis, farmers do not change their practices maintaining an overall increase in maize at the expense of grassland ("business-as-usual (BAU) strategy").

- The second assumes a CAP “Greening strategy” favouring grasslands. Following this hypothesis, farmers increase grassland area at the expense of silaging maize area. All cereals and oilseeds are converted to grass.
- The third assumes a CAP “Cropping strategy” favouring crops. In this case, farmers increased the percentage of cereals by 5% compared to the 2004 reference year.

Scenarios were developed either by considering the farms’ takeover and enlargement or not. In the long-term assessment paper, we limit our quantitative analysis to scenarios considering the enlargement. Further assumptions shared by all exploratory scenarios are that farmers do not change production systems, and all farmers assume the same coping strategies.

In parallel to exploratory scenarios, three backcasting scenarios were developed at the time horizon of 2027 by crossing hypotheses on the evolution of different landscape components (CAP evolution and land use, bocage, riparian wetlands) and checking for internal consistency.

- 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) and keeping wetlands open.
- The second assumed that the disappearance of farms due to difficult economic conditions met water-quality targets.
- The third predicted a substantial decrease in water quality (increased nitrate concentration) and a loss of biodiversity due to the transition to agro-energy cropping systems. In this scenario, wetlands are dedicated to hunting.

Once narratives were defined, researchers illustrated LUCC spatially using the L1 platform and GIS model, and then impacts on the water resource were estimated.

2.4 Modelling LUCC and impacts on the water resource

The land structure dynamics were estimated by relying on the expertise of local stakeholders. As a result, 17 of the 31 farms on the Lestolet in 1998 were identified as ones that would cease operations by 2020. Of these 17, 6 farms are taken over by a young farmer and the other 11 by neighbouring farms.

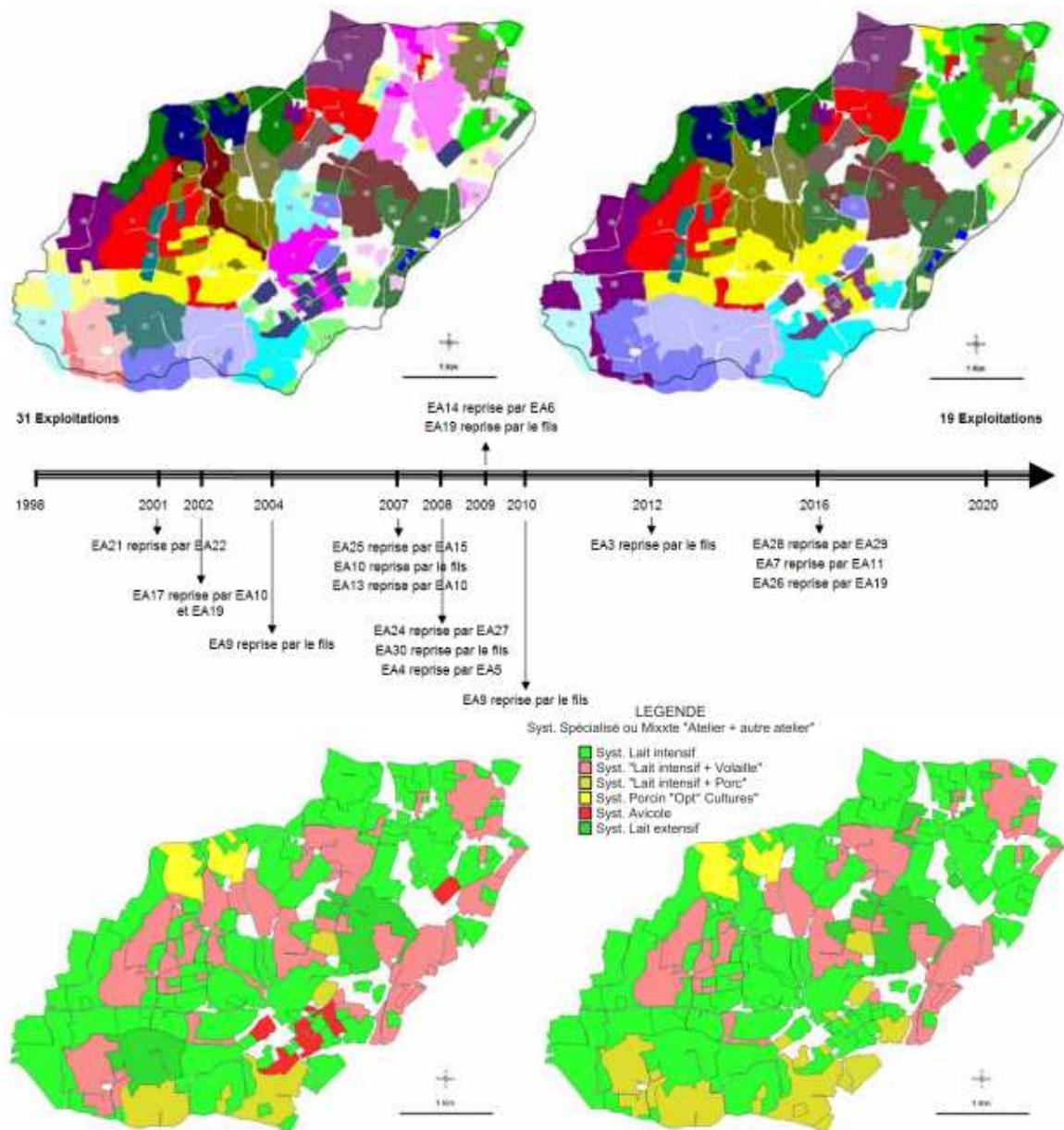


Figure 14 – Estimated in farm size for the Lestolet watershed between 1998 and 2020.

For modelling exploratory scenarios LUCC, scenario-makers estimated the evolution of crops and grassland percentages, their spatial distribution, and the extension of the bocage and wetlands using the L1 platform (Gaucherel et al., 2006; Houet, 2006). This platform is a dynamic and spatially explicit modelling platform that produces an annual mapping of the types of occupation and land use to the time horizon of the scenario. Moreover, the model can impose that, at a given date, the cropping patterns of different production systems change. This feature is particularly relevant to reflect the influence of the CAP reform on land use patterns. Regarding backcasting scenarios, scenario-makers used a GIS to represent the LUCC of Lestolet in 2027 spatially, corresponding to the narratives.

Based on the LUCC maps, scenario-makers esteemed the following impacts:

- The cumulative distribution of corn areas relative to the distance to the hydrographic networks (model adapted from Ruiz et al., 2004) and the frequency of return in corn on parcels for the exploratory scenarios
- The risk of sub-surface transfers of nitrogen considering the land use and the presence of hedgerows using the Landbuf model (Viaud, 2004)
- The areas contributing to surface flow transfers of phytosanitary products and phosphorous considering the effects of hedgerows via the Odissés model (Bocher, 2005)
- The influence of land use on water flows considering pre-determined runoff coefficients via the RuiCells model (Langlois and Delahaye, 2002).

2.5 Scenarios results

Forecasting scenarios were first presented in the form of narratives. An example of forecasting scenario narrative is given in Box 2. Then scenario-makers presented LUCC through maps (Figure 15) and stacked graphics. Together with land-cover changes envisioned by scenarios, some indicators of land structure dynamics were also presented (e.g. the number and the production systems of farms in 1998 and 2020 and the average farm size, see Table 7 and 14. The impacts of the farm enlargement were discussed qualitatively with the aid of scenarios. Namely, by comparing different scenarios, researchers highlighted that the farms' enlargement slightly favours the increase of crops and their

grouping in broader patches. Impacts on water quality and quantity were presented in a qualitative way.

Backcasting scenarios' narratives and maps (Figure 16) were also presented.

Box 2: The CAP in favour of grasslands narrative

Following the CAP reform of 2006, coupled with pessimistic wheat price projections, farmers remain sceptical. The Chambers of Agriculture and other advisory bodies are launching a communication campaign on the opportunity offered by the new CAP funding system. Planting grass instead of wheat is profitable (fewer treatment costs, no need to hire farm equipment or call external agricultural works companies for sowing and harvesting), especially as farmers already have the equipment needed for minimum grassland management (annual mowing). They also gain much free time, a demand becoming increasingly strong in the profession. Their reaction was immediate: they changed their production system to a predominantly grassland system and, subsequently, their crop rotation. There are many individual initiatives, and the dissemination by proximate diffusion plays a significant role in the spread of this adaptation strategy. Ultimately, all farmers changed their production system after the 2006 CAP. In all the study sites, the farmers are relatively young. The few farmers who ceased their activity between 1998 and 2020 find new owners: the installation subsidies and the legal structure of the GAECs make it possible to compensate for retirements through the arrival of young farmers. The size of the farms is increasing, following the evolution presented in Table 7.

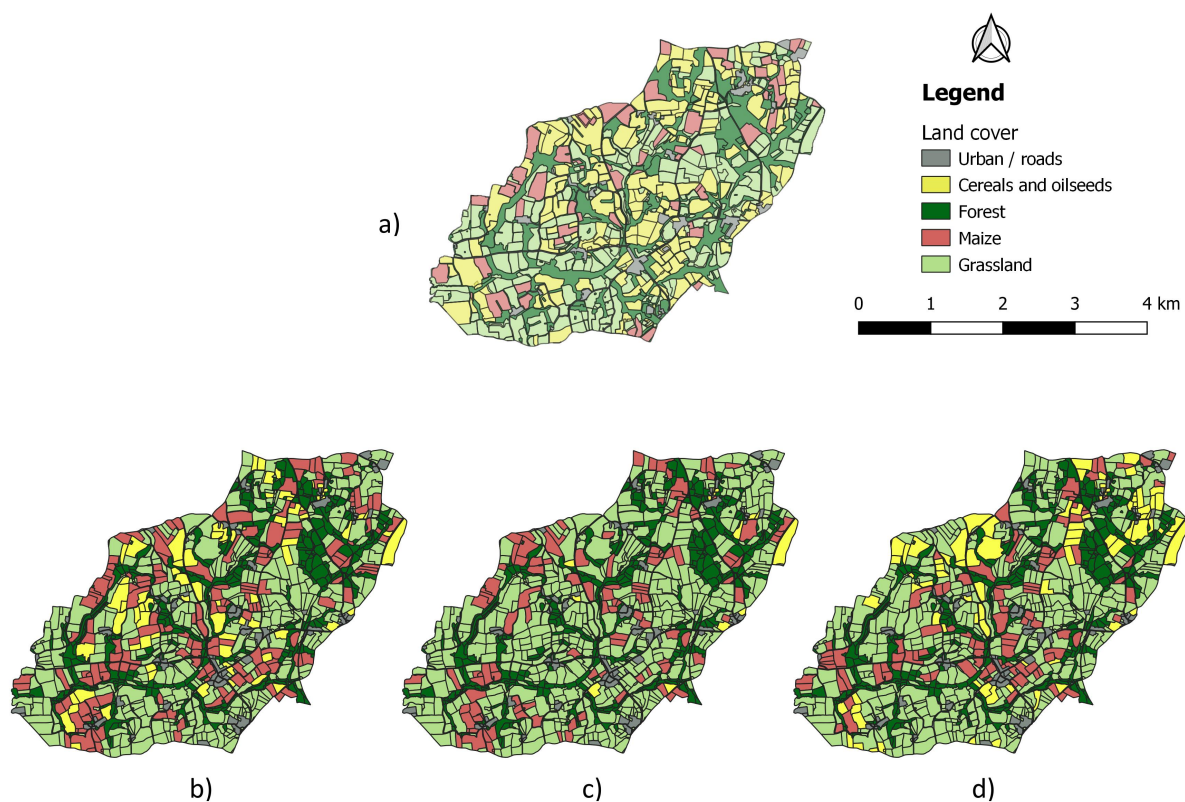


Figure 15 – Land-cover maps for the Lestolet watershed. Observed land-cover in 2019 (a) and envisioned in 2020 with the L1 platform for the Business as usual (b), Greening (c), and Cropping forecasting scenario (d).

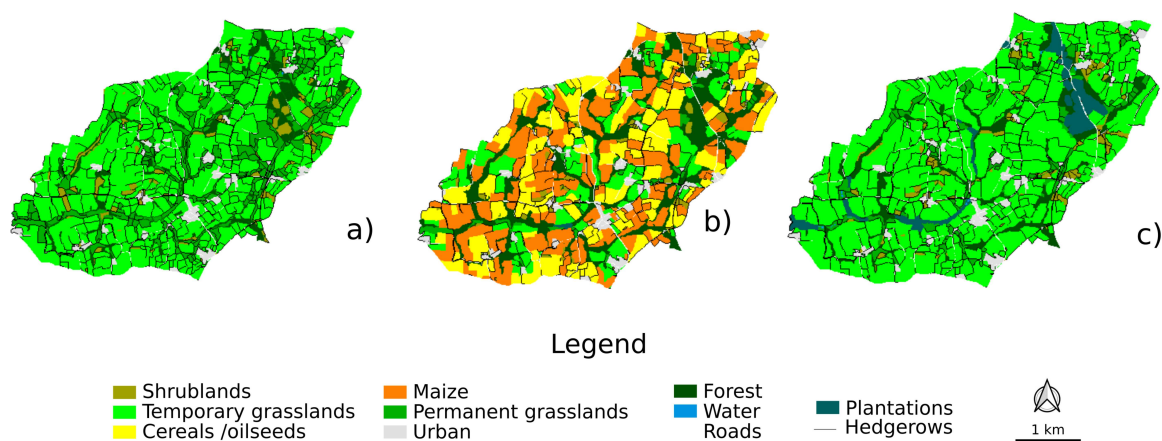


Figure 16 – Envisioned land-cover maps for the Lestolet according to the first a), second b), and third c) backcasting scenarios.

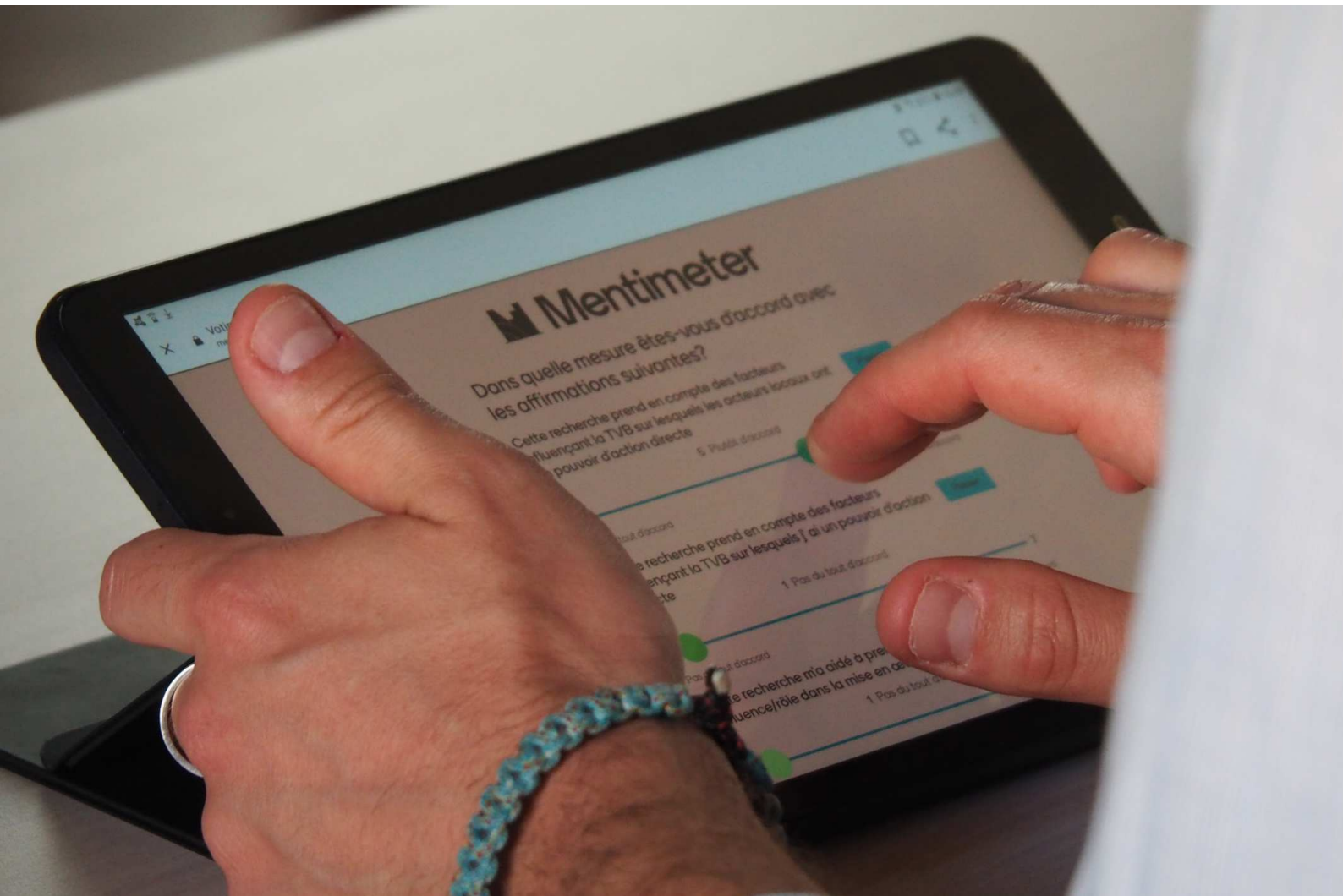
Production system	1998 (31 farms)	2020 (19 farms)
Syst. “Dairy/meat cattle”	17 farms. (50% UAA du WS)	11 farms. (58% UAA du WS)
Syst. Mixte “Cattle + Poultry”	8 farms. (27%)	4 farms. (20%)
Syst. Mixte “Cattle + Pork”	2 farms. (6%)	2 farms. (11%)
Syst. Hors-sol “Pork”	1 farms. (3%)	1 farms. (3%)
Syst. Hors-sol “Poultry”	1 farms. (2%)	-
Syst. “Extensive / Organic Cattle”	2 farms. (10%)	1 farms. (6%)
For 2% of the UAA, the farmers could not be identified and therefore the production size		
Average farm size	1998	2020
GIS data	40-60 ha	80-100 ha
Source: ONIC 2000 Institut de l'élevage, 2004	51 ha	+15-20 on average in BZH until 2012

Table 7 – Evolution of the agricultural production systems according to the estimated farm enlargement.

3 Partial conclusion

This chapter summarised all the material used in this thesis. The first set concerns the study of the Couesnon watershed (Eastern Brittany) made and delivered to stakeholders in 2021. The second set concerns the Lestolet, a sub-catchment of the Blavet watershed (central Brittany) made and presented to stakeholders in 2005. Both scenarios' narratives were developed jointly with local actors involved in water management and agriculture. The two sets of spatially explicit scenarios are composed of narratives envisioning the effects of socio-economic and environmental drivers on the landscape and LUCC maps. Moreover, while both case studies esteem the impacts of intensive agricultural land use changes on water resources, the Blavet one focuses on the impacts of LUCC on biodiversity as well. In terms of scenario types, for the Couesnon watershed, scenario-makers developed forecasting scenarios only, while for the Lestolet, forecasting and backcasting scenarios were developed.

OUTCOMES OF SCENARIOS IN THE SHORT TERM



1 Introduction: dissemination pathways as multipliers of outcomes

In this first evaluation article, we collect the short-term reaction to LUCC scenarios from a broad audience who got to know scenarios through some dissemination workshops without participating in the co-production phase.

As highlighted in the introduction of this thesis, co-production is one of the pillars of sustainable studies, in which ALICE scenarios are inscribed. However, despite the consistent expected outcomes associated with this phase, co-production is accessible to a limited number of local actors. Therefore, in this chapter, we chose to focus on dissemination as a complementary impact pathway to co-production with less consistent but widely shared associated outcomes.

The principal aim of this chapter is to see if ALICE scenarios are perceived as usable, allowing the emergence of some personal, group and eventually system outcomes in the mid-long term. Besides, some first emerging short-term outcomes are also examined and discussed. Consequently, this paper will often discuss “perception” rather than outcomes emphasising the question: “do respondents perceive scenarios as usable?” rather than “have scenarios been useful?” which we will address in priority in the following chapters.

To verify the role of the dissemination pathway in fostering outcomes, we diffused scenarios to different consistent groups of local actors, selecting technicians, representatives and farmers as the most representative of land managers in agricultural landscapes. Considering the need for a consistent number of respondents per group and the full agenda of some local actors, we chose a quantitative assessment method enriched by notes on collective discussions, leaving more in-depth and time-consuming verification for the mid and long-term evaluation. However, the statistical approach we adopted does not come just with benefits. One backdrop is the impossibility of considering complex respondents’ profiles. Indeed, we decided to classify respondents based only on their familiarity with the study area and their current professional activity. For example, we consider farmers a uniform class without considering their agricultural practices or social and professional background. Similarly, we did not distinguish representatives according

to the structures in which they exercise their function. Although we are well aware of the limits of this approach, the quantitative method we applied prevents us from considering more nuanced categories. Moreover, for this chapter, we exclude people participating in the co-construction phase since they were not enough to constitute a standalone category. At the same time, their stronger implications in the project prevent us from including them in the other categories without introducing important biases. In the following chapter, we will address this limitation by reintroducing in the sample the participants of the co-production phase and giving some background information regarding the interviewees.

This chapter has been submitted as an original research paper to the *Environmental Science and Policy* journal (under review).

Rigo R., T Houet, Gonthier C. (Under review) Evaluating and maximising the outcomes of LUCC scenarios: strategies for an effective dissemination, *Environmental Science and Policy*

2 Article: Evaluating and maximising the outcomes of LUCC scenarios: strategies for an effective dissemination

R. Rigo, T. Houet, C. Gonthier

Abstract

Land use and land cover change (LUCC) scenarios are often co-produced by researchers and a reduced group of local actors. While most scenarios' evaluations analyse feedback from actors involved in the scenarios making, restricting the diffusion of scientific results to the co-construction group can limit their potential to support land management. In this study, we investigate if disseminating the scenarios to an external audience can enhance the outcomes of scenarios fostering the use of scientific knowledge in local decision making. We presented LUCC scenarios in 12 workshops and collected feedback from 147 local actors, including representatives, water management technicians, farmers and students. Findings indicate that despite the original aim of the scenarios being to support the integration of Blue and Green Infrastructures (BGINs) in land management, the primary benefits were to increase knowledge about technical land-management concepts and challenges and to re-discuss preconceived notions and traditional practices. In addition, we observed that respondents' professional activity, the consideration of the research's credibility, and the perceived importance of BGIN significantly influence the evaluation. We conclude that scenarios outcomes can be maximised by making the expected outputs and outcomes (including social ones) explicit and by acknowledging local actors' priorities, backgrounds, and roles in land management during the dissemination.

2.1 Introduction

The acceleration of the environmental crisis has shifted the focus of science from understanding environmental processes to seeking solutions. In this context, scientific research has become more transdisciplinary, valuing co-design and co-production (Shrivastava et al., 2020). In parallel, both civil society and scientists believe in the need for a stronger engagement of researchers in environmental policies (Cologna et al., 2021) and for a persistent dialogue between the scientific community and local actors (Skea et al., 2021).

The production of land use and land cover change (LUCC) scenarios, i.e. projections about the future patterns of land usage (see Gomes et al., 2020 for an example), is one example of synergy between science and society. Indeed, scenarios are often the result of co-production, in which researchers and local actors share their expertise to envision and model possible evolutions of the landscape. From landscapes changes, researchers can estimate the impacts on natural resources and social dynamics, allowing stakeholders to find scientifically sound pathways to sustainability (Vergragt and Quist, 2011). By co-creating different visions of the future, scenarios have the potential to develop a shared understanding of complex systems in which social, economic, and environmental variables are considered (Pereira and Ferrier, 2020). Moreover, divergent values and different visions of the future are also often included in scenario-making to promote social learning (Johnson et al., 2012) and enable transformative outcomes (Nikkels et al., 2021). Hence, scenarios promise to work both as boundary objects that facilitate dialogue between different groups and interests (Burt et al., 2021; Carlile, 2002) and as decision-making support tools (Ferrier et al., 2016).

Those two complementary ways of using research outputs (i.e. scenarios in this case), fall respectively into research's conceptual and instrumental use. The first is the use of outputs to influence how stakeholders conceptualise a problem. The latter is the direct use of research outputs to support management actions (Mitchell, 2019). The conceptual and instrumental use of research can be further produce outcomes: "changes in values, attitudes and behaviour in the world beyond the walls of the research institute" (Matthews et al., 2011, p. 247). In their systematic review, Karcher et al. (2021) identify several social outcomes, including increased awareness, the presence of learning processes, changes in organisational structures and the development of a shared understanding. Most recurrent instrumental outcomes are using research results to identify management alternatives, choose management strategies, and directly include results in policy and technical documents (Rigo et al., 2022).

Nevertheless, translating scientific knowledge into benefits for stakeholders is complex (Glavovic et al., 2021). Barriers to producing positive outcomes can arise both in the co-construction phase of scenarios, in the restitution and in the dissemination phase. In this article we will refer to restitution, as the moment when results are presented to

the stakeholders involved in the co-production of scenarios. We refer to dissemination as the phase when results are presented to an external audience. To overcome these barriers, research on how to develop more salient, credible and legitimate scenarios is multiplying (e.g. Van Voorn et al., 2016; Wodak and Neale, 2021). Moreover, the evaluation of scenarios is shifting from quantifying outputs to identifying outcomes (Hamilton et al., 2019; Matthews et al., 2011). The present work is part of this dynamic and focuses more specifically on identifying the outcomes of scenarios in the dissemination phase.

At a local level, a limitation to research-based land-management practices is a missing common understanding of environmental and social issues between actors (Kolkman and Van der Veen, 2006). In addition, poor communication and a lack of knowledge of what the different stakeholder groups perceive as valuable and meaningful can decrease the perceived stakes of scenarios, hindering outcomes. To investigate how scenarios can support a heterogeneous audience in learning about environmental issues and, ultimately, integrating the outputs of scenarios in their professional activities, we believe it is suitable to focus not only on the co-construction phase, but also on dissemination. Indeed, limited resources and unbalanced power relations (Ansell and Gash, 2008; Reed, 2008; Williams, 2004) inherently limit the number of participants in the co-construction; conversely, these constraints are relaxed in the dissemination, allowing a broader public to access the scenarios.

While there have been different attempts to evaluate the outcomes of scenarios (e.g. Cobb and Thompson, 2012; Kowalczyk and Turnhout, 2012; Mitchell et al., 2016; see also Yeeun Lee et al., 2022 for a review of evaluation frameworks), evaluations often focus on feedback from homogeneous stakeholder groups or generalise results from mixed groups (see Inman et al., 2011 for an exception using environmental decision support systems). In addition, most evaluations come from stakeholders involved in the co-construction phase (Allington et al., 2018; Beach and Clark, 2015; Hedelin et al., 2021; Wyatt et al., 2021), while little attention is accorded to dissemination to a broader audience (see Matthews et al., 2011 for an exception). Although dissemination is time-demanding and often considered a side task for researchers (Kassab, 2019), it can be a crucial phase in enhancing the outcomes (Metzger et al., 2017; Šucha and Sienkiewicz, 2020). Assessing priorities, and expectations on scenarios and the perceived contribution for local land users and other stakeholders remains essential to make dissemination more

effective in producing outcomes.

Our study builds on the outputs of the Alice project, which developed scenarios for agriculture and land planning strategies in North West France (see Houet et al., 2022, for a detailed description of the project). The original aim of these scenarios was to evaluate the effectiveness of different Blue and Green Infrastructure Networks (BGINs) strategies for water resources and biodiversity. We endeavoured to make the Alice scenarios readily available and understandable for a broad audience, and we evaluated the perceived outcomes of scenarios when presented to local actors. For this purpose, we organised several workshops to present the scenarios and collect feedback through an interactive questionnaire. We then analysed the collected data according to respondents' characteristics. This paper shows that the main variables impacting the perceived outcomes of scenarios were the respondent's professional activity, the consideration of the research's credibility, and respondents' belief in the importance of BGINs. In addition, we found that the primary outcomes of the scenarios were to support a learning process on landscape dynamics and to re-discuss preconceived notions and traditional practices.

The paper is organised as follows: Section 2.2 briefly describes the scenarios we presented during the workshops, the topics we want to investigate, and the methods we used to analyse the data. Section 2.3 analyses how the different actors perceived each of the topics. Based on the results, in Section 2.4, we discuss the major outcomes of scenarios, provide insight on how to adapt the dissemination phase of scenarios to different stakeholders, and reflect on the contributions and limitations of the study. Finally, Section 2.5 concludes the article.

2.2 Materials and Methods

2.2.1 Context and case background

In 2021, the Alice project used modelling and participatory methods to develop a scenario-based approach for the Couesnon watershed (west France), combining land use and land cover changes. The project resulted in five scenarios from 2020 to 2050 published in Houet et al. (2022). Scenarios aimed to evaluate the effectiveness of the BGINs policy on water resource and landscape connectivity and help land managers define BGINs and incorporate them into local management plans.

The case study area is a river catchment of 1 130 km² located in North West France, which discharges into the bay of Mont-Saint-Michel. The site is characterised by intensive agriculture, mainly for dairy production in the upper part, while vegetables and cropping systems dominate the polders at the interface with the sea. In addition, characteristic landscape elements are the bocage, a network of hedgerows of variable density and connectivity, and small wooded patches isolated in the agricultural matrix. Since the 70s, the Couesnon has faced water quality issues that gradually decreased from the 90s (Dupas et al., 2018; Eau du Bassin Rennais, 2019).

First, Alice's researchers developed five scenarios composed of narratives and spatially explicit LUC maps showing different future landscapes for 2050. To produce the narratives, local stakeholders assumed contrasted evolutions of the Common Agricultural Policy (CAP) and the consequent adaptation of agricultural practices at the local level and of local land planning strategies (such as different degrees of BGINs preservation in land management and different degrees of demographic increase on the territory). All five scenarios shared a common hypothesis on global warming. Once local actors defined the five contrasted narratives, researchers transposed them into LUC maps at the watershed scale. Then, they evaluated the evolution of biodiversity using landscape connectivity as a proxy and the water quality and quantity between 2018 and 2050 for each scenario to assess the BGINs policy's efficiency.

The authors measured landscape connectivity as the mean value of wetlands, woodland, and grassland connectivity and presented them through maps. Water quantity was estimated as summer and winter flow for the Couesnon river, and water quality as the concentration of nitrates and phosphorus in the water during summer. The outputs showed that water quantity would considerably decrease (around 40%) in all scenarios due to climate change, triggering a higher concentration of pollutants. Moreover, the scenarios highlighted how the effectiveness of BGINs in ensuring connectivity and good water standards mainly depended on agricultural land users' decisions, over which the current management plans have no influence.

2.2.2 Dissemination of scenarios

2.2.2.1 Restitution workshops

We presented the scenarios produced by the Alice project to a broad audience that did not participate in the co-construction of narratives. The final workshop structure resulted from four pilot trials that allowed choosing the polling system, refining survey questions and length, and establishing the contents of the presentation. We excluded this trial sample from the analysis.

From June to December 2021, we organised 12 more workshops lasting between 2h30 and 3h. In each session, we presented the methodology and results of the Alice project to an audience homogeneous in terms of professional activity. Along with the presentation of the scenarios, participants used an interactive polling system to fill out a survey designed to investigate our research questions.

147 local actors participated in the workshops and responded to the survey, including representatives of local municipalities and the Brittany region; water management technicians; farmers and farmers representatives at the local and regional level; students at the local agricultural high school; and university students attending the master's degree of land planning, environment, and development. Different audiences attended separate workshops to keep a restricted number of participants per session and avoid power imbalances and conflicts of interest. In this way, we encouraged active participation in the discussions and facilitated free expression. Audiences mostly attended the workshop in person. However, we also proposed the option of attending by videoconference when restrictions due to the COVID-19 health crisis prevent some attendees from participating. We held only one workshop entirely online.

2.2.2.2 Participants

To gather participants, we identified groups of stakeholders potentially interested in the results of scenarios or the scenario-making approach. We then contacted a correspondent from each stakeholder group who proposed the workshop to their social network. Respondents to the survey were between 17 and 73 years old ($M = 37$ years, $SD = 18$), and 44% worked and/or lived in the area (of which 38% were farmers, 14% were technicians, and 45% were representatives). All participants were French speakers. We removed 6 records from participants who answered less than 50% of the survey.

Respondents could report up to two professional activities. We divided respondents into three professional categories: farmers, local and regional government representatives, and technicians. 67 respondents initially identified themselves in one and only one of those categories. Given their training, we considered students from the agricultural high school as farmers ($n = 31$) and master's degree students in land planning, environment, and development ($n = 18$) as technicians. When a respondent identified themselves as a farmer plus one of the two other categories, we included them in the category "Farmer" ($n = 11$). Finally, we included respondents who identified themselves as both representatives and technicians in the category "Technicians" ($n = 2$). 4 respondents did not report their professional activity but were assigned to a group based on the workshop session, and 8 were not classified in any of the categories because of missing information. The final dataset included responses from 54 farmers, 39 representatives, and 51 technicians. The result's robustness to this classification was checked by repeating the analysis related to professional activity after excluding respondents identifying themselves in more than one category ($n = 17$); the results yielded similar conclusions.

2.2.2.3 Survey and analysis method

At the beginning of the workshop, we provided the respondents with a tablet computer. We administered the questionnaire using Mentimeter, a software that allowed the audience to respond via tablets (or personal devices for those attending online) and see responses in real time. To limit group biases, we only showed aggregated results for each question once all respondents had answered. We used the interactive survey results to support discussions where participants could share and argue their answers. We also took comprehensive notes of the debates for each session; some of the comments made by participants are reported in the results section to contextualise quantitative results.

The survey was designed to investigate our five main research questions: 1) Respondents' perception of the contribution of scenarios in identifying the territory's dynamics and challenges; 2) Respondent's perception of the most probable scenario and contribution of scenarios in thinking about future landscape trajectories; 3) Correspondence between scenarios results about water quality and quantity and respondents' expectations based on their prior knowledge; 4) Contribution of scenarios quantitative results about biodiversity and water resources for respondents' professional activity; 5) Perceived contribution of the

scenarios in tackling territorial challenges.

The survey consisted of 33 questions, of which 15 addressed the contribution of scenarios in respondents' professional activities, understanding landscape dynamics and challenges, and envisioning actions to improve environmental issues. Those questions asked the level of agreement or disagreement on a seven-point scale (1 = disagree strongly; 2 = disagree somewhat; 3 = disagree slightly; 4 = Neutral; 5 = agree slightly; 6 = agree somewhat; 7 = agree strongly). The remaining questions addressed factors which could influence attitudes towards the contribution of scenarios: personal background, the evaluation of the workshop, and perceived plausibility of the scenarios. We summarise the 5 main research questions and the corresponding points of the survey in Table 1.1.

Since the data were ordinal variables, we used non-parametric tests for the statistical analysis of responses. Part of the main analyses sought to compare responses between groups of respondents of different professions and different levels of familiarity with the area. For this purpose, we used the Kruskal-Wallis test (to compare three groups) or the Mann-Whitney U test (to compare two groups). When a significant difference appeared with the Kruskal-Wallis test, we performed pairwise post-hoc comparisons using the Mann-Whitney U test with Bonferroni correction. Because non-parametric tests are vulnerable to heteroskedasticity, we verified the results of non-parametric tests with parametric ones (Welch's ANOVA and Welch's t-test, respectively) when variances substantially differed across groups. We used Spearman's non-parametric correlation coefficient to check for correlations between the questions. We used the Wilcoxon test to test whether responses were significantly different from the neutral point of the scale (for example, significantly on the "agreement" side). Finally, we compared respondents' answers to different questions using the Pairwise Wilcoxon test. The survey questions and a table summarising the analysis are available in Appendix 2.

Topic	Survey sections
Contribution of scenarios in understanding the territory's dynamics and challenges	Contribution of scenarios in: <ul style="list-style-type: none"> - Identifying territory's challenges (<i>Identify challenges</i>); - Considering more variables/notions when thinking about landscape dynamics (<i>Consider influential variables</i>) - Understanding landscape dynamics (<i>Understand landscape dynamics</i>)
Respondent's perception on the most probable scenario and contribution of scenarios in thinking about future landscape trajectories	Identifying the most probable scenario; Contribution of scenario in envisioning different landscape evolutions than previously envisioned (<i>Envisioning futures</i>)
Correspondence between scenarios results and respondents' expectations based on previous knowledge	Correspondence between results and expectation on: <ul style="list-style-type: none"> - Water quantity (<i>Water quantity expectation</i>); - Water quality (<i>Water quality expectation</i>)
Contribution of scenarios quantitative results for respondents' professional activity	To what extent the results regarding the following topics are likely to be mobilised in respondent's professional activity: <ul style="list-style-type: none"> - Water (<i>Instrumental water</i>); - Biodiversity (<i>Instrumental biodiversity</i>)
Contribution of scenarios in tackling territorial challenges.	Contribution of scenarios in understanding personal role in BGINs; <ul style="list-style-type: none"> - Influence of BGINs at t0 (<i>Influence on BGINs</i>) - Influence of BGINs at t1 (<i>Understanding role on BGINs</i>) Difference between the contribution of scenarios in: <ul style="list-style-type: none"> - Understanding landscape dynamics (<i>Understand landscape dynamics</i>) - Support action (<i>Take action</i>)

Table 1.1 – Research topics and correspondent survey sections. In brackets, the denomination which is reported in the analysis results.

2.3 Results

As shown in Table 1.2, the Kruskal-Wallis test indicates a difference in familiarity with the concept of BGINs between professional activities. The post-hoc comparisons indicate that farmers were significantly less familiar with the concept of BGINs compared to representatives and technicians. Indeed, during the workshops, farmers often agreed that they received little or no information on BGINs. Farmers also perceived the BGINs as less relevant than technicians and representatives (Table 1.2). Spearman's Rho coefficient

2. Article: Evaluating and maximising the outcomes of LUCC scenarios: strategies for an effective dissemination

showed a positive correlation between being familiar with the concept of BGINs and perceiving them as a significant concern for the territory. We provide the correlation test results in Table 1.3. Respondents expressed confidence in the research results (Mdn = 5). Confidence did not change significantly between the different professional activity groups, nor according to the familiarity with the study area (Table 1.2). Moreover, 99% of the respondents felt free to express their points of view. As many as 68% of respondents actively participated in the discussions.

	Farmers N = 54		Technicians N = 49		Rep. N = 30		KW (p-value)	Dunn Test
	Mdn	MR	Mdn	MR	Mdn	MR		
<i>Familiarity with BGINs</i>	3**	4.75	6***	2.62	5*	3.4	31.88 (<0.001)***	Far<Rep**; Far < Tec***; Rep<Tec
<i>Importance BGINs[°]</i>	5***	3.09	7***	1.64	6***	1.72	35.20 (<0.001)***	Far < Rep *** , Far < Tec ***
<i>Influence on BGINs</i>	5.5***	2.81	5***	2.94	5**	3.03	0.57 (0.75)	ns
<i>Research evaluation</i>	5***	2.85	6***	2.49	5***	2.71	3.08 (0.214)	ns

Table 1.2 – Level of familiarity with BGINs, level of perceived importance of BGINs, level of perceived influence on BGINs, and evaluation of research quality by professional activity. Median value (Mdn), average rank (MR), and the Kruskal-Wallis and Dunn test results. Significance levels of Mdn values refer to the Wilcoxon signed rank. p < 0.05; ** p < 0.01; *** p < 0.001*. ° indicates the presence of heteroscedasticity. We do not report the results of the non-parametric tests as they do not significantly differ from the parametric ones.

2.3.1 Understanding territory dynamics and challenges

We designed three survey questions to investigate whether scenarios helped better comprehend the territory. We asked respondents to what extent they agreed with the following questions: “Thanks to this study, I have improved my global understanding of the territory’s challenges”; “This study allowed me to consider more variables/notions that I had not previously considered”; and “This research is useful to understand the dynamics of the landscape better”. We estimated differences in responses depending on professional activity (Kruskal-Wallis test and post-hoc test) and familiarity with the study area (Mann-Whitney test). Finally, we estimated correlations with ordinal control variables using Spearman correlation (Table 1.3).

Respondents agreed that scenarios helped them understand landscape dynamics (Mdn = 6) and, to a minor extent, helped them understand the challenges faced by the territory and consider more variables (Mdn = 5). We found no significant difference in the results depending on the familiarity with the study area (see Table 1.4). Regarding professional activity groups, technicians ranked the contribution of scenarios in understanding landscape dynamics significantly higher than farmers (see Table 1.5).

Considering BGINs as an important issue for the territory was positively correlated with perceiving a substantial contribution of scenarios in identifying the territory’s challenges, considering more variables when thinking about landscape dynamics, and understanding landscape dynamics better. Similarly, we found a positive correlation between the level of confidence in the research results and the same three variables. Previous knowledge of the concept of BGINs is also positively correlated with perceiving a substantial contribution of scenarios in identifying the territory’s challenges (Table 1.3).

When explaining why scenarios supported a better comprehension of landscape dynamics and challenges, respondents often evoked the systemic vision provided by scenarios:

"The scenarios allow us to refine notions, and to see them from a systemic point of view." (Representative at the ecological transition commission of one of the Couesnon councils)

Conversely, some respondents gave a low score to the contribution of scenarios in understanding landscape dynamics because they are based on assumptions. As assumptions are made on socio-economic dynamics and their translation and adaptation to the local specific contexts of the Couesnon watershed, some respondents commented that the results were not general enough to provide transposable knowledge on landscape dynamics

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.	16.
1. Familiarity with BGINs	-	<.001***	.051	.708	.010*	.003**	.708	.012*	.801	.882	.292	.868	.014*	.001**	.03*	.022*
2. Importance BGINs	-	.	.071	.841	<.001***	.922	.233	.094	.078	.001**	.048*	.469	<.001***	.009**	.006**	.024*
3. Research evaluation	-	.	.140	<.001***	.996	0.110	.120	<.001***	.013*	.001**	.004**	<.001***	<.001***	.162	<.001***	0.071
4. Personal influence on factors	-	.	.	.	<.001***	.004**	.080	.718	.959	.574	.445	.743	.214	<.001***	.004**	.043*
5. Local actors influence on factors	-524	.117	.156	.520	<.001***	.028*	.003**	<.001***	.003**	<.001***	.004**
6. Influence on BGINs	-655	.747	.926	.091	.858	.040*	.313	.274	.932	.885
7. Understanding role on BGINs	-010**	.594	.002**	.002**	.036	.472	.055	.034*	0.261
8. Water quantity expectation	-	<.001***	.441	.821	.537	.048*	.163	.523	.085
9. Water quality expectation	-476	.065	.429	.29	.958	.190	.156
10. Identify challenges	-	<.001***	.015*	<.001***	.033*	.114	.010**
11. Consider influential variables	-006**	.006**	.133	.012*	.504
12. Envisioning futures	-980	.095	.008**	.693
13. Understand landscape dynamics	-063	.016*	<.001***
14. Instrumental water	-	<.001***	.025*
15. Instrumental biodiversity	-093
16. Take action	-

Table 1.3 – Spearman's non-parametric correlations between questions. Significance levels: p < 0.05; ** p < 0.01; *** p < 0.001*.

Outcomes of scenarios in the short term

	Familiar with the area N = 58		Unfamiliar with the area N = 73		KW (p-value)	Dunn Test
	Mdn	MR	Mdn	MR		
<i>Identify challenges</i>	5***	2.72	5***	2.77	1963.5 (0.767)	Ns
<i>Consider influential variables</i>	5***	2.88	5***	3.01	1897.5 (0.535)	Ns
<i>Envisioning futures</i>	4	3.98	4	4.03	1767.5 (0.535)	Ns
<i>Understand landscape dynamics[°]</i>	5***	2.63	6***	2.87	1769.5 (0.829)	Ns
<i>Take action</i>	5***	3.23	5***	3.51	2019 (0.270)	Ns
<i>Water quantity expectation</i>	5***	3.55	5***	3.04	2215.0 (0.517)	Ns
<i>Water quality expectation</i>	5**	3.42	5*	3.23	1932.5 (0.478)	Ns
<i>Instrumental water</i>	5***	2.89	5***	2.82	2025.5 (0.994)	Ns
<i>Instrumental biodiversity[°]</i>	5***	3.05	5***	2.79	2222.0 (0.401)	Ns
<i>Understanding role on BGINs</i>	5*	3.65	5**	3.32	1738 (0.159)	Ns

Table 1.4 – Median value (Mdn), average rank (MR), and results of the Kruskal-Wallis and Dunn test relatively to the familiarity with the study area. Median value (Mdn), average rank (MR), and results of the Kruskal-Wallis and Dunn test relatively to the familiarity with the study area. Significance levels of Mdn values refer to the Wilcoxon signed rank. $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$. [°] indicates the presence of heteroscedasticity; we verified results using non-parametric tests.

2. Article: Evaluating and maximising the outcomes of LUCS scenarios: strategies for an effective dissemination

	Farmers N= 54		Technicians N= 49		Representatives N= 30		KW (p-value)	Dunn Test
	Mdn	MR	Mdn	MR	Mdn	MR		
<i>Identify challenges</i>	5***	2.85	5***	2.91	6***	2.62	1.21 (0.545)	Ns
<i>Consider influential variables</i>	5***	3.00	5***	3.06	5***	2.86	0.70 (0.703)	Ns
<i>Envisioning futures</i>	4	4.22	4	3.93	4	4	1.58 (0.454)	Ns
<i>Understand landscape dynamics^o</i>	5***	3.17	6***	2.43	5***	2.74	7.60 (0.022)*	Tec > Far*
<i>Take action</i>	4**	3.78	5***	2.85	5***	3.39	6.08 (0.048)*	Tec > Far*
<i>Water quantity expectation</i>	5***	3.32	5***	2.71	5*	3.34	2.27 (0.322)	Tec > Far*
<i>Water quality expectation</i>	4	3.68	5*	3.27	5	3.38	6.36 (0.042)*	Ns
<i>Instrumental water</i>	5***	3.13	5***	2.77	5.5***	2.43	6.49 (0.039)*	Rep > Far*
<i>Instrumental biodiversity^o</i>	5***	3.19	5***	2.75	5***	2.68	3.37 (0.186)	Ns
<i>Understanding role on BGINs</i>	5**	3.32	4	4.06	5**	3.03	11.5 (0.003)	Rep > Tec**, Far > Tec*

Table 1.5 – Median value (Mdn), average rank (MR), and results of the Kruskal-Wallis and Dunn test relatively to the professional activity. Significance levels of Mdn values refer to the Wilcoxon signed rank. p < 0.05; ** p < 0.01; *** p < 0.001*. ^o indicates the presence of heteroscedasticity; we verified results using non-parametric tests.

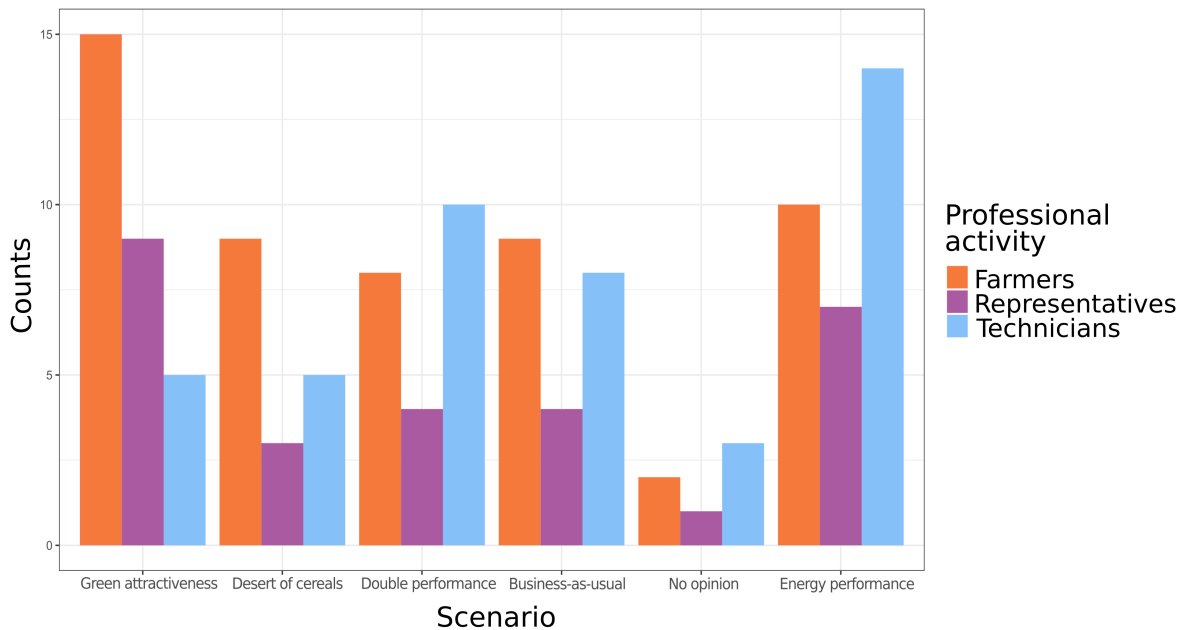


Figure 1.1 – Most probable scenario according to respondents’ professional activity.

2.3.2 A heterogeneous vision of the future

At the beginning of the workshop, we asked respondents if they had ever thought about the possible long-term evolutions of their work area. 87% responded “yes” or “yes, often”. After presenting scenarios, we asked which of the presented scenarios they believed was more likely to occur. The respondents’ answers reflected a diversity of visions regarding the region’s future (see Figure 1.1).

Indeed, even among people familiar with the area and from the same group of professional activities, there was no consensus about the more likely scenario.

“It’s evident that we all have different opinions. We would all have had the same opinions if you had come 20 years ago. But now there is a huge difference between farmers.” (Farmer from the Couesnon)

Most respondents agreed that their vision of the future was not a fixed and well-structured conviction but could change multiple times over a short period. Moreover, their conviction was strongly related to a specific geographical area. For these reasons, respondents tended to disagree slightly that the scenarios changed their idea of the future (Mdn = 4).

2.3.3 Correspondence between scenarios and expected results

As the Couesnon watershed has historically faced water quality issues and is increasingly affected by water quantity shortages, local actors often discuss the evolution of water resources. The scenarios showed that water quality and quantity issues would increase regardless of the evolution of the agricultural context. In this section, we investigate if local actors shared the same knowledge about the incoming tensions on water and if scenarios increase this knowledge and alert about future tensions.

After presenting the scenarios, we asked respondents if water quantity and quality results corresponded to their expectations. Regarding water quantity, farmers' and representatives' answers did not significantly differ from the neutral value of the Likert scale, while technicians' responses were significantly on the "agreement" side (Table 1.5). We found a positive correlation between the level of confidence in the research results and consistency between results on water quantity and prior expectations (Table 1.3). Technicians considered results about water quantity significantly closer to their expectations than results about water quality ($W = 77$, $p = 0.021$).

Since the water quality is improving in the Couesnon, many respondents were surprised to see a degradation of water quality in all scenarios, including the most virtuous ones regarding sustainable agricultural practices. Nevertheless, no participant questioned the results. Since regulations and environmental measures constrain agricultural practices, such as limiting nitrate inputs, some farmers and technicians did not expect to see a degradation in water quality. Some respondents did not consider that a reduced water quantity leads to a major concentration of pollutants and consequently to water quality degradation. This explains the mismatch between results and expectations about water quality. Although respondents felt that scenarios alone did not have the power to change their preconstructed vision of the future, they recognised the contribution of scenarios in opening their minds to the possibility that water quality will not follow a predictable trend.

2.3.4 Contribution of scenarios quantitative results on biodiversity and water for professional activity

The results of the Alice project show possible future changes in water quality (concentration of nitrates and phosphorus in underground water), water quantity, and landscape connectivity between the present and 2050 according to the five scenarios. One of the original aims of the study was to produce valuable data for water management at the watershed level. To verify if scenarios accomplished the original aim and if local actors could benefit from the provided data, we asked to what extent respondents agreed with the following questions: “The results on water resources / biodiversity are likely to help me in my professional activity.” Participants felt that the results provided by scenarios on biodiversity and water were likely to be implemented in their job (Mdn = 5 for both variables). However, the information on water resources was less likely to be mobilised by farmers than by representatives. On the contrary, there were no significant differences in how participants with different professional activities rated results regarding biodiversity (Table 1.5). Moreover, the representatives considered results on water quantity more likely to be mobilised in their practices than results on biodiversity ($W = 4, p = 0.042$).

Qualitatively speaking, the debates reflected the higher consideration accorded to water results than biodiversity, as most of the discussion focused on the contribution of scenarios to water management. For technicians of the Brittany region, results regarding water quantity and quality constituted incentives to work on better management of agricultural rotations and fertilisation. Another participant commented that the quantitative results of scenarios pushed technicians to think more about nature-based solutions for water management. Technicians also discussed how scenarios could promote parcel exchanges to facilitate agricultural work and support the diffusion of landscape elements that limit water quality degradation. The main leverage identified during discussions was to generate more interest in the already available tools for parcel exchanges.

“We already discussed the impact of amicable exchange of agricultural fields on water quality. For the green algae, it didn’t work. We must think about how to generate interest [in amicable exchanges].” (Technicians for the agriculture service of Brittany Region)

One reason explaining the high scores of technicians to the professional relevance of the scenarios is the nature of their job. Indeed, many of them work to raise awareness of farmers or representatives regarding environmental issues and are thus often engaged in

debates. Therefore, they benefit from scientific evidence to support their points of view and previous convictions with scientific knowledge.

"[Scenarios are helpful for my professional activity] because they provide scientific and factual evidence to our arguments because we are often engaged in debates. And we need to encourage our elected representatives to have a forward-looking vision and debate to define a desirable future." (Technician from the national association of watershed representatives)

"It's useful to support the debate and challenge elected officials on what they can and cannot do." (Technician from the national association of watershed representatives)

Nevertheless, the data resulting from the scenarios were seen as too general (e.g. giving the order of magnitude of the increase of concentration of pollutants in the water) to be used as support in technical documents. Some mentioned difficulty in identifying the contribution of scenarios regarding water management, as they felt powerless. External influential factors or decisions taken at another political level would limit local actors influence on environmental issues. Moreover, scenarios showed that the diminution of water during the summer period will be mainly a result of climate change, leaving respondents with the feeling of being left without no leverage. Regarding the trajectory of agriculture and its impacts on biodiversity and water, respondents often highlighted that significant decisions influencing the evolution of agriculture are taken at the European rather than local scale.

"I work with representatives who ask me the meaning of voting for a SAGE when the Common Agricultural Policy doesn't go in a good direction." (Technician from the national association of watershed representatives)

Indeed, considering that the results regarding biodiversity and water were likely to be put into practice in the respondents' jobs was positively correlated with belief in the fact that the study included factors over which respondents had a direct power of action. It was also positively correlated with being familiar with the concept of BGINs.

Scenarios were represented in terms of maps and narratives, and discussions took place after each survey session. Therefore, we asked participants to what extent the three supports (maps, narratives, and debates) were effective for understanding and internalising the new information. Farmers and technicians considered maps and discussions more effective than narratives, while representatives ranked the three supports equally.

2.3.5 Contribution of scenarios in tackling territorial challenges

Understanding one's role in managing an issue is the first step to acting. Therefore, we divide this section into two parts: first, we investigate the contribution of scenarios in understanding one's role in the implementation of BGINs; secondly, we investigate if respondents perceived the research as beneficial to push them to action.

2.3.5.1 Contribution of scenarios in understanding one's role in BGINs

We found no significant predictor of considering the scenarios an effective tool to understand one's role in the implementation of BGINs, except for professional activity. Indeed, farmers and representatives felt the scenarios had a higher contribution to understanding their role in the context of BGINs than technicians (Table 1.5). On multiple occasions, technicians highlighted how they did not perceive scenarios as awareness-raising tools because of their professional activity:

“[The low rating we gave on this question] is a matter of our role: taking actions in favour of the environment, it's already my role.” (Technician from a farmers'union)

2.3.5.2 Contribution of scenarios in putting in place land management actions

During the workshop, we asked participants to note to what extent they agreed with the questions: 1) “This research is useful to better understand the dynamics of the landscape”; 2) “This research is useful to put actions in place”. Comparing these two questions showed that all professional categories gave significantly higher ratings to the first (farmers: $W = 85$, $p = 0.012$; representatives: $W = 4$, $p = 0.015$; technicians: $W = 91$, $p = 0.016$), indicating that they all considered scenarios as more helpful as a tool to better understand landscape dynamics than as a tool to support implementing concrete actions. Farmers considered the contribution of scenarios in supporting action significantly lower than technicians (Table 1.5). The results also indicated that perceiving a useful contribution of scenarios in supporting action was positively correlated with having a high previous knowledge of BGINs, considering BGINs a significant issue, and considering that the study included factors over which respondents had a direct power of action (Table 1.3).

During the discussions, people who did not recognise themselves in any of the analysed professional activities and who were excluded from the quantitative analysis expressed reluctance to consider scenarios helpful in supporting action.

“I am at a loss as to how to deal with BGINs as a resident.” (Resident of Couesnon)

Similarly, students attending the master’s degree discussed their feeling of powerlessness as residents without decisional power in environmental management. Nevertheless, they recognised that they could get involved in environmental NGOs.

Several comments arose about the general contributions and limitations of scenarios in tackling environmental issues. Some were common across different actors, whereas others were specific to one group. The most recurring positive aspect of scenarios for technicians and representatives is that they address land management from a multidisciplinary perspective. For example, technicians from the Brittany Region volunteered to participate in the meeting to have a broader vision of how different elements interact in the landscape and to investigate possibilities of developing more consistent and coherent politics to support the agroecological transition. At the end of the workshop, they recognised that the meeting reinforced their belief in a tight collaboration between the different services of the region (urban development, agriculture, environment. . .) that still work separately. In addition, before the workshop, they identified hedgerows as a landscape element that fosters different ecosystem services. During the workshop, they also recognised and discussed the role of permanent grassland.

“ [The workshop] allows us to see that it will be necessary to imagine how to link the different services of the region: water, urbanisation, planning, agriculture. [Scenarios are] a tool where several policies intersect.” (Technician of the Brittany region)

Similarly, some technicians from the national association of watershed representatives recognised the value of a more integrated transition policy.

“What we take home is that it is interesting to put the landscape at the centre of a transition policy.” (Technician from the national association of watershed representatives)

Some local representatives also evoked the multidisciplinary character of scenarios, but they viewed the utility of multidisciplinary more from the learning perspective. They discussed the contribution of scenarios in clarifying the links between different landscape elements.

Participants also discussed several limitations regarding the contribution of scenarios in tackling environmental challenges. Even though some participants recognised that scenarios consider many aspects of regional development, others deemed that they were too focused on environmental aspects. The marginal attention to social aspects and impacts hindered some representatives' interest.

“When we talk about BGINs or wetlands, we emphasise the contribution to biodiversity or hydrology, but this is not what makes administrators attentive. We need sociological information about how we represent a territory. The main question of the BGINs is probably not the biodiversity, but how people accept to implement them and see what is possible and feasible to implement.”
(Technician from the national association of watershed representatives)

The methodology used to develop scenarios was another limiting factor. The modelling itself requires simplifications on how different variables interact. Nevertheless, some participants underlined how the model integrated neither feedback between environmental responses and human choices, nor the influence of agri-food chains on farmers' decisions, ultimately hindering their confidence in scenario results. Furthermore, some actors were not in full agreement with the hypotheses chosen to feed models and found it challenging to understand the level of uncertainty of the results, triggering a low level of confidence in the scenarios. In addition, some technicians agreed that representatives are often sceptical about scientific knowledge, especially in modelling, which can prevent technicians from referring to scenarios to support their points of view.

2.4 Discussion

2.4.1 Dissemination maximises cognitive outcomes

Our study highlights that, in the short-term, LUC scenarios effectively promote social outcomes, such as learning about landscape dynamics and landscape management challenges. Scenario makers must recognise this type of outcome as an achievement for a research-driven project and a valuable outcome of scientific knowledge. Moreover, knowing the factors that foster or hinder outcomes is crucial for an efficient dissemination strategy. In this sense, the lessons learned from this study can be applied to maximise cognitive outcomes of punctual dissemination activities.

As the first step of a dissemination activity, it is crucial to create (or verify if it already exists) a common understanding and a consensus on the importance of the main concepts

used in the scenarios. In our case study, respondents had very different knowledge of BGINs, and there was no consensus on their importance in landscape management. Considering BGINs as an important tool for land management positively influenced several outcomes, such as understanding influential variables and landscape dynamics, recognising territorial challenges, and how to mobilise scenario results in one's professional activity. In this regard, two options are possible: in the long term, promoting a better knowledge of the concept could enhance the perceived importance of BGINs; in the short term, it is beneficial to make the base concepts explicit and avoid using technical terms building on something more familiar such as connectivity.

Quantifying the impact of scenarios on significant variables for the area is also crucial. Since water management is a major issue in the Couesnon watershed, respondents perceived water quality and quantity indicators as more relevant for their professional activities than indicators on biodiversity. This is particularly true for representatives who must prioritise interventions and manage land use and resource conflicts in the territory. Nevertheless, showing the impact of scenarios on other indicators highlights how different landscape elements and ecosystem services are intertwined and fosters a deeper understanding of landscape dynamics. The presence of multiple indicators interested professionals working in different land management sectors (such as agriculture, water management and biodiversity) and permitted them to acknowledge and criticise well-established practices that hinder sustainable land management. The way technicians used the term "multidisciplinary" supports this conclusion: they mostly used the word when comparing the ability of scenarios to put together different aspects of land management, as opposed to organisational structures that force them to work on a particular landscape element.

Another crucial element that impacts the outcomes of scenarios is the audience's feeling of influencing the variables selected to define scenarios. In the dissemination phase, researchers can reinforce that feeling by listing authentic past experiences showing the power of local actors to impact LUCC. For example, some locally managed regulatory mechanisms, such as the Agri-Environment and Climatic Measures, have effectively limited the decline in grassland surfaces (Rigo et al., 2022).

Using a wide range of supports to show and discuss scenarios can foster the outcomes. In our case study, farmers and technicians agreed that maps and discussions were more

effective than narratives. On the other hand, representatives ranked the three supports equally as narratives allowed social variables to emerge. While some maps and narratives elicited some criticism, respondents generally appreciated the discussions. Using an interactive tool to submit the survey facilitates discussions and allows the participants to comment on their answers and compare them with the distribution of the results. The high percentage of participants taking part in discussions confirmed participants' engagement.

It is worth noting that disseminating scenarios can have positive outcomes regardless of the audience's familiarity with the study area. Indeed, the contributions of scenarios were mainly learning outcomes that can be applied to different contexts.

Lastly, our study highlights that higher confidence in the research positively influences the understanding of landscape dynamics and territory challenges. The presence of the person who develops scenarios clearly fosters respondents' confidence. When we consider researchers' time and financial constraints, a question arises: to what extent and under which conditions can they delegate scientific results dissemination? Even though answering this question is beyond the scope of this article, we stress the effectiveness of the dissemination phase in producing cognitive outcomes. A starting point could be to propose a limited number of workshops gathering representatives of stakeholders groups that can, in turn, raise awareness in their networks.

2.4.1.1 Moving towards instrumental outcomes

Social outcomes, such as learning, were not clearly identified as expected outcomes at the beginning of the project but ended up being the most important ones. Conversely, although it was the final goal of Alice scenarios, respondents seemed sceptical about considering the scenarios as a support tool to improve policy actions. Far from being an isolated case, this finding confirms the results of Karcher et al. (2021) that highlight the widespread inconsistency between expected and achieved outcomes for academic studies and the general tendency to social social outcomes.

Even though researchers conducted the initial research in partnership with water management and urban management structures, the quantitative outputs of scenarios appeared more suited to representatives' professional needs. Indeed, technicians felt that

the data provided in scenarios were too general to be used as an operational tool, while representatives claimed a possible use of scientific evidence to support their political positions. This point highlights how the scenarios did not completely meet the demand of institutional partners who were originally identified as potential users, making it difficult to achieve the instrumental outcomes. Limiting the gap between institutional partners' expectations and results of scientific research projects is necessary to reinforce a tight and permanent collaboration network of researchers and institutional stakeholders.

Without ignoring the intrinsic uncertainty of scientific outputs due to the new methodologies or applications, we advocate making this uncertainty explicit at the beginning of the project. Together with making expected outputs and uncertainties explicit, expected outcomes should also be co-defined, and full recognition should be given to social outcomes.

As Thompson et al. (2017) show, carrying out transdisciplinary research in traditional structures can create tensions, and they identify highly structured deliverables as a method to limit conflict. Financing programs such as the Interreg and Horizon2020 have the power to enforce the co-definition of expected outcomes for action-oriented projects. In those projects, to require deliverables signed both by the administrative partners and researchers could be a way to enforce it. In research projects involving multiple academics in different regions, defining the goals and outputs of the global project is common practice. We believe that, once the project is approved, co-defining outputs and outcomes at the site level with local actors will be beneficial. Apart from limiting mismatches between expectations and outcomes, this would promote a better understanding of the political and administrative context in which researchers operate and reinforce the science-policy interface at a local level.

2.4.1.2 Contributions and limitations of the study

Prior studies have documented the potential of participatory LUCC scenarios for land management, focusing on feedback from local actors who participated in the scenario-making (Hedelin et al., 2021). While disseminating to a large audience has been recognised as one of the steps for building effective scenarios in supporting environmental actions (Metzger et al., 2017), researchers have given little attention to this step. Here, we covered this gap by pointing out the outcomes of disseminating LUCC scenarios. To

our knowledge, this is the first study providing quantitative evidence of outcomes of scenarios for a heterogeneous audience who did not participate in the scenario-making.

We consider facilitating shared knowledge and re-discussing well-established practices as the main outcomes of the dissemination. A measure of success is that when local groups heard about our proceeding, we were sought out to present scenarios (Matthews et al., 2008).

However, some limitations are worth noting. Although we followed a protocol to limit group biases during the survey, some biases were still present. In particular, the presence of scenario-makers in the workshop is prone to provoke acquiescence bias. As people participated in the workshop voluntarily, a selection bias was also present.

The methodological constraints of statistical analysis made it necessary to group respondents to a limited number of professional activities. Nevertheless, we recognise the heterogeneity of backgrounds among people within the same professional category. The design we chose was sufficient to allow several results to emerge, but a more qualitative analysis could be adapted to account for hybrid profiles.

We encourage scholars to conduct similar work for scenarios developed in a different social and science-policy interface context. In our case, academics initiated the Alice project and only then looked for institutional partners. Repeating the same experience for scenarios demanded by institutions could enrich the discussion.

Lastly, we analysed reactions to our scenarios in the short term. Even if we found that scenarios promoted a learning process and created the space to re-discuss well-established practices, at this stage, we cannot verify if this first step will boost positive actions for sustainable land management. Different studies show that outcomes change over time (Hamilton et al., 2019; Matthews et al., 2011) and can occur several years after the dissemination (Rigo et al., 2022). Future work should include follow-up assessments, including interviews and grey-literature analysis, to evaluate if improving shared knowledge and reconsidering established practices result in tangible outcomes.

2.5 Conclusion

In this study, we analysed the data collected during 12 workshops in which we presented LUCC scenarios to a widespread audience. We aimed to understand to what extent scenarios can produce outcomes for an audience who were not involved in the step of co-creation. We found that social outcomes, were the primary benefits of the scenarios. Therefore, we believe that presenting scenarios to a wide range of local actors can be beneficial in creating a shared understanding of land management issues and facilitating sustainable land management. Nevertheless, social outcomes were not clearly identified as expected outcomes at the beginning of the project, while researchers and administrative partners expected scenarios to support land management decisions directly. In this regard, making explicit the expected outputs and outcomes, including social outcomes at the beginning of the project, can be beneficial for limiting mismatches between expectations and outcomes. In addition, we found that different actors valued scenarios differently according to their professional activity, consideration of the research's credibility, and the perceived importance of BGINs. Acknowledging that not all actors have the same priorities, backgrounds, and roles in land management, it is crucial to adapt the dissemination of scenarios to a specific audience to maximise outcomes.

3 Additional results and conclusion of Chapter 1

In this chapter, we analysed how local actor groups perceive the representation of future LUCC, their awareness of expected water management challenges and their knowledge of technical concepts. Moreover, we verified if scenarios were perceived as usable, intended as potentially applicable in the respective professional activities, and resulting from a credible research process.

Regarding knowledge of technical concepts, we registered a significant difference between groups. Indeed farmers had lower knowledge of the concept of BGINS and accorded lower importance to this network of landscape elements than the other two groups. Moreover, **farmers declared a lower consciousness of expected water management challenges**. Conversely, the **expected LUCC vary significantly across and within groups**, showing an absence of homogeneous visions.

Regarding the **instrumental usability of scenarios**, all groups positively evaluated the research (above the median value), and **representatives evaluated water-related results higher than farmers**. Nevertheless, more variability in answers was registered between farmers and technicians than representatives.

Generally, **scenarios were perceived as salient and credible**, and we received positive feedback on the co-production process followed by scenario-makers positively impacting legitimacy.

During the workshops, we discussed the central role of hedgerows in water quality and ecosystem services. Nevertheless, not everyone had equivalent knowledge of the practices related to the maintenance of hedgerows. For example, farmers acknowledge the common practice of making trees sick to circumvent the law prohibiting the removal of hedgerows. However, while representatives seemed aware of this practice, regional technicians expressed surprise at hearing it. This knowledge gap can be explained by the fact that in our sample, representatives were elected in local municipalities, and some were previously farmers ($n = 6$) or were familiar with the agricultural sector. While our protocol did not statistically verify the knowledge of that practice across groups, our observation highlights that **some taboos in land management are not discussed openly**. We

believe such taboos prevent a fruitful discussion on effective policies fostering economic and environmental sustainability.

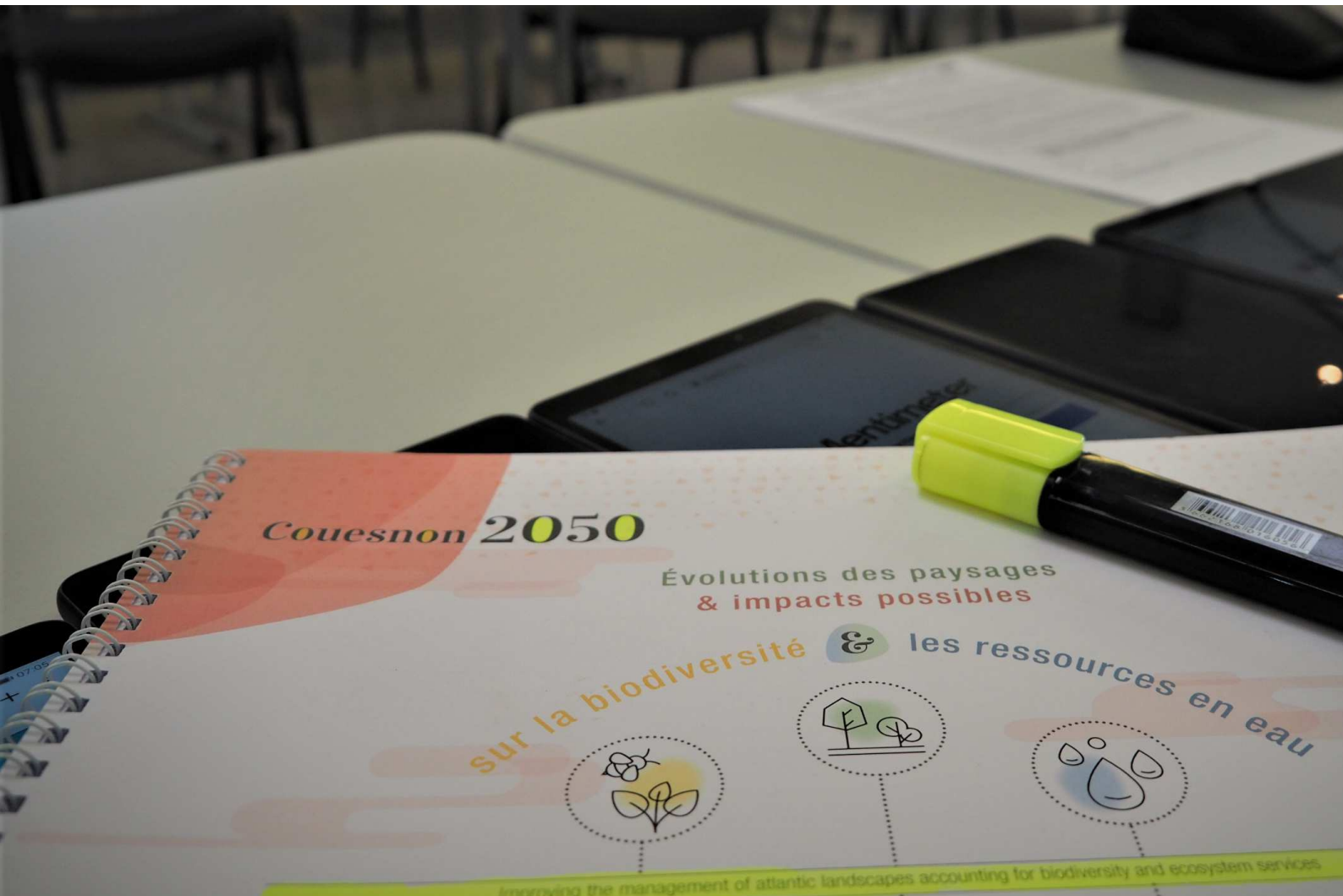
Apart from assessing the usability of scenarios, we detected some first outcomes. Indeed, **workshops permitted levelling knowledge on expected environmental challenges and agricultural practices.**

To conclude, this short-term evaluation article allowed us to:

- **Verify the usability of scenarios:** respondents expressed confidence in the research results regardless of their professional activity and familiarity with the study area. The co-creation phase was perceived as essential in establishing the study's legitimacy showing the first complementarity between impact pathways. On the saliency side, local actors consider water results more salient than biodiversity, reflecting the tensions on water resources in the territory. Moreover, the results of scenarios are more likely to help representatives in their professional activities than technicians.
- **Detect an incoherence between expectations and respondents'perceived usability of scenarios:** scenarios were developed in partnership with a technical structure aiming to help land managers define BGINs and incorporate them into local management plans. Nevertheless, scenarios appear more salient for representatives than technicians.
- **Detect short-term outcomes:** some personal, cognitive outcomes were detected in the short term. Indeed scenarios levelled up knowledge on expected challenges and agricultural practice and brought new knowledge in those sectors of activities respondents are not specialised in (i.e. the concept of BGINs for farmers and standard practices bypassing the legal restrictions for technicians working at broader organizational levels).

While the evaluation framework is easily replicable, organising workshops is time consuming. However, this first evaluation allows setting the bases of outcomes evaluation for the different types of local actors, which will permit better audience targeting relative to expected outcomes.

OUTCOMES OF SCENARIOS IN THE MID-TERM



1 Introduction: scenarios as boundary objects?

In this second article, we shift the focus from assessing the usability of scenarios to evaluating their mid-term outcomes. The dynamic evaluation approach helps to differentiate the outcomes according to the time of appearance. Knowing at what time lag outcomes manifest themselves can help determine their evolution and give insights on appropriate evaluation timing to detect the presence/absence of specific outcomes. Moreover it can support an efficient planning of scenario-related projects. Imagine, for example, a two-step project with a first awareness rising step through scenarios and a second intervention on developing leverages of change. In that case, it would be essential to set the follow-up part when functional outcomes arise or are still present.

While the following article analyses the emergency of different types of outcomes, we decided to observe them primarily from the angle of policy integration. Indeed, we assume that scenarios can function as a support tool for more integrated land management by showing the interdependencies between landscape elements and ecosystem service and the limits of the public sector divided into silos. Throughout the dissemination pathway, we reached several local actors implied in different land management aspects. This permitted us to examine if and how scenarios assumed the expected function in different communities of practice. Moreover, scenarios are developed at a relevant spatial extent as the area coincides with the water management organisation level and overlaps with the urban management organisation level.

In this analysis, we use the concept of boundary objects as physical objects allowing knowledge transfer and cooperation between different groups of actors. Indeed, different local actors worked together in the co-construction phase and exchanged experiences, knowledge and practices of their community to construct storylines (i.e. the technicians from the SAGE and the SCoT, the Agricultural Counsellors, and the researchers). Conversely, people participating in dissemination workshops came from relatively homogeneous communities. Nevertheless, on a few occasions, some heterogeneity was present. In particular, during one session (ZA Armorique), inhabitants, representatives, and farmers were gathered, and the workshop with the Brittany Region brought together technicians from the same structure but different services. On a weaker base compared to co-production, respondents could then exchange points of view and practices in response

to scenarios. Moreover, mobilising this concept is particularly pertinent in this chapter because the relatively short evaluation time lag allows respondents to refer to personal cognitive outcomes (such as increased or enriched knowledge). Still, enough time passed to permit the raising of group outcomes such as cooperation between actors.

The conclusion of this chapter will expand the analysis of the outcomes of scenarios under the prism of boundary objects. While part of this analysis is already present in Section 2, the article's focus on integrated management pushed us to leave out comments on the workshop at the ZA, in which participants did not come from institutional contexts. From the methodological perspective, we base the article of this chapter on interviews, and we include in the sample some local actors previously excluded because of the constraints imposed by the quantitative analysis. Participants in the co-construction phase and inhabitants of the Couesnon watershed are then represented in the sample. Including people who participated in the co-construction permits differentiating outcomes according to the impact pathway through which participants got in contact with scenarios and the consequent difference in time invested in the project. The qualitative approach also allows us to consider something overlooked in the previous chapter: a nuanced analysis of the respondents' profiles. Indeed, in this second article, we will detail the principal mission of representatives and technicians (e.g. water management and agriculture technicians), and we will provide more details on some of the interviewees' backgrounds in the chapter conclusions.

It is worth noting that the socio-political conditions changed between the short-term evaluation and the moment of interviews (April to June 2022) and significantly influenced the evaluation. In particular, the war in Ukraine started in February 2022 and caused a cereals price-pick in France (Neveu, 2022). Hence, the public debate, previously marked by COVID-19-related subjects, became centred on the current Russian-Ukrainian conflict.

Finally, to avoid confusion, it is essential to highlight the incoherence of terms used in the article and the manuscript. Indeed, in the following article, we refer to the evaluation as a long-term one, but we insert it in the mid-term evaluation chapter. We opted for this terminology because the evaluation is performed a few months after the diffusion of results which corresponds to a mid-term evaluation in the thesis structure but a long-term evaluation from the ALICE lens.

This chapter has been submitted as an original research paper to Land (under review).

Rigo R. and Houet T. (submitted) Do land use and land cover scenarios support more integrated land-use management? Land

2 Article: Do land use and land cover scenarios support more integrated land-use management?

R. Rigo, T. Houet, C. Gonthier

Abstract

Traditional top-down approaches that focus on marked-led punctual responses struggle to preserve essential landscape elements for environmental sustainability. To remedy this failure, more integrated policies reflecting the interdependencies of the socio-ecological systems are needed. Land-use and land-cover change (LUCC) scenarios are tools that seek this goal by promoting an integrated vision of the landscape dynamics, pointing out the inconsistency between the "silozation" of the public sector and the need for integrated management. In this paper, we analyse the outcomes of some LUCC scenarios, including their role in encouraging integrated management. To assess outcomes, we interviewed local actors who participated in the co-construction process or got to know scenarios during some dissemination workshops. Collected qualitative data were analysed with a thematic and lexicometric analysis. Results highlight the double role of scenarios as a catalyst of an already present political will to promote integrated management and as a rising awareness tool. Indeed, group-level outcomes (e.g. citing the results of scenarios in political decision-making and increased collaboration between institutions) arose for stakeholders participating in the co-creation phase or having the will to develop integrated management initiatives. Additional personal outcomes include increased awareness of environmental-related challenges and the consolidation of non-formalised knowledge. We argue that proposing complementary impact pathways for sustainable science improves research outcomes for land management and, with a moderate marginal effort, dissemination practices can consistently increase co-produced knowledge outcomes by generating positive feedback.

2.1 Introduction

We live in an era in which science-based technology and scientific knowledge are broadly available (Glavovic et al., 2021; Renn, 2018), and current scientific knowledge warns of the necessity of an urgent change in socio-economic paradigms to face a multi-dimensional socio-environmental crisis (González-Márquez and Toledo, 2020). Terms like “sustainability” and “low-carbon transition” are gaining an increasingly important place not only within the scientific community (Fang et al., 2018; Kajikawa et al., 2014; Wim-badi and Djalante, 2020) but also in public debate and political discussion (Yeh, 2020). While scientists highlight the need to value and protect nature for its intrinsic value (Pereira and Ferrier, 2020), in capitalist systems, decisions are still predominantly taken with a neoclassical approach (Brand and Wissen, 2013; Spash and Hache, 2022) overlooking scientific knowledge and citizens’ mobilisations against this approach. In the rural context, the environmental degradation due to intensive agriculture and the limited ecological ambition of the recently approved Common Agricultural Policy (CAP) represents the reticence to change the traditional paradigm (Lasa Lopez, 2022; Pe’er et al., 2020). Indeed, the CAP and other complementary traditional top-down and fiscal approaches are still the foundation of the agricultural economy even if they struggle to promote environmental sustainability, for example, failing to conserve landscape elements (Bodin et al., 2016) essential to preserve biodiversity, water, and soil. The division of the public administration into ‘silos’ has been recognised as a substantial barrier to implementing integrative policies capable of simultaneously supporting social, economic and environmental well-being (Candel and Biesbroek, 2016; Duffy and Cook, 2019).

In this paper, we want to analyse the outcomes of some watershed-level land-use and land-cover change (LUCC) scenarios, including their role in encouraging integrated management. To analyse the outcomes of LUCC scenarios, we selected the scenarios published by Houet et al. (2022) as case study. The methods through which scenarios were produced and diffused and the spatial extent and resolution of scenarios are central variables for our evaluation. Indeed, scenarios were co-constructed with water and urban land managers and diffused to a broader audience throughout a series of workshops (Rigo et al., submitted). The evaluation of LUCC scenarios outcomes is composed of two steps: in the short-term (during workshops), we evaluated the perceived usability of scenarios through an interactive survey; then, 7 to 11 months after the workshops, we interviewed some participants to identify personal and group outcomes (with a high emphasis on policy in-

tegration) and contextualise them in the administrative and political context. This article focuses on this second evaluation, called hereafter ‘long-term’ assessment, and considers feedback from stakeholders who participated in the co-construction process and those who participated only in the diffusion workshops.

The paper is organised as follows. Section 2.2 briefly resumes literature on policy integration, including the concepts of boundary objects and impact pathways that underpin our analysis. Section 2.3 describes the LUCC scenarios and the relative geographical and administrative context. Then, Section 2.4 details the interview protocol and analysis methods. The following section reports the interviews results and links with the short-term survey. In this part, we analyse the network of local water management actors and their connections with the agricultural and urban management sectors at the organisation level they operate. Then, using a lexicometric and thematic analysis, we analyse the long-term outcomes of scenarios. In Section 2.6, the paper discusses the role of scenarios in fostering collaboration between different actors and implications for integrated management, the implication of a coherent spatial extent and resolution in producing outcomes and the theoretical and practical limitations of the study. Lastly, Section 2.7 concludes the paper.

2.2 Literature review

The concept of policy integration refers to "the collaboration of actors from two or more policy domains in order to integrate aims and concerns derived from one policy domain into another" (Tosun and Lang, 2017, p. 553). Initially applied to marine policy (Tosun and Lang, 2017), integration is gaining attention in environmental management, which is generally confronted with cross-sectoral wicked problems (Duffy and Cook, 2019). Nevertheless, the development of integrative policies is hampered by the division of the public administration into "silos" composed of relatively stable groups of actors in charge of sub-sectoral policies and with a specific perception of environmental issues (Candel and Biesbroek, 2016). This "pillarisation" or "silozation" complicates collaboration between administrations and services and hinders a more holistic way to approach cross-cutting problems (Candel and Biesbroek, 2016; Duffy and Cook, 2019). In their framework, Metz and Glaus (2019) highlight how policy integration can be promoted not just by a change in the legal framework but also by favouring the involvement of actors in policymaking, while other authors highlight the critical contribution of social innovation (Marini Govigli et al., 2022; Nijnik et al., 2022). The capacity of public institutions to provide integrated

policies has been studied at different spatial scales (see Candel et al., 2016, for a study at the European level; Molenveld et al., 2021, at the national level; and Metz and Glaus, 2019, at the watershed level) and for different environmental issues. In particular, concerning the water management context, Murgue et al. (2015) show that a low integration between water and land use issues is one of the most significant challenges for sustainable management.

Despite some application limits (Lang et al., 2017), the production of transdisciplinary action-oriented knowledge that helps to understand socio-ecological systems (Fang et al., 2018) has been recognised as a potential way to foster policy integration and enhance decision-making capacity (Clark and Dickson, 2003; Miller et al., 2014). By engaging non-scientists in the production of multidisciplinary action-oriented studies, sustainability science can create bridges between different actors, services and projects (Posner and Cvitanovic, 2019). In this reflection, the concept of boundary objects is central. Indeed, it can be applied to any object that is flexible enough to facilitate communication between actors from different communities of practices (Wenger, 1998) or social worlds (Star and Griesemer, 1989). At the same time, a boundary object can be used and interpreted differently to satisfy the specific needs of the groups (Star and Griesemer, 1989). Furthermore, boundary objects comply with two other conditions: they address practical information needs, and they can be applied across different groups while maintaining a shared identity (Star, 2010; Steger et al., 2018). Boundary objects can then facilitate collaboration and learning between people with different backgrounds interacting through them (Fischer and Ostwald, 2003). By analysing how learning occurs at boundaries, Akkerman and Bakker (2011) identify identification, coordination, reflection, and transformation mechanisms. The first is related to knowing the other's practices; the second is about creating stable exchanges; the third is about developing broader or different perspectives on practices, and the latter is about co-creating new practices.

Besides studies on learning in the presence of boundaries, well-established literature explores a whole panel of research potential outcomes occurring at different time lags (see Carden, 2004; Reed and Rudman, 2022; Weiss, 1979 for some examples). Hamilton et al. (2019) categorise research outcomes at the project level (i.e. credibility, saliency and legitimacy of the research), individual level (such as an increased system understanding), group level (such as an instrumental use of research results and increased collaboration

between stakeholders), and finally, system level (e.g. a systematic change in attitudes). One central element to consider when analysing outcomes is how research is produced and communicated. As synthesised by Muhonen et al. (2020), the interaction between scientists and other stakeholders can assume different forms leading to different impact pathways. The authors identify 13 typologies of pathways to societal impact that go from the linear "classical pipeline pathway", in which scientific knowledge passes from scientist to society through a "knowledge creep" to more complex interaction models. Although impact pathways and societal outcomes of research are relatively well known, scientists can lack an in-depth understanding of the land management system, including a global vision of the multitude of stakeholders and the relations between them (Bürgi et al., 2004). This partial comprehension of social dynamics can lead to inefficient interaction strategies and hinder potential outcomes.

This study focuses on the outcomes of LUCC scenarios for land management. LUCC scenarios can be defined as tools that provide a spatially explicit representation of how land use and land cover may develop in a pre-defined time-lapse often by combining narratives with mathematical modelling (Houet, Aguejdad, et al., 2016). While scenarios had been previously recognised as boundary objects in different contexts (Lebel, 2013; Salmi et al., 2012), here we focus on particular types of scenarios largely used in local land management for their support in sharing visions, values and needs of different stakeholders and facilitate shared problem framing. Moreover, LUCC scenarios have the potential to promote integrative management by reflecting interactions between landscape elements and socio-economic evolutions (Badham et al., 2019) beyond the "silozation" of the public sector. In scenario-making, modelling characteristics and social outcomes are deeply interconnected. For example, suppose the goal is to highlight interactions between landscape elements and socio-economic evolutions (i.e. the development of different agricultural systems or an evolving population density). In that case, a high spatial resolution is needed up to the parcel level. Nevertheless, a higher spatial resolution is often assimilated with a limited covered area potentially mismatching the operative boundaries of some stakeholders implicated in land management. For example, water and land management are often the competence of separate administrative sectors with jurisdiction over different and overlapping areas (Garrick et al., 2022). Therefore, a trade-off between spatial resolution, the accuracy of modelling landscape elements interactions, and spatial extent exists (Houet et al., 2022). For this reason, identifying the appropriate spatial extent and

impact pathway to promote inter-service and inter-institutional collaborations is essential to reach land-management sustainability.

2.3 Context and Materials

In North West France, where this study takes place, the bocage (hedgerow network) is iconic. In addition to a substantial cultural and economic value and its influence on biodiversity and field microclimate (Forman and Baudry, 1984; Montgomery et al., 2020) several studies certified the influence of this landscape element on soil-water transfer (Ghazavi et al., 2008) and groundwater quality (Thomas and Abbott, 2018). Nevertheless, despite the legal protection and local initiatives favouring the maintenance of bocage, the linear is decreasing at the Brittany scale (Chever et al., 2021; Houet et al., 2022). The decrease in hedgerows economically benefits farmers who take advantage of selling wood and of a uniform landscape mosaic more accessible to cultivate. Although from the farmers' point of view, removing the bocage is sometimes the logical consequence of a barely rentable and time-consuming job. This local example more largely shows how the present land management and specific top-down measures fail to translate scientific knowledge into practices. Rather than focusing on market-led responses targeting specific sectors, scholars highlight the urgent need to tackle sustainability issues from an integrated socio-ecological systems approach that reflects the interdependencies of the environmental system (Bondin, 2017; Martínez-fernández et al., 2021).

The scenarios we evaluate are developed under the Alice project and published in Houet et al. (2022), and study the impact of agriculture and urban changes on water quality, quantity, and biodiversity through the lens of landscape connectivity for the Couesnon watershed. We select those scenarios because they consider the implementation of the Blue and Green Infrastructures (BGINs) policy, which is the local declination of the EU Biodiversity Strategy, as one driver of land use and land cover changes that limits the possible expansion of urban areas. Furthermore, the scenarios highlight the multiple roles of landscape elements that compose BGINs making them a suitable tool to encourage integrated management between various and separated actors and land-management sectors.

Scientists impulsed the project and developed it in collaboration with water and urban land managers. Narratives were co-constructed with an enlarged panel of local actors and fed a LUCC model to simulate future landscape changes (Houet et al., 2017; Houet et

al. (in prep)). Results were diffused to a broad audience throughout 12 workshops (see Appendix 3.1 for more details; Rigo et al., submitted). In each workshop, we presented the methodology and results of scenarios to a homogeneous audience in terms of professional activity. Following the Muhonen et al. (2020) framework, we followed two pathways to create research impact: the "collaboration pathway" for the local actors involved in the co-creation of scenarios and the "interactive dissemination pathway" for local actors assisting in dissemination workshops. During the workshops, participants discussed the results of the scenarios and the implications on their professional activity. Moreover, we used an interactive polling system to verify that local actors generally considered scenarios usable (intended as legitimate, salient, and credible) and effective in raising awareness of future land management problems and understanding landscape elements' interdependency (Rigo et al., submitted). The survey showed that respondents' confidence in the research results was high and did not change significantly between the different professional activity groups, nor according to the familiarity with the study area. In addition, representatives considered results showing water quality and quantity evolutions more relevant for their professional activity than results on biodiversity trends. Conversely, technicians and civil society did not express any significant difference.

Scenarios envision LUCC for the Couesnon river catchment (1 130 km²) located in North West France (Figure 2.1). The interest of this area is that residents are sensitive to water management tensions as farming activities led to significant water quality issues (Dupas et al., 2018; Eau du Bassin Rennais, 2019). Nevertheless, water quantity tensions due to climate change recently started to warn local actors as an emerging environmental problem. Moreover, the agricultural lands are characterised by the bocage: a hedgerows network in the agricultural matrix that composes part of the BGINs.

On the administrative level, the multiscale decision system is well represented, but at the same time, it is not over complex. Indeed, Alice project scenarios were developed at a consistent extent for local water managers: the SAGE Couesnon (an administrative structure in charge of the sustainable management of water resources for the Couesnon watershed). Regarding urban land management, the principal organisation level is the intermunicipalities¹: a grouping of municipalities that jointly manages local public services and promote sustainable development in urban and rural territories. Nevertheless, several

1. Établissements publics de coopération intercommunale (EPCI) in french

intermunicipalities can jointly manage urbanisation via a SCoT. Nine intermunicipalities cover the Couesnon, two cover two-thirds of the territory and share the same SCoT. At the same time, most of the SCoT belongs to the Couesnon Watershed.

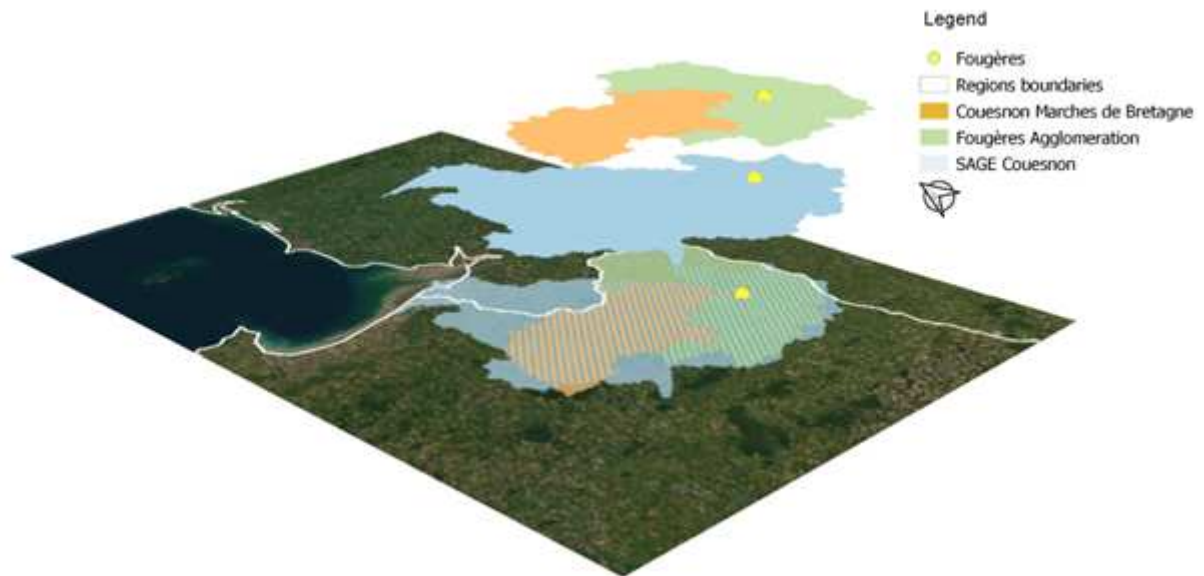


Figure 2.1 – Scenarios extent covers the Sage Couesnon area (light blue). The intermunicipalities of Couesnon Marche de Bretagne (in orange) and Fougères agglomeration (in green) share the same urbanisation policy regime (the SCoT pays de Fougères). The yellow dots represent the city of Fougères.

2.4 Methods

7 to 11 months after the workshops, we selected some of the participants for the in-depth interview. One or more interviewees from each workshop were selected, prioritising actors with solid interpersonal connections with the other participants and high visibility on the initiatives and actions taken by their organisation/group of stakeholders. We esteem this evaluation time lag long enough to let some group effects emerge while allowing interviewees to remember workshop supports and discussions (See Appendix 3.2 for details on interviews timing and Interviewees' anonymised data). Informed consent to participate in the study has been given by all interviewees orally. We organised workshop sessions based on a first draft of the actors analysis (Figure 2.2). Workshop participants and interviewees represent the main actors involved in water management, agriculture and urban planning at different organisation levels. To limit acquiescence bias, the researcher who conducted

the interviews participated in the dissemination phase but not in the scenario-making one.

In total, we conducted 20 interviews lasting between 27 and 88 min (52 min on average). The interview was divided into three main parts: 1) First, we conducted a semi-structured interview. This part aimed to understand the interviewees' professional activity, the links between the organisation they belong to and other land management actors, and the main contributions of participating in the workshop (we asked a follow-up question regarding the salient points of the workshop if needed). With this part of the interview, we aimed to have a first insight into the representation interviewees have of the scenario's outcomes and interviewees' characteristics that mainly define it; 2) The second part was a reactivation interview aiming to understand the outcomes of scenarios besides the principal ones. In this part of the interview, we looked at a booklet resuming the main point of scenarios methodology and results that we distributed at the end of the workshops. Moreover, we showed the answers to the interactive polling we collected during the workshop; 3) We concluded the interview with a framing part in which the interviewer framed how the interviewee lived the workshop and which were the outcomes of scenarios for him/her. Reactions to this part allowed us to detail some outcomes and verify that the interviewee framed the situation likewise.

Interviews were transcribed manually with the aid of Sonal software (Alber, 2018) and examined with a thematic and lexicometric analysis. The former, performed on the entire corpus, permits refining the scheme of actors related to land management, their connections and the organisation level at which they operate. Moreover, it allows for identifying the globality of the outcomes of scenarios for each interviewee. Interview citations are translated literally from the original language (French) to English. Lexicometric analysis was performed on a sub-corpus using the Iramuteq (Interface de R pour les Analyses Multidimensionnelles de Textes et de Questionnaires) open-access software. We included all the parts of interviews related to the workshops' primary outcomes in the sub-corpus, and we coded each interview extract as a text associated with variables (code of the interviewee, professional activity, coherence between the interviewee's working scale and scenarios extent). We organised the sub-corpus into a single file, standardised acronyms, and combined compound words into single ones following the procedure suggested by Camargo and Justo (2013). The sub-corpus was then automatically lemmatised, and words were divided into active forms (adjectives, adverbs, nouns and verbs) used for analysis

and supplementary forms excluded from the analysis.

After preparing the corpus, we performed a Descending Hierarchical Classification (DHC) using the ALCESTE method (Reinert, 1993) that allows sorting the text into separate text classes with a highly similar internal vocabulary and different vocabulary between classes. To quantify the associative strength between words and the respective class, Iramuteq uses the chi-square test (χ^2). Only words with $\chi^2 \geq 3.84$ (corresponding to a probability of 0.05% to randomly associate the word to the class) are considered in the classification. Classes and relations between them are shown as a dendrogram and through a factorial correspondence analysis (FCA) resulting from the DHC (Camargo and Justo, 2013). The FCA allows us to analyse for each generated class the statistically most significant words plotted on a Cartesian plane. Once the classes were identified, we qualitatively analysed the extracts containing the classified words.

2.5 Results

2.5.1 The land management system

The scheme presented below (Figure 2.2, detailed in Appendix 3.3) permits a visual representation of the administrative documents, the financial mechanisms and the multiplicity of local actors related at different scales to water, agriculture and urban management impacting the Couesnon watershed. Interconnections between scales and sectors are mainly administrative (integrating documents into lower-level directives and legal documents), financial (funding projects or incentives) and technical (support in the definition of policies and administrative documents). Actors are divided according to their sector (water, agriculture and urban management), their organisation level (Communal, Sub-regional, Watershed, Regional, National, Continental) and their nature (Administration, political, technical, and civil). This non-exhaustive scheme is centred on the water management issue.

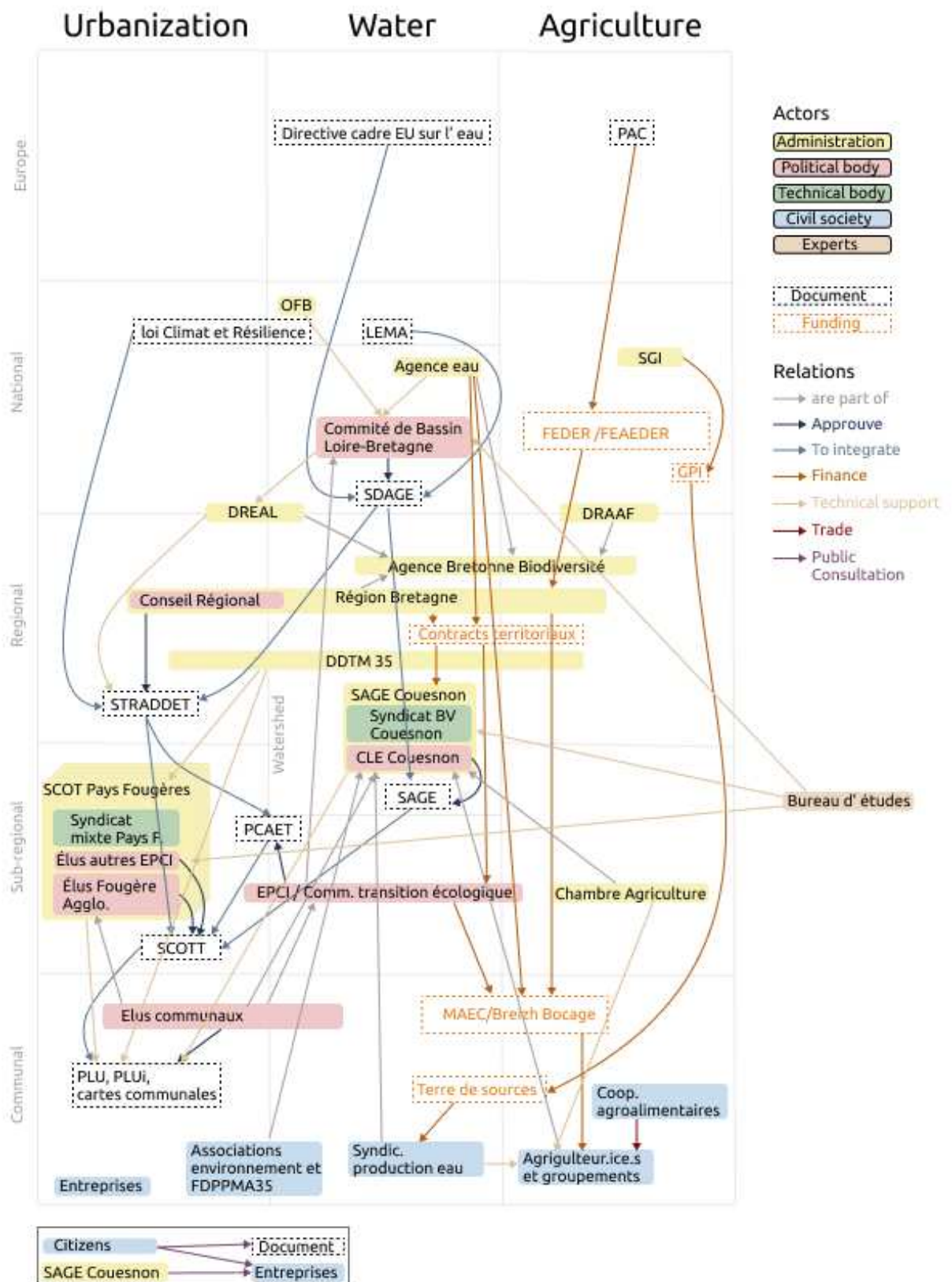


Figure 2.2 – Actors involved in the Couesnon water management and their relations with urban management and agriculture actors. The scheme is not exhaustive and does not represent elements belonging to agriculture and urban management, which are not related to water management.

Water is primarily managed at the watershed level, and the spatial extent of scenarios reflects this organisation. The main actors for water management are the Syndicate of the CLE Couesnon, which together compose a structure in charge of, respectively, managing and approving the SAGE, a document that integrates the SDAGE, a strategic master plans for managing river basins. The SDAGE and the SAGE are integrated with urbanism via legal documents and human connections in the form of technical support. Conversely, an integration between water policies and agriculture depends on the voluntary subscription of farmers to funding mechanisms, primarily coming from The European Union and integrated with regional fundings and sustainable farming projects (Breizh bocage and Terre de Source² being the most cited in the interviews). At the local level, using an agricultural system beneficial for water quality and quantity rests on the possibilities and will of farmers. The most coherent level to promote integrative water and agricultural policies in the current administrative system seems to be the regional one, where transversal political and administrative structures are present.

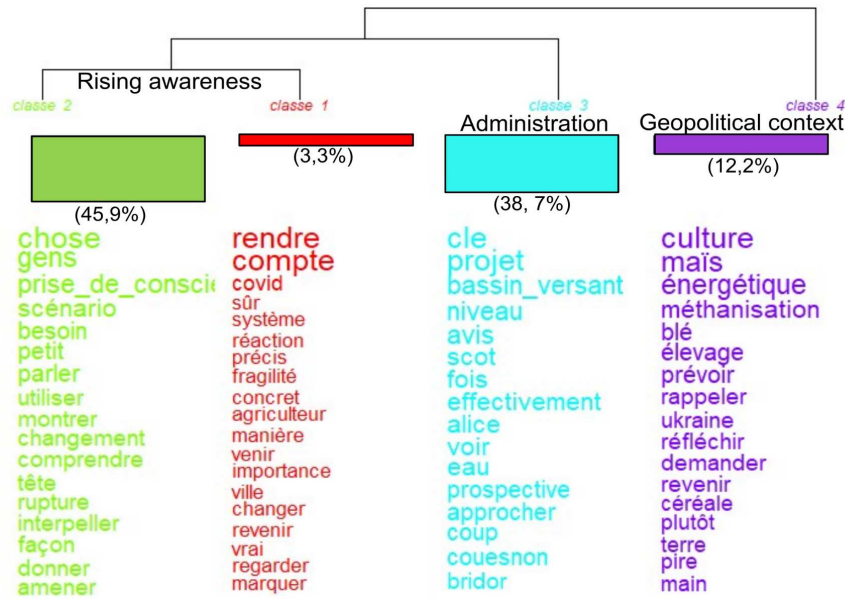
2.5.2 Lexicometric analysis

To understand how interviewees represented scenarios, we analysed the semi-structured part of the interviews (regarding primary contributions of the workshop) with lexicometric analysis (DHC). The analysis was performed on a corpus of 6424 occurrences, including 486 hapaxes (7.57%), with an average of 338 occurrences per text. The active forms included in the analysis were 747. 98.37% of text segments were used for the analysis, which is considered an efficient use of ECU (Camargo & Justo, 2013). The DHC, performed on the ensemble of interviews, shows that the discourse is structured around four main semantic blocks (Figure 2.3). The second class and the first one (the most significant ones) regroup rising-awareness-related words. The third addresses the application of scenarios in the administrative context, while the fourth regroups “geopolitical context” related words. Technicians and politicians are the ones who use more words linked to the instrumental applications, while farmers and inhabitants (coded as "civils") relate scenarios more as a rising awareness tool. Moreover, interviewees mostly cited agriculture and water-related words in the classes related to scenario outcomes, while urban management-related words did not appear.

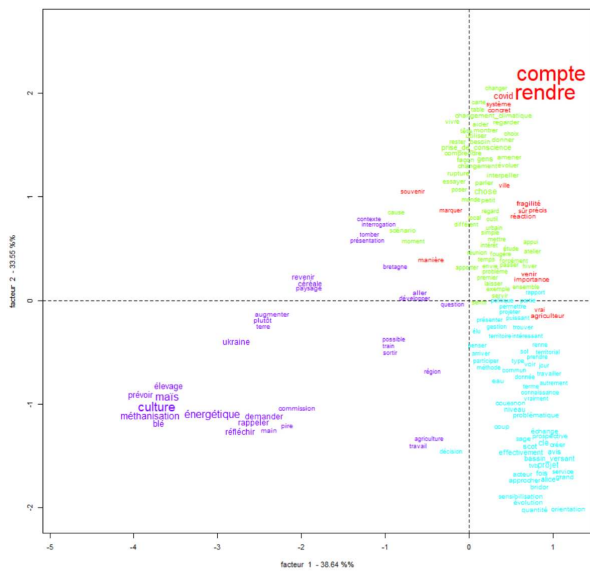
Analysing the context of the words included in the fourth class, it becomes evident how interviewees connected one of the scenarios, which described an increase in cereals,

2. Terre de source official webpage (accessed on 01/12/2022) : <https://terresdesources.fr/>

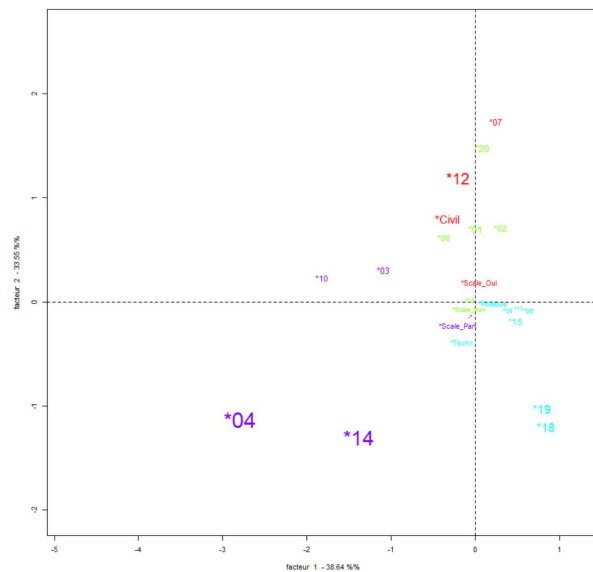
Outcomes of scenarios in the mid-term



a)



b)



c)

Figure 2.3 – a) Dendrogram of the four lexical named classes obtained from the DHC of the active words. The percentages represent the distribution of the classified words for each category (e.g. category one groups 3,3% of the classified words); b) FCA of t the active words in each of the lexical classes obtained in the DHC; c) FCA of the variables in each of the lexical classes obtained in the DHC.

to the current cereal plantations due to the ongoing Ukrainian war and the consequent rise of cereal prices. On the contrary, technical elements of scenarios, like spatial extent and resolution, the hypothesis made, or the protocol followed to develop the scenarios, were rarely cited in this first part of the interview.

The “geopolitical context” theme, brought up by the lexicometric analysis, is not semantically related to the outcomes of scenarios. Nevertheless, interviewees perceived it as connected to it. Going back to the entire corpus and analysing it qualitatively, we see that people talk about the present geopolitical context as a breaking moment that tilts the world toward one of the scenarios. Even if we cannot state a causal effect between assisting the workshops and an increased ability to identify connections between landscape elements, interviewees show a high level of transversality when talking about the actual geopolitical context. For example, interviewees citing the increase in cereals also talked more broadly about a uniformisation of landscape and its effects on water quality and the economy.

“Three things struck me: the apocalyptic scenario of all wheat, the fact that Brittany could get out of this economy based on dairy, and the fact that the most ecological and alternative scenario was the least applicable. For me, it was a sort of: "But why this scenario, which is the most local, the one that respects the ecology and people, is not the one that will finally be implemented?". And then we always come back to economic questions. And I wonder today, with the war in Ukraine, if we are not going towards more cereals here too? And so the whole landscape changes" (LA 12, Inhabitant)

“It allows us to ask questions from a land use point of view, but also considering the energy aspect. What does it mean that the farmer creates energy and what are the potential consequences on our soil?” (LA 13, Inhabitant)

2.5.3 The land management system

The lexicometric analysis shows that interviewees considered scenarios as a rising awareness tool and as a support for administrative procedures. With a thematic analysis, we identified more specific outcomes of the scenario workshop for each interviewee (Table 2.1). Following the framework of Hamilton et al. (2019), we group outcomes into individual and group ones.

Outcomes of scenarios in the mid-term

Interviewee Code	Role	Participation	Spatial scale coherence							
				Rising awareness	Consolidate point of view	Learning/ Diagnosis of current situation	Collaboration between actors	Base for successive works	Decision making/ Influence on the political will	
03	Farmer	W	Y	1	0	1	0	0	0	
07	Farmer	W	P	0	0	1	0	0	0	
13	Inhabitant	W	N	1	0	0	0	0	0	
12	Inhabitant	W	Y	1	1	1	0	0	0	
20	Representative	W	Y	0	0	0	0	0	0	
04	Representative	W	Y	1	0	0	0	0	0	
05	Representative	W	Y	1	1	0	0	0	0	
15	Representative-environment	W	Y	1	1	0	0	0	1	
02	Representative-environment	W	Y	1	0	0	0	0	0	
01	Representative-environment	W	P	1	0	0	0	0	0	
06	Water Technidan	W	N	1	0	0	0	0	0	
17	Water Technidan	W	N	1	0	0	0	0	0	
18	Water Technidan	W	N	0	1	0	0	0	0	
08	Water Technidan	CC	Y	0	1	0	1	1	0	
14	Water Technidan	CC	P	1	0	0	0	0	0	
11	Agriculture Technidan	W	Y	1	1	1	0	0	0	
16	Environment Technician	W	P	0	0	1	0	0	0	
19	Environment Technician	W	P	0	1	0	1	0	1	
09	Environment Technician	W	N	0	0	0	0	0	0	
10	Environment Technician	W	N	0	0	0	0	0	0	

Table 2.1 – Outcomes for the integrity of interviewees resulting from thematic analysis, a green case represents the presence of the outcome. Coherence between the area covered by scenarios and interviewee organisation level (yes (Y) when the organisation level corresponds to the Couesnon or is entirely included in the Couesnon; Non (N) when the organisation level corresponds to another watershed or is entirely outside the Couesnon watershed; partially (P) when the organisation level partially superposes the Couesnon watershed, e.g. SCoT Pays de Fougères); Interviewee’s participation (participation in the co-construction phase - CC, or in workshops - W).

2.5.3.1 Individual-level outcomes

The most recurrent outcomes cited by the interviewees were individual. Indeed, interviewees often cited a raised awareness of water tensions, a consolidated political point of view, and learning technical concepts or factual information as outcomes of scenarios.

The interviewees cited increased awareness of water and biodiversity problems the area could face in the upcoming years and the importance of taking countermeasures.

“What will happen in 20 or 30 years if the corn surface increases by 30% to 40% as planned? That shocked me.” (LA 04 - Representative)

“Above all, the awareness of the fragility and the importance of reacting... In the scenarios, you well showed that today’s choices will operate for 2050.” (LA 15 - Representative)

In the survey submitted during the workshops, participants stated that the contribution of scenarios was higher in understanding territory dynamics than in understanding challenges faced by the territory. Nevertheless, in the long term, interviewees primarily

cited an increased awareness of future water problems.

Other interviewees stated that the workshop consolidated a non-formalised awareness.

“This study marked me, and the fact that it reinforced my thought gives it strength. Because we say to ourselves: “what I feel is confirmed by a serious study”, and therefore, it allows us to be more confident in the debates that can take place elsewhere.” (LA 05 - Representative)

Specific results of scenarios and contents were cited in the semi-structured interview, showing the acquisition of specific notions.

“1/3 of the Couesnon flow rate taken by the city of Rennes... Some key figures like that. We were not aware of this. [...] From memory, [the quantity of water] also shocked us. The volume did not change much, but it was the distribution. The water did not arrive at the right time for agriculture. And this is catastrophic.” (LA 03 - Farmer)

We did not consider as learning outcomes an increased knowledge on the methodology of scenario-making, which technicians particularly cited.

2.5.3.2 Group-level outcomes

For most interviewees, outcomes did not go beyond the personal level. However, some group-level outcomes were cited. Furthermore, the short-term survey underlined that representatives and technicians were more likely to use results of scenarios than civil society and considered water resources data more likely to be mobilised than those on biodiversity. Long-term interviews reflect the survey results.

During the workshops, technicians and representatives recognised the multidisciplinary scenarios as an effective tool for fostering integrative management. In the interview conducted several months after the workshops, technicians at the Brittany Region and the SAGE Couesnon confirmed that statement recognising increased transversality in their actions directly linked with scenarios.

First, a technician of the SAGE Couesnon recognised a tighter collaboration between the SAGE and SCoT, two structures with different domains of competencies (the former is competent in water management only, while the latter in land management only):

“There was an interesting joint work between SCoT and SAGE when we worked together on the Alice project. [...] The same list of people worked

on their workshops. [...] Because of this exchange that was created, he made me intervene several times in the SCoT environment commission to present water quantity problems. He saw that we were talking about [urbanisation] differently with the Alice project, and he said to himself: "this message via the SAGE and the Alice project [...] allows the representatives to see that tomorrow they will be confronted with water quantity problems." (LA 08 - water technician)

"We wouldn't have participated if only BGINs were considered, we wouldn't have been legitimate. That's also why [...] I said that I couldn't see myself working on this without the SCoT, which works on the land use planning part." (LA 08 - water technician)

It is important to underline how both cited structures participated in the co-creation stage of scenarios. Hence, the two structures consolidated their exchanges during the whole co-creation process.

The second example comes from the regional administration, in which specific departments and services are in charge of agriculture, water, and urban management (see Appendix 3.3 for more details). In this case, technicians working at the regional level participated only in a scenarios dissemination workshop.

"It was good for us to have this exchange between the Region's services because sometimes we have different logic. [The workshop] allowed a real exchange in transversality, no matter the position of the services. [Before the workshops], a small group already existed, but it was not easy to lead. It was even a bit stuck. Sometimes there were misunderstandings, and it was difficult to reach an agreement. I think that [the workshop] was the starting point for moving forward. In the weeks that followed, we succeeded in making a common proposal to articulate our policies on the bocage, on water, and on the BGINs. This is not yet the end of the road, but I think that the work between technical services progressed a little afterwards. [...] For the moment, we don't have the political validations. There are a lot of steps to go through. But it has made us think. That's for sure." (LA 19 - Environment technician)

Notably, technicians at the Brittany Region spontaneously contacted us to organise the workshop. In this context, scenarios must be considered as tools that accelerated an already present dynamic in which technicians wanted to increase the transversality of their policies. Moreover, the incoherent spatial extent between scenarios and their organisation level was not a limitation.

The CLE directly cited scenarios in a decision-making process. Indeed, the Alice project scenarios entered the political discussion when the CLE had to give an opinion on the implantation of the agrifood industry Bridor on the territory.

“For the CLE, there was a before and after [Alice]. We saw it in the decisions that followed. [...] For Bridor this was very clear. [...] Before Alice, the question of today’s decisions on long-term projections was not necessarily taken into account. [...] When the day for the notice³ arrived, we did not oppose to the installation, because it is not our vocation, but we warned a lot about the fact that there was a limit that must not be reached. In fact, it was necessary to avoid situations with too much water consumption. [...] With the Bridor case for all the representatives of the CLE that was like a little thing that happened, like saying: "Ouch, there we have a problem! It’s our water. We don’t have much of it already. We have to think about our next decisions". [...] There was a real shift, and this was felt in the relations between the territory of the Couesnon watershed through the CLE and Rennes. For the first time, we dared to say: be careful. You have to leave us some water. [...] It is this "gently" that the CLE never dared to say. We said it.” (LA 15 - Representative)

In this case, the member of the CLE cited the scenarios as a scientific source alerting the significant diminution of water quantity in the watershed by 2050. The CLE then asked the industry to estimate water consumption for the long term as a condition for the implantation of the industry. While this notice remains a punctual decision and not a system change, the same interviewee cited a desirable change in the decision-making system realizing the need of consistent societal changes and new institutional procedures to effectively tackle modern socio-ecological challenges. Indeed, the interviewee evoked the urgency to change the paradigm that identifies the economic committee as the first institutional instance to give an opinion on the implantation of industries while the analysis of water resource availability comes at the end of the decision-making process.

2.5.3.3 Other outcomes

In the months following the workshops, the scientific and administrative main partners were invited to the annual conference of the Brittany biodiversity agency to present

3. Extract from the notice translated from french: « The Bridor file establishes forecasts up to 2030. However, industrial activity is expected to continue beyond that date. The results of the Alice project conducted by scientists in the Couesnon watershed have highlighted the risk of a decrease in the water flow by half during the low-water period by 2050. Global changes are announced by the IPCC for a horizon further away than 2030 (2050 and 2100) and can no longer be ignored. The Bridor file, like all ICPE and Water Law files, should be able to evaluate the impacts of their activities beyond the date on which their investments are planned » Available at https://www.liffre-cormier.fr/wp-content/uploads/2022/02/2021-09-02_Avis-CLE-COUESNON.pdf (accessed on 22/12/2022)

the Couesnon scenarios as an example of a research project designed to support decision-making. Moreover, the research team and the SAGE Couesnon prolonged their collaboration to detail quantitative results of scenarios. Detailed results are expected to be further reused by the SAGE Couesnon to develop agricultural water use scenarios.

Moreover, Alice project's scenarios were also cited in the working version of the roadmap for the BGIN's management of the Regional Directorate for the Environment, Development and Housing (DREAL) Bretagne⁴ as an example of research as an awareness and decision support tool.

From the scientific side, this project pushed the leading researcher and colleagues to develop a project aiming to identify, experiment and evaluate regulatory and economic leverages to transition towards more sustainable agriculture. The project is co-constructed and managed with the Regional Agricultural Council, the dominant regional farmer syndicate that contacted the author after the workshops. This project aims at co-developing, co-testing and co-monitoring integrated and multiscale indicators of agriculture and landscape changes based on trajectory-based objectives that will be compared with Alice scenarios has a reference set of (un-)desirable futures. The leverages that will be tested concern land tenure (reforming parcel distribution around farmsteads) and the integration of agroecological infrastructure (hedgerows and grassy riparian wetlands) within the agricultural production system. The proposal had been submitted in early December 2022 for a 6 to 7 years project of several billion euros.

2.6 Discussion

2.6.1 Between collaboration and integrated management

The need for more integrative management is generally acknowledged by local actors. Nevertheless, joint initiatives with different land management services are not the norm in our case study. Legislative obligations assure a basic level of integration between water and urban management, mainly managed locally (watershed and intermunicipalities levels). However, integration between water management and agriculture is limited, reflecting the absence of significant leverages at the local/watershed level and the primacy of European and regional policies (Houet et al., 2022).

4. Direction Régionale de l'Environnement, de l'Aménagement et du Logement in French

In our study, interviewees recognised the role of scenarios in strengthening the collaboration between communities of practice. First, between the SAGE and SCoT, and second between different services of the Brittany region. In the second case, even if services come from the same structure, they have specific habits, missions and tools. In the workshops in which representatives of these structures participated, the notion of "boundary" was most explicit (i.e. the interviewees referred to different domains of competencies or different logics and tools). Nevertheless, in both workshops, a shared vocabulary was already present, and the scenarios per se did not bring new fundamental knowledge. Using the classification of Akkerman and Bakker (2011), learning occurred through a reflection process in which technicians from different services/structures looked at their practices simultaneously and reflected on how to coordinate them. When we did the evaluation, technicians from the Region made a joint proposal to articulate their financial and administrative tools, but a political agreement is still needed to approve it. Despite the role of scenarios in tightening collaboration, the exchanges that followed the workshops were not structured around scenarios but around day-to-day work issues. In this sense, the scenarios did not foster integrative management but instead pointed out existing organisational limitations or controversial policies and reactivated, thanks to the dissemination phase, a social dynamic of inter-structures/inter-sectors collaboration aiming at more integrated land management. Similarly, the notion of boundary objects for the scenarios we evaluate does not seem pertinent as the study was impulsed by the scientific side and did not focus on practical information needed by the different structures. Nevertheless, scenarios had the merit of bringing people together and tightening cooperation between local actors, a first step towards incrementing policy integration.

2.6.2 The influence of spatial scale and impact pathways on scenarios outcomes

Regarding the spatial extent, the mismatch between the extent of scenarios (the Couesnon watershed) and administrative boundaries (Brittany region) was not a barrier to promoting cooperation. To consolidate the pre-existent will of working in transversality, technicians of the region were primarily interested in the connections between landscape elements, better expressed with the local extent and high-resolution scenarios than more global scenarios. Far from meaning that the spatial extent and resolution of scenarios have no impact on promoting integrative management, we argue that in this case, lo-

cal scenarios were suited even if uncoherent with the Brittany boundaries. At the local level, the SAGE and SCoT occasionally worked together to advise local administration on local urban management plans. However, their technicians did not participate in the scenario-making with a conscious willingness to foster collaboration between their structures. Therefore, a coherent extent was crucial to interest those structures in the co-creation process that reinforced connections. A coherent area covered by scenarios was also crucial for the emergence of an instrumental outcome: the inclusion of Alice project's results in the note regarding Bridor's installation. Indeed, the citation of water quantity results was possible because scenarios reflected the local reality.

An adequate spatial extent also fostered curiosity for the dissemination workshops for participants who did not have specific expectations, such as representatives of the local intermunicipalities. Most of those representatives recognised that scenarios help them to deepen awareness of local water tension. Beyond the individual nature of this outcome, an elected representative at the intermunicipality Pays de Fougères and at the CLE, esteemed that this higher awareness facilitated collaboration between representatives who assisted in the workshop. Indeed, scenarios facilitated a common understanding of the situation, and water-quantity issues became a not to question problem. Moreover, the fact that results were tailored to their territory was crucial to limit opposition. To understand the complementarity between co-production and dissemination, it is worth noting that the same representative who helped us organise the workshop for the local intermunicipalities did it because she is part of the structure involved in the co-construction phase and knew the process that led to the results.

Despite the case study nature of this evaluation, we believe that the lessons learned are transposable. Indeed, the complementarity of co-production and dissemination pathways can be applied to any sustainability science study. Moreover, the double role of scenarios as a catalyst of an already present political will to promote integrated management or as a rising awareness tool can be transposable to other scenarios.

2.6.3 Limitations and open questions

This study showed that scenarios succeed in fostering group outcomes, including for structures working at a broader organisational level. Nevertheless, while the workshops fostered interdisciplinary exchanges between structures working at the same level, inter-

viewees did not report inter-scale outcomes. Creating ad-hoc workshops that mix actors working at different organisational levels could help test the contribution of scenarios in generating inter-scale debate. Moreover, as economic leverages primarily drive farmers' decisions, scenarios should integrate economic indicators such as yield loss due to climate change and biodiversity decline to promote the integration of agriculture and water management at the local level.

Interviewees recognised the contribution of scenarios concerning agriculture and water tensions. Nevertheless, despite being essential pillars of the scenarios, urbanisation and biodiversity were under-represented in their discourse. The only two people who discussed urbanisation either implied in the whole scenario-making process or put consistent effort in the dissemination phase. A bias in these results can be due to the interviewees selection. Indeed, while the sample contains several farmers and agricultural technicians, only one urbanisation technician took part in the interviews. However, even non-specialised figures like inhabitants and representatives referred primarily to agriculture and water. This finding suggests that when the interaction between scientists and society is repeated and time-consuming, working on multidisciplinary axes can effectively promote a multidisciplinary point of view in analysing complex phenomena such as landscape changes. On the contrary, when the interaction is short, the raised awareness of complex dynamics and expected challenges are limited to concepts previously considered important.

Regarding the assessment time, setting the appropriate timing is difficult for different reasons. First, on the research side, the timing of the projects imposes some constraints; secondly, on the administrative side, the revision timing of official planning and management documents is not quickly and publicly available. Getting that information without regular access to internal dynamics and decisions can be complicated and time-demanding. Similar to the strong call for open science, on the institutional side, easier access to updated schedules on administrative document decisions would be beneficial. Long-term assessment results may still evolve, and some instrumental outcomes may arise when local technical documents, such as the SCoT and SAGE, will be revised. Thus, it questions the most appropriate time lag between the dissemination of scenarios and the evaluation of their contribution to integrated land management, which can not be determined univocally but is rather dependent on the administrative and political context. The time lag we chose could then be considered not as long-term outcomes as made here from a scientific

perspective but assimilated to rather mid-term outcomes.

In addition, according to the interviewee, the instrumental use of scenarios was possible thanks to the dissemination process. Indeed, diffusing the results to representatives created a common discussion ground based on scientific elements. While action prioritisation remains in the hands of representatives, an external voice bringing scenarios results allowed to set the water quantity problem on the table. In this case study, the implication of scientists as a "neutral" element who does not bring political convictions, but scientific elements have been perceived as necessary for representatives to consider water tensions as factual. In a moment where the opportunity window to reverse the climate change trend is sharp (IPCC, 2021), scientists are increasingly assuming political positions and actively fighting against climate change. Without questioning the appropriateness of the advocacy of scientists (Nelson and Vucetich, 2009), this consideration raises the question: when should scientists keep a "neutral" posture? And when do they need to speak loudly? Answering this question goes beyond the scope of this paper. Nevertheless, expanding the literature questioning how and in which situation scientists should take a precise political posture appears crucial.

Finally, while the fine-scale facilitated awareness and collaboration at a regional and sub-regional scale, the authors are sceptical about enlarging these results on coarser resolution scenarios applied at a national or continental scale. If this study does not explore outcomes for scenarios at different scales, it proposes a robust methodological approach to do so. Moreover, the authors claim to promote a self-evaluation of future scenario-based scientific projects, an additional step that is rarely made, articulating quantitative and qualitative methods during both phases of co-constructing and disseminating scenarios.

2.7 Conclusions

This study aimed to identify the outcomes of some LUCS scenarios, including their role in encouraging integrated management. Based on the analysis of a local case study, we conclude that:

1. Joint initiatives with different land management services are scarce and local actors generally acknowledge the need for more integrative management.
2. Despite the lack of scenarios in tackling practical information needed by the dif-

ferent structures, local actors recognised the role of scenarios in strengthening the collaboration between communities of practice. This is especially true for actors participating in co-production and dissemination workshops in which the notion of “boundary” was most explicit.

3. The scenarios dissemination workshop fostered the emergence of integrative management initiatives. Nevertheless, while the initiative roots can be found in the reflections around scenarios, technical discussions on how to integrate different land management services were based on external sources.
4. While a spatial extent of scenarios coherent with operational boundaries was necessary for involving local actors in the co-creation phase and for the arising of instrumental outcomes, it was not necessary when the political will to promote integrated management was already present.
5. Finally, we found a strong complementarity of co-production and dissemination pathways in fostering social outcomes.

3 Additional results and conclusion of Chapter 2

This chapter analysed outcomes arising a few months after the dissemination process using semi-structured and reactivation interviews. During the restitution of scenarios to the co-production team and dissemination workshops, some interviewees agreed to remove anonymity from the survey. Access to the nominal answers allowed us to rediscuss the short-term vision of the scenarios. Among the 20 interviewees, 16 consented to remove anonymity. Of them, 14 declared in the short-term survey that scenarios supported some learning outcomes; however, only 6 maintained the same opinion in the mid-term interview. Indeed, some learning outcomes that enjoyed a broad consensus in the short-time assessment (especially the levelling up knowledge on challenges and practices) lost their consensus as the months passed. On the other side, the only person who used this study as a base for additional work originally stated that the results of the scenarios were not helpful for his professional activity.

Moreover, we highlighted how the scenarios were used in an instrumental way leading to the citation of the results of scenarios in a notice written by the CLE Couesnon warning on the long-term consequences of installing a factory on the water resource. Nevertheless, it is essential to specify that the notice did not prevent the factory from obtaining the installation permit. On the contrary, what obstacles the project is an ongoing civil movement. Indeed, citizens and associations demonstrated against the factory installation with multiple marches and mobilisations on the site designated for the construction of the factory, in defence of the environment (especially of wetlands), and for the preservation of water resources.

In the article, we analyse two cases where scenarios increased collaboration between different communities of practice (SCoT and SAGE and technicians from the Brittany Region). In both cases, respondents worked on or got to know scenarios with people who did not belong to the same community. The ZA Armorique workshop is another case in which the heterogeneity of respondents' profiles was consistent. Indeed, the inhabitant participating in the ZA workshop interviewed in the mid-term assessment alluded to the consistent knowledge gap between her and the farmers regarding the impact of a changing environment on agricultural practices. Regarding boundary types, a syntactic boundary was present in the ZA workshop, and learning occurred through forming a shared vocab-

ulary and identification. This extract from the interview illustrates it well:

“For example, I remember that at one point you said that there would be more drought in the summer and more rain in the winter. And I remember that the three farmers who were there looked at me like that (widening eyes) because, of course, the whole system changes. And when you’re in the city, you don’t realise it. [...] It marked me because I realised it seeing the reaction, because I didn’t know it technically how important this climate change is and that they are without means in front of that. What are they going to do? It’s their world that’s spilling out.” (Inhabitant)

For the interviewee’s experience, scenarios helped to increase the empathy (Kouprie and Visser, 2009) of a person from a different social and geographical dimension towards farmers who live next door. As we have reported in the article, in the other two cooperation examples, a shared vocabulary was already present, and learning occurred through a reflection process in which different actors reflected on how to coordinate their practices.

In the article, we presented outcomes of scenarios without comment on the specific contribution of maps in triggering outcomes. Indeed, in our workshops, we presented scenarios as a unique tool composed of narratives and maps without focusing on LUC maps specifically. Nevertheless, we consider it interesting to comment on this specific support briefly. First, in the short-term survey, farmers and technicians considered maps and discussions more effective than narratives, while representatives ranked the three supports equally. In the mid-term interviews, 12 out of 20 interviewees cited either maps, narratives or discussions as something they remembered. For nine interviewees, the most vivid souvenir was LUC maps, regardless of their familiarity with the Couesnon. Although maps are remembered as the visual aspect of the presentation, no one commented on maps’ details, for example, referring to trends emerging in certain watershed zones. The literature on maps as boundary objects is vast. Nevertheless, in our case, they were presented and received as part of the scenarios. Moreover, the discussions during workshops were structured around the survey questions, leaving a little margin to structure their discussions around maps and use them as support freely.

Lastly, it is worth noting how the discourse on agricultural practices drastically changed from the short to the mid-term. Indeed, in the short term, farmers underlined the heterogeneity between their agricultural practices and opinions. Conversely, in the mid-term interviews, most interviewees referred to consistent expected growth in the wheat surface.

“[W]ith the war in Ukraine, the price of wheat has doubled... This is the worst-case scenario: corn, wheat... All cereals. Cows imply a huge workload. If the [price of] cereals goes up, the livestock industry will collapse. It’s clear this is the worst case scenario, and it’s a plane headed straight for that one.”
(Farmer)

The geopolitical conditions changed how people see landscape trajectories and pushed them to have a more homogeneous vision of the future. Nevertheless, as we saw in the article, some could reconnect a changing landscape with environmental risks, showing an increased capacity to analyse the socio-ecological system.

To conclude, this mid-term evaluation article allowed us to:

- **Verify the mid-term outcomes of scenarios:** while outcomes were mainly personal and cognitive, we detected some group outcomes when the presence of boundaries was most explicit. Indeed, collaboration was fostered between technicians from different land management structures who participated in the co-construction phase and between technicians from different services of the same structure who solicited a dissemination workshop.
- Highlight that a strong political will for integrated management allowed scenarios to act as catalysts and **impulse an integrated management initiative** even for an audience who participated solely in the dissemination phase.
- **Recognise that scenarios entered the decision-making process in a way not envisioned by the academic team:** the Bridor factory case. Indeed we detected a direct use of scientific information from a water management organisation that was called to give an opinion on a decision impacting the area’s economic development. Scenarios were then mobilised to guide a collective decision based on long-term effects reasoning.
- **Detect a positive feedback loop between co-production and dissemination** of scenarios: co-production was essential for local actors to recognise the study as usable. In return, dissemination was crucial for local actors defending the necessity to express concern about the factory implant. Indeed, as many representatives knew the study and considered it usable, representatives could use scenarios in a political way and reach the final group decision.

- **Highlight shifts in respondents'opinion between the short and mid-term** and the role of reactivation events in the perceived usability of scenarios: i.e. the initially shared opinion on the support of scenarios in levelling up knowledge on challenges and practices lost its consensus as the months passed between people who did not rediscuss scenarios or related topics. On the other side, the usability of scenarios was reconsidered by the person who used them as a base for additional work.

OUTCOMES OF SCENARIOS IN THE LONG TERM



1 Introduction: reconstructing the past

In the first two chapters, we draw a picture of a time-specific situation to understand how people perceived scenarios and their outcomes in the short and mid-term at a fixed instant. This chapter takes a long-term approach. To do so, we analyse scenarios developed 15 years ago by interviewing local actors, reconstructing and comparing the observed LUCC with those considered in the scenarios and considering social changes on the territory over the years.

In this chapter, the modelling aspects of scenarios take a more important place, and the notion of plausibility and accuracy are discussed. Indeed the following paper considers the spatial extent of scenarios (administrative vs farm-level boundaries) as a central element and relates it to the accuracy of scenarios. In conclusion of this chapter, we will relate the spatial extent of scenarios to their outcome, enriching conclusions of the previous chapter.

The following paper is the first written chronologically. The lessons learned by the Lestolet Case study are summarised in the article's tables. Nevertheless, they might seem partial at this point in the dissertation. In the general conclusions, we will enrich those findings with lessons from the Couesnon case study. The introduction of this chapter was included in the general introduction of the thesis.

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2 Article: Contributions of local LUCC spatially explicit scenarios for water management: lessons learned from an ex-post evaluation

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Abstract

Although potential benefits and limits of scenarios are well known, few studies verify their outcomes 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 outcomes of those scenarios reflect expectations and to understand which factors influenced the occurrence of outcomes. 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 outcomes of any future scenarios.

2.1 Introduction

2.1.1 Classification of scenarios

Since their initial application in the military (Bradfield et al., 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 (Garb et al., 2008; Oliveira et al., 2018; Palomo et al., 2011) 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

et al., 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 et al., 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 et al., 2003). In forecasting scenarios, the developer makes some assumptions on the evolution of key driving forces (e.g. changes in macro-economic factors, changes in human behaviors and preferences. . .), and 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 and Van Notten et al., 2003 for some 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 et al., 2012; Van der Voorn et al., 2017), such as backcasting scenarios which are normative by nature (Milestad et al., 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 et al., 2013; Chermack et al., 2001; Durance and Godet, 2010; Wilkinson, 2009). 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 geopropective approach: a type of study that integrates the spatial dimension (e.g. neighbouring effects of land covers and land uses, emerging properties of socio-ecological changes) 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).

2.1.2 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 et al., 2004; Palomo et al., 2011). Moreover, they can help to clarify the interactions between different variables (Hagemann et al., 2020; Swart et al., 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).

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

- *Instrumental outcomes* where scenarios serve to inform decision makers and improve policy actions;
- *Conceptual outcomes* 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 outcome is indirect, and it may arise time after the communication of scientific knowledge;
- *Political outcomes* 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 outcomes 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 et al., 2017; Clark et al., 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, p. 91). To improve scenarios’ plausibility, land change science community often combines LUCC models with participatory narratives to evaluate possible quantitative outcomes on resources and ecosystems services (Houet, Marchadier, et al., 2016; Houet, Aguejdad, 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 outcomes on public decision making empirically (Bowman et al., 2013; European Environment Agency, 2009; Langhammer et al., 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 outcome 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 Brittany (western France). We analysed scenarios built in 2004 for the year 2020 published by Houet (2006) and Houet et al. (2008)

and Houet, Loveland, 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 outcomes, as a support tool for the definition of the 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 outcomes 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, and 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 outcomes 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 outcomes and to understand which factors influenced the occurrence of outcomes (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, 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 outcomes of the scenarios; (2) the elements that increased or decreased outcomes; and (3) which factors

contributed to variations between scenarios and reality. In parallel, we compared the observed LUC 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.

2.2 Materials

2.2.1 Study site: landscape and institutional description

The study site is the Lestolet secondary watershed (1320 ha), located in the Blavet watershed in the Côtes d'Armor department (Brittany) (Figure 3.1), 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 participated in the scenario-building process and other potential end-users.

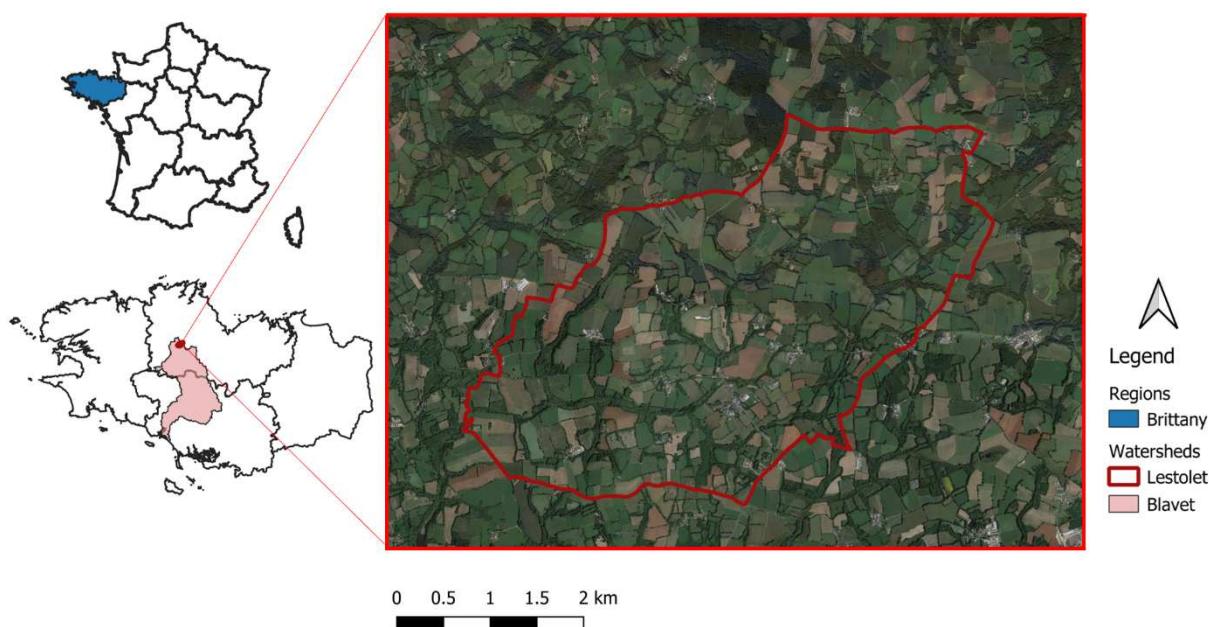


Figure 3.1 – The Lestolet watershed (red outline) located in central Brittany (France) on the northern edge of the Blavet watershed (reddish area).

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 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; Syndicat 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 (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 et al., 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 re-organized 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.

2.2.2 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; 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 Section 2). 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 back-casting 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.

2.3 Methods

To meet the objectives of this study, we couple qualitative and quantitative methods. Qualitative analysis firstly allowed us to understand the outcomes of scenarios and what enabled or inhibited them. As plausibility is considered one of the main 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 outcomes of scenarios on decision making, qualitative analysis mainly fed guidelines to design realistic and attainable scenarios.

2.3.1 Qualitative analysis of scenarios outcomes 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 reconstruct 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 outcomes based on whether or not they thought that the scenarios had produced these outcomes (Harrell and Bradley, 2009). Questions were followed by prompts, according to recommendations presented in Kallio et al. (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 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 outcomes of scenarios (the interview protocol is available in Appendix 4.1). We analysed the data collected using a thematic analysis (Braun and Clarke, 2006) (see Maguire and Delahunt (2017) for an application and Roman 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.

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

We compared Land Parcel Identification System¹ (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

1. Registre parcellaire graphique (RPG) in French

are widely used metrics to perform comparison of categorical maps (Cohen, 1960; Pontius et al., 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, 2003, 2008).

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 et al. (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 et al., 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 actual production systems of farms, 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%.

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 back-casting 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 outcomes arise from one or the other.

2.4 Results

Three main themes emerged from interviews: (1) significant outcomes of scenarios, (2) scenarios' related features that influenced their usefulness and (3) external factors that influenced their usefulness. Appendix 4.2 provides results of transcript analysis and quotations for each of the themes. Scenario outcomes were divided according to the scenario usage (instrumental, conceptual and political). We then associated with these outcomes the scenario and process attributes and the external conditions that influenced each of them.

2.4.1 Significant outcomes of scenarios

2.4.1.1 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.

2.4.1.2 Conceptual use

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

2.4.1.3 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 group² (GIEE) to manage and take advantage of marginal lands. Local 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)

2.4.2 Features influencing the use of scenarios

LAs identified scenarios and process-related features that enhanced or prevented scenario outcomes on decision making (Table 3.1).

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 outcome 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.

2. A collective of farmers that develops local projects to reach social, economic and environmental goals. Groupements d'intérêt économique et environnemental in French

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 outcome 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.

2.4.3 Comparison of scenario projections with observed changes Through

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),

Outcomes of scenarios in the long term

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 (-) 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 (+).
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).		
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 (-).

Table 3.1 – Scenario outcomes and factors that influence scenario use. Scenario attributes and process attributes influence the related outcomes in a positive way. External conditions can have a positive (+) or negative (-) influence on scenario outcome.

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.

2.4.3.1 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 4.3 provides details of K indexes. When comparing scenarios and observed trajectories, all scenarios overestimated the presence of grassland during the entire period, while cereals and oilseeds were generally underestimated (Figure 3.2). 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 4.4).

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 Measures³, a regulatory mechanism that began in 2015 available in 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

3. Mesures agroenvironnementales et climatiques (MAEC), in french

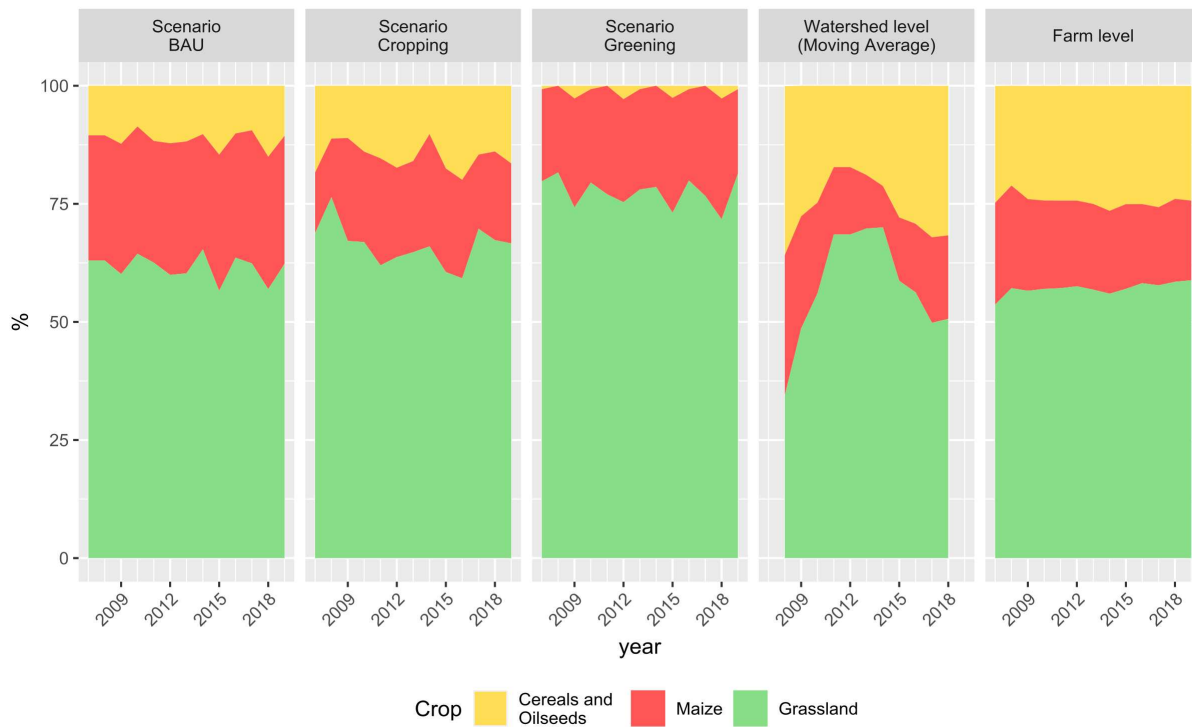


Figure 3.2 – Trajectories of crop percentages resulting from each scenario compared to those observed inside the Lestolet watershed (“Watershed level”) and for all farms that had at least one field inside the Lestolet watershed (“Farm level”). Scenarios: “business-as-usual” (BAU) (increase in maize at the expense of grassland), Greening (increase in grassland at the expense of maize) and Cropping (increase in wheat at the expense of grassland).

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 2.2.2.

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 (Figure 3.3). 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 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 (Figure 3.4). Conversely, the farmers who did change their production system reported more drastic LUCC, mainly in the cropping direction (see Appendix 4.5 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.

2.4.4 Improving scenarios outcomes: recommendations

Merging results from the qualitative and quantitative analysis, we developed practical guidelines for researchers to enhance outcomes of scenarios on decision making (Table

Outcomes of scenarios in the long term

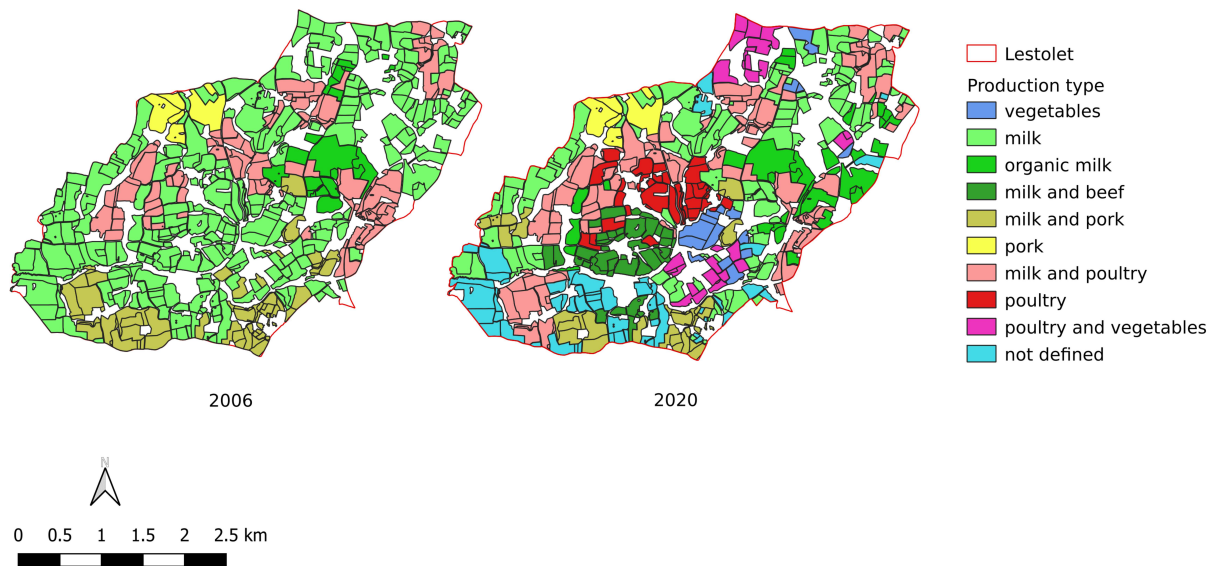


Figure 3.3 – Observed distribution of farm production systems in 2006 and 2020 in the Lestolet watershed.

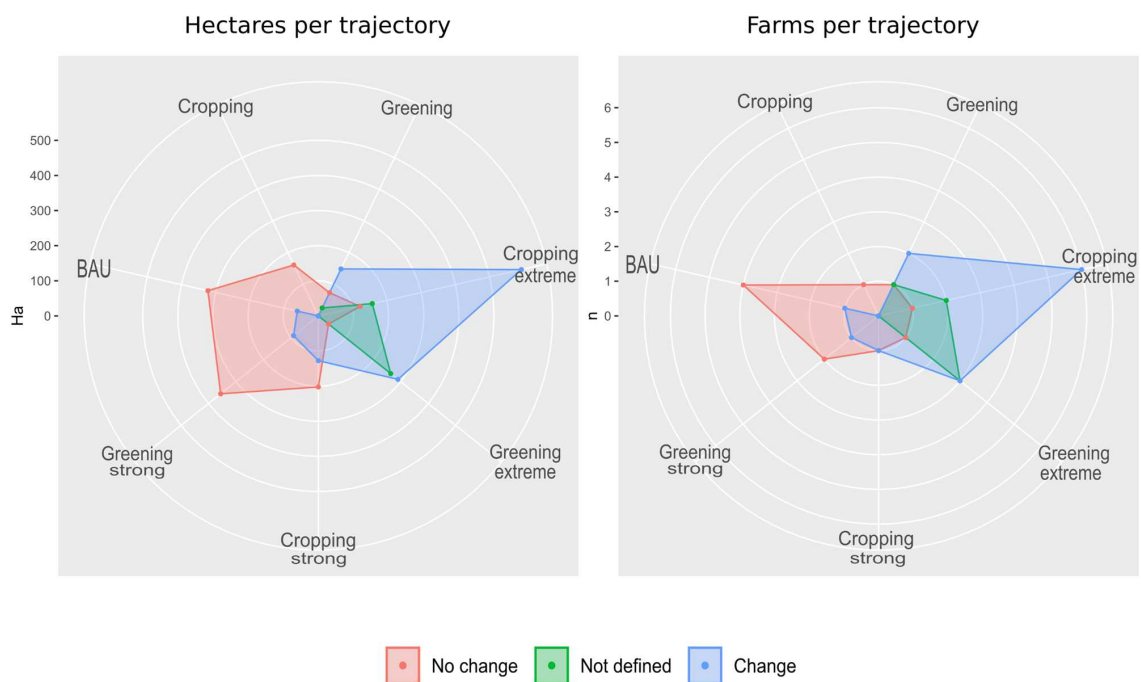


Figure 3.4 – Observed distribution of farm production systems in 2006 and 2020 in the Lestolet watershed.

3.2). 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.

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 <ul style="list-style-type: none"> • Consider the land-planning scale • Consider the spatial scale at which variables impact landscape dynamics 	Instrumental CognitiveInstrumental
	Maximize result dissemination	Allow different agents' behaviours Define a communication strategy <ul style="list-style-type: none"> • 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 Define indicators and metrics to present scenario impacts	Instrumental InstrumentalConceptual
	Allow a change in the way of thinking	Allow multiple aspects (social, economic, environmental) to arise and include them in narratives Identify elements of originality to include in narratives	Conceptual Political Conceptual
Result dissemination	Maximize communication impact	Stress the elements that break codes of thinking	Conceptual
		Use different communication materials, such as maps and narratives Tailor communication to stakeholder groups <ul style="list-style-type: none"> • For farmers, avoid talking directly about environmental issues 	Conceptual Conceptual Instrumental
		Disseminate to the largest number of stakeholders possible Analyse management implications of the study along with the final users	Conceptual Political Instrumental

Table 3.2 – Elements to consider during the stages of the scenario-building process to enhance scenario outcomes.

2.5 Discussion

2.5.1 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 outcomes had been partly met, some context related factors and some scenarios characteristics hindered the visibility of the research in the local community and its outcomes 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 approach (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 outcome that was clearly expected was an instrumental one. Being aware of the different outcomes that may arise from scenarios can help to set up a scenario-building process that also maximizes cognitive and, eventually, political outcomes without harming the instrumental one.

2.5.2 Predictive ability and scenarios outcome

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 (e.g. no change in production systems and homogeneous farmer behaviour). In agreement with the results of Houet and Verburg (2022), 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 et al. (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 outcome 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 outcomes 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.

2.5.3 Theoretical and practical limitations

Our results provide evidence of outcomes 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 outcomes, 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 outcomes. 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.

2.6 Conclusions

We found that scenarios supported water managers in the definition of land management policies and produced several conceptual and political outcomes 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 outcomes 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 outcomes on decision making.

3 Additional results and conclusion of Chapter 3

In this paper, we showed that some outcomes of scenarios appeared years after the project in response to external events. In this regard, it is worth noting that a dissemination process was carried out by a participant in the co-construction phase (member of the Agricultural Council) who presented scenarios to farmers. The definition of the GIEE in response to newcomers taking advantage of the wood was supported by this dissemination effort, not controlled by researchers. The long-term evaluation also showed the contribu-

tion of scenarios to the policy-making process. Nevertheless, the scenarios we evaluated were part of the mobilised knowledge but were not directly used to support policy-making. Indeed, the SAGE Blavet commissioned a consultancy firm (ASCA) to elaborate scenarios with the specific aim of informing the definition of the SAGE Blavet 2007. The scenarios proposed by the consultancy firm were partially based on and completed the scenarios proposed by Houet (2006), but the technician identified the consultancy firm as the principal knowledge provider.

“When we worked on the different possible scenarios of what will [the Blavet] become in 10/20 years, we worked in working groups with different actors, and ASCA provided all the knowledge we might need to work on the specific themes. It was economic data, geographical data, and maps... there was a bit of everything. [...] [The Blavet scenarios] were on more general themes. It was one element among others.” (Technician SAGE Blavet)

In this sense, the support tool for defining the water management plan was policy-pull research partially based on scenarios we evaluated.

From the modelling perspective, we saw that LUCC trajectories envisioned by scenarios did not reflect the observation. Part of the reason can be explained by a modelisation done at the watershed extent rather considering all the parcels belonging to farms that own at least one plot within the watershed. Nevertheless, lack of data can significantly constrain the integration of farmers' decision-making in models and local actors never cited modelling at a watershed level as a drawback/limitation. Consequently, considering the internal dynamic in a farm can improve the accuracy of modelisation and spatialisation of agricultural practices, while complaining with the administrative boundaries can be beneficial for integration in policies.

To conclude, this long-term evaluation article allowed us to:

- **Contribute to the definition of factors influencing scenarios' plausibility.** Considering a spatial scale that matches the one at which the LUCC drivers produce their effects, the difference in land tenure inside and outside the watershed boundaries, the difference in farming decision-making and the changes in production systems in modelling could be explored to enhance plausibility and, consequently, the definition of environmental impacts.

- **Detect long-term outcomes** In particular, we observed that scenarios indirectly entered policy-making. Indeed Lestolet scenarios supported more comprehensive studies commissioned by the SAGE Blavet and provided by a consultancy firm that were used instrumentally to define official planning instruments. Moreover, we observed that external events occurring years after the scenario-making triggered the memory of scenarios. Scenarios were then mobilised in a cognitive way during the decision-making process leading to the constitution of a GIEE.
- **Identify factors influencing outcomes in the long term.** I.e. spatial extents that lead to more accurate LUCC modelling might not be the most appropriate to induce instrumental outcomes when they do not match organisational boundaries. Moreover, institutional aspects (such as the limited collaboration between institutions and the re-transcription of results via consultancy firms) significantly conditioned the outcomes of scenarios.

GENERAL CONCLUSIONS

This final chapter will combine and reframe the lessons learned within the theoretical concepts evoked throughout the thesis. Moreover, general conclusions applicable to scenario-making and sustainable studies will be drawn. Therefore, we structure the conclusion as follows: first, we expose the theoretical contribution of the thesis; second, we discuss the thesis' limitations and perspectives for LUCC scenarios; and third, we conclude by discussing perspectives to better align science-push research with the aims of sustainable studies.

1 Theoretical contribution

In the introduction, we structured our four research questions around two main topics: the outcomes of scenarios and their influencing factors. While this structure gave us a clear framework to analyse the case studies, to separately present outcomes and influencing factors causes a consistent loss of information. For this reason, in the following section, we present the registered outcomes of LUCC scenarios, anticipating some first crucial influential factors. Then, in Section 1.2, we detail the effects of time and impact pathways on outcomes.

1.1 Structuring the outcomes of land use studies

Several classifications of outcomes associated with scientific projects exist in the literature. In the thesis, we referred to frameworks that, first, classify outcomes into personal, inter and intra-group and systemic outcomes (Hamilton et al., 2019) and, second, into cognitive, political and instrumental ones (Mckenzie et al., 2014). **In this chapter, we move away from those classifications and summarise the outcomes according to the level of primary conditions needed for outcomes to appear.** Figure 3.5 resumes the outcomes of scenarios we detected in the two case studies, the process they followed, and the conditions that allowed them to emerge. Nevertheless, we only consider outcomes for local actors leaving aside the impacts on the research (which we briefly discussed in Section 2.5.3.3). Furthermore, the conditions we cite are necessary but not sufficient to generate outcomes. Indeed, even when one or more conditions are satisfied, external events could hinder the progression of the process.

As reported in the literature, **usability is the first condition**, as local actors must perceive scenarios as legitimate, salient and credible to trigger any outcome. If this first

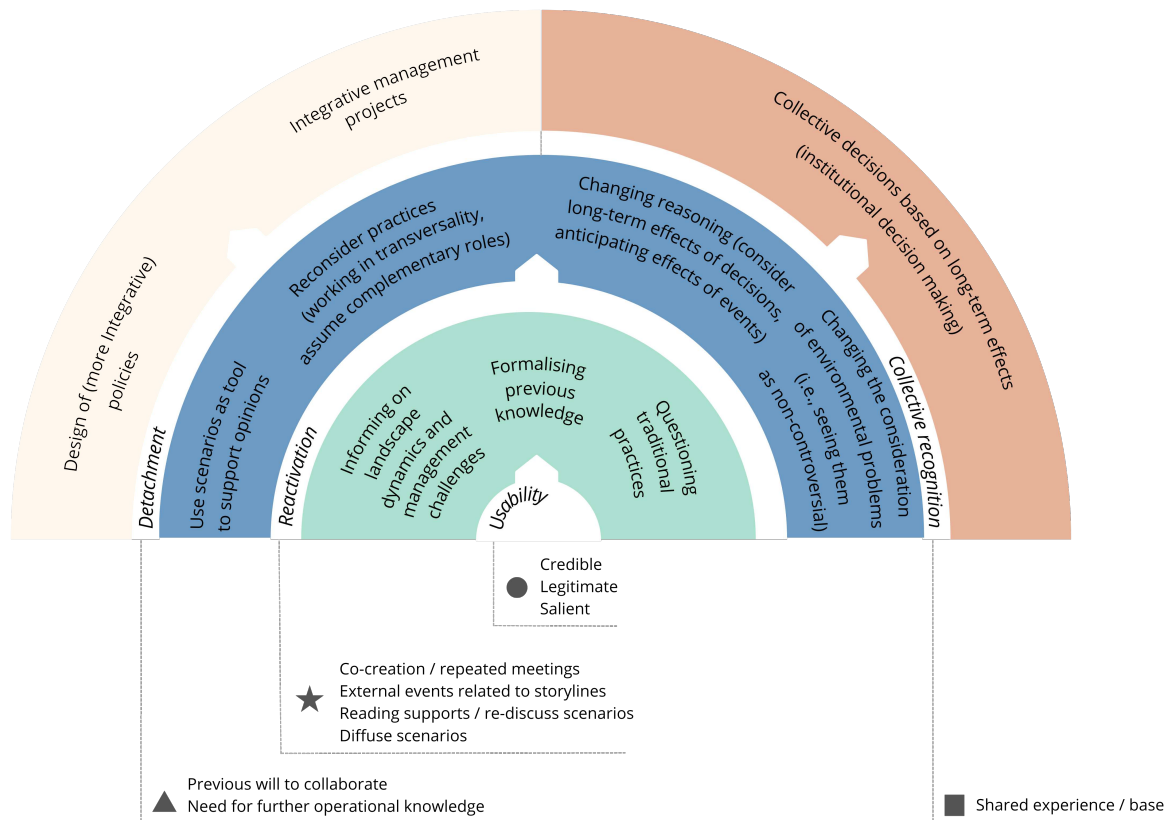


Figure 3.5 – Outcomes of scenarios (in coloured semi-circles) according to an increasing degree of conditionality (from the center to the outside). Conditions for outcomes emergence (in white semicircles) are detailed below the semi-circle.

A usable LUCS scenario (which has the ● characteristics) can result in light blue outcomes. If a reactivation process happens driven by ★ events, it can result in dark blue outcomes. Then, if a collective recognition process happens when ■ conditions are presents, peach outcomes can arise. Finally, ▲ conditions can cause a detachment process and light peach outcomes.

condition is fulfilled, some personal outcomes can arise. In the first step, local actors who enter into contact with scenarios receive or structure information on landscape dynamics and expected management challenges. They can formalise previously acquired non-formal knowledge and question traditional practices in light of the new information. Whether local stakeholders receive or structure information depends on the dissemination pathway through which they relate to scenarios (dissemination or co-production in our case).

After the first exposure to scenarios, **a reactivation process can appear**, facilitating the evolution of additional outcomes. Reactivation happens when an event returns to memory concepts and knowledge mobilised in the co-creation/dissemination. Different events can function as reactivation triggers: external events that remind some hypothesis or result of the scenario; reading scenarios' communication supports; being involved in scenarios-related discussions; or being implied in further dissemination activities. In our case studies, long and mid-term interviews also functioned as reactivation triggers. We also consider participation in the co-creation process as a reactivation trigger as local actors involved in co-creation participate in multiple workshops and dive back into the scenarios several times. The reactivation mechanism can lead to several personal outcomes: the use of scenarios to support personal opinions, a reconsideration of traditional practices, a different way of reasoning, and finally, a changed consideration of environmental problems.

Afterwards, group outcomes can arise either directly or indirectly. We divide here between outcomes strictly related to scenarios (intended both as the outputs and as the impact pathway through which local actors were involved) and outcomes that can be registered after the intervention of scenarios but unrelated to the scenarios themselves. **Via collective recognition, science-pushed scenarios can directly enter institutional decision-making** by supporting decisions based on long-term effects. To reach this group outcome, a consistent number of members must have reached the previous stage either through a shared experience with scenarios or because of previous consciousness, and the new ideas must be aligned. In our experience, collective recognition led to decision-making (i.e. the Bridor case) but did not enter the policy-making process. Indeed, local-level decision-making follows structured procedures and protocols that necessitate specific knowledge formats.

Science-pushed exploratory scenarios also supported decision-making indirectly following a detachment process. First, scenarios fostered collaboration within a specific community (e.g. farmers of Lestolet who created a GIEE) and between different communities of practices that met in the dissemination or co-construction phase (e.g. Brittany region's services who worked on a joint policy proposal). While the collaboration led to concrete decisions, such as structuring joint policy proposals or building projects to manage unwanted effects of external events, it was structured around separate topics and tools. Second, they supported policy-pushed studies that served in the design of technical documents (e.g. SAGE Blavet). In these two cases, the detachment process was generated by the need for more adapted knowledge for decision-making or a previously strong will to collaborate. In this case, scenarios worked as catalysts of a pre-existing will to collaborate on a joint policy proposal.

Knowing which conditions of Figure 3.5 are present in the moment of the science-policy interaction and which could be facilitated helps scenario-makers and local actors pre-define attainable goals and tailor the intervention strategy. For example, suppose the goal is to raise awareness of expected environmental management problems. In that case, intervention can be more focused on the effects of management practices and external factors (e.g. climate change) on the specific territory. Conversely, if the goal is to foster collaboration and integrative management between local actors with high awareness of possible resource tensions, the intervention can focus on the effects of preserving landscape elements on different environmental and socio-economic variables.

To summarise the outcomes process, we borrow the "divergence, emergence and convergence" concept developed by Sirr and Ratcliffe (2003). Even if initially applied to private strategic planning, this concept can also fit the outcomes associated with co-production and dissemination of scenarios. Indeed, a scenario can lead to a panel of new questions, perspectives and ideas, creating a divergence from the initial state (personal cognitive outcome). Then debate around future challenges and implications of different possible futures can let collective opinions/goals emerge (cognitive and political group outcomes). Finally, instrumental group outcomes can arise through the collective recognition of the new idea and convergence of opinion.

1.2 Main factors influencing outcomes

1.2.1 The effects of time in a changing institutional, social and geopolitical context

The co-creation phase was essential in fostering collaboration and transversality in a public sector divided into silos. Indeed, multidisciplinary projects must face the limited legitimacy of one structure to work on several subjects, and it is in this narrow legitimacy that science-pushed scenarios find their place. While the direct implication of the results of scenarios in policy-making is limited, science-pushed scenarios have the merit to **confer around them different actors with legitimacy on separate angles of environmental decision-making**. Moreover, we observed high heterogeneity in the ways local actors approach scenarios. Different ambitions and motivations pushed administrations, political institutions and other local actors to participate in scenarios co-creation and dissemination workshops. For this reason, we must consider that scenarios do not operate in a neutral space but are instead immersed in a force field in which each stakeholder group has unique competencies, goals, operating rules, and relations to other institutions. As with any other tool, the contribution of scenarios to environmental management depends not only on the scenarios' technical aspects but also on the user.

The high heterogeneity of stakeholders' approach to scenarios and the consequent effect on outcomes pushed us to represent the outcomes of science-pushed scenarios based on an increased conditionality rather than on time lag. Indeed, **even if there is a consequentiality in some outcomes, the impact of time is controversial** and focusing on it suggests that more complex outcomes need more time to arise. However, for some actors, outcomes can stagnate long in one stage, possibly without reaching the next one, while for others, they can reach outcomes subjected to high levels of conditionality very fast. Moreover, we observed that scenario-supported decision-making could arise quickly if the conditions are reunited when co-production or diffusion occurs. To strengthen the idea that a series of conditionalities, more than time, influence the impact of scenarios, we drive attention to two outcomes we registered: the creation of a GIEE and a Region policy proposal. In our scheme, we classified the creation of integrative management projects and the policy design in the same stage. Indeed, both happen after a detachment process and have a tangible influence on land management. Nevertheless, we registered the creation of a GIEE years after the creation and dissemination of scenarios, while the

Region made a policy proposal just a few months after the dissemination. The quick rise of group outcome was possible because technicians from the Brittany region contacted us to present scenarios when the conditions to reach higher impact stages were reunited. For them, scenarios were an additional element that reinforced the conviction to question traditional practices. Furthermore, having a joint workshop in which scenarios were presented stimulated the practice of regularly organising transversal meetings that worked as reactivation triggers. The will to collaborate was already there, so the reactivation and detachment process occurred fast. Conversely, for the creation of the GIEE, the reactivation event had been the arrival of external people taking economic advantages from the selling of wood that happened in 2016, 12 years after the presentation of the scenarios.

This example also allows us to discuss the “opportunity window” concept that, borrowed from public policy and entrepreneurship (Kingdon and Stano, 1984; Wickham, 2006), can be related to the outcomes of scenarios. We refer here to the opportunity window as the moment when outcomes can emerge, determined by stability in the actors involved in local land management and by the presence of institutional and geopolitical context related to the scenarios’ storylines. Indeed, the link between scenarios and the creation of integrative management projects was possible because one person, extremely active on the territory as an agricultural counsellor at the moment of scenario-making, was still working on the territory when external people arrived. In the same case study, other local actor groups cited the change in political representatives as a significant barrier to the emergence of outcomes.

For the Lestolet farmers, the change in the geopolitical context recalled something that was evoked by storylines triggering a reactivation process that made local actors reconsider practices and propose an integrative management project (the GIEE). Similarly, in the Couesnon case study, the outbreak of the war in Ukraine triggered a reactivation process allowing inhabitants to recognise the effect of the war on local environmental resources. Consequently, introducing elements that breaks the code of thinking in the storylines is vital because when some event related to storylines happens, it can trigger reactivation, even if it is not precisely the one cited in scenarios.

In this section, we drew attention to the conditionalities for outcomes more than temporality. Nevertheless, setting our protocol according to different time evaluations al-

lowed us to observe that reactivation can still occur years after the scenario-making if external events (re)open the opportunity window.

1.2.2 Co-production and dissemination

The benefits of co-production on legitimacy, saliency, credibility, and other outcomes are well studied in the literature (Djenontin and Meadow, 2018) and have been partially discussed in Chapter 1 and the introduction. In this chapter, we discuss the contribution of co-production compared to dissemination and the limits of co-production in a science-pushed context.

First, the relation between co-production and saliency can be re-discussed within the science-pull and policy-pushed research framework. Indeed, although we can generally say that co-production fosters saliency, science-pushed research allows a little room for manoeuvre for institutional partners in shaping the format of results (Sterk et al., 2009). In our most recent case study, the SAGE Couesnon accepted to be involved in the Alice project under the condition of having some elements on water. Nevertheless, there was no specific reflection on the data and the format needed. The restitution workshops also reflected this lack of planning on expected results. Indeed, while results on water quality were available at a finer resolution, we presented the results at the outfall to simplify the communication. It was only during the evaluation phase that technicians reported that nitrates and phosphorus concentration projections at a finer resolution better suited their needs. Consequently, we realised that a communication error could considerably hinder the technicians' usability perception of scenarios. Even if preliminary meetings were held between the institutional partners and the research side and scenarios were co-produced, expected results were discussed on a too broad base to enable instrumental outcomes of scenarios in the institutional decision-making.

In the Alice case study, the results of co-produced scenarios were diffused to a wide range of local actors, and dissemination produced several outcomes on plural occasions. The best example of complementarity between dissemination and co-production has been quickly discussed in Chapter 2. When we intervened in local political bodies, scenarios supported personal outcomes, especially in what concerns the consideration of environmental problems. Indeed, since the scenarios were tailored to their territory and showed a degradation of water quality and a diminution of water quantity regardless of the sce-

narios, local actors who assisted in the workshop started to think of water management tensions as non-controversial. It is worth noting that the contact person between local representatives and us was a member of SAGE Couesnon, deeply convinced of the need to preserve the water resource and used our workshop to support her political opinion. Disseminating workshop functioned as a vehicle for a well-structured political opinion, but that was disseminated by researchers external from the political dynamics. The increased awareness of local representatives then led to a collective decision based on scenarios that had not been envisioned at the beginning of the project.

Dissemination was then made possible because of the legitimacy developed with co-creation and allowed to widen the spectrum of occasions in which scenario results were relevant and applicable to science-based decisions. Conversely, in the Lestolet case, scenario-makers did not actively impulse dissemination. Nevertheless, one member of the chamber of agriculture who participated in the co-creation process diffused scenarios to the farmers with whom she worked. Ideally, when political dynamics do not require an external/neutral person to limit tensions, dissemination could be done by people participating in the co-production phase. However, some partners involved in co-creation shared their concerns in disseminating the results of scenarios because of the insufficient knowledge of technical aspects of the study, particularly regarding the modelling of LUCC. Moreover, weak connections between institutions make autonomous dissemination to stakeholder groups who did not participate in the co-production unrealistic. Therefore, the expected involvement of co-production participants in disseminating study results within their respective institutions should be discussed explicitly at the beginning of the project.

In conclusion of this section, we believe that **coupling co-production and dissemination of science-pushed research can support scientific-based decisions** in the context of fragmented land management. Indeed, as the socio-economic context changes constantly and local actors are called to respond to changing conditions, it is impossible, at the co-production stage, to foresee all cases in which scenarios could be mobilised to support decisions and actions. However, disseminating scenarios allows for multiplying the chances to provide valuable information and shape the way of thinking of people that will be called to take actions influencing land-use land-cover change. Moreover, to resume the theoretical contributions of this thesis, we give an overview of the answers to our research questions in Figure 3.6.

1a) How do science-push scenarios modify how territorial dynamics are understood outside the land-management decision-making process?

Coherently with the literature, usable scenarios helped inform land dynamics and management challenges, formalise previous knowledge and question traditional management practices.

2a) The effect of time: do local actors' perceptions of outcomes change over time? For which type of actors and for which type of outcomes?

The impact of time is controversial, and the opportunity window for scenarios can be broad or narrow depending on the stability of local actors and a favourable institutional and geopolitical context. However, regardless of the type of actors, cognitive outcomes tended to disappear with time when reactivation did not happen.

2c) Are there any other influential factors besides time and impact pathways?

The presence of a reactivation, collective recognition and detachment process mainly influenced the outcomes of usable scenarios.

2b) Complementarity between impact pathways: what is the contribution of (less)more time-consuming pathways on outcomes?

Scenarios were perceived as usable thanks to the co-creation phase. In return, dissemination lead to a better consideration of local water quantity issues. The increased awareness resulted in a collective decision that had not been envisaged at the beginning of the project. Dissemination thus widened the spectrum of occasions in which the scenario results found relevance and usability.

1b) Do science-pushed scenarios enter into the land-management decision-making process? In which way?

Yes, it did it indirectly by fostering collaboration within and between communities of practice.

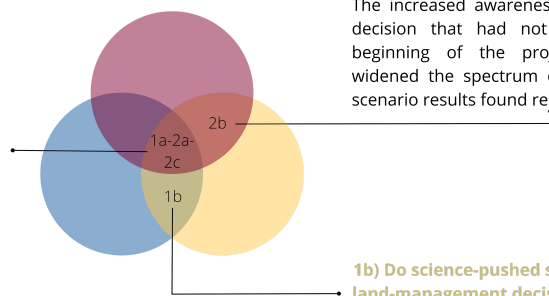


Figure 3.6 – Concise answers to research questions

2 Limits of the study and scientific perspectives for LUCC scenarios

In discussing limits and perspectives, it is essential to comment on our **choice of taking a case study approach**. Working on case studies allowed us to dive deeply into scenario-making processes and their social and institutional context. Moreover, it allowed us to set up a temporal assessment and work on disseminating Alice’s scenarios. Since outcomes evaluation for scenarios is not a significantly developed practice yet, finely studying specific scenarios contributes to the comprehension of the outcomes of these tools from the cognitive, political and instrumental aspects. Nevertheless, a literature review on the expectations of scenario makers on outcomes and how scenarios are developed (science-pushed/policy-pull scenarios) could strengthen our findings.

This thesis assesses the contribution of LUCC scenarios for local land and water management, and it is structured around a short, mid and long-term evaluation. Nevertheless, **the administration and research follow different calendars**. This calendar mismatch can impede evaluating the outcomes of scenarios at the most opportune moment,

particularly concerning instrumental outcomes for decision and policy-making. E.g. the review phase of the SCoT pays de Fougères will end in 2023, impeding an assessment at the end of the revision phase in the context of this thesis. While we esteem that the time-lag we selected for the mid-term interview was suitable to point out the social outcomes of scenarios, we potentially missed some instrumental outcomes occurring throughout the revision phase. Besides outcomes, an additional evaluation at the end of the revision could help understand which kind of data and supports are used by technicians and representatives to take collective decisions. Moreover, it could deepen the understanding of the practical and potential complementarity between science-pushed scenarios and the rest of the documentation mobilised in decision and policy-making.

In addition, we could not interview one of the local actors who participated in the co-production stage of the Couesnon scenarios and who could give us some insights on possible conflicts between the researchers and the institutions. Indeed, one technician of the SCoT was critical of research results showing that, while SCoTs can effectively control the expansion of grey infrastructure, they do not have a consistent impact on connectivity which mainly depends on agricultural land uses. Nevertheless, we interviewed a representative from the same structure who did not report any particular criticism or conflict.

Another point to investigate further is the **contribution of integrating past evolutions of LUCC and their causes in the scenarios**. In the scenarios we evaluated, the notion of past LUCC has been integrated via the LUCC reconstruction used to calibrate the models and define the business-as-usual storyline. Nevertheless, the storylines had been perceived as determined by factors over which the ensemble of the local actors have direct influence, but not a single one. In Chapter 1, we cited that reconstructing the past could also be used to highlight the margins of manoeuvre of local stakeholders and the effects of local stakeholders' decisions on the LUCC. For example, showing in which moment the LUCC followed administrative or political decisions or showing the concentration of pollutants in the water associated with past land use and land cover could enhance the consideration of the long-term effects of present decisions and foster reflection on action levers.

Regarding the structure of the workshops, we chose to standardise the presentation for all stakeholder groups. This choice was necessary to have comparable survey and interview

data and provide future assessment guidelines. Nevertheless, **a tailored presentation could enhance cognitive impacts and registered outcomes**. Moreover, even if the person who conducted the evaluation interview was not directly involved in the scenario-making phase, she was still perceived as internal to the project. The biases introduced by an internal evaluation have been discussed in each paper in relation to the specific adopted protocol.

Moreover, even if workshops were not designed to identify leverages for more sustainable land management, participants identified the following leverages: 1) the institution of a well-designed parcelling to improve water quality (e.g. facilitating re-parcelling that pushes farmers to plough in the direction of the slope to limit runoff, or favouring permanent grassland in critical parcels for the nitrate input to watercourses); 2) the insertion of a consulting phase of environmental and resource-management institutions at the beginning of a decision-making process; 3) or yet the obligation of providing a long-term estimation on water and other resources consumption to cross with estimations of resource availability for any construction project. **A dedicated workshop could detail the feasibility and impacts of leverages proposals and fostering concrete transformation**. Indeed, similar to previous studies (see, Totin et al., 2018, for an example), this consideration suggests that relying solely on scenarios may not effectively encourage transformative change. Conversely, the scenario-making must be considered as a tool to solve a concrete unacceptable, unstable or unsustainable situation (Kahane, 2012) more than an end in itself.

Another **element to explore is the possible synergies between policy-pulled and science-pushed scenarios**. Indeed, while our research focused on science-pushed projects, policy-pulled or projects co-pilot by scientific and private/institutional partners also exist. In the case of French water management, a foresight exercise is mandatory to define management strategies. In this context, (policy-pulled) scenarios are usually commissioned by an administrative structure and are provided by consultancy firms. Those firms, are submitted to market laws that push them to restrict the analysis to the evolution of landscape elements impacting water quantity and quality and restrict the novelty of scenarios. In our experience, local actors in charge of water management often referred to scenarios provided by private consultancy firms as the "classical scenarios". Although analysing the benefit of these "classical scenarios" goes beyond the scope of this thesis,

local stakeholders mainly referred to an imposed use of those scenarios and reported a general lack of the transversality and flexibility that characterise science-pushed scenarios. Investigating synergies between public research scenario-making and consultancy firms' expertise can help overcome the limited cognitive outcomes of policy-pull scenarios and limited instrumental outcomes of science-push ones.

Even if technical aspects of LUCC modelling were not the focus of this thesis, we want to discuss the **effect of choosing a specific spatial extent and resolution**, which we partially anticipated in the central chapters. In Chapter 2, we showed how scenarios developed for a different spatial extent from the organisation level can still produce group outcomes if clear expectations on the workshop are present. Conversely, a coherent spatial scale is vital when there is no strong expectation and expected outcomes are personal. Chapter 3 discusses the need to consider plot resolution and farm-level dynamics when developing agricultural LUCC scenarios to accurately model agricultural practices (such as keeping livestock closer to the farm). Nevertheless, this does not mean that administrative boundaries should be overlooked. First, it is essential to interest local administrations in the study and to avoid legitimacy problems when working on other watersheds. Second, the watershed level is appropriate when estimating the effects of LUCC changes on environmental variables, such as the change in the transfer of nitrates in groundwater. To meet the double need of increasing accuracy while maintaining coherence with organisational levels, exploring farm-level models and then considering the effects on environmental variables within watershed boundaries could be of interest.

Lastly, while studying potential outcomes of scenarios is crucial, it remains a narrow perspective. Indeed, while we highlighted how scenarios support environmental management, we do not intend to give a general opinion on the viability and need for this tool. To do so, beside benefits of scenarios, we would have to assess their cost in terms of time, money and intellectual resources. This thesis clarifies the potential outcomes of scenarios and conditions that allow them to arise. **Determining if the balance between the cost needed to develop scenarios and their benefits in terms of expected outcomes is viable is left to define case by case.**

3 Contributions and perspectives for sustainable studies

Sustainable studies are intrinsically linked with actionable science and the idea of a locally-based knowledge aiming to alleviate socio-ecological problems. The number of scientific projects and funding engaged in producing this knowledge has grown in the last decades (Arnott et al., 2020; Fang et al., 2018), and co-production has become the norm (Nature editorial, 2018). Nevertheless, introducing participatory phases in knowledge production is not enough to facilitate transformative changes (Beier et al., 2017; Díaz et al., 2019; Pelling et al., 2015; Van Bruggen et al., 2019). Indeed, while we observed a genuine attempt to go beyond the historical “two communities approach” of science, the co-production phases of the case studies we studied had mainly an extractive purpose aiming to support the creation of knowledge/tools designed principally to reach scientific goals. **This supremacy of scientific ambition over transformative change is reflected in different aspects of knowledge production.** First, the ideas at the origins of our case studies projects were the development of fine-scale scenarios in agricultural landscapes and studying the impact of different blue and green infrastructure strategies on water resources (Lestolet and Couesnon) and biodiversity (Couesnon). Second, the affiliation process of institutional partners came once the project was approved and with little manoeuvre in the definition of expected outputs. Lastly, the common definition of expected outputs between institutional partners and researchers was overlooked (see Chapter 3). In this sense, the results of Arpin and Collin (2019), showing that collaborations are generally judged more satisfactory by researchers than practitioners, should alert. Indeed, while science-driven projects are intrinsically valuable and can produce outcomes, including instrumental ones, we warn against putting much emphasis on the action-oriented side of such projects. In fact, we believe that using the hat of action-oriented studies, even when research is not primarily driven by “real world problems”, will empty of meaning a field of study that finds all its legitimacy in this historical moment.

Moreover, the meaning of actionable science itself should be discussed. Indeed, recent definitions and applications of this concept carry the idea that action is determined at the institutional level (see the definition of Pearman and Cravens, 2022, as an example). Nevertheless, we register a general increase in bottom-up civil movements (Hayes, 2006; Thackeray et al., 2020), including actions of civic disobedience that result in more radical

and fast concrete changes than institutional attempts (see Section 3). In this context, it is a matter of discussion whether it is appropriate to link actionable science explicitly (and almost exclusively) to the policy context. Far from being just a linguistic matter, detaching the concept of action from an institutional context that clearly shows its limits in tackling environmental issues could foster the ambition of science in supporting civil movements and lobbies.

If we look at our study retrospectively, it was rooted in the fundamental idea that new (co-constructed) knowledge would lead to a transformation through more sustainable practices. Nevertheless, we must acknowledge the little transformative changes associated with this approach. Interesting insights to interpret the limited transformative capacity of sustainable studies (Shrivastava et al., 2020) are offered by the literature defining transformative knowledge as the result of transformations practices rather than a condition for transformation (Bennett et al., 2016; Colloff et al., 2017). Indeed, innovative experiences such as those in the real-world labs and the *territoires ecoles* show how gathering, structuring and diffusing already existing transformative practices support scaling up. According to this approach, starting from success stories and working to diffuse them produce broader impacts than creating knowledge from which innovative practices should be deduced. Studying the role of science in understanding and diffusing sustainable practices, more than knowledge, seems particularly adapted to the objective of sustainable studies. For example, suppose the final goal is to support farming practices that are less detrimental to the environment and economically viable. In that case, the role of scientists can be not to promote the emergence of new practices, but to influence which existing practices are selected and retained (Folke et al., 2021) for example by providing scientific evidence of the benefits of specific practices (see Teschner and Orenstein, 2022, for an example on transitions in vineyards). Moreover, understanding and widely communicating under which conditions the economic model can be adapted to the local socio-economic and environmental conditions could have a substantial transformative potential.

Finally, besides researchers' ambitions and will, **research structures and financing systems can significantly push sustainable studies towards producing transformative knowledge**. Indeed, in light of our observations, producing action-oriented research in a science-pushed project seems, if not a contradiction, at least left to the sensibility and competencies of the researchers. To overcome this issue, the research fund-

ing for sustainable studies should go beyond evaluating expected outcomes and demand coherence between outcomes and impact pathways and the definition of a joint agenda setting between academic and non-academic partners (Schneider et al., 2019). Moreover, requiring interdisciplinary teams that include experts in philosophy of science, political science, sociology, and economy seems a prerogative to overcome the primacy of environmental aspects over social and economic ones (Schoolman et al., 2012) and meeting the need to better define (Alvarez et al., 2010) and reach expected outcomes. In this sense, it can be interesting for research structures to have people working transversally on multiple projects with expertise in the science-society interface.

In conclusion, this thesis provides a perspective to structuring scenario-making in accordance to the desired outcomes and existing conditions. By combining quantitative and qualitative methods, we gave some evidence of personal and group outcomes of scenarios and we showed the ambiguous role of time in their emergence. While the analysis of the outcomes of scenarios was previously quasi exclusively reserved for co-construction processes, we expanded the discourse to dissemination practices highlighting synergies between those two impact pathways. Despite our research in anchored in scenario-making, our findings pushed us to join a much larger discussion on how to better align participatory methods to the finality of sustainable studies. With this thesis we then join our voice to the many other pledging for a research that effectively address the challenges of our century.

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APPENDICES

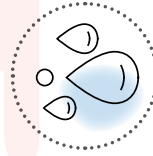
1 Appendix Materials

1.1 Couenson 2050 dissemination booklet

Couesnon 2050

Évolutions des paysages
& impacts possibles

sur la biodiversité & les ressources en eau



Improving the management of atlantic landscapes accounting for biodiversity and ecosystem services



Le projet Interreg ALICE

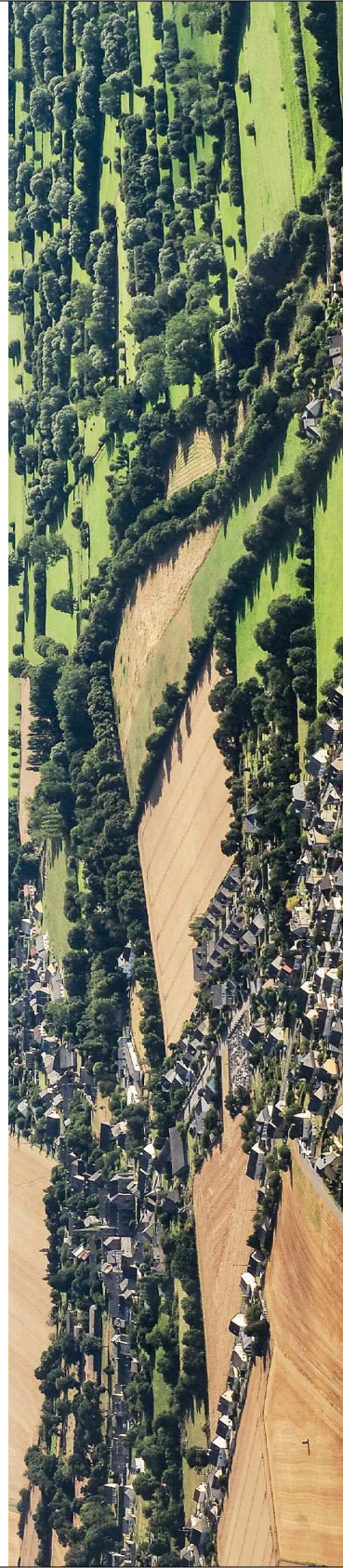
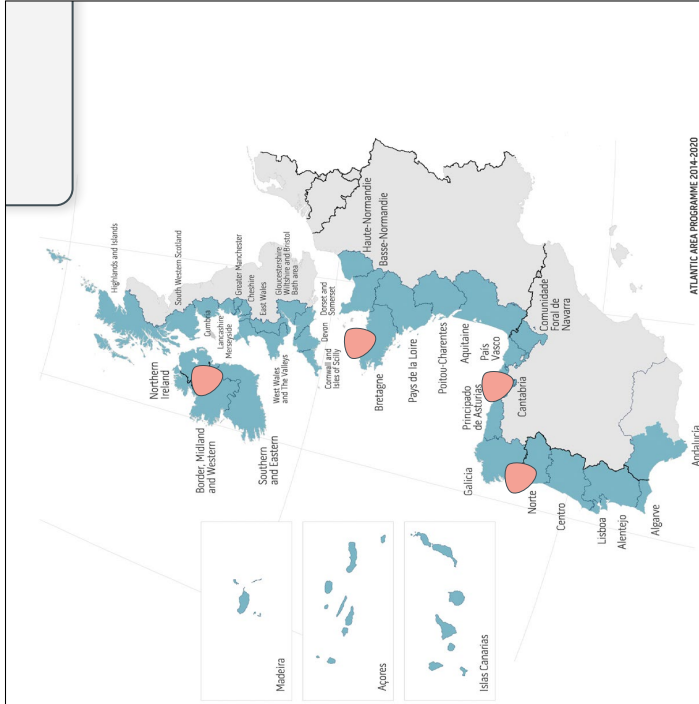
Vers une meilleure gestion des paysages atlantiques par le développement d'outils de caractérisation de la biodiversité et des services écosystémiques

ALICE est un projet de recherche-action européen, financé sur 4 ans et dont l'objectif est d'aider à améliorer la conservation de la biodiversité et les services écosystémiques associés au travers d'outils de planification territoriale tels que les Trames Verte et Bleue.

Il regroupe 15 partenaires (centres de recherche, collectivités territoriales, ONG, entreprises privées)

Il s'appuie sur 4 sites de démonstration représentatifs de la diversité des paysages de la façade Atlantique :

- Carlingford Lough (Irlande du Nord)
- Bassin versant du Couesnon (France)
- Bassins versants de la Pas, Miera et Ason (Espagne)
- Bassin versant de la rivière Paiva (Portugal)



Edito

La prospective

L'objectif de ce projet n'est pas de prédire l'avenir mais d'explorer les **futurs possibles** du territoire étudié au travers de scénarios prospectifs.

ALICE, programme de recherche-action en partenariat avec des acteurs locaux, a pour ambition de rassembler des éléments d'appréciation, chiffrée ou non, concernant la pluralité des futurs possibles.

Ce regard sur l'avenir a pour but d'éclairer la prise de décisions pour conduire à un avenir plus conforme à nos préférences que s'il n'y avait pas eu cet éclairage prospectif.

Au cœur de cette posture, il s'agit d'évaluer les Trames Verte et Bleue, comme **politique publique de préservation de la biodiversité dans l'aménagement du territoire**.

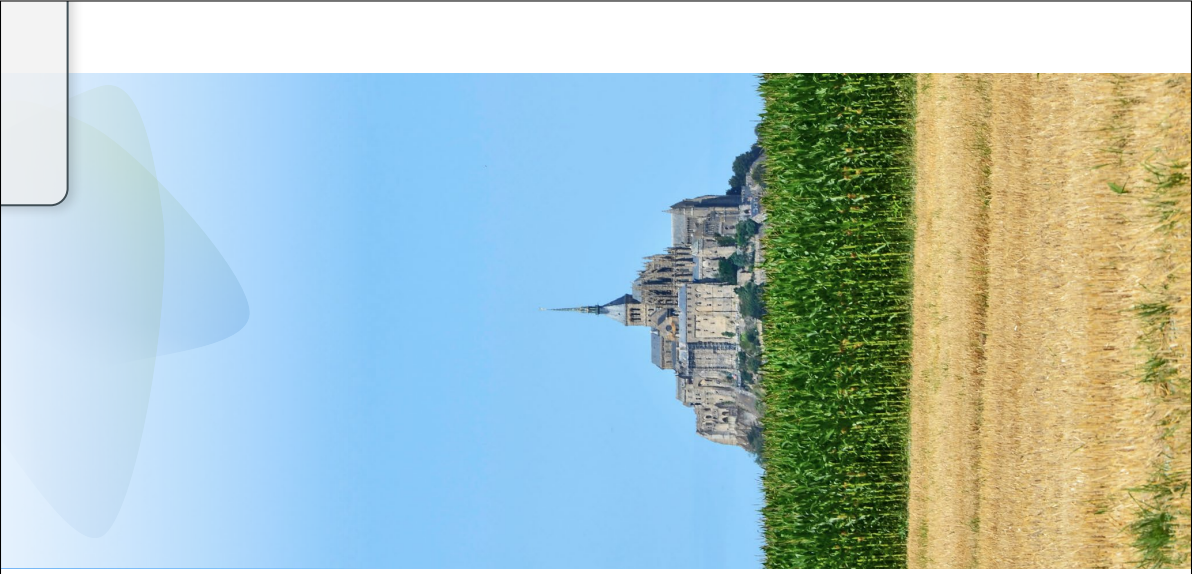
Cette évaluation concerne aussi bien leurs **limites** que leurs **potentialités** à considérer les services écosystémiques dans leur ensemble, pour une gestion plus durable des territoires.

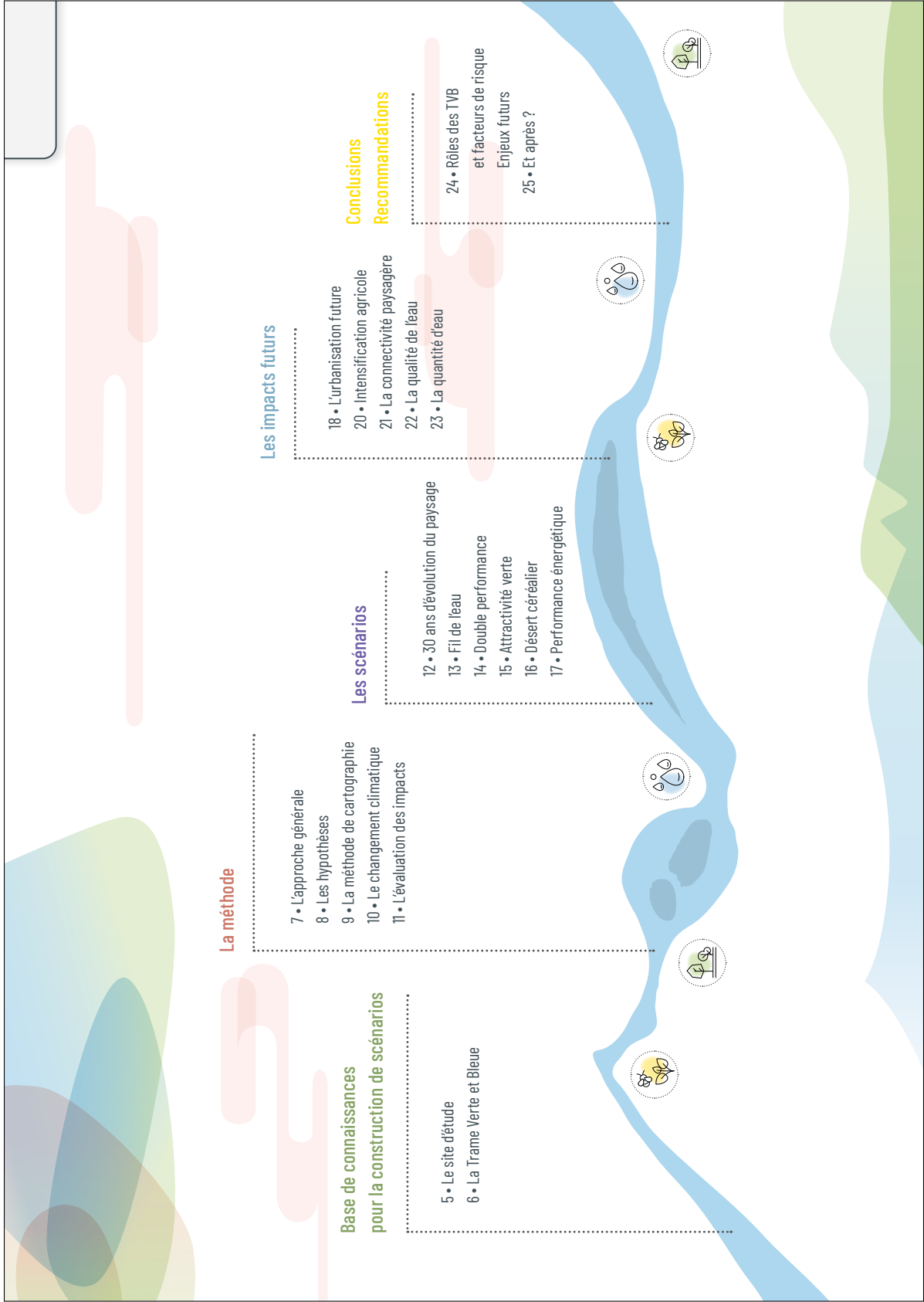
Ce livret, construit par des **scientifiques, en partenariat avec des acteurs locaux** restitue la démarche scientifique, les principaux résultats, et propose une synthèse et des recommandations destinés aux acteurs locaux.

Au final, s'il pourra plus particulièrement toucher les usagers du territoire du Couesnon, nous espérons qu'il puisse inspirer plus largement les territoires au-delà des limites de son bassin versant.

T. HOUET

Directeur de Recherche CNRS
Géographe UMR LETG-Remes





Le bassin versant du Couesnon

Géographie

- D'une superficie de 1130 km², le bassin versant du Couesnon bénéficie d'un climat de type océanique.
- Il s'étale sur plus de 60 communes d'Ille et Vilaine et 15 communes de la Manche réunissant pas moins de 90 000 habitants.
- Le Couesnon, après avoir parcouru 115 km, se jette au pied du Mont-Saint-Michel.
- Il est alimenté par des cours d'eau aux débits très largement tributaires de la pluviométrie.



La **faible perméabilité** du sous-sol, composé principalement de roches métamorphiques (schiste, grès...) ou plutoniques (granite), contribue à un réseau hydrographique très dense (près de 1700 km de linéaire de cours d'eau pérenne ou non) et la présence de nombreuses zones humides de fonds de vallées.

L'**occupation agricole prédomine** sur le territoire et l'agglomération de Fougères constitue la zone la plus urbanisée et industrialisée.

Au **Nord** du territoire, dans les polders du Mont-Saint-Michel, les grandes cultures et les cultures légumières dominent le paysage.

La **partie centrale** quant à elle se caractérise par un système de polyculture-élevage laitier dominant, présentant une riche mosaïque de prairies, cultures fourragères (maïs) et de céréales / oléo-protéagineux (blé, colza).

La densité de prairies varie selon la géologie :

• Zones granitiques

(Trans-la-Forêt, Roz / Couesnon, Le Coglais), aux **sols moins profonds** et au relief plus vallonné, présente un paysage bocager encore bien marqué où les prairies dominent sur les zones les moins favorables (pentes, zones de fonds de vallées...);

• Zones plus planes

Les zones plus planes aux **sols plus profonds** présentent un paysage plus ouvert, au bocage relictuel, avec des parcelles plus grandes et plus productives.

Ces paysages sont ainsi représentatifs de la forte densité d'élevages présents sur le territoire. Les principales forêts sont celles de Fougères à l'est et de Villecartier à l'ouest.

Alors que la **tendance démographique** était plutôt à la baisse avant 1999, celle-ci s'est inversée suite à l'ouverture en 2003 de l'autoroute des estuaires reliant Fougères à Rennes. Fougères, avec ses 21800 habitants, constitue le pôle urbain le plus structurant. Des communes nouvelles comme Maen Roch, Pontorson et Saint-James contribuent à la structuration du territoire.

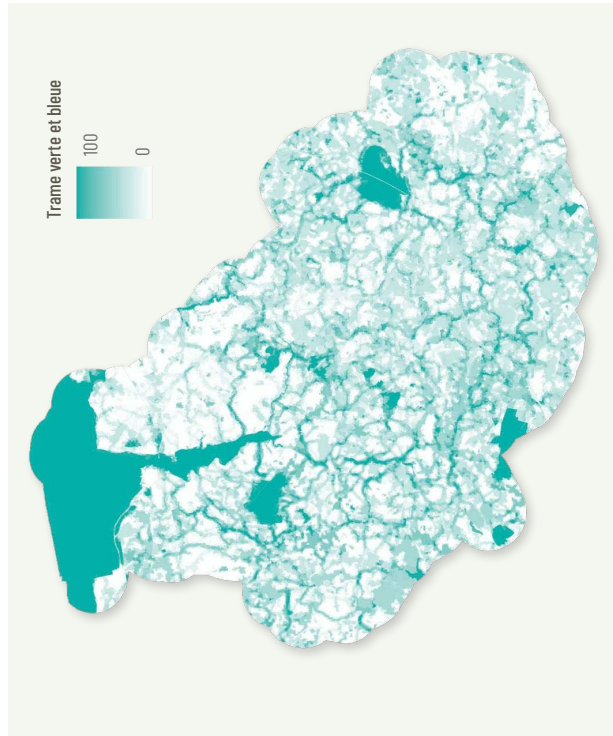


La Trame Verte et Bleue (TVB)

Objectif

Mise en œuvre dans les SCoT (Schéma de Cohérence Territoriaux), la TVB consiste à préserver les corridors écologiques entre des réservoirs de biodiversité. Document réglementaire opposable, elle contraind l'urbanisation définie dans Plan Locaux d'Urbanisme (PLU) des communes et intercommunalités.

La carte (ci-dessous) élaborée en partenariat avec le bureau d'étude SDEVY (Toulouse) représente ces corridors et leur importance en terme de connectivité entre ces réservoirs de biodiversité. La TVB est particulièrement dense sur le Couesnon en raison de la forte densité de prairies, de cours d'eau, de zones humides et d'éléments boisés (petits bois, bocage).



Les enjeux de gestion sur le Couesnon

● La qualité de l'eau

Bien que quelques tronçons de rivières (secteur Est et amont) présentent des concentrations en nitrates supérieures à la norme Européenne de potabilité (50 mg/L), la majeure partie d'entre elles ont des concentrations comprises entre 20 et 40 mg/L. **L'origine de cette pollution est essentiellement agricole.**

Les pesticides impactent également le Couesnon dans son ensemble, et plus particulièrement la zone maraîchère des polders.

● La quantité d'eau

L'alimentation en eau potable (AEP) est importante sur le Couesnon : 15,3 millions de m³ sont prélevés en moyenne chaque année. Près de 50 % sont exportés hors du territoire pour alimenter l'agglomération rennaise. Outre la qualité de l'eau qui peut impacter l'AEP, **le maintien d'un débit minimal est nécessaire pour préserver la biodiversité aquatique.**

● Les zones humides

La restauration des cours d'eau (arasement d'ouvrages) et des zones humides est un enjeu important pour atteindre le bon état écologique des masses d'eau imposé par la Directive Cadre Européenne sur l'eau. C'est également un levier d'action pour améliorer la gestion qualitative et quantitative de l'eau. Cette mosaïque d'habitats présente un intérêt majeur, notamment pour la faune. L'une des zones humides – le marais de Sougeal – est reconnue pour son intérêt pour la préservation des oiseaux, des poissons (brochets) et de la présence de quelques plantes protégées.

● La Baie du Mont-Saint-Michel

L'ensemble des pratiques agricoles situées dans la baie et en amont impacte la qualité et la quantité d'eau qui, par corollaire, influe sur **la qualité écologique des prés salés** (colonisation par le chientend maritime), **la ressource conchylicole et la sédimentation d'un site classé au patrimoine mondial de l'UNESCO.**

Approche générale

Utilisation d'images satellites pour reconstruire et quantifier les changements d'occupation et d'usage du sol

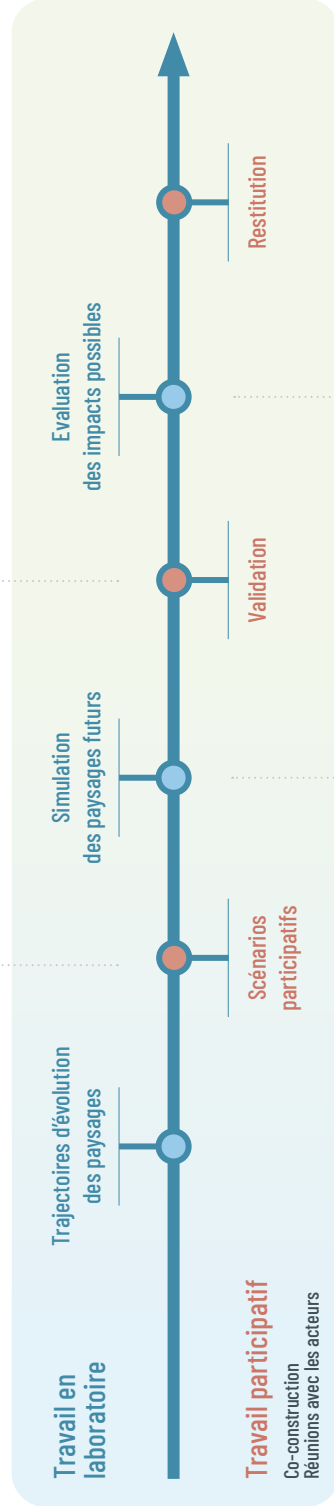


Développement d'un modèle informatique de simulation des changements d'occupation et d'usages du sol



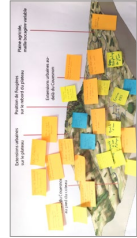
Utilisation de modèles informatiques pour évaluer les impacts environnementaux, utilisant les cartes produites comme donnée d'entrée.

Cela permet d'évaluer l'impact des changements paysagers entre 2018 et 2050 et de comparer les scénarios.

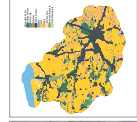


Co-construction de scénarios prospectifs à 2050, en lien avec les enjeux de gestion des Trames Verte et Bleue :

- 1 • identification des principaux facteurs d'évolution des paysages,
- 2 • construction de scénarios contrastés,
- 3 • déclinaison / adaptation de ces scénarios au territoire du Couesnon



Présentation des scénarios (récits + cartographies) aux acteurs locaux ayant pour objectif d'affiner et de valider les hypothèses des scénarios



Diffusion des résultats sous la forme de réunions publiques, présentations, et livret de synthèse (ce livret)



La construction des scénarios

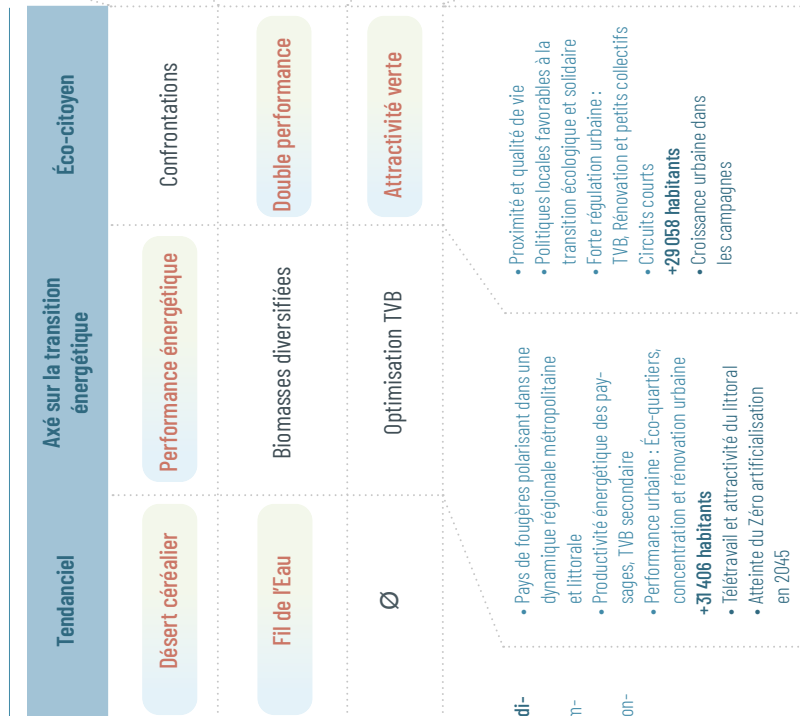
La TVB est le produit de 2 logiques globalement indépendantes

DÉVELOPPEMENT TERRITORIAL +/- AMBITIEUX PORTÉ PAR LES ÉLUS

- Déclinaison SCOT dans les PLU / PLUi • Degré de volontarisme
- Attentes sociales en matière de mode d'habiter

DYNAMIQUE AGRICOLE DÉPENDANTE DE FACTEURS MACRO-ÉCONOMIQUES

- Orientations de la PAC
- Règles de conditionnalité
- Logique de développement des filières agricoles



Développement de la céréalisation

Filière lait productive au centre du développement agricole

Diversification et Autonomie

- Attractivité (loisements, ZAC) **conditionne** le développement durable
- Concurrence communale / intercommunale
- Préservation des paysages / environnement : subsidiarité à la politique nationale
- **+24 855 habitants**
- Péri-urbanisation tendancielle

HYPOTHESES

HYPOTHESES

- Déclin de l'élevage dans l'ouest au profit des PECO
- Elevage de niche / proximité
- Production de biomasse (Politique Agricole Énergétique 2032): céréales
- Grosses unités de méthanisation
- Valorisation Céréales hiver et maïs
- Abandon des fonds de vallée
- Elevage relictuel centré sur l'herbage

PAC 2025 (primes à l'ha, éco-conditionnalités)

- Spécialisation accrue bassins de production
- Intensification (à base de maïs ensilage)
- Maîtrise des flux par la méthanisation
- Généralisation des pratiques raisonnées
- Elevage permet de conserver des terres difficiles

Révolution PAC 2025 : Paiements pour Services Environnementaux (PSE)

- Orientation économique ► protection alimentaire :
- Elevages herbagers + diversification
- Maraîchages collectifs
- Extensification de l'élevage
- Utilisation des fonds de vallée

Les 5 scénarios les plus contrastés sont explorés plus en détails pour le projet ALICE

INSEE Analyses Bretagne n°89 et 90
Observatoire Foncier, AUDIAR, Janvier 2018

La cartographie des scénarios

Une modélisation spatiale innovante : à l'échelle parcellaire

Le modèle FORESEM permet de simuler, de façon cartographique, des changements d'occupation et d'usage du sol, et leurs interactions. Il intègre des cartes de probabilités de changement générées par la calibration du modèle sur un passé proche et des cartes de contraintes pour chaque usage ou occupation du sol, améliorant ainsi leur localisation.

Par exemple, l'urbanisation se fera préférentiellement à proximité des zones déjà urbanisées et du réseau routier, mais uniquement dans des zones urbanisables définies dans les PLU / PLUi.

Au sein de l'usage agricole, il simule les rotations culturales, en respectant des assolements désirés (proportion de prairies, maïs, blé/oléo-protéagineux, autres cultures). Ainsi, le blé sera localisé préférentiellement dans les plus grandes parcelles pour favoriser de meilleurs rendements, mais pas sur des sols trop humides pour éviter qu'il ne verse, contrairement au maïs. Le modèle intègre aussi la déprise agricole. En effet, certaines parcelles agricoles en fonds de vallée où sur les terres les plus défavorables, sont souvent

abandonnées et entraînent une évolution naturelle vers une recolonisation arbutive puis arborée. Ce changement d'occupation du sol entraînera un abandon du milieu.

L'intérêt de ce modèle réside dans sa capacité à prendre en compte de nombreux paramètres scénaristiques comme une évolution des quantités de cultures à l'échelle du territoire étudié, de futurs PLUi ou zones de contraintes telles que les TVB définies dans les SCOT.

Sources : Palka et al. (in Prep) Simulating interactions and feedbacks between land use and land cover changes for prospective scenarios with FORESEM. Houet T., Grémond M., Vaccqué L., Forget Y., Bourrier F., Petitier A., Puisseau A., Bernardie S., Grandjean G., (2017) Downscaling scenarios of future land use and land cover changes using a participatory approach: an application to mountain risk assessment in the Pyrenees (France). Regional Environmental Change, 17(8): 2293-2307, <http://link.springer.com/article/10.1007/s10113-017-1171-z>

FORESEM : FOREcasting landscape SCEnarios Model*

* Modèle de simulations paysagères sur la base de scénarios

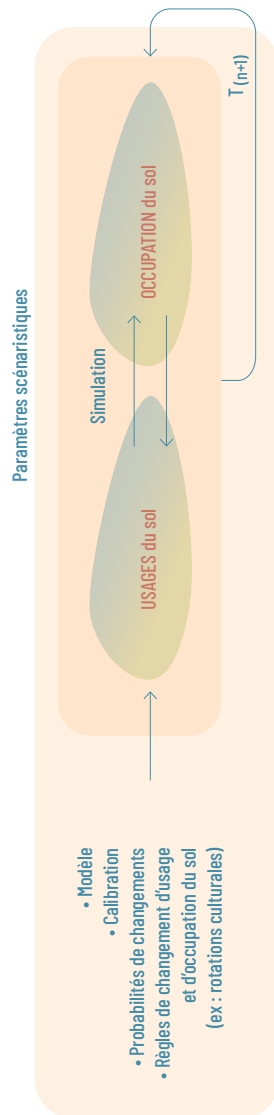
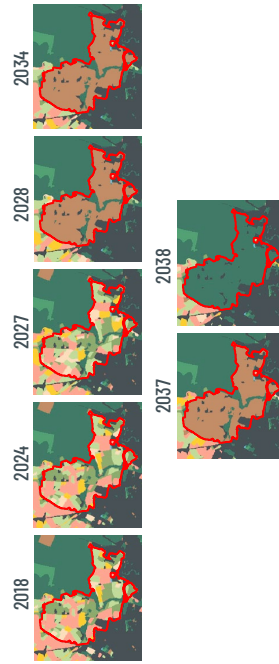


Illustration de la simulation de rotations culturales en bordure de forêt jusqu'en 2028, date à laquelle est prévue la mise en place d'un projet sylvicole fictif (délimitation en rouge), dont les nouvelles plantations, assimilées à la classe recolonisation (marron), mettront plus de 10 ans avant d'être considérées comme une forêt (vert foncé).



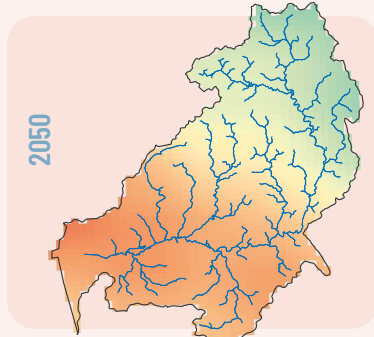
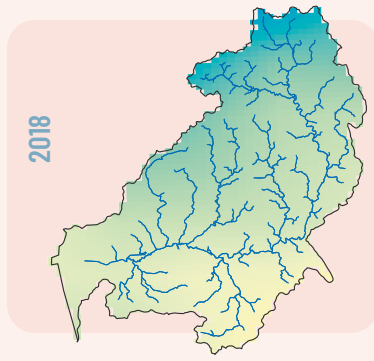
Le changement climatique

Les projections de changement climatique utilisées dans cette étude sont basées sur les scénarios du GIEC (2007). Pour envisager les situations les plus contrastées, les estimations se basent sur le scénario le plus pessimiste (RCP 8.5)

Conséquence sur le climat local en 2050

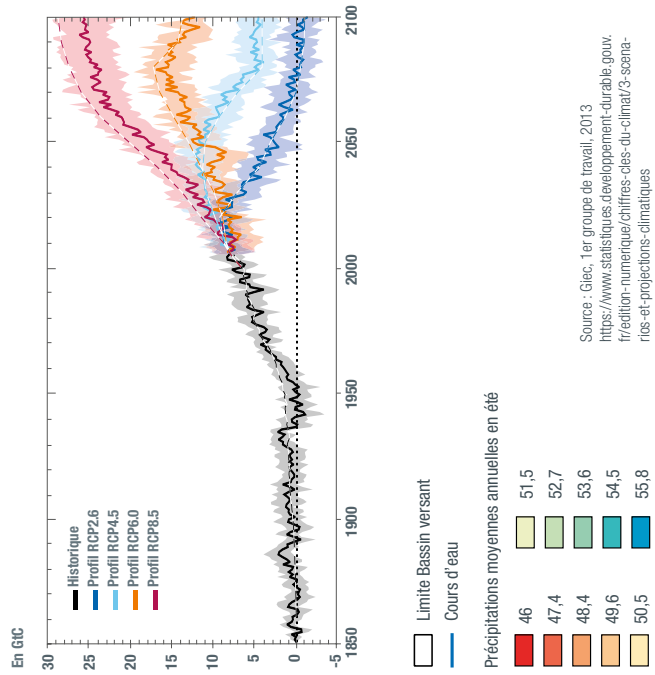
- Des hivers plus doux et plus humides
- Des étés plus chauds et plus secs (-5 à -8 mm / mois)
- Hausse des températures moyennes annuelles
- Hausse des précipitations annuelles

+1,4 à 1,6°
+14 à 20%



Pmm moyennes mensuelles estivales

Projections des émissions liées aux énergies fossiles suivant quatre profils d'évolution de GES (Les RCP du GIEC)



Source : Giec, 1er groupe de travail, 2013
<https://www.statistiques.developpement-durable.gouv.fr/edition-numerique/chiffres-clés-du-climat/3-scenarios-et-projections-climatiques>

L'évaluation des impacts

Evaluation des impacts futurs

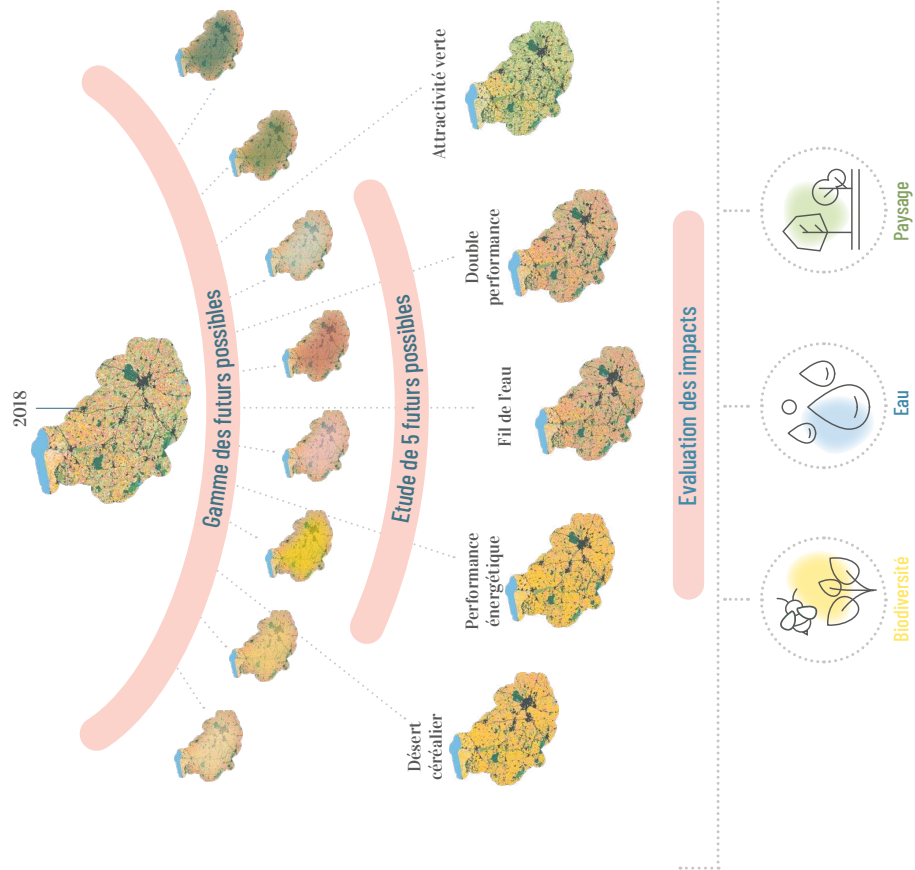
Cartographies actuelle et futures

Les cartographies actuelle (2018) et futures (2050) sont utilisées :

- ▲ pour évaluer directement les **changements paysagers** (urbanisation future, zone d'intensification agricole, etc.) et du **changement climatique**,
- ▲ Pour alimenter d'autres modèles publiés dans la littérature scientifique afin d'évaluer les **impacts** des changements paysagers sur certains **services écosystémiques** (Martínez López et al, 2019) :
- **les ressources en eau en terme de quantité et de qualité** (Alvarez Cabria & al 2016),
- **les paysages au travers de l'intensification agricole et de l'urbanisation,**
- **la biodiversité au travers de la connectivité écologique du paysage.**

Limites : les évaluations quantitatives des impacts restent génériques aux divers sites d'études du projet ALICE, et ne tiennent malheureusement pas compte des spécificités locales.

NB : pour les besoins de l'étude, un territoire légèrement plus vaste a été considéré, tenant compte d'une zone de 3km autour des limites du bassin versant du Couesnon.



30 ans d'évolution du paysage

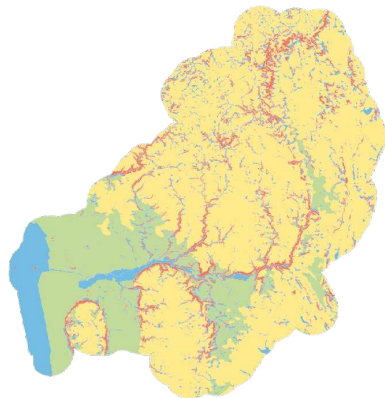
Organisation du paysage et évolution passée

L'évolution du paysage est essentiellement liée à la dynamique agricole.

Depuis les années 1990, suite aux changements de politiques agricoles (PAC), elle se caractérise principalement par :

- ▲ un agrandissement des parcelles agricoles,
- ▲ une disparition progressive du bocage,
- ▲ l'augmentation des surfaces de maïs au détriment des prairies.

Cette dynamique est cependant moins prononcée sur les massifs granitiques du site d'étude. Les bords du Couesnon se caractérisent par une évolution de mosaïques paysagères diversifiées : de grandes surfaces de pâturages et quelques rose-lières en aval (secteur de Sougéal) à une mosaïque de zones humides fauchées et pâturées dans les têtes de bassins versants, en passant par des ripisylves dans les vallées les plus encaissées aux versants marqués.



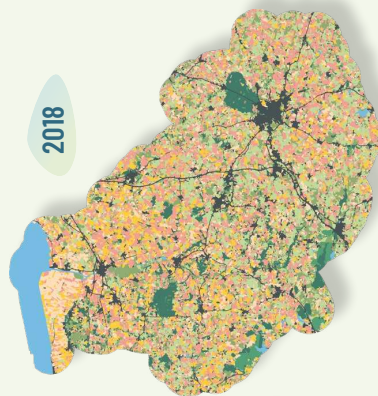
- Plaines (sols profonds)
- Massifs aux sols peu profonds
- Fonds de vallée
- Versants marqués



1990



2006



2018

- Eau
- Urbain
- Arbustes
- Forêt mixte
- Forêt de feuillus
- Blé
- Maïs
- Autres cultures
- Prairie temporaire
- Prairie permanente

Entre 1990 et 2018, le territoire du Couesnon est le témoin d'une intensification significative de l'agriculture qui se traduit par une diminution considérable des prairies (-40 000 ha environ). Elles sont remplacées pour la plupart par des cultures alors que d'autres, en fond de vallées, se sont transfor-

mées en ripisylves (environ +4 300 ha). Au cours de cette période, l'artificialisation du territoire a fortement augmenté en raison de l'étalement urbain d'une part et de la création de l'autoroute A84 d'autre part (+ 5 950 ha au total).

Scénario

Fil de l'eau

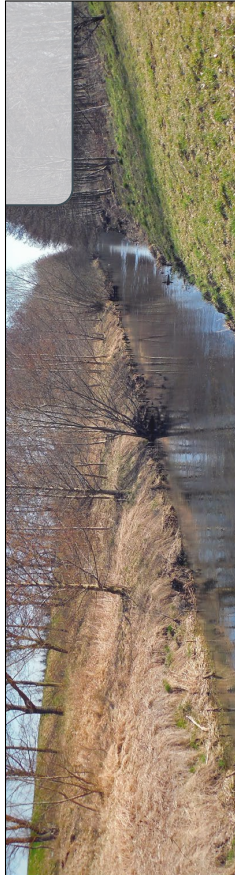
Le récit

Le développement territorial poursuit les logiques actuelles de concurrence entre territoires et d'urbanisation des zones périurbaines, couplé à un renforcement de la spécialisation dans une filière laitière intensive.

L'**identité agricole** s'inscrit dans la continuité de l'identité actuelle où le Couesnon participe à la filière laitière industrielle du Grand Ouest. Des élevages laitiers hors sol et la culture du soja se développent. Sur les plateaux, le grandissement des parcelles se poursuit au profit de cultures de céréales et du maïs plus particulièrement, contribuant à la disparition tendancielle du bocage non protégé réglementairement. La conditionnalité des aides agricoles garantit la conservation de quelques haies, localisées en bord de route ou en limite d'exploitation agricole. Les prairies se maintiennent uniquement en bordure des cours d'eau, dans les zones humides accessibles.

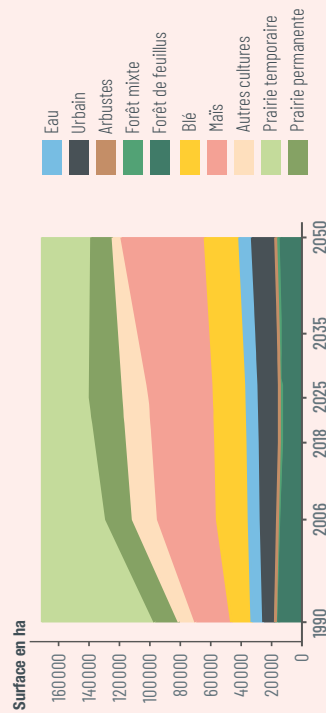
En termes d'**urbanisation**, les bourgs s'étendent à la faveur de la construction de lotissements de maisons individuelles. La rénovation urbaine existe mais reste limitée : des bâtiments agricoles sont transformés au profit d'un usage résidentiel. Parallèlement, les zones artisanales et économiques poursuivent leur développement le long de l'autoroute A84.

Le **changement important réside dans la création de réservoirs et de retenues collinaires**. En effet, accentuées par les effets du changement climatique, les tensions sur la ressource en eau augmentent du fait de la céréalisation de l'agriculture sur le bassin versant et de la croissance démographique de l'agglomération rennaise. Ces ouvrages sont ainsi financés par cette dernière.



Le paysage en 2050

Les surfaces urbanisées totalisent 15 411 ha (contre 12 844 ha en 2018).
 L'abandon a progressé de +3272 ha (7791 ha en 2018).
 Les surfaces agricoles (1302 km²) sont couvertes par :
 • 42 % de maïs,
 • 36 % de prairies (dont les deux tiers de moins de 7 ans)
 • 22 % d'autres cultures (blé / oléo-protéagineux, autres).
 Les haies totalisent encore un linéaire de 7298 km (8915 km en 2018).



	Bocage (Linéaire boisé en Km)	Ratio Surface en Herbe / SAU	Surface en maïs (km ²)
2018	8915	412 %	412
Fil de l'eau	7298	35,8 %	550

Scénario

Double performance

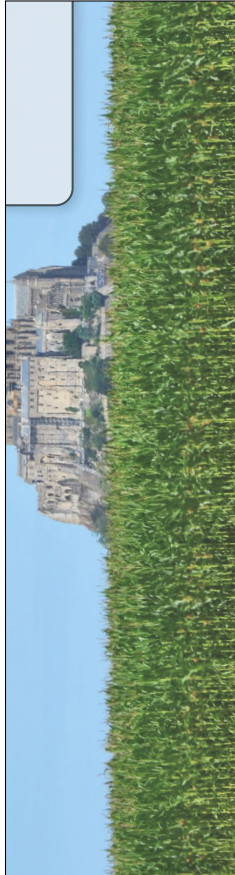
Le récit

La population a pris conscience de la nécessité d'adapter son mode de vie pour faire face au réchauffement climatique. Ce développement territorial privilégie la proximité et la qualité de vie. La recherche d'un cadre de vie « au vert » revitalise les villages ruraux. Victime de son succès et face à la demande, les campagnes sont le support d'une légère artificialisation ne permettant pas d'atteindre le zéro artificialisation.

Ce développement territorial à connotation environnementale se heurte parfois au développement agricole centré sur une intensification de la filière lait dans laquelle le territoire poursuit sa spécialisation. Les surfaces en maïs augmentent au détriment des prairies. Plusieurs leviers sont mobilisés par les politiques publiques pour appuyer et harmoniser ces dynamiques territoriales et agricoles :

- investissements pour **développer les filières locales**,
- abondement des aides en faveur de la **conversion à l'agriculture biologique** pour certaines fermes,
- mesures compensatoires pour favoriser le **respect des prescriptions environnementales** fondées sur des bonnes pratiques plus que sur des aménagements paysagers par les agriculteurs,
- **valorisation du bois** des haies,
- projets de petites unités de méthanisation absorbant les surplus d'effluents d'élevage, etc.

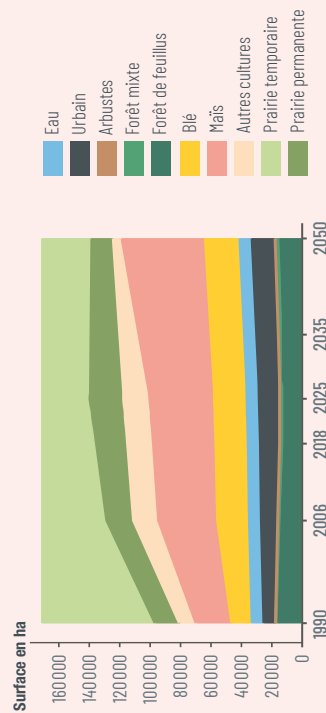
En outre, le pari est fait que la génération suivante sera plus formée et mieux sensibilisée : l'argent jusqu'alors dédié à la sensibilisation pourra être dévolu aux missions de police environnementale pour sanctionner les atteintes à l'environnement. Au final l'application des prescriptions devient de plus en plus effective dans le territoire, mais n'a pas de traduction paysagère tangible. De son côté, l'agriculture reste liée aux grosses entreprises agro-alimentaires aux logiques de multinationales. Si la volonté de répondre aux changements de mentalités est affirmée, le schéma classique de hausse de la production reste prépondérant dans la manière de penser le modèle économique agricole.



Le paysage en 2050

En 2050, les **nouvelles surfaces urbaines** (1302 km²) sont couvertes :

- à 42 % par du maïs,
 - 36 % par des prairies (dont les deux tiers de moins de 7 ans)
 - et 22 % par d'autres cultures (blé / oléo-protéagineux, autres).
- Le bocage se maintient autour des villages et des hameaux ainsi qu'en limite d'exploitations agricoles et totalise encore 7299 km (-166 km par rapport à 2018).



	Bocage (Linéaire boisé en Km)	Ratio Surface en Herbe / SAU	Surface en maïs (Km ²)
2018	8 915	41,2 %	412
Double Performance	7 299	35,8 %	550

Scénario

Attractivité verte

Le récit

Le développement territorial est centré sur la proximité et la qualité de vie avec, en parallèle, un développement agricole promouvant une transition agricole écologique, autonome et diversifiée, ancrée dans son territoire et rémunérée pour les services écosystémiques qu'elle rend.

La PAC incite les agriculteurs à produire autrement avec la mise en œuvre des paiements pour services environnementaux (PSE) qui permettent de rémunérer l'entretien du bocage et des zones humides. Les élus locaux introduisent activement des produits bio et locaux dans la restauration collective mais aussi dans les supermarchés du territoire. Un remembrement vert a été mené à l'initiative des collectivités locales avec l'aide de la Chambre d'agriculture, de la SAFER et de collectifs d'agriculteurs. Cet échange foncier permet de **limiter le parcelllement** et **assurer des économies d'échelles** (diminution des déplacements par exemple) et une **plus grande diversification des rotations** en l'absence d'illots spécialisés en cultures. Seules les **haies** situées dans les **illots cultivés** tendent à disparaître mais contribuent à maintenir un bocage dense malgré tout*. Les paysages se caractérisent par des **élevages majoritairement herbagers**, qui valorisent au maximum les prairies naturelles de fonds de vallées, couplé à des cultures orientées essentiellement vers la **production alimentaire** (maraîchage, céréales, graines productives, oléagineux...). Sur les **plateaux**, des **éoliennes** sont installées sur les zones venteuses.

Les élus locaux investissent massivement dans la **restauration des cours d'eau et des zones humides**, anciennement drainées. Sur le plan de l'urbanisme, la **rénovation urbaine et les écoquartiers** sont privilégiés en dehors des centres bourgs. La recherche d'un cadre de vie « au vert » **revitalise les villages ruraux**. Victime de leur attractivité, les campagnes sont le support d'une **légère artificialisation** ne permettant pas d'atteindre le zéro artificialisation. Le développement des filières éoliennes et bois bocage est encouragé pour assurer un **approvisionnement énergétique local**.

* l'hypothèse d'une baisse tendancielle a été retenue malgré la mise en œuvre récente de mesures pouvant aider à maintenir le bocage (mesures de replantations compensatoires, PLU, labell...)

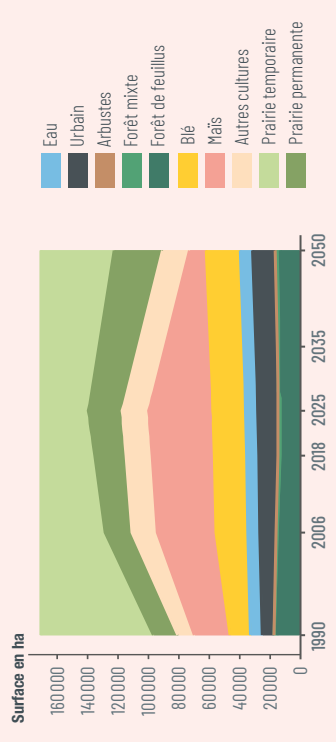


Le paysagisme en 2050

- Les surfaces agricoles (1315 ha) sont couvertes de :
- 8 % par du maïs,
 - 61 % par des prairies (dont plus d'un tiers de moins de 7 ans) localisées principalement sur les pentes et dans les fonds de vallées,
 - et 31 % par d'autres cultures (blé / oléoprotéagineux, autres).

Le maillage bocager reste dense (7889 km, -174 km par rapport à 2018) et se maintient autour des villages et des hameaux, ainsi qu'en limite d'exploitations agricoles.

En 2050, les **nouvelles surfaces urbanisées totalisent 15 139 ha** (contre 12 844 ha en 2018) et **se distribuent autour des pôles urbains et dans les campagnes**. L'abandon a progressé à la faveur d'une **légère déprise agricole de + 2 334 ha** (781 ha en 2018).



	Bocage (Linéaire boisé en Km)	Ratio Surface en Herbe / SAU	Surface en maïs (km²)
2018	8 915	41,2 %	412
Attractivité verte	7 741	61,3 %	104



Scénario

Désert céréalier

Le récit

Le développement territorial poursuit les logiques actuelles de concurrence entre territoires et d'urbanisation des zones périurbaines, couplé à une céréalisation du territoire.

L'identité agricole fondée sur la céréalisation du territoire s'inscrit sur une rupture d'identité assez nette, centrée sur la production énergétique, mais reposant sur des germes de changement déjà à l'œuvre en 2018 en Bretagne.

Les cultures de céréales (blé, coïza, maïs) se développent massivement partout. Elles alimentent des usines de méthanisation qui s'implantent sur le bassin versant.

L'élevage, désormais très limité, n'est plus vraiment visible dans le paysage : seules quelques prairies se maintiennent en fond de vallées et dans les Espaces Naturels Sensibles protégés.

De même, quelques arbres isolés parsèment les plateaux.

Les haies ont quasiment disparu du parcellaire agricole (~2 012 km) : on n'en trouve plus qu'en bordure des lotissements qui se construisent à la lisière des bourgs historiques, en bordure des routes ou en limite d'exploitation agricole.

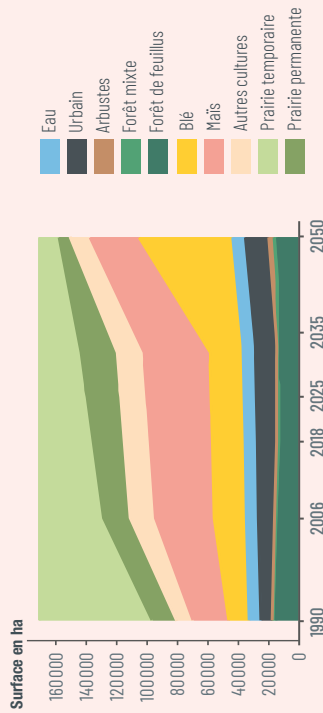
En termes d'urbanisation, les bourgs s'étendent à la faveur de la construction de lotissements de maisons individuelles. La rénovation urbaine existe mais reste limitée : des bâtiments agricoles sont transformés au profit d'un usage résidentiel. Parallèlement, les zones artisanales et économiques poursuivent leur développement le long de l'autoroute A84.

Le changement important réside dans la création de réservoirs et de retenues collinaires. En effet, accentuées par les effets du changement climatique, les tensions sur la ressource en eau augmentent du fait de la céréalisation de l'agriculture sur le bassin versant et de la croissance démographique de l'agglomération rennaise. Ces ouvrages sont ainsi financés par cette dernière.

Le paysage en 2050

Les surfaces agricoles (1302 ha) sont couvertes :

- à 25 % par du maïs,
 - 15 % par des prairies (dont un tiers de moins de 7 ans)
 - et 60 % par d'autres cultures (blé / oléo-protéagineux, autres).
- Le bocage ne totalise plus que 6903 km de haies. En 2050, les surfaces urbanisées totalisent 15 410 ha (contre 12 844 ha en 2018), l'abandon a progressé de ~6 014 ha (779 ha en 2018).



	Bocage (Linéaire boisé en Km)	Ratio Surface en Herbe / SAU	Surface en maïs (Km ²)
2018	8 915	41,2 %	412
Désert céréalier	6 903	15,6 %	324



Scénario

Performance énergétique

Le récit

Le développement territorial s'organise autour de la transition énergétique et est en cohérence avec le développement agricole caractérisé par un développement de la céréalisation et des filières dédiées à la production énergétique (biomasse végétale).

La crise de 2014 à 2016 avait préfigurée de profonds changements avec les disparitions de petites exploitations laitières mais également de grosses exploitations laitières qui étaient en phase de conversion à l'agriculture biologique. Le contexte macro-économique, la démographie agricole et la PAC engendrent une forte diminution du nombre d'agriculteurs sur le territoire. Les reprises par de grands céréaliers Normands ou de la Beauce engendrent un agrandissement des exploitations et un développement des filières énergétiques couplant énergie éolienne et biomasse agricole :

- le maïs alimente de gros méthaniseurs implantés sur le territoire
- les filières blé et colza assurent la production d'agro-carburants.

Certaines exploitations possèdent leur propre unité de méthanisation. Le lait issu de la filière industrielle classique décline du fait de la concurrence des PECO (Pays d'Europe Centrale et Orientale) plus compétitifs. La production de lait bio local augmente même si elle reste minime, de même que la viande locale, en réponse à la demande des habitants du territoire. Les exploitations en agriculture biologique pratiquent pour une large partie d'entre elles la vente directe.

L'urbanisation se réalise principalement dans l'agglomération Fougèreise, dans de nouveaux écoquartiers (petits collectifs) à énergie positive ou dans le cadre d'opérations de rénovation à haute performance énergétique prévues dans le SCoT, favorisant la densification. Le zéro artificialisation est atteint en 2045. La généralisation du télétravail visant à minimiser les dépenses énergétiques des migrations pendulaires participe également à une urbanisation des pôles urbains et des zones proches du littoral, plus attractives.

Le paysage en 2050

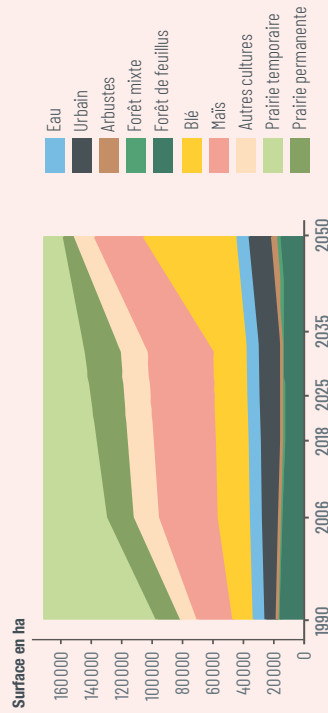
Les prairies se maintiennent uniquement en bordure des cours d'eau, dans les zones humides moins propices à la céréaliculture.

Les plateaux, ouverts, sont massivement cultivés et parsemés d'éoliennes.

Les surfaces agricoles (1302 ha) sont couvertes :

- à 25 % par du maïs,
- 15 % par des prairies (dont un tiers de moins de 7 ans)
- et 60 % par d'autres cultures (blé / oléo-protéagineux, autres).

Le bocage ne totalise plus que 6942 km de haies. En 2050, les surfaces urbanisées totalisent 14 777 ha (contre 12 044 ha en 2018), l'abandon a progressé de +6804 ha (7791 ha en 2018).



	Bocage (Linéaire boisé en Km)	Ratio Surface en Herbe / SAU	Surface en maïs (Km²)
2018	8 915	41,2 %	472
Performance énergétique	6 942	15,6 %	324

Comparaison des images du futur



L'urbanisation future

Cette carte montre les zones où l'urbanisation est susceptible de se produire à l'horizon 2050 pour un ou plusieurs scénarios.

En rose clair sont représentées les zones urbanisées dans un seul scénario, les teintes jaune, vert et rose foncé, les zones qui sont urbanisées dans plusieurs scénarios.

Le rôle majeur des axes majeurs de communication

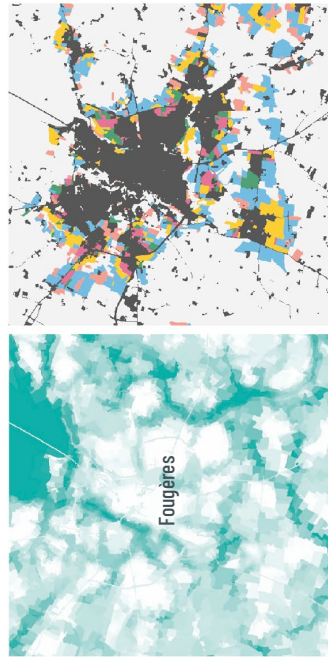
L'urbanisation simulée dans les 5 scénarios montre une **attractivité de l'agglomération de Fougères et des communes proches de l'autoroute** (Saint-Aubin-du-Cormier, Saint-Brice-en-Coglès, Saint-Etienne-en-Coglès, Saint-James, ...). Les communes qui supporteront le plus probablement l'extension urbaine sont les communes présentant une accessibilité élevée aux pôles urbains du bassin versant (Fougères) et en dehors (Remes). Ainsi, les communes à l'ouest du bassin versant et plus éloignées du réseau routier rapide voient leur développement urbain plus limité.

Identification de zones potentielles d'enjeux

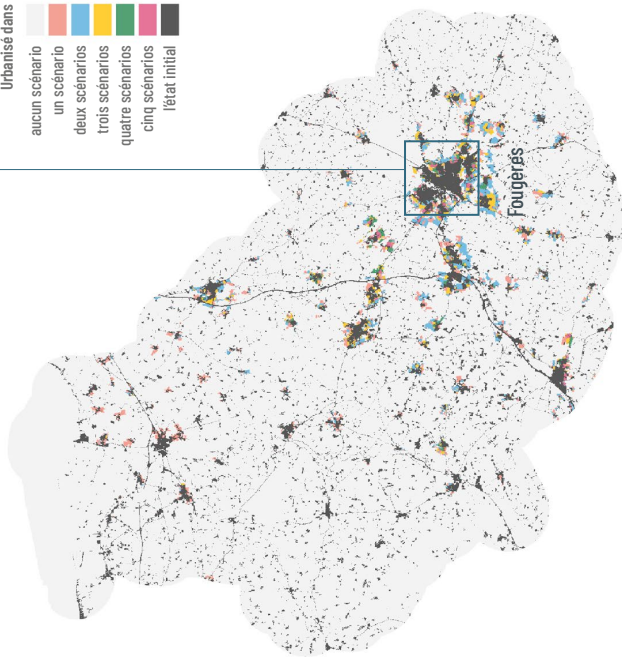
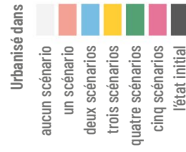
- Les zones présentant les teintes vert et rose foncé correspondent aux zones les plus **susceptibles d'être urbanisées à l'avenir quelle que soit l'efficacité des SCoT** adoptés.
- Les zones présentant les teintes les plus claires correspondent aux **espaces susceptibles d'être urbanisés suivant les évolutions possibles des choix sociétaux** en matière de modes d'habiter ("se mettre au vert" vs. "efficacité énergétique des centralités") et des **gouvernances locales** en matière d'urbanisation ("coopération intercommunale" vs. "compétition en matière d'attractivité communale").

Certaines de ces zones peuvent ne présenter aucune contrainte particulière. D'autres peuvent faire l'objet d'enjeux paysagers, écologiques ou encore sociétaux à moyen terme qui n'avaient pas été identifiés jusqu'à maintenant.

Par exemple, autour de Fougères, les zones susceptibles d'être urbanisées sont, quelque soit le scénario, situées dans des secteurs présentant une faible connectivité écologique.



Trame verte et bleue



Intensification agricole

Une baisse des rendements en cultures

En raison du changement climatique, des baisses de rendements des cultures sont prévues :

- ▶ Rendements en maïs : -5,2% à -14,9%
- ▶ Rendements en blé : -2% à -5%

Ces baisses sont compensées par l'augmentation des surfaces concernées.

Identification des zones susceptibles d'être les plus intensives

Ces illustrations montrent les **occurrences pour le maïs (en haut) et le blé (en bas)**, c'est à dire le nombre de fois qu'une parcelle est recouverte par ces cultures sur la période 2018-2050 pour les scénarios les plus intensifs.

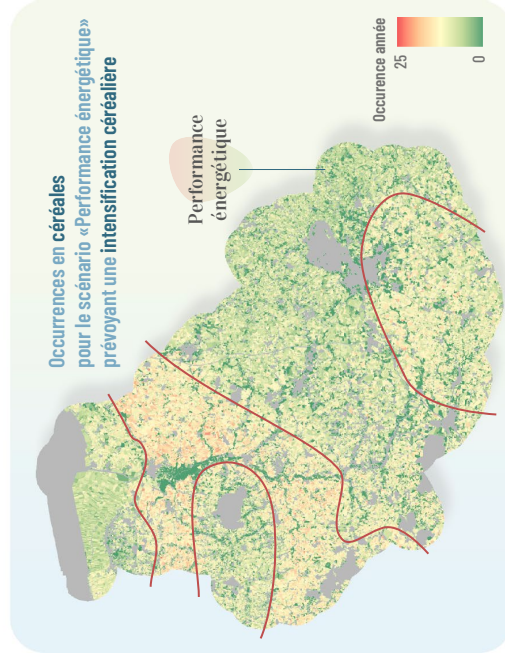
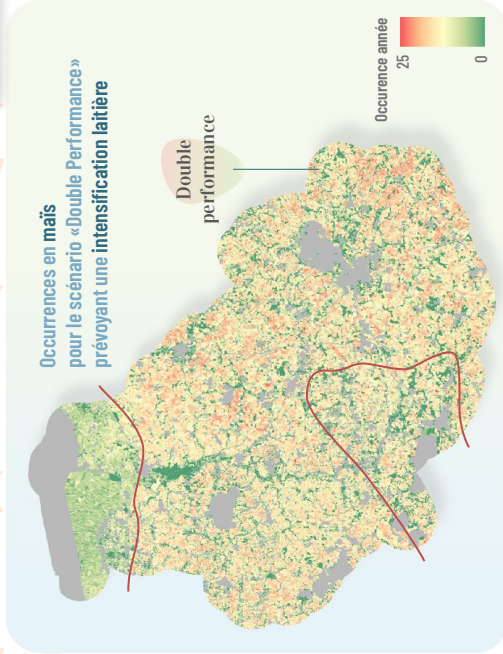
Quelque soit l'**intensification agricole** considérée, la plaine située dans la basse vallée du Couesnon autour du marais de Sougéal, faisant un arc de cercle entre Bazouges la Pérouse, Antrain, Pontorson et Plaine Fougères, est celle qui devrait être la plus intensive à l'avenir dans le bassin versant du Couesnon. Dans une moindre mesure, le secteur au **Sud et à l'Est de Fougères sera aussi concerné**.

Dans le cas d'une **intensification laitière, toute la partie amont du Couesnon, ainsi que le Coglais devraient se démarquer fortement**.

Le risque d'une demande accrue des besoins en eau pour l'irrigation

Pour **compenser la baisse des précipitations** qui impactera les rendements, une hausse de la demande en eau à des fins d'irrigation est probable.

Par ailleurs, une **baisse plus forte des rendements en blé** doit être envisagée car les impacts de la hausse des précipitations hivernales (risque d'érosion des sols) et printanières (risque de verse du blé) ne sont pris en compte ici.



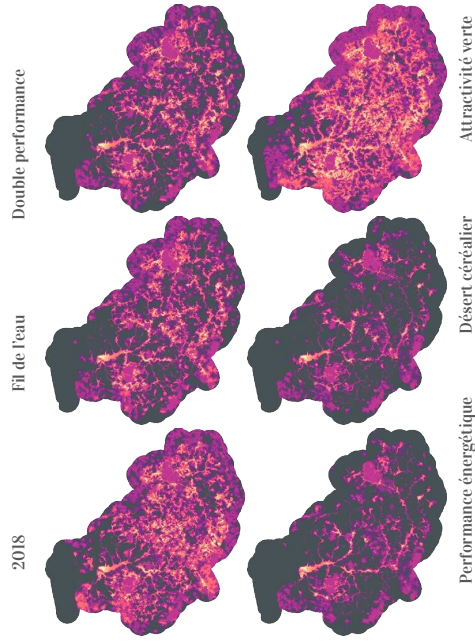
Impacts sur la connectivité paysagère

La connectivité paysagère

La connectivité paysagère est définie ici par la somme des connectivités dites humides, boisées et prairiales, pour des espèces « parapluies », représentatives d'autres espèces inféodées à chacun de ces milieux. La connectivité représente les zones de déplacements théoriques de chacune d'elles à partir de leur zones d'habitats préférentiels, de la perméabilité du milieu et de leur capacité de déplacement.

Les cartes suivantes représentent la connectivité paysagère pour 2018 et les cinq scénarios :

- Fil de l'eau,
- Double performance,
- Performance énergétique,
- Désert céréalier,
- Attractivité verte.



Impact majeur de l'agriculture

L'agriculture influe fortement sur les connectivités paysagères futures. Les scénarios d'intensification agricole engendrent des pertes allant de -13 à -48 % de connectivité humide, de -25 à -32 % de connectivité boisée et de -29 à -87 % de connectivité prairiale. Le verdissement de la PAC (Attractivité verte) permettrait une augmentation de +42 à +63 % de connectivités humide et prairiale. La régression du bocage quelque soit le scénario, engendre une perte minimale de près de 10 % de connectivité boisée à l'horizon 2050.

Une céréalisation de l'agriculture diminuerait par deux la connectivité paysagère globale, une intensification laitière à base de maïs ensilage une baisse de 22%.

Des SCoT efficaces pour préserver les corridors écologiques du développement urbain

Si l'on compare les scénarios désert céréalier / performance énergétique, il est possible de mesurer l'impact d'un SCoT très efficace et bien respecté: ce sont 0,9 % de connectivité humide et 1,6 % de connectivité boisée en plus qui sont préservées comparativement au cas où celui-ci n'est pas bien respecté. Cela témoigne donc de leur efficacité pour préserver les corridors écologiques du développement urbain.

L'impact d'un changement de préférences du lieu de vie des ménages est du même ordre de grandeur.

Perte de connectivité par rapport à 2018 (en %)

	Connectivité		
	humide	boisée	prairiale paysagère
Fil de l'eau	-13,08	-25,28	-29,31
Double performance	-13,47	-23,44	-29,94
Attractivité verte	42,46	-9,80	63,75
Performance énergétique	-47,52	-32,27	-87,52
Désert céréalier	-48,46	-33,80	-87,42

Impacts sur la quantité d'eau

Une influence marquée du changement climatique

Que les scénarios de changements d'occupation et d'usage du sol à 2050, les quantités d'eau sont sensiblement impactées par le changement climatique avec un **débit estival presque divisé par 2 en été** et un débit légèrement supérieur en hiver par rapport à 2018.

La même pour des scénarios de changement climatique moins extrêmes car les régimes de pluies sont identiques pour les scénarios RCP 4.5 et 6.0. L'impact sur les débits devrait être maldré tout plus limité.

Enfin, la hausse des températures de l'eau, cumulée aux débits plus faibles, pourraient avoir des impacts majeurs sur la faune aquatique.

Valeurs estimées en période estivale

Valeurs à l'exutoire		Débit estival (m ³ /s)	Débit hivernal (m ³ /s)	T°
2018		3,01	10,9	16,5° C
Fil de l'eau		1,88	11,4	17,6° C
	Double performance			
Attractivité verte		1,70	12,73	17,6° C
Performance énergétique		non calculés pour ces scénarios		
Désert céréalier		non calculés pour ces scénarios		

Un risque accru dans le cadre des scénarios d'intensification agricole

Si les évaluations n'ont pas été faites pour les scénarios orientés vers la production énergétique, les valeurs doivent être proches des autres scénarios en raison de l'influence majeure du changement climatique.

Ces évaluations ne tiennent pas compte de modifications probables des pratiques agricoles (création de retenues collinaires, pompages pour l'irrigation),

ni de la hausse des prélèvements d'eau destinés à l'alimentation en eau potable compte tenu des évolutions démographiques.

Les débits du scénario « Attractivité verte » sont probablement sous-estimés car les actions de restauration des zones humides considérées dans ce scénario et permettant un soutien à l'étiage ne sont pas prises en compte non plus.



Impacts sur la qualité de l'eau

Une dégradation de la qualité de l'eau liée à l'évolution des débits

Quels que soient les scénarios de changements d'occupation et d'usage du sol à 2050, **la baisse des débits engendrera une hausse des concentrations estivales en polluants (effet sirop).**

L'ensemble des valeurs doivent être prises avec précaution car le modèle utilisé n'est pas adapté au contexte breton (pas de prise en compte de l'évolution du bocage, ni de la restauration des zones humides). Par contre, elles permettent d'émettre des hypothèses sur les marges de manœuvre.

Les nitrates

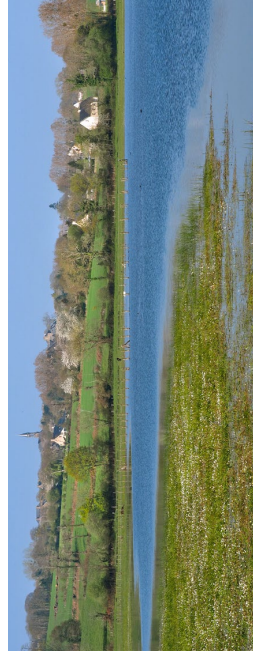
Les scénarios d'intensification laitière prévoient une hausse importante des concentrations azotées en lien avec la hausse nette des effluents. L'évolution des usages agricoles vers la transition écologique et la transition énergétique permettent tant bien que mal de rester sous la limite des 50 mg/L en nitrates. Néanmoins, les concentrations mentionnées pour le scénario « Attractivité verte » sont probablement surestimées : la restauration des zones humides n'est pas prise en compte.

Le phosphore

La problématique d'une pollution de l'eau par le phosphore émerge dans le cas des scénarios d'intensification agricole uniquement qui auront pour conséquence de faire émerger des problèmes d'eutrophisation et engendrer d'importants surcoûts de traitement. Si le modèle tend à sous-estimer les concentrations en phosphore, seul le scénario « Attractivité verte » permet de maintenir des taux identiques à ceux rencontrés aujourd'hui.

Et les pesticides ?

Le modèle utilisé ne traite pas des pesticides, malheureusement. Néanmoins, une forte hausse des contaminations par les pesticides en quantité et en variété doit être considérée dans le cas des scénarios orientés vers la transition énergétique compte tenu de la forte hausse des surfaces en céréales (traitements sécuritaires).



Station Cousnon - Antrain	Nitrates (mg/L)		Phosphore (mg/L)	
	Obs.	Sim.	Obs.	Sim.
2018	34	24	0,11	0,07
Fil de l'eau Double performance Attractivité verte Performance énergétique Désert céréalier		79	0,23 ± 0,5	
		47	0,12 ± 0,3	
		47	0,30 ± 0,7	

Conclusions

Une hausse probable des tensions sur l'eau

Le changement climatique aura tendance à **impacter les ressources en eau**, tant sur les quantités que sur la qualité, dans un contexte tendanciel de croissance démographique sur le territoire du Couesnon et sur l'agglomération rennaise que le Couesnon alimente en eau potable. **Un impact fort du changement climatique pourrait réduire à néant des décennies d'amélioration des pratiques agricoles.**

Combiné à une intensification agricole, la tension sur l'eau va s'accroître d'une part, en raison d'une hausse probable de la demande en eau à des fins **d'irrigation** compte tenu de l'impact du changement climatique sur les rendements, et d'autre part, en raison de contaminations nouvelles en nitrates, phosphores et pesticides selon les orientations laitière ou énergétique des productions agricoles.

Seul un maintien des éléments constituant la Trame Verte et Bleue peut limiter les tensions futures sur cette ressource renforçant l'enjeu majeur que constitue la restauration et l'intégration des zones humides et du bocage dans les usages agricoles et des collectivités locales.

Les Trames Verte et Bleue : un rôle allant au-delà de la biodiversité !

Le rôle des TVB ne se limite pas à la biodiversité (préservation de connectivités écologiques). Leur maintien / préservation implique des usages agricoles qui auront, par incidence, des impacts positifs sur la ressource en eau (limitation des pollutions agricoles diffuses, augmentation des réserves utiles et soutien à l'étiage...). D'autres évaluations doivent être réalisées sur la régulation des inondations, la limitation de l'érosion des sols pour mesurer pleinement les avantages qu'elles procurent...

Les facteurs de risque sur l'efficacité à moyen et long terme d'un SCoT

▲ **L'agriculture** a une influence majeure sur les continuités écologiques, bien plus forte que l'urbanisation.

▲ Si des leviers ne sont pas trouvés pour influencer / orienter localement le développement agricole des certaines exploitations, l'efficacité des SCoT pourra être réduite à néant.

▲ L'évolution des **préférences des ménages** en matière de logement (la campagne, logement collectifs, etc.) et **la continuité et le volontarisme** des politiques locales après des élections municipales sont les principaux risques pour les SCoT.

Réconcilier «développement territorial» et «agriculture»

Les scénarios créés sur le bassin versant du Couesnon illustrent une réalité : **la faible intégration de l'agriculture dans le développement territorial**. Les politiques en matière de développement urbain sont déjà fortes et ambitieuses. Leur efficacité dépend :

▲ de visions à long terme de l'aménagement du territoire quelle que soit la gouvernance territoriale,

▲ d'une évolution profonde du contexte politique-co-réglementaire à l'échelle de l'Europe (PAC) et de la Région afin d'éviter que les développements agricoles et territoriaux se poursuivent de façon complètement séparée.

Aujourd'hui, il s'agit de savoir **comment réconcilier des enjeux économiques agricoles globaux** (à forte tendance d'intensification) **avec des enjeux de gestion territoriale intégrée aux échelles locales ?**

Et après ?

Un déterminisme géographique favorable ?

La géologie, l'histoire et la culture locale procurent au Couesnon une forte identité de "terre d'élevage". Ils constituent aujourd'hui une opportunité pour inscrire à une transition écologique forte, synonyme de développement durable car **certains secteurs sont "naturellement" favorables à une diversification et une désintensification de l'agriculture**. Néanmoins, le changement climatique pourrait fragiliser cette transition si celle-ci n'est pas anticipée suffisamment tôt.

Limiter l'intensification agricole ?

La transition écologique ne peut être envisagée qu'avec l'agriculture, principal acteur de la gestion et de l'entretien des territoires. La mise en place d'une politique intégrée de mesures d'aides ou compensatoires visant le maintien des prairies (permanentes), des éléments arborés et des zones humides est indispensable pour limiter les impacts négatifs sur les services écosystémiques. Les mécanismes à définir et à mettre en œuvre tant au niveau Européen que régional, devront être largement communiqués à la population pour éviter le "syndrome des bonnets rouges" (taxe supplémentaire). Il conviendra dans le même temps de **faire évoluer les SCoT, d'innover en matière de politique de gestion territoriale, pour influencer sur l'agriculture potentiellement sous la forme d'incitations, de contraintes voire d'aides participatives**.

Affiner et compléter les évaluations

Les situations évoquées sont probablement caricaturales, volontairement extrêmes et ne présentent pas de situation idéale. Cet exercice a le mérite **d'identifier les tendances lourdes et d'évaluer leur ordre de grandeur**. Certaines évaluations méritent d'être affinées, notamment sur le rôle des éléments de la TVB sur les ressources en eau. Il est également indispensable de **mesurer les impacts et retombées économiques** de chacun de ces scénarios, pour mieux évaluer les mesures à mettre en œuvre pour favoriser un développement plus durable.

De la nécessité d'un Observatoire Prospectif du Paysage

Au-delà de projections très contrastées, il conviendrait de mettre en place **un outil de veille stratégique** (observatoire prospectif du paysage ?) afin de pouvoir comparer l'évolution des changements d'occupation et d'usage du sol par rapport aux trajectoires des scénarios prospectifs. En effet, un suivi des changements paysagers à des échelles fines permettrait d'identifier de façon précoce les facteurs explicatifs d'une évolution indésirable et de localiser des zones présentant des trajectoires à risque.



Remerciements

L'ensemble des chercheurs impliqués dans le projet ALICE remercient chaleureusement l'ensemble des partenaires du projet, notamment le **SAGE Couesnon**, ainsi que **l'ensemble des institutions publiques, associations et personnes** ayant participé aux réunions participatives relatives à la construction des scénarios prospectifs.

Nous remercions le **bureau d'étude SGEV T** pour avoir réalisé et mis à disposition gracieusement une cartographie des Trames Verte et Bleu retenant la même méthode que celle utilisée par le syndicat du SCoT du Pays de Fougères.

Nous remercions également la **Zone Atelier Armorique**, dispositif scientifique du CNRS, pour avoir mis à disposition des bases de données de suivi à long terme des paysages.

Enfin, nous remercions l'ensemble des **personnes participant aux réunions publiques** de restitution des résultats liés aux scénarios prospectifs "Couesnon 2050" pour leur intérêt et leur mobilisation.

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Notes

27



The page contains a large area for notes with horizontal dashed lines. On the left side, there is a decorative graphic with overlapping blue, green, and red shapes. On the right side, there are three circular icons: a leaf, a house, and a water drop. The page number '27' is located in the top right corner.



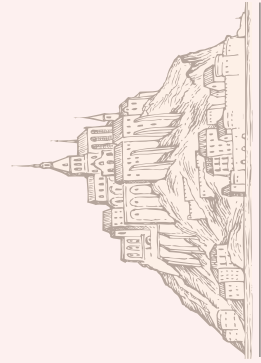
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1.2 Norois and Houet's article describing the socio-demographic and geographical context of the Lestolet

Modélisation prospective de l'occupation du sol en zone agricole intensive

Evaluation par simulations dynamiques de l'impact de l'évolution des exploitations agricoles dans la France de l'Ouest

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RÉSUMÉ. La réforme de la Politique Agricole Commune programmée en 2006 et la dévitalisation des campagnes provoquant un agrandissement prononcé des exploitations agricoles soulèvent la problématique de l'évolution des modes d'occupation des sols et de ses conséquences sur l'environnement. L'élaboration de scénarios prospectifs spatialisés à l'échelle locale constitue une méthode puissante pour donner une image des futurs possibles d'un territoire agricole. Lorsque celui-ci est porteur d'enjeux sur la gestion qualitative de l'eau (tel qu'un bassin versant), ces images peuvent aider les décideurs à mettre en place des actions de gestion de la ressource efficaces localement et durables. L'objectif de ce travail est d'évaluer l'influence respective de la réforme de la PAC et de l'agrandissement des exploitations agricoles sur les changements d'occupation des sols à l'aide de simulations dynamiques effectuées avec une plateforme de modélisation. Les résultats montrent que ces deux facteurs ont des conséquences différenciées sur les changements d'occupation des sols à l'échelle d'un petit bassin versant (1300 ha) : la direction, le rythme et la distribution spatiale des changements d'occupation et d'utilisation des sols diffèrent.

ABSTRACT. The reform of the CAP which should come into force in 2006 and the depopulation in rural countries that induces significant enlargement of farms refer to the problematic of land use and land cover changes and its environmental impacts. Construction of prospective scenarios spatialized at a fine scale is a powerful method to provide alternative future images of an agricultural area. When this area is concerned by stakes of water quality management (like a watershed), these images may help decision-makers to implement efficient and sustainable water management policies. The aim of this paper is to evaluate respective influence of the 2006's CAP reform and farm extensions on land use changes from dynamic simulations based on a modeling platform. Results show that these two factors have differentiated consequences on land use and cover changes at a little watershed scale (1300 ha): direction, rhythm and spatial distribution of land-use and landcover changes differ.

MOTS-CLÉS : Prospective spatialisée, scénario, changements d'occupation du sol, simulations dynamiques, exploitation agricole, successions culturales.

KEYWORDS: Spatial prospective, scenario, landcover changes, dynamic simulations, farm, crop successions.

Introduction

Les changements actuels des usages des sols en région agricole intensive reflètent des stratégies d'acteurs multiples qui se situent à des échelles spatiales très différentes (Europe, Etat, Région, Commune, bassin versant). L'ensemble des variables économiques (Politique Agricole Commune, GATT¹, OMC², marchés, proximité des industries agro-alimentaires, etc.) et environnementales (Mesures Agri-Environnementales, Directive Cadre sur l'Eau, Schéma d'Aménagement et de Gestion des Eaux, Contrat Territoriaux d'Exploitation relayés par les Contrats d'Agriculture Durable, etc.) agissent de façon directe ou indirecte à l'échelle de l'exploitation agricole (Corgne, 2005 ; Houet et Hubert-Moy, 2004). L'agriculteur intègre l'ensemble de ces variables par les choix d'assolements qu'il réalise d'une année sur l'autre ou dans une vision à plus long terme afin de répondre à ses objectifs économiques, voire environnementaux.

Les types d'occupation du sol au sein d'une exploitation agricole dépendent essentiellement du système de production adopté par l'exploitant. Suivant une typologie qui peut être plus ou moins détaillée, chaque système de production se caractérise par un assolement lui-même défini par les proportions de chacune des cultures principales réparties sur la surface agricole utile. Dans les régions d'élevage telle que la Bretagne, les prairies temporaires (ray-grass anglais ou italien), le maïs, les céréales et oléo-protéagineux constituent les cultures principales les plus courantes. Les exploitants agricoles raisonnent l'utilisation de leurs parcelles en fonction des conditions physiques du milieu (pente, type de sol, degré d'hydromorphie, etc.), mais aussi en fonction de l'organisation de leur travail (distance au siège d'exploitation, taille des parcelles, éclatement du parcellaire de l'exploitation, successions agronomiques) (Corgne, 2005). Les travaux de C. Thenail (1997) illustrent les modifications du système technique de production et de la gestion territoriale de l'exploitation dès lors qu'un évènement intervient (réforme, changement d'exploitant, etc.). Parmi ces évènements, les réformes de la PAC et les changements des structures foncières des exploitations constituent des moteurs forts dans les changements d'usage des terres. Toutefois, l'impact de ces évènements sur l'évolution de l'occupation du sol est assez mal connu, bien qu'ils participent pour une part non négligeable à la dégradation ou à l'amélioration des milieux, notamment à la qualité des sols et de la ressource en eau.

L'élaboration de scénarios prospectifs constitue une méthode puissante pour s'interroger sur les devenirs possibles d'un territoire, et aider à la prise de décisions (Poux, 2003 ; Mermet et Poux, 2002 ; Poux *et al.*, 2001). L'objectif de ce travail est d'évaluer quantitativement et spatialement l'influence respective de la réforme de la PAC et de l'agrandissement des exploitations agricoles sur les changements d'occupation des sols à l'échelle d'un bassin versant à l'aide de simulations dynamiques effectuées avec une plateforme de modélisation. Les simulations sont réalisées sur un bassin versant localisé en Bretagne centrale, le Lestolet, faisant l'objet d'un programme de reconquête de la qualité de l'eau, dans un contexte agricole où l'élevage bovin est dominant (Fig. 1). La localisation de zones à risque vis-à-vis des transferts de flux constitue un enjeu fort pour la préservation à moyen et long terme de la ressource en eau.

Après avoir succinctement exposé comment la PAC 2006 et les modifications des structures foncières pourraient orienter l'évolution de l'occupation des sols à l'échelle d'une exploitation, l'expérience de modélisation permettant de produire des simulations selon

¹ General Agreement on Tariffs and Trades

² Organisation Mondiale du Commerce

plusieurs scénarios contrastés sur le site d'étude est présentée et les premiers résultats relatifs à l'impact respectif de la PAC et du foncier sur l'occupation des sols sont montrés.

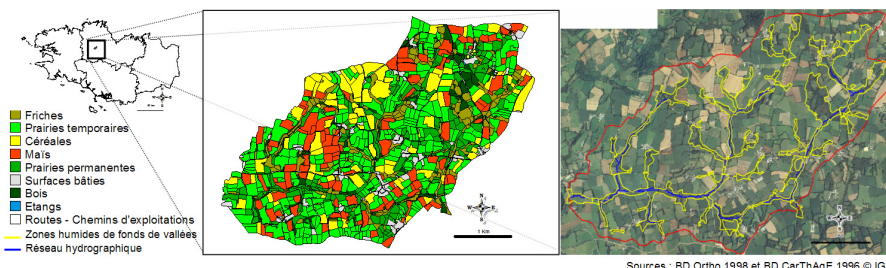


Figure 1. Localisation du bassin versant du Lestolet et modes d'occupation des sols et délimitation des zones humides de fonds de vallées 1998 (Hubert-Moy *et al.*, 2003)

Figure 1. The Lestolet watershed location and its landcover and riparian wetlands boundaries in 1998 (Hubert-Moy *et al.*, 2003)

La PAC et l'évolution de la structure foncière des exploitations agricoles, facteurs d'évolution de l'occupation des sols

Il s'agit de présenter l'impact de l'évolution des exploitations sur les types d'occupation des sols à travers l'évolution des assolements liée à la réforme de la PAC prévue en 2006 et leur agrandissement foncier.

LA REFORME DE LA PAC DE 2006 ET SON INFLUENCE SUR L'OCCUPATION DES SOLS À L'ECHELLE DE L'EXPLOITATION AGRICOLE

La réforme de la PAC constitue un facteur agissant sensiblement sur l'évolution des modes d'occupation des sols. Elle engendre des contraintes économiques auxquelles l'exploitant s'adapte, par exemple en modifiant son assolement. Les primes attribuées aux céréales et aux maïs fourragers dans le cadre de la PAC de 1992 se sont ainsi traduites en Bretagne par une augmentation de la part des cultures au détriment des prairies temporaires et naturelles mais suivant des amplitudes variables pour des secteurs aux paysages agraires et aux productions dominantes différentes (Hubert-Moy *et al.*, 2003).

La prochaine réforme de la PAC annoncée pour 2006 soulève aujourd'hui la problématique de son influence sur l'évolution des types d'occupation des sols d'un territoire (bassin de production, bassin versant, etc.) et de son incidence environnementale. Les stratégies d'adaptation des exploitations du Grand Ouest à la PAC 2006 et leurs impacts sur les types d'occupation des sols, le bocage et les zones humides, ont été déduites lors d'une réunion regroupant des experts³ en agronomie, en prospective, en écologie du paysage, sur l'agriculture bretonne, sur les zones humides et des questionnaires de l'eau et de l'espace agricole. Ces stratégies ont ensuite été confortées à l'aide d'enquêtes de terrains ayant concernées 167 exploitations dispersées sur les quatre départements bretons (Geslot, 2005) et par des experts de l'ONIC⁴.

³ Les experts sollicités sont Xavier Poux (AScA / RGTE CIRED-ENGREF), Jacques Baudry (INRA-SAD Armorique) et Bernard Clément (ECOBIO)

⁴ Office National Interprofessionnel des Céréales – Experts sollicités : Yves Bonhomme et Stéphanie Geslot

Pour une exploitation, deux stratégies antagonistes sont envisageables :

- Dans le premier cas, la PAC incite à l'extension des systèmes herbagers, ce qui est synonyme d'une future désintensification de la production agricole. Le découplage total des aides permettrait alors aux exploitants de percevoir la même somme à l'hectare (à + ou - 25 %) quels que soient les couverts implantés. Par exemple, dans le cas d'élevages laitiers et/ou allaitant, l'exploitant ayant beaucoup de terres pourrait faire le choix de baisser ses coûts de production par l'implantation d'herbages (passage à une gestion plus extensive). Dans le cas où l'exploitant est relativement proche de la retraite, n'a ni emprunt à rembourser ni repreneur, celui-ci pourrait tirer un revenu convenable de son activité et réduire considérablement sa charge de travail en implantant des prairies pour lesquelles les primes n'exigent qu'un entretien minimal (fauche annuelle ou semestrielle).
- Dans le second cas, la PAC favorise l'implantation de céréales, ce qui se traduit par une intensification de la production. Dans le cas d'élevages laitiers, les exploitants ayant peu de terres, pourraient faire baisser le coût de leur production en augmentant la production laitière par vache. Ils devraient alors réduire légèrement leur cheptel augmentant ainsi la part de maïs fourrager par vache. Les surfaces en blé et autres céréales pouvant quant à elles légèrement augmenter afin d'assurer le versement de 100% des aides « grandes cultures ». Dans le cas d'exploitations n'ayant plus d'emprunts à rembourser et devant mettre leurs bâtiments d'élevages aux normes, les élevages pourraient disparaître, des céréales pouvant être implantées sur l'ensemble des terres labourables. Leur revenu proviendrait alors des marges réalisées sur les céréales à fortes valeurs ajoutées (blé, colza, chanvre, lin,...) ou d'autres cultures (légumes industriels, etc.).

L'IMPACT DES CHANGEMENTS DE LA STRUCTURE FONCIERE DES EXPLOITATIONS

Peu de recherches portent sur l'impact des changements de la structure foncière des exploitations sur l'usage des terres car les mécanismes qui régissent ces changements sont très mal connus. De plus, les données sur la structure foncière actuelle des exploitations sont difficilement accessibles. En outre, ces données ont été élaborées de façon très ponctuelle avant la mise en place récente des déclarations PAC à partir d'orthophotoplans ou des diagnostics phytosanitaires du territoire des exploitations, ce qui ne permet pas d'étudier précisément et de façon exhaustive les dynamiques du foncier agricole.

La Bretagne connaît une forte diminution de sa population active agricole en Bretagne. Le nombre d'exploitations était de 92000 en 1988, contre 51200 en 2000 (Agreste, 1998 ; Agreste, 2001). Leur taille moyenne est passée de 33 ha en 2000 contre 19 ha en 1988. Dans un temps comparable (1985-1997), la proportion de surfaces en herbe (prairies temporaires et permanentes) par rapport à la SAU bretonne est passée de 47,3 % en 1985 à 39,5 % en 1997 ; celle des cultures (céréales + maïs fourrager) de 39,1 % à 48 % (Agreste, 1998). Ainsi, si l'agrandissement des exploitations a accompagné la hausse des cultures, l'existence d'une relation de causalité n'a jamais été démontrée. D'autres facteurs, comme la réforme de la PAC de 1992 où encore les quotas laitiers, sont mis en avant pour expliquer cette évolution (Houet et Hubert, 2004).

Parmi les quelques travaux portant sur l'impact des changements des structures foncières sur l'utilisation des terres, ceux de C. Thenail et J. Baudry (2001) et J. Baudry *et al.*, (2003) ont montré que l'exploitant est amené à adapter son assolement et ses règles d'allocation des cultures en fonction de la configuration spatiale de son exploitation (importance de sa surface agricole utile, distribution spatiale, taille et géométrie de ses parcelles en plus de leurs caractéristiques agronomiques). En résumé, les changements de la structure foncière des

exploitations modifient les règles d'usages des terres (allocation spatiale des cultures, utilisation des parcelles humides...). Mais les conséquences sur l'occupation des sols à l'échelle d'un territoire agricole (par exemple un bassin versant) n'ont pas encore été mesurées.

Méthodologie

Les simulations dynamiques et spatialement explicites sont effectuées sur le site du Lestolet à l'aide d'une plateforme de modélisation de paysages (L1) suivant des scénarios prospectifs contrastés. En fonction des stratégies d'adaptation à la réforme de la PAC 2006 et des modifications des structures foncières envisageables sur le site d'étude, trois scénarios ont été construits afin d'éclairer leur influence probable sur l'occupation agricole des sols à l'échelle du bassin versant. Le premier prolonge les évolutions actuellement observées ; le second est construit sur une hypothèse d'évolution vers un système herbager sous l'impulsion de la PAC du fait de la situation actuelle des exploitations du Lestolet sans prendre en compte les changements fonciers ; enfin le dernier fait évoluer les structures foncières sans considérer les changements d'assolement liés à la réforme de la PAC.

PRESENTATION DU SITE D'ETUDE

Le bassin versant du Lestolet, d'une superficie totale de 1320 ha, est situé dans le Sud-ouest du département des Côtes d'Armor, en Centre Bretagne (Fig. 1). Territoire au bocage dense (124 m/ha en 1998) et aux zones humides de fonds de vallées très présentes (17 % du bassin versant), l'utilisation du sol est quasi-exclusivement agricole. Les communes couvrant le bassin versant s'inscrivent dans une dynamique de dévitalisation prononcée de son tissu démographique : leur densité de population baisse de -10 à -40 % entre 1982 et 1999, avec moins de 30 hab/km² en 1999 (INSEE, 1982 ; INSEE, 1999), et leur population agricole vieillit avec moins de 20 % d'actifs agricoles de plus de 55 ans en 1979 contre près de 60 % en 1999 (ONIC, 1979 ; ONIC, 2000).

En 1998, 31 exploitations sont connues pour avoir tout ou partie de leurs terres sur le Lestolet⁵. Ce site se spécialise depuis le début des années 1980 dans l'élevage bovin, la production avicole ayant été affectée par les crises des années 1990 (Houet et Hubert-Moy, 2004). Les exploitations « bovin lait/viande » sont largement dominantes (20) par rapport aux exploitations mixtes « bovin + volailles » (7) ; l'élevage hors-sol porcin ou avicole est peu présent (1 exploitation de chaque) ; les exploitations mixtes « bovin + porcs » sont peu nombreuses (2). Cela se traduit par une dominance des prairies temporaires (473 ha) et permanentes (178 ha) et des superficies en maïs et céréales plus faibles (respectivement 224 et 198 ha).

Enfin, le Lestolet fait l'objet d'un programme de reconquête de la qualité de l'eau (Bretagne Eau Pure) suite à la dégradation de ses eaux par les nitrates, qui a contribué à la mise aux normes des bâtiments d'élevage dans le cadre des Plans de Maîtrise des Pollutions d'Origine Agricole (PMPOA 1 et 2).

⁵ La cartographie des exploitations agricoles du Lestolet est soumise à une clause de confidentialité.

MODELISATION A TRAVERS LA PLATEFORME L1

La plateforme L1

La plateforme de modélisation L1 se présente comme un noyau commun de données, de connaissances et de méthodes (empiriques, statistiques, etc.) autour duquel gravitent des modèles (sous la forme de modules) dédiés à différentes applications (Fig. 2). La comparaison des plateformes de modélisation existantes en matière de simulation dynamique du paysage (Gaucherel *et al.*, soumis ; Houet et Gaucherel, sous presse) a montré que la spécificité de L1 tient dans la description discontinue et évolutive du paysage agricole sur le plan géométrique et attributaire, dans l'intégration des interactions entre des variables représentées à différentes échelles, d'une gestion souple de la dynamique temporelle (tous les pas de temps possibles) et d'une modélisation des décisions humaines et des forçages naturels (Gaucherel et Baudry, 2004 ; Gaucherel *et al.*, 2004a). Par comparaison, si la plateforme CORMAS (Bousquet *et al.*, 1998) gère particulièrement bien les processus socio-économiques et décisionnels à travers son système multi-agents, elle se concentre essentiellement sur la communication entre agents pour modéliser les dynamiques spatio-temporelles des activités humaines (Tyssot *et al.*, 2005) et non sur l'évolution spatio-temporelle des composantes du paysage. De même, si le modèle CLUE (Veldkamp et Fresco, 1996 ; Verburg *et al.*, 2002) gère particulièrement bien les relations multi-scalaires (modélisation de décisions politico-économiques, événements climatiques, etc.), il ne permet pas d'actions géométriques (telles qu'un arasement de haie, une réunion de parcelles, etc.) et semble par corollaire peu adapté à restituer des scénarios d'évolution de modes d'occupation des sols à une échelle fine, celle de la parcelle.

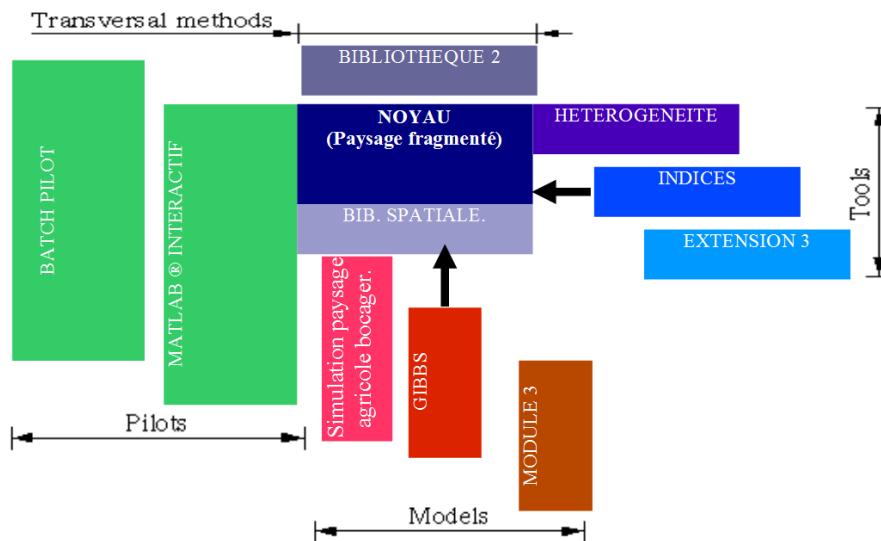


Figure 2. Architecture de la plateforme L1 (dans Gaucherel *et al.*, 2004a, adapté)

Figure 2. L1 platform architecture (in Gaucherel *et al.*, 2004a, adapted)

La généricité de la plateforme L1 lui permet d'être actuellement utilisée dans plusieurs domaines : la foresterie (Gaucherel *et al.*, 2004b), l'écologie (flux de population) et l'écologie du paysage (Gaucherel *et al.*, sous presse ; Viaud, 2004). L'application dédiée à la modélisation de l'évolution d'un paysage agricole bocager utilise des données spatiales et

temporelles. Les premières décrivent les composantes du paysage (parcellaire, bocage, occupation du sol, degré d'hydromorphie, limites spatiales et système de production des exploitations). Les secondes sont destinées à représenter les dynamiques d'évolution de ces composantes (évolution des exploitations, vitesse d'agrandissement du parcellaire, évolution des assolements par système de production, successions culturales, évolution de la densité bocagère, localisation et nombre d'arasements et de créations de haies, vitesse de fermeture et évolution de l'extension spatiale des zones humides de fonds de vallées). La simulation dynamique est issue de la réalisation, à un pas de temps annuel, de l'ensemble ou d'une partie des processus d'évolution des paysages agricoles bocagers (successions culturales, création/arasement de haies, reprise d'exploitation, etc.) et de leurs interactions spatiotemporelles. Par exemple, la reprise d'une exploitation par une exploitation voisine, va engendrer l'année suivante une modification des successions culturales. Ces processus (reprise d'exploitation et successions culturales) interviennent à deux échelles différentes (parcellaire, exploitations agricoles). La localisation précise dans un espace géographique permet à chacune des parcelles de connaître l'exploitation englobante à laquelle elle appartient et son système de production, sa distance par rapport au siège d'exploitation, et ainsi, par corollaire, de déterminer le type de succession culturale va intervenir sur chacune d'entre elles. Le paysage résultant du premier pas de temps va être ensuite utilisé comme paysage initial (t) au pas de temps (année) suivant (Fig. 3). Cette application peut être considérée, d'après la classification de T. Cheng (2005), comme un *spatio-temporal object model*, où l'approche objet ne tient pas dans la structuration informatique (orienté-objet) mais dans les relations spatiales entre les objets spatiaux (relation de voisinage – topologie –, relation multi-scalaire – englobé/englobant –).

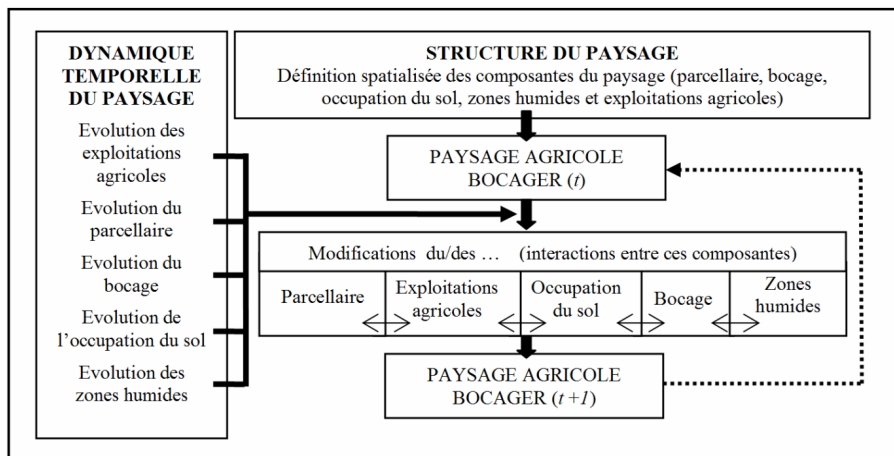


Figure 3. Fonctionnement général de l'application dédiée à l'évolution d'un paysage agricole bocager de la plateforme L1

Figure 3. General functioning of the patchy landscape modelling module of the L1 platform

Une étude récente (Houet et Gaucherel, sous presse) a permis d'évaluer la sensibilité et la robustesse du modèle en simulant l'évolution passée des structures paysagères et des modes d'occupation des sols sur le bassin versant du Lestolet sur une période de 18 ans (1981-1998). La comparaison spatiale et quantitative des changements simulés avec les changements réels observés a montré que L1 reproduit des dynamiques d'évolution et une organisation spatiale de la mosaïque paysagère de façon cohérente. La validation de la plateforme L1 a permis

d'ouvrir le passage vers le domaine exploratoire par la simulation de scénarios prospectifs qui est exclusivement centrée sur l'occupation des sols dans cet article.

Règles de définition des assolements

On peut considérer que, pour chaque système de production (spécialisé « lait » intensif, spécialisé « lait » extensif, mixte « lait + porc », etc.), un exploitant va utiliser ou chercher à utiliser ces terres de façon relativement similaire chaque année. Cette utilisation vise à la fois à assurer le bien-être animal (pâtures), la production de fourrages et/ou de cultures nécessaires à l'alimentation des cheptels et enfin de produire des cultures destinées à la vente. La définition d'assolements moyens pour chacun des systèmes de production a été réalisée à partir de données de télédétection récentes (1999, 2002), de relevés de terrain (2003, 2005) et d'enquêtes auprès des agriculteurs (Geslot, 2005, Menasseri, 2004). Il s'agit de valeurs moyennes, peu représentatives de la diversité des situations (d'un site à un autre, d'une exploitation à l'autre, d'une année sur l'autre) provenant potentiellement de contraintes climatiques (sécheresse, etc.), agronomiques (successions culturales) et structurelles (lourds investissements, etc.).

Cette application a bénéficié de développements quant à la structuration des successions culturales dont le principe de fonctionnement est décrit par T. Houet et C. Gaucherel (sous presse). Dans la précédente version, un seul grand type de successions était appliqué aux différents systèmes de production. Cela suffisait à représenter de façon simplifiée l'assolement annuel des systèmes de production « bovin lait/viande » et « mixte à base bovine », mais était inadapté aux systèmes de production spécialisés (« porcin » et « bovin extensif »). Dans cette version, les successions sont différenciées en fonction des systèmes de production et de la spécificité des rotations pratiquées (Fig. 4). Ces successions culturales ont été élaborées à partir de données de télédétection sur la période 1996-2002 sur trois sites en Bretagne dont le Lestolet (Hubert-Moy *et al.*, 2003), à partir des travaux de S. Corgne (2005) et V. Viaud (2004) ainsi que d'un partenariat scientifique avec l'INRA-Sad Armorique. Pour chacun des systèmes de production, les successions culturales peuvent varier en fonction de la distance au siège d'exploitation, du précédent cultural, de la taille et du degré d'hydromorphie de la parcelle.

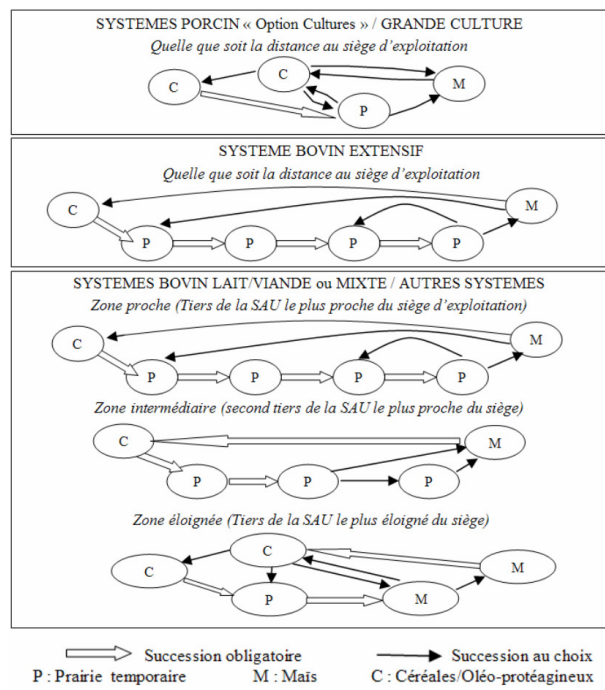


Figure 4. Définition des successions culturales par système de production

Figure 4. Crops successions for each system of production

LES SCENARIOS PROSPECTIFS

Trois simulations sont réalisées sur le Lestolet. Elles débutent en 1998, date à laquelle des données exhaustives sont disponibles, et projettent une image jusqu'en 2020 à un pas de temps annuel. Elles traduisent spatialement trois scénarios prospectifs qui ont été construits avec des experts et des acteurs locaux (§ 2.1).

Scénario A ou « le scénario de référence »

Le premier scénario, appelé « scénario A », consiste à prolonger les tendances actuelles. Il se fonde sur les hypothèses peu vraisemblables que la réforme n'ait pas lieu (et donc que les assolements n'évoluent pas) et que les structures foncières des exploitations agricoles restent les mêmes jusqu'en 2020. Le scénario A constitue le scénario référent.

Scénario B ou « l'influence de la réforme de la PAC de 2006 »

Le second, dénommé « scénario B » illustre la mise en place de la PAC en 2006 sur le Lestolet. Les exploitations bovines présentes en 1998 sont relativement grandes et possèdent quasiment toutes des bâtiments mis aux normes. Ces caractéristiques soutiennent l'hypothèse d'une réforme favorable à l'implantation aux prairies modifiant fortement les assolements théoriques de l'ensemble des systèmes de production (Fig. 5). Les céréales disparaissent au profit des prairies.

L'implantation d'herbe à la place du blé est une opération d'autant plus rentable que, tendanciellement, le prix du blé en Europe baisse pour répondre aux exigences du GATT et s'aligner sur les cours internationaux. Les économies proviennent des moindres coûts de traitement engendrés, de l'arrêt de location de matériels agricoles ou du recours à des ETA pour les semis et les récoltes. De plus, ils disposent déjà du matériel nécessaire à la gestion minimale des surfaces en herbe (fauche annuelle). Ils gagnent aussi beaucoup de temps libre, exigence qui devient de plus en plus forte dans la profession. Les structures foncières des exploitations n'évoluent pas durant la simulation.

L'hypothèse d'une modification généralisée des assolements en 2006 par l'ensemble des exploitants est simplificatrice. Toutefois la comparaison des scénarios A et B présente l'intérêt de mettre en évidence l'influence de la réforme de la PAC de 2006 suivant une hypothèse très contrastée. Ainsi, il est probable que la situation future se situe dans l'intervalle de ces deux situations.

Scénario C ou « l'impact de l'agrandissement des exploitations »

Le troisième scénario ne fait évoluer que les structures foncières des exploitations. Les assolements existants en 1998 ne changent pas tout au long de la simulation. Le nombre d'exploitations sur les trois communes concernées a fortement régressé entre 1979 et 2000 (-60 % en moyenne) engendrant un agrandissement croissant de leur taille moyenne (22 ha en 1979 contre 51 ha en 2000 [ONIC, 1979 ; ONIC, 2000]). D'après les données disponibles (âge des exploitants, SAU, etc.), il a été estimé que 17 exploitations sur les 31 existantes en 1998 cesseront leur activité d'ici 2020. Sur ces 17 cessations, 6 exploitations sont reprises par un jeune et les 11 autres par des exploitations voisines. Elles ont lieu entre 2001 et 2016 : 1 reprise en 2001, 1 en 2002, 1 en 2004, 3 en 2007, 3 en 2008, 2 en 2009, 1 en 2010, 1 en 2012 et 3 en 2016. La taille moyenne des exploitations sera alors d'environ 90 ha mais avec de forts contrastes entre les « grandes » exploitations (100 à 130 ha) et les « petites » exploitations (environ 50 à 60 ha).

Les observations récentes montrent que l'agrandissement d'une exploitation se réalise essentiellement soit (1) par une reprise de la totalité d'une exploitation proche, soit (2) par une reprise de quelques parcelles suite au démembrement d'une exploitation. Pour des raisons informatiques, la modélisation de l'agrandissement des exploitations a été simplifiée et s'effectue par la reprise de la totalité d'une exploitation dès lors que son exploitant approche de l'âge de la retraite (estimé entre 55 et 60 ans). L'exploitation reprenneuse est géographiquement proche et son exploitant relativement jeune (23-40 ans). Enfin, les reprises déterminées par les experts poursuivent la tendance observée d'une spécialisation vers la production « bovin lait/viande » conformément aux scénarios de l'Institut de l'élevage (2004).

Systèmes de production	Assolement avant 2006			Assolement après 2006		
	P	M	C-OP	P	M	C-OP
Bovin lait et/ou viande	65 %	20 %	15 %	80 %	20 %	0 %
Mixte bovin + volaille	55 %	30 %	15 %	70 %	30 %	0 %
Mixte bovin + porc	70 %	15 %	15 %	85%	15 %	0 %
Porcin « option cultures »	10 %	10%	80%	90%	10%	0%
Volaille	35 %	55 %	10 %	45 %	55 %	0 %
Bovin extensif / bio	90 %	5 %	5 %	95 %	5 %	0 %

P : Prairies M : Maïs C-OP : Céréales / Oléo-protéagineux

Figure 5. *Evolution des assolements par système de production suite à la réforme de la PAC en 2006 (d'après Houet et Gaucherel, sous presse)*

Figure 5. *Evolution of landcover proportions for each system of production after the 2006 CAP reform (from Houet and Gaucherel, in press)*

Ces hypothèses sont simplificatrices : elles ne tiennent pas compte des situations économiques des exploitations (faute de données disponibles) et n'envisagent pas de reprise progressive des parcelles d'une exploitation qui est démembrée après cessation d'activité par plusieurs exploitations voisines. Elles présentent cependant l'intérêt d'évaluer l'effet d'un mouvement généralisé de reprise d'exploitations de proche en proche. L'influence de l'agrandissement de la structure foncière des exploitations est évaluée en comparant les scénarios A et C.

Résultats

L'influence respective de la réforme de la PAC et de l'agrandissement foncier des exploitations sur l'évolution de l'occupation du sol d'ici 2020 a pu être quantifiée et spatialisée grâce aux simulations dynamiques et spatialement explicites réalisées avec la plateforme L1.

L'IMPACT DE LA PAC 2006

Conformément au scénario B, la réforme de la PAC 2006 se traduit par une augmentation de la part de prairies à l'échelle du bassin versant. Les changements générés semblent plus forts que ceux engendrés par la réforme de la PAC de 1992 (Houet et Gaucherel, sous presse). La simulation B permet d'évaluer quantitativement l'impact de la PAC à l'échelle du bassin versant : la proportion de prairies passe de 43,9 % de la surface totale du bassin versant avant 2006 à 52,3 % en moyenne entre 2007 et 2020, soit une hausse d'environ 116 ha (Fig. 6b). La part moyenne de maïs avant 2006 était de 17,5 % et atteint 13,8 % après la réforme. La part de céréales restante après 2006 est 2,2 %, contre 7,7 % avant la réforme.

La comparaison de la simulation A avec la simulation B (Fig. 6a et 6b) témoigne de l'influence explicite de la PAC 2006. Dans le premier cas, les proportions d'occupation des sols présentent une faible variabilité interannuelle due aux rotations culturales. Dans le second cas, les répercussions de la réforme de la PAC 2006 sont sensibles et quasi-immédiates : les prairies se généralisent sur des espaces qui étaient en maïs ou en céréales avant la réforme. Les céréales ont quasiment totalement disparues.

La distribution spatiale des cultures (Fig. 7a et 7b) est similaire entre les scénarios A et B : elles se localisent aux mêmes endroits sur le bassin versant en 2008 et 2018, de façon majoritairement dispersée, avec toutefois la présence de quelques petits îlots de parcelles cultivées.

Suite à la PAC de 2006, la place croissante des prairies (temporaires et permanentes) dans l'assolement tend à ralentir légèrement la fermeture des zones humides de fonds de vallées. Quelques parcelles de prairies permanentes⁶ ne sont plus abandonnées et n'évoluent plus en friches dans le scénario B comparativement au scénario A (99 ha de prairies permanentes en 1998 ; 85 ha en 2020 pour le scénario A contre 82 ha dans le scénario B).

⁶ Leur faible nombre provient du fait que les exploitants susceptibles d'utiliser ces parcelles humides n'ont pas tous été identifiés. Elles n'ont donc pas toutes été prises en compte dans la simulation et le calcul des types d'occupation du sol dans les zones humides.

L'IMPACT DE L'AGRANDISSEMENT DES EXPLOITATIONS AGRICOLES

La spécialisation croissante dans la production « bovin lait/viande » de ce secteur issue de l'agrandissement des exploitations agricoles tend à diminuer légèrement la part de prairies de 43,9 % en 1998 à environ 42 % en 2020 (Fig. 6c). Dans le même temps, la part en maïs est restée pratiquement constante (autour de 18 %) et celle des céréales a légèrement augmenté (de 7,7 % à 8,9 %). Ainsi, les reprises foncières contribuent à augmenter de près de 20 ha entre 1998 et 2020 la surface en céréales à l'échelle du bassin versant.

Cette restructuration foncière des exploitations a principalement des répercussions sur la localisation des cultures (maïs et céréales). La comparaison des scénarios A et C (Fig. 7a et 7c) montre une tendance au regroupement des parcelles cultivées en îlots au sein d'une exploitation. Ceci est accentué par la juxtaposition de parcelles de cultures de diverses exploitations qui sont repoussées dans les auréoles les plus lointaines du modèle concentrique qui se met en place autour des bâtiments d'élevage. Par conséquent, les haies situées autour de ces parcelles représentent une gêne potentielle importante pour les engins agricoles et une surface non négligeable pour augmenter les rendements, les rendant particulièrement exposées au risque d'arasement.

Enfin, l'agrandissement foncier tend à accélérer la fermeture des zones humides de fonds de vallées (120,5 ha de friches et de bois en 1998 ; 134,7 ha en 2020 pour le scénario A contre 143,4 ha dans le scénario C). Cela se justifie par deux facteurs : les exploitants sont de moins en moins nombreux augmentant ainsi la charge de travail nécessaire à l'entretien des prairies humides ; les parcelles humides d'une exploitation venant d'être reprise se situent désormais potentiellement plus loin de leur nouveau siège, augmentant ainsi le risque d'abandon.

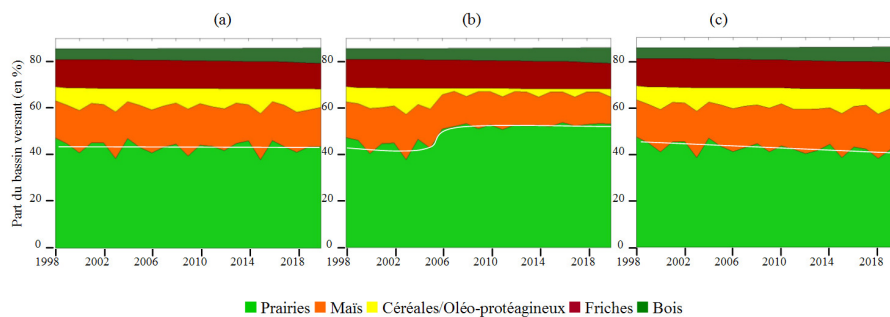


Figure 6. Evolution de la proportion des types d'occupation du sol à l'échelle du bassin versant dans le cas du (a) scénario A, (b) scénario B et (c) scénario C.

Figure 6. Evolution of landcover proportions at the watershed scale for the (a) scenario A, (b) scenario B and (c) scenario C.

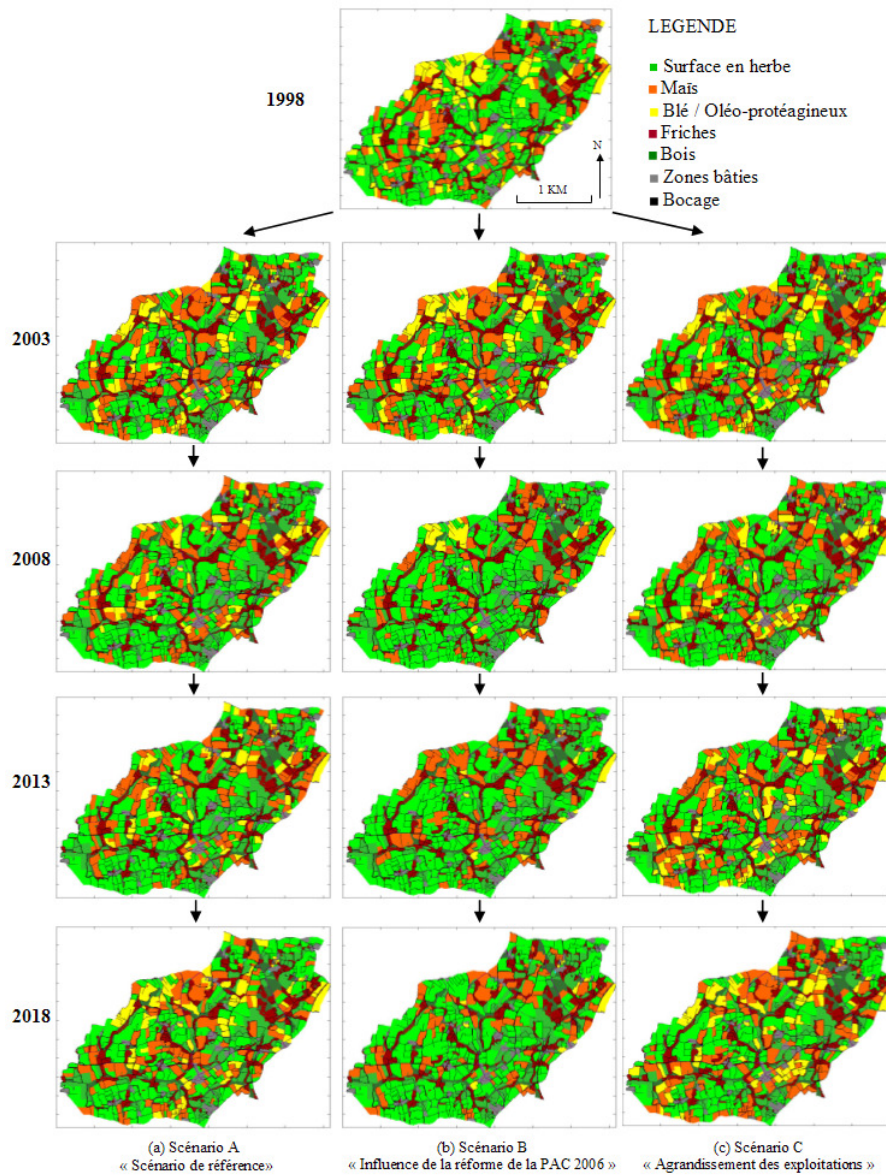


Figure 7. Evolution des modes d'usage des terres en 1998, 2008 et 2018 à l'échelle du bassin versant dans le cas du (a) scénario A, (b) scénario B et (c) scénario C.

Figure 7. Evolution of land use and landcover in 1998, 2008 et 2018 at the watershed scale in the (a) scenario A, (b) scenario B et (c) scenario C.

LA LOCALISATION DE ZONES STRATEGIQUES POUR UNE GESTION DURABLE ET EFFICACE DE L'EAU

La culture du maïs constitue une plante à risque vis-à-vis de la qualité de l'eau puisqu'elle n'est pas sensible à une sur-fertilisation et qu'elle peut parfois engendrer l'absence de couverture hivernale des sols favorable aux transferts de flux polluants de surface (phosphore, pesticides) et de sub-surface (nitrates). Les cartographies annuelles des modes d'occupation des sols produites par la plateforme L1, permettent de réaliser des cartes de fréquence de retour en maïs pour les trois scénarios prospectifs (Fig. 8).

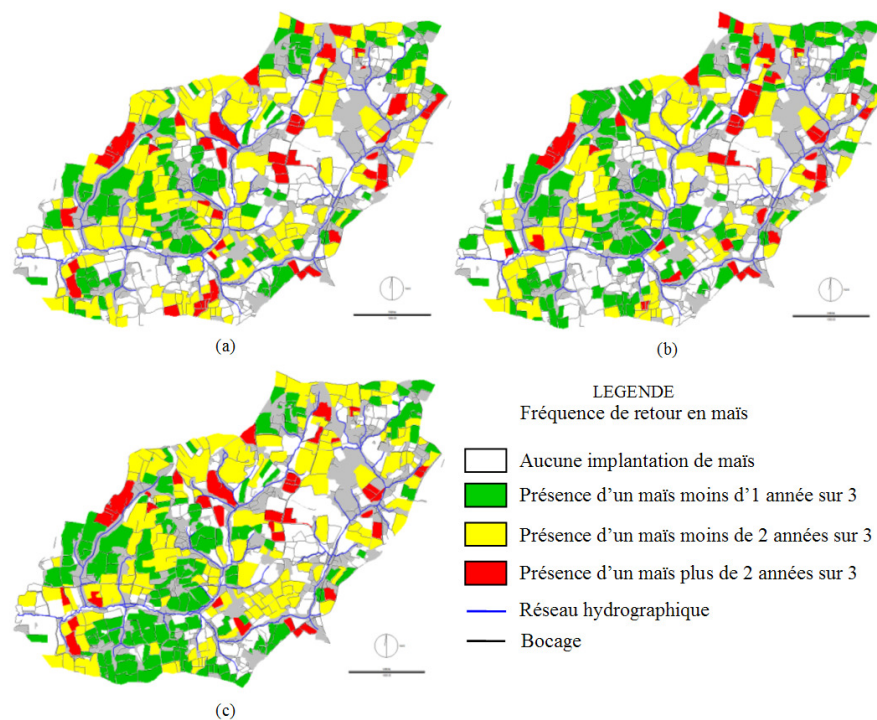


Figure 8. Localisation des espaces stratégiques de gestion de l'eau dans le cas du (a) scénario A, (b) scénario B et (c) scénario C.

Figure 8. Localization of strategic water management areas for the (a) scenario A, (b) scenario B and (c) scenario C.

La localisation des zones présentant une forte fréquence de retour constitue un outil d'aide à la gestion durable et efficace de l'eau, d'une part car il tient compte de la longue durée, d'autre part car ces zones sont localisées finement et enfin parce qu'il intègre plusieurs hypothèses aux conséquences contrastées. Par ailleurs, la localisation de celles situées à proximité des cours d'eau peut permettre aux gestionnaires de l'eau ou acteurs agricoles de mieux sensibiliser à des pratiques raisonnées les exploitants qui les utilisent.

La localisation des haies situées à proximité des parcelles occupées par du maïs au moins une année sur deux, apporte là encore des informations précieuses pour une meilleure gestion de l'eau. Ces haies sont susceptibles d'être arasées alors même qu'elles peuvent avoir un rôle tampon essentiel vis-à-vis de la qualité de l'eau.

Bilan et discussion

La modélisation prospective de l'occupation des sols effectuée sur le Lestolet a permis de montrer que la réforme de la PAC de 2006 et l'agrandissement des exploitations en zone agricole intensive spécialisée dans l'élevage bovin ont des incidences différenciées sur l'évolution des modes d'occupation des sols à l'échelle d'un bassin versant à l'horizon 2020. Les simulations dynamiques, fondées sur trois scénarios prospectifs, ont montré de façon quantifiée et spatialisée l'ampleur, le rythme et la répartition spatiale des évolutions de l'occupation du sol pour chacun des scénarios : la réforme de la PAC de 2006 peut tendre vers une augmentation sensible des surfaces en herbe ; à l'inverse, l'agrandissement des exploitations tendrait à légèrement accroître la part de cultures.

La mise en évidence des impacts respectifs de la réforme de la PAC de 2006 et de l'agrandissement des exploitations agricoles permet désormais d'envisager la construction d'un scénario prospectif spatialisé les intégrant simultanément. Un tel scénario interroge sur l'influence cumulée et antagoniste de ces deux facteurs sur l'évolution de la proportion des prairies à l'échelle du bassin versant, ainsi que sur le devenir et la vitesse de fermeture des zones humides de fonds de vallées.

La simulation dynamique et spatialement explicite de scénarios prospectifs, à l'aide de la plateforme L1 met aussi en évidence des espaces stratégiques à l'échelle d'un bassin versant pour la gestion de la ressource en eau. Elle permet de localiser (1) des zones où la pression sur la structure bocagère est forte, (2) des zones à risque vis-à-vis des transferts de flux polluants où des couverts hivernaux doivent être préconisés en raison de fortes fréquences de retour en maïs et enfin, (3) des parcelles à risque fort localement et dans le long terme en raison de leur proximité au réseau hydrographique et de leur fortes fréquences de retour et où les conseils en matière de pratiques raisonnées prennent toute leur importance. D'autres espaces présentant des enjeux importants, tels que les parcelles humides où le risque d'abandon et de fermeture peut réduire les potentialités dénitrifiantes des zones humides de fonds de vallées, pourraient être mis en évidence en comparant la situation initiale avec la situation finale.

Toutefois, même si cette plateforme est particulièrement adaptée pour la modélisation paysagère à l'échelle locale, elle est encore à l'état de prototype qui peut être optimisée, notamment sur l'inertie de la chaîne de calcul. Il faut entre 1h15 et 3h pour réaliser chacun des scénarios. Si elle permet de modéliser de façon simplifier les décisions humaines et les forçages naturels à l'aide de règles déterministes, stochastiques et/ou téléonomiques laissant peu de place à l'incertitude, il apparaît que le couplage avec un Système Multi-Agent peut contribuer à améliorer la modélisation.

Enfin, si certaines hypothèses des scénarios prospectifs peuvent apparaître un peu trop simplifiées, la traduction de leurs incidences dans le temps sur un territoire en offre une vision qui n'en est pas moins plausible. L'exploration de l'incertitude liée à l'évolution à long terme à travers l'expérimentation d'hypothèses complémentaires et/ou contrastées (peu probables mais envisageables) constitue une démarche essentielle pour aider à une gestion durable de l'eau. Les simulations ne cherchent pas à prédire l'avenir avec exactitude mais permettent de localiser et de quantifier les marges de manœuvres existantes. La méthode des scénarios

prospectifs spatialisés à l'échelle locale constitue un outil puissant d'aide à la décision pour les gestionnaires de l'eau afin de mieux cibler et orienter les conseils auprès des agriculteurs et les aménagements à réaliser.

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2 Appendix Chapter 1

2.1 Printed version of the workshop survey

Questionnaire - Ateliers de recherche participative territoriale

1. Et vous ?

1.1 Comment allez-vous aujourd'hui? :

- J'ai plein d'énergie
- Je ne sais pas à quoi m'attendre
- Enthousiaste par Mentimeter
- Fatigué.e

1.2 Quel âge avez-vous?

1.3 Habitez-vous et/ou travaillez-vous sur le territoire évoqué lors de l'atelier ? :

- Oui
- Non

1.4 Vous vous considérez plutôt comme... ?

- Agriculteur.rice exploitant.e ou représentant.e des agriculteur.rices
- Représentant.e (élu.e) d'une collectivité territoriale
- Un.e technicien.ne / Chargé.e de mission / Structure d'animation d'un territoire
- Un.e scientifique
- Etudiant.e
- Autre :

Êtes-vous familier.ère avec le concept :

	Pas du tout familier.ère			Neutre			Très familier.ère	
1.5 De changement d'utilisation du sol	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
1.6 D'aménagement du territoire	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
1.7 De trames verte et bleue	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

1.6 Avez-vous déjà réfléchi à la manière dont le territoire sur lequel vous travaillez pourrait évoluer sur le long terme ?

- Pas du tout
- Plutôt pas
- Plutôt oui
- Oui souvent

2. Les TVB

Dans quelle mesure êtes-vous d'accord avec les affirmations suivantes?

	Pas du tout d'accord			Neutre			Tout à fait d'accord	
2.1 L'analyse des changements d'occupation et d'usage du sol est un enjeu majeur pour le territoire	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
2.2 La création des trames vertes et bleues (TVB) est un enjeu majeur pour le territoire	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
2.3 Pensez-vous avoir une influence/rôle sur la TVB ?	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

3. Méthodologie

	Pas du tout d'accord			Neutre			Tout à fait d'accord	
3.1 La méthodologie utilisée est-elle claire?	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

4. Les scénarios

4.1 Quel scénario est le plus proche de l' idée que vous aviez de l' avenir?

- Fil de l'eau
- Double performance
- Attractivité verte
- Désert céréalier
- Performance énergétique
- Je n'avais pas d'idée sur le futur

4.2 Selon vous, quel est le scénario le plus probable?

- Fil de l'eau
- Double performance
- Attractivité verte
- Désert céréalier
- Performance énergétique
- Je ne sais pas

5. Les impacts

Dans quelle mesure êtes-vous d'accord avec les affirmations suivantes?

	Pas du tout d'accord			Neutre			Tout à fait d'accord	
5.1 Les résultats produits sur la quantité d'eau correspondent à ce que j'imaginai pour l'avenir	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
5.2 Les résultats produits sur la qualité d'eau correspondent à ce que j'imaginai pour l'avenir	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

6. Évaluation de la recherche et ses implications

Dans quelle mesure êtes-vous d'accord avec les affirmations suivantes?

	Pas du tout d'accord			Neutre			Tout à fait d'accord	
6.1 Les connaissances produites par les scénarios sur les ressources en eau sont susceptibles de m'aider dans mon activité	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
6.2 Les connaissances produites par les scénarios sur la biodiversité sont susceptibles de m'aider dans mon activité	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
6.3 Cette recherche prend en compte des facteurs influençant la TVB sur lesquels les acteurs locaux ont un pouvoir d'action directe	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
6.4 Cette recherche prend en compte des facteurs influençant la TVB sur lesquels j' ai un pouvoir d'action directe	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
6.5 Cette recherche m'a aidé à prendre conscience de mon influence/rôle dans la mise en œuvre des TVB	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
6.6 Grâce à cette étude, j'ai amélioré ma compréhension globale des enjeux d'un territoire	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
6.7 Cette étude m'a permis de prendre en compte davantage de variables/notions auxquelles je n'avais pas pensé auparavant	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
6.8 Grâce à cette étude, ma perception de l'avenir a changé	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

D'après vous, cette recherche est utile pour

	Pas du tout d'accord			Neutre			Tout à fait d'accord
6.9 Mieux comprendre les dynamiques du paysage	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
6.10 Agir sur le territoire	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Dans quelle mesure pensez-vous que les outils suivants sont un bon moyen de présenter les résultats?

	Pas du tout d'accord			Neutre			Tout à fait d'accord
6.11 Cartes	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
6.12 Récits	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
6.13 Discussions	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

7. Évaluation de l'atelier

Dans quelle mesure êtes-vous d'accord avec les affirmations suivantes?

	Pas du tout d'accord			Neutre			Tout à fait d'accord
7.1 La qualité technique de cette recherche était élevée	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
7.2 J'ai confiance dans les résultats de cette recherche	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

7.3 Pendant l'atelier, vous êtes senti.e libre d'exprimer votre point de vue ?

- Oui
- Non
- Je ne sais pas
- Oui, mais je n'ai pas exprimé mon point de vue

8. Évaluation supplémentaire

Seriez-vous disponible pour une évaluation supplémentaire des scénarios ? Si oui, pouvez-vous indiquer un contact mail/téléphonique? Attention ! Si vous indiquez ici votre contact, les réponses vont plus être anonymes

2.2 Structure and analysis of the workshop survey

Structure and analysis of “ Questionnaire - Ateliers de recherche participative territoriale »

Control variables:

- 1.3 Affection for the territory (Work or live in the Couesnon)
- 1.4 Job (farmers, politicians and élus, technicians, researchers, student, other)
- 1.7 Familiarity with BGINs (Êtes-vous familier.ère avec le concept BGINs);
- 2.2 Importance of BGINs (La création des trames vertes et bleues (TVB) est un enjeu majeur pour le territoire);
- 2.3 Influence on BGINs
- 6.3, 6.4 Perception of factors included in the research (Cette recherche prend en compte des facteurs influençant la TVB sur lesquels j' ai/les acteurs locaux ont un pouvoir d'action directe)
- 7.1 Research evaluation (La qualité technique de cette recherche était élevée, J'ai confiance dans les résultats de cette recherche);
- 7.3 Freedom of expression

Sections

- **S1: Contribution of scenarios in understanding the territorial dynamics and challenges**
 - 6.6 - Identify challenges : Grâce à cette étude, j'ai amélioré ma compréhension globale des enjeux d' un territoire
 - 6.7 - Consider influential variables: Cette étude m'a permis de prendre en compte davantage de variables/notions auxquelles je n'avais pas pensé auparavant
 - 6.9 - Understand landscape dynamics: Cette recherche est utile pour mieux comprendre les dynamiques du paysage
- **S2: Respondent's perception on the most probable scenario and contribution of scenarios in thinking about future landscape trajectories**
 - 1.6 - Envisioning futures : Avez-vous déjà réfléchi à la manière dont le territoire sur lequel vous travaillez pourrait évoluer sur le long terme ?
 - 4.2 - Probable scenario: Selon vous, quel est le scénario le plus probable?
- **S3: Correspondence between scenarios results and respondents' expectations based on previous knowledge**
 - 5.1 – Water quantity expectation: Les résultats produits sur la quantité d'eau correspondent à ce que j'imaginai pour l'avenir
 - 5.2 – Water quality expectation : Les résultats produits sur la qualité d'eau correspondent à ce que j'imaginai pour l'avenir
- **S4: Contribution of scenarios quantitative results for respondents' professional activity**
 - 6.1 – Instrumental water: Les connaissances produites par les scénarios sur les ressources en eau sont susceptibles de m'aider dans mon activité

-
- 6.2 – Instrumental biodiversity: Les connaissances produites par les scénarios sur la biodiversité sont susceptibles de m'aider dans mon activité
 - 6.11, 6.12, 6.13 – Maps, Narratives, Discussions: Dans quelle mesure pensez-vous que les outils suivants sont un bon moyen de présenter les résultats? (Cartes, Récits, Discussions)
 - **S5: Contribution of scenarios in tackling territorial challenges.**
 - 6.5 – Understanding role on BGINs: Cette recherche m'a aidé à prendre conscience de mon influence/rôle dans la mise en œuvre des TVB
 - 6.9- Understand landscape dynamics: Cette recherche est utile pour mieux comprendre les dynamiques du paysage
 - 6.10 – Take actions: cette recherche est utile pour agir sur le territoire

Hp	Section	Question code	Analysis
Control variables: Affection for the territory; job; Previous familiarity with BGINs; Perceived BGINs relevance; Previous knowledge on personal role on BGINs; Personal influence on considered factors; Local actors' influence on considered factors; Confidence in the research; Freedom of expression		1.3; 1.4; 1.7; 2.2; 2.3; 6.3; 6.4; 7.1; 7.3	
Correlation between Knowing BGIN's and perceive them as a major stake for the territory	Dataset description	1.7 and 2.2	Spearman correlation
Previous familiarity with BGINs vs job and affection for the territory	Dataset description	1.7 and 1.4; 1.3	- Mann Whitney - Kruskal Wallis + Dunn test (Bonferroni correction)
Relevance of the concept of BGINs vs job and affection for the territory	Dataset description	2.2 and 1.4; 1.3	- Mann Whitney - Kruskal Wallis + Dunn test (Bonferroni correction)
Previously knowledge on personal influence on BGIN's vs job and affection for the territory	Dataset description	1.7 and 1.4; 1.3	- Mann Whitney - Kruskal Wallis + Dunn test (Bonferroni correction)
Research evaluation vs job and affection for the territory	Dataset description	7.1 and 1.4; 1.3	- Mann Whitney - Kruskal Wallis + Dunn test (Bonferroni correction)
Identify challenges and Consider influential variables vs job and affection for the territory	S1	6.6; 6.7 and 1.4; 1.3	- Mann Whitney - Kruskal Wallis + Dunn test (Bonferroni correction)
Understand landscape dynamics vs job and affection for the territory	S1	6.9 and 1.4; 1.3	- Mann Whitney - Kruskal Wallis + Dunn test (Bonferroni correction)
Envisioning futures vs job	S2	1.6 and 1.4	- Pairwise Wilcoxon test
Probable scenario vs job	S2	4.2 and 1.4	- Visual comparison
Water quantity expectation and water quality expectation vs job and affection for the territory	S3	5.1; 5.2 and 1.4; 1.3	- Mann Whitney - Kruskal Wallis + Dunn test (Bonferroni correction)
Instrumental water and Instrumental biodiversity vs job and affection for the territory	S4	6.1; 6.2 and 1.4; 1.3	- Mann Whitney - Kruskal Wallis + Dunn test (Bonferroni correction)
Maps, Narratives, Discussions vs job	S4	6.11; 6.12; 6.13 and 1.4	- Pairwise Wilcoxon test
Understanding role on BGINs vs job and affection for the territory	S5	6.5 and 1.4; 1.3	- Mann Whitney - Kruskal Wallis + Dunn test (Bonferroni correction)
Understand landscape dynamics and Take action vs job and affection for the territory	S5	6.9; 6.10 and 1.4; 1.3	- Pairwise Wilcoxon test

3 Appendix Chapter 2

3.1 List of dissemination workshops

Date	Structure	Place	N. Participants
2021-04-22	Commission Locale de l' Eau	Fougères	24
2021-06-14	Commission transition écologique de Fougère	Fougères	14
2021-06-16	Élu·e·s de Maen Roch	Maen Roch	11
2021-06-16	Élu·e·s pays de Fougères	Fougères	9
2021-07-12	Association National des Elus du Bassin Versant (ANEB)	Online	15
2021-09-09	Chambre d' Agriculture	Fougères	5
2021-09-17	Zone Atelier Armorique	Vieux-Viel	5
2021-09-22	Assemblée des agriculteur·ice·s	Trans la foret	10
2021-09-23	Lycée Agricole	Dol de Bretagne	34
2021-09-24	Association des Techniciens de Bassin Versant Bretons (ATBVB)	Rennes	10
2021-10-01	Région Bretagne	Rennes	6
2021-10-11	Master Aménagement	Rennes	18
2021-12-01	Fédération nationale des syndicats d'exploitants agricoles (FNSEA)	Loudéac	10
2021-04-22	Commission Locale de l' Eau	Fougères	24

Table A.3 – Details of the Couesnon scenarios dissemination workshops.

3.2 Anonymised data from respondents

Int. Code	Sex	Job	Job class	Dissemination pathway	Consistent spatial scale	Workshop date	Interview date	Interview duration
01	F	Representative SCoT – Intermunicipalities mayor of a municipality	Representative	Dissemination	Partial	16/06/2021	12/04/2022	56:42
02	F	Dairy production farmer	Farmer	Dissemination	Yes	16/06/2021	19/04/2022	55:14
03	M	Mayor of a municipality	Representative	Dissemination	Yes	22/09/2021	11/04/2022	58:32
04	M	Mayor of a municipality	Representative	Dissemination	Yes	16/06/2021	19/04/2022	1:02:53
05	M	Technician water management structure	Technician	Dissemination	Non	16/06/2021	21/04/2022	1:20:13
06	M	Farmers representative	Farmer	Dissemination	Partial	12/07/2021	21/04/2022	1:22:15
07	M	Technician water management structure	Technician	Co-construction	Yes	01/12/2021	25/10/2022	36:26
08	F	Intern land management structure	Technician	Dissemination	Non	04/06/2021	25/04/2022	58:05
09	M	chamber of agriculture advisor	Resident	Dissemination	Yes	11/10/2021	26/04/2022	34:10
10	F	Resident – Teacher in a agricultural school	Resident	Dissemination	Non	11/10/2021	27/04/2022	27:33
11	F	Technician of an environmental structure	Technician	Co-construction	Partial	09/09/2021	29/04/2022	34:45
12	F	Representative Intermunicipalities	Representative	Dissemination	Yes	17/09/2021	02/05/2022	59:05
13	F	Intern land management structure	Technician	Dissemination	Non	23/09/2021	29/04/2022	40:17
14	M	Technician water management structure	Technician	Dissemination	Non	04/06/2021	09/05/2022	49:24
15	F	Mayor of a municipality	Representative	Dissemination	Yes	14/06/2021	09/05/2022	1:09:19
16	F	Technician water management structure	Technician	Dissemination	Partial	24/11/2021	10/05/2022	36:03
17	F	Mayor of a municipality	Representative	Dissemination	Non	24/09/2021	16/05/2022	43:37
18	F	Technician water management structure	Technician	Dissemination	Non	12/07/2021	23/06/2022	58:36
19	F	Technician of an environmental structure	Technician	Dissemination	Partial	01/10/2021	28/06/2022	48:52
20	M	Mayor of a municipality	Representative	Dissemination	Yes	17/09/2021	16/05/2022	52:48

3.3 Main actors implied in water management for the Couesnon watershed and relations between them

Figure 2.2. represents the main actors implied in water management for the Couesnon watershed, the relationships with other land-use actors, and the principal administrative documents. We divide actors according to their primary fields of action (water, agriculture and urban management) and the spatial extent of their action (Communal, Sub-regional, Watershed, Regional, National, Europe). This non-exhaustive scheme is centred on water management; we do not represent all elements belonging to urban management and agriculture, which are not related to water management. Only the main actors, documents and connections are represented.

Actors (are part of):

We divide actors in:

Administration: governmental agency or organisation charged with managing and implementing regulations. It can be composed of technical agencies and political bodies.

Political body: governmental body composed of elected representatives.

Technical body: organisation composed of technicians in charge of implementing actions.

Civil society: citizens, businesses and non-governmental organisations.

Experts: external professionals who support specific actions.

Outside boundaries: political body outside the selected boundaries.

The main actors are:

Public establishments of inter-municipal cooperation (EPCI): grouping of municipalities that ensures the State's public policies application locally. They can jointly manage certain local public services and/or promote sustainable development in urban and rural territories.

SCOT Pays de Fougères: It comprises representatives in charge of adopting the planning document and a technical structure (Syndicat mixte Pays de Fougères) in charge of the implementation. 2/3 of the Couesnon watershed surface belongs to the SCOT Pays de Fougères and the rest to 4 other SCOTs.

Local Water Commission (CLE): Political body composed of 50% of EPCI and public organisations representatives, 25% of water users representatives, and 25% of State representatives.

SAGE Couesnon: It comprises the CLE and a technical structure (Syndicat Bassin Versant du Couesnon). 2 EPCIs cover most of the watershed's surface (Fougères

Agglomeration and Couesnon Marche de Bretagne). The rest belongs to 6 other EPCIs. The Couesnon watershed (and the SAGE) covers 73 municipalities (30 of which are entirely within the watershed).

Chambre of Agriculture: Public organisation representing all the economic agents of agriculture and supporting farmers in developing their businesses. It operates at the national, regional and local levels.

Departmental directorate of the Territories d’Ille-et-Vilaine (DDTM 35). An administrative body that ensures the balanced and sustainable development of urban and rural areas through agricultural, urban planning, construction, development and transportation policies.

Regional council: Political body composed of Regional representatives directly elected by citizens.

Brittany Region: Regional administrative body divided into Directions and departments. For our study, the Climate, Environment, Water and Biodiversity direction (natural heritage department and water department), the economic development direction (agriculture department), and the planning and equality department are relevant.

Brittany Agence for Biodiversity: A regional organisation that supports projects in favour of biodiversity. It is composed of representatives of several Brittany actors acting to sustain biodiversity (i.e., DREAL, Région Bretagne, and Loire Bretagne Water Agency).

Regional Directorate for the Environment, Development and Housing (DREAL):

Regional-based national organisation under the Ministry of Ecological Transition.

Regional Directorates of Food, Agriculture and Forestry (DRAAF): Regional-based national organisation under the Ministry of Agriculture and Food Sovereignty. Part of the financing committee of the Brittany Agence for Biodiversity.

Secrétariat général pour l’investissement (SGI): French administration under the authority of the Prime Minister.

Loire-Brittany River Basin Committee: A political body composed of 40% EPCI representatives, 40% of water users representatives and 20% of state representatives.

Loire Bretagne Water Agency: A public institution that provides financial and technical assistance for actions related to water and the environment.

French Office of Biodiversity (OFB): A national public institution dedicated to protecting and restoring biodiversity.

Documents (To integrate and approve):

Common Agricultural Policy (CAP): European policy which defines the European subsidies for agriculture.

Water Framework Directive: With this European directive approved in 2000, European Union member states committed to reaching a good quality and quantity status of water bodies. This framework defines common goals. Member states must enact the directive into national law.

Law on water and aquatic environments (LEMA): Loi du 30 décembre 2006, that enact the Water Framework Directive in France.

Loi Climat et Résilience: French law enacted on 22nd August 2021 to fight climate change and strengthen resilience. It imposes to achieve zero net artificialisation (ZAN) by 2050.

Water Development and Management scheme Directive (SDAGE): Planning document that sets the guidelines for six years to achieve the expected objectives of "good water status" at the watershed level (Loire-Bretagne). The Loire-Brittany River Basin Committee approves it. SDAGE directives must be integrated into the SAGE.

Water Development and Management scheme (SAGE): It defines how to reach the directives defined in the SDAGE at a smaller watershed level (Couesnon watershed). It comprises a Sustainable Development and Management Plan (PAGD) and a Regulation. The PADG defines the priorities of the territory in terms of water policy and aquatic environments, the objectives and measures to achieve them. It evaluates the technical and financial means necessary for its implementation; the Regulation defines the allocation of water resources and priorities for use. The regulation and cartographic annexes are legally enforceable against third parties. The CLE approves the SAGE, and a techni-

cal structure carries out its measures. SAGE directives must be integrated into the SCOT.

Regional plans for planning, sustainable development and territorial equality (STRADETT):

A regional document that sets political vision, priorities and mid-long-term goals regarding land use planning. The Regional Council adopts it. STRADETT directives must be integrated into SCOTs and PCAET.

Territorial coherence scheme (SCOT): An urban planning document that determines and ensures the coherence of all sectoral policies, particularly in terms of housing, mobility, commercial development, environment and landscape at the supra-municipality scale. The SCOT pays de Fougères covers the EPCI Fougères Agglomération et Couesnon Marche de Bretagne. Representatives of EPCI approved it. SCOT directives must be integrated into local planning documents (PLU, PLUi, Cartes Communales).

Local Urbanism Plan (PLU), Intermunicipality Local Urbanism Plan (PLUi), and communal maps: Local. Communal and intermunicipality urban planning documents that determine the use of land. Communal representatives directly elected by citizens approve it.

Territorial climate-air-energy plan (PCAET): A planning tool at the intermunicipality scale defines strategic and operational objectives and the action program to mitigate climate change, develop renewable energy and control energy consumption. EPCI representatives approve it. PCAET directives must be integrated into SCOTs.

Fundings (Finance):

Watershed Territorial contracts: Financial tools proposed by the Loire Bretagne Water Agency (for the Couesnon watershed, they are co-financed by the Brittany and Normandy Regions and the departments of Ille-et-Vilaine and Manche) to support action in favour of achieving good ecological status of water bodies. The Syndicat du Bassin Versant du Couesnon and the EPCIs benefit from the watershed territorial contract. Grand Plan d'investissement (GPI): A National funding that aims (among other goals) to accelerate the ecological transition. Terre de source project: financed by the GPI and carried by the collectivity Eau du Bassin Rennais, supports farmers in the catchment areas to reduce their impact on water quality.

European regional development fund (FEDER) and

European Agricultural Fund for Rural Development (FEADER). European funding, whose management is assigned to the regional councils

European financing instrument of the CAP dedicated to rural development. Around $\frac{3}{4}$ of this funding is managed by the Regions, Around $\frac{1}{4}$ by the State,

Agri-environmental and climatic measures (MAEC) are measures to support farms that are committed to the development of practices that combine economic and environmental performance. They are co-financed by FEADER (EU), Loire Bretagne Water Agency et le conseil Régional de Bretagne. Breizh Bocage: Financing tool for hedgerow plantations. It is financed via FEADER funds, the Loire Bretagne Water Agency, the Bretagne Region, departments and intermunicipalities.

Tecnical support:

In French land use, management actors mutually support drafting administrative documents or implementing actions. For example:

SAGE Couesnon, the DDTM 35, and the SCOT Pays de Fugères to intervene at the municipal level in person or via an informative notification to help local actors include

the SCOT and SAGE directives in PLU and PLUi.

The DDTM 35 supports SCOT Pays de Fougères in the conception and application of the SCOT. The Chamber of Agriculture supports farmers via training courses, administrative and legal support for their businesses, and technical support for natural resources management and environmental projects.

The administrations regularly hire consulting firms to conduct feasibility studies that guide the definition of administrative documents and management projects.

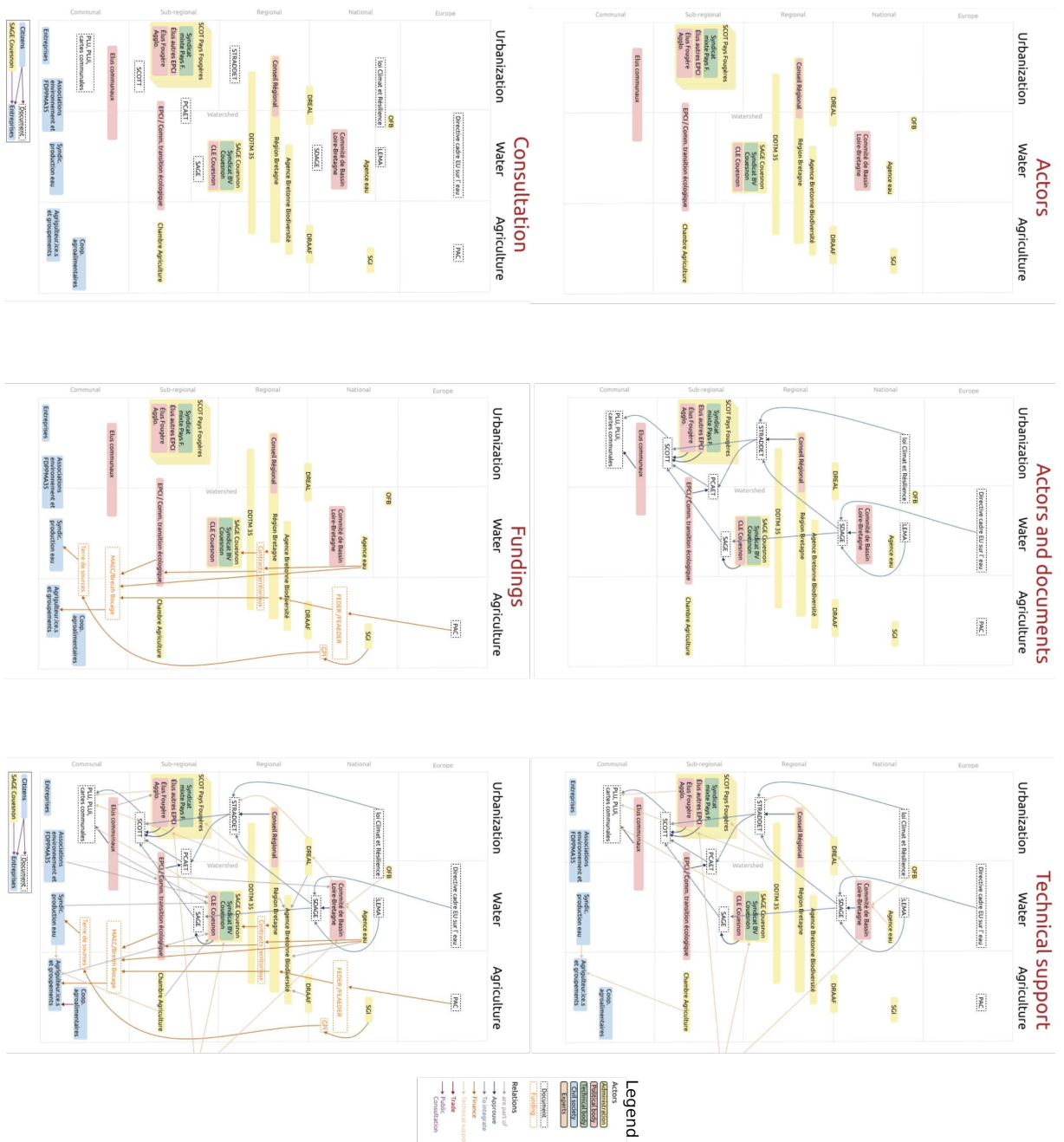


Figure A.7 – Actors involved in the Couesnon water management and their relations with urban management and agriculture actors. Relations are classified in 1) approval and integration of documents; 2) technical support; 3) consultation; 4) Funding.

4 Appendix Chapter 3

4.1 Interview protocol

1. Protocole d'entretien

- Date:
- Lieu de l'enquête:
Interviewee:
- Interviewee organization:
- Participation de l'interviewee aux ateliers de 2005:

Section	Sous-section	à	Script	✓
Introduction (10 min)	présentation personnelle et de recherche	Tous	Recherche doctorale : vérifier l'hypothèse selon laquelle les scénarios ont une influence sur la prise de décision des acteurs impliqués dans l'aménagement du territoire. Actuellement sur une évaluation à long terme Directeur : Thomas Houet , scénarios qu'il a proposés pour sa thèse de doctorat.	
	Processus d'entretien	Tous	<p>Cette interview vise à obtenir des informations sur la précision des scénarios proposés par Thomas Houet en 2006 et leur utilité pour la prise de décision. L'étude mentionnée a été menée il y a 14 ans, et elle a fourni trois principaux scénarios pour les changements d'utilisation et de couverture des sols de 1998 à 2020 pour le bassin versant de Lestolet, et son impact sur la qualité de l'eau.</p> <p>Les prévisions avaient été élaborées selon une méthode participative: en 2005, des techniciens et des agriculteurs locaux ont été réunis pour identifier les principaux facteurs ayant un impact sur la modification du paysage, qui ont ensuite été utilisés dans l'étude.</p> <p>Nous menons actuellement cet entretien avec des techniciens travaillant dans le domaine de la gestion des terres dans les régions de Lestolet (qui ont participé ou non aux ateliers mentionnés).</p> <p>L'entretien se déroulera en deux parties. La première est importante pour nous, car elle nous permet de comprendre clairement comment l'utilisation des terres a changé au cours des 14 dernières années et quels en ont été les principaux facteurs. Nous avons fait une analyse préliminaire en utilisant des données RPG¹ pour voir comment l'utilisation du sol a changé. Cette première partie a également pour but de valider cette analyse par des personnes ayant une expertise locale.</p> <p>La deuxième partie portera sur l'utilité de l'étude. Dans cette deuxième partie, nous voulons évaluer si l'étude a été utilisée d'une manière ou d'une autre dans la prise de décision locale en matière de gestion de l'eau; et quels ont été les effets de l'étude (le cas échéant).</p> <p>Cet entretien sera enregistré et durera environ une heure et demie. Vous pouvez refuser de répondre à toute question.</p>	

¹ Registre Parcellaire Graphique, données en libre accès donnant des informations annuelles sur les cultures agricoles présentes au niveau de l'ilot ou de la parcelle.

	Utilisation de données	Tous	Les informations que vous fournirez seront anonymisées et utilisées exclusivement dans le cadre de TerraNova. Plus précisément, les résultats des entretiens serviront à la rédaction d'un article scientifique visant à vérifier si les scénarios spatialement explicites sont des outils efficaces pour la gestion des terres. Les données seront stockées pour toute la durée du projet TerraNova sur un serveur/matériel sécurisé sous le contrôle des chercheurs. Après la fin du projet, les données transcrites et anonymisées des entretiens seront stockées sur Zenodo (un outil d'archivage des données de recherche et de partage des résultats financé par la Commission européenne via les projets OpenAIRE) et seront détruites lorsqu'elles ne seront plus nécessaires. Signer les conditions de confidentialité	
	Autres questions	Tous	Avez-vous des questions avant que nous commencions l'entretien?	
Changement de paysage (30 min)	Changement de paysage	Tous	L'étude que nous évaluons a présenté plusieurs trajectoires possibles de changement du Lestolet (Haut-Blavet) entre 2006 et 2020. Pouvez-vous nous décrire quels ont été les principaux changements qui se sont produits sur le territoire durant cette période?	
		Tous	<ul style="list-style-type: none"> Les scénarios envisagent des changements en termes de type de cultures, en termes de nombre et de dimensions des exploitations et de type d'exploitation (porc, lait...). Comment pensez-vous que les changements du Lestolet ont changé par rapport à ces variables? 	
		Tous	<ul style="list-style-type: none"> Présentation de l'analyse préliminaire des données (image1, image2, image 3) Dans quelle mesure pensez-vous que ces graphiques et cartes représentent bien ce qu'il s'est passé sur le bassin versant du Lestolet? 	
		Tous	<ul style="list-style-type: none"> Nous avons donc dit que... Quels étaient les moteurs de ces changements? 	
		Tous	<ul style="list-style-type: none"> Les scénarios considèrent la PAC et l'expansion de l'exploitation agricole comme principaux moteurs de changement. Selon vous, quel a été l'impact de ces variables sur le territoire? 	
		Tous	<ul style="list-style-type: none"> Selon nos données, de plus en plus d'exploitations agricoles (AE) se tournent vers le porc. Dans quelle mesure pensez-vous que cela soit vrai? 	
		Tous	<ul style="list-style-type: none"> Si c'est le cas, pouvez-vous décrire les moteurs de ce changement? Si ce n'est pas le cas, pouvez-vous décrire le type d'EA le plus courant sur le territoire? 	
		Tous	<ul style="list-style-type: none"> Afficher les cartes de type AE. Dans quelle mesure pensez-vous que cette carte peut correspondre à la réalité? (Image 4) 	
		Tous	<ul style="list-style-type: none"> Si elles ne sont pas réalistes, quelles sont les erreurs potentielles? 	
			Je vous remercie de m'avoir donné un aperçu de ce qui s'est passé sur le territoire, nous pouvons maintenant passer à la deuxième partie de l'interview. Je vais vous poser quelques questions pour comprendre quel est l'impact de l'étude de Thomas sur la prise de décision.	
L'utilité de la thèse de Thomas (50 min)	L'utilité de la thèse de Thomas	No ateliers	Avez-vous déjà entendu parler de l'étude de Thomas avant que je vous contacte pour l'interview? <ul style="list-style-type: none"> Si oui, à quelle occasion? Comment avez-vous eu connaissance de l'étude? Si non, passez à la suivante	

		Tous	<p>À quelle fréquence faites-vous référence à des scénarios dans votre travail quotidien? Avec quel objectif faites-vous référence à des scénarios? (S'ils n'ont jamais entendu parler de l'étude, passez à la partie sur la clôture)</p>	
		Tous	Quel genre de scénarios avez-vous déjà considéré pour votre travail?	
		Tous	Avez-vous déjà utilisé l'étude / les scénarios réalisés sur le Lestolet à des fins professionnelles?	
		entendu parler	<p>Avez-vous déjà fait référence aux résultats de l'étude de Thomas comme base pour votre travail?</p> <p>Sinon, pourriez-vous me donner quelques raisons pour lesquelles vous n'avez pas fait référence à l'étude dans votre travail?</p> <p>Est-ce que vous pouvez m'indiquer qu'est-ce qu'aurait pu contribuer à améliorer l'étude?</p>	
	Utilisation indirecte des scénarios	entendu parler	<p>Je vais maintenant vous donner une liste des éventuels impacts indirects d'une étude scientifique. Pouvez-vous me dire lesquels résultent de cette étude pour vous? Les questions peuvent sembler très générales, mais nous irons plus en détail par la suite.</p> <p>Cette étude a été utile pour Améliorer vos connaissances; Cette étude vous a permis de changer de point de vue sur certaines idées préalables que vous aviez; Cette étude vous a permis de prendre en compte davantage de variables/notions dans votre travail auxquelles vous n'aviez pas l'habitude de penser auparavant; Cette recherche vous a permis de créer un nouveau réseau de personnes travaillant sur des thèmes similaires ; Cette recherche vous a permis de renforcer des liens avec des personnes appartenant à un réseau préexistant; Cette recherche a permis de créer une vision collective de l'avenir; Cette recherche a permis de créer une compréhension collective de la situation de l'époque de la qualité de l'eau et de l'utilisation des terres dans le Lestolet; Cette recherche a permis de créer une compréhension collective des défis futurs de la qualité de l'eau et de l'utilisation des sols dans le Lestolet; Cette recherche vous a permis de mettre en évidence certaines insuffisances du système de gestion des terres.</p>	
			<ul style="list-style-type: none"> Nous avons donc dit que la recherche de Thomas a eu un impact sur....., mais pas sur..... <p>Pour être un peu plus précis: L'acquisition de connaissances Pouvez-vous me dire ce que l'étude vous a apporté en termes d'acquisition de connaissances? Les connaissances que vous avez acquises grâce à l'étude vous ont-elles été utiles dans votre travail quotidien par la suite?</p> <p>Idées préalables Pouvez-vous me donner un exemple d'idées que vous avez changé grâce à l'étude de Thomas? En considérant d'autres variables</p>	

			<p>Pouvez-vous me donner un exemple de variables/notions que l'étude vous a aidé à prendre en compte?</p> <p>Création de réseaux Pourriez-vous m'en dire un peu plus sur les liens qui ont été créés grâce à ce projet?</p> <p>Compréhension collective de la situation Pensez-vous que la compréhension de la situation était homogène entre les techniciens avant le début du projet? En quoi différent-ils?</p> <p>Vision collective de l'avenir/challenges futurs Pensez-vous que la vision de l'avenir était homogène entre les techniciens et les agriculteurs avant le début du projet? S'il y a eu création d'une vision collective: cette vision collective a-t-elle facilité la prise de décision par la suite? Si ce n'est pas le cas: pouvez-vous me dire pourquoi vous pensez que l'étude n'a pas réussi à créer une vision collective de l'avenir?</p> <p>Inadéquation du système de gestion des terres Pourriez-vous m'en dire un peu plus?</p>	
		entendu parler	<ul style="list-style-type: none"> Y a-t-il d'autres impacts que nous n'avons pas abordés et que vous aimeriez mettre en lumière? 	
Influence de la participation	Oui ateliers		Dans quelle mesure pensez-vous que la participation aux ateliers influence la perception de l'utilité de l'étude?	
	Oui ateliers		<ul style="list-style-type: none"> De quelle manière pensez-vous que les ateliers préparatoires ont été utiles? 	
	Oui ateliers		<ul style="list-style-type: none"> Diriez-vous que l'étude n'a eu un impact que sur les personnes qui ont participé aux ateliers? 	
		Nous pouvons maintenant passer aux questions liées aux obstacles à l'utilité de l'étude.		
Obstacles à l'utilisation des scénarios	entendu parler		Vous m'avez dit précédemment que (Ex vous n'avez jamais utilisé l'étude de manière directe pour produire des documents techniques), pourriez-vous me dire à votre avis ce qui a empêché son utilisation ?	
	entendu parler		<ul style="list-style-type: none"> Quelle était la relation entre les techniciens et le chercheur au moment des ateliers / quand vous avez entendu parler de l'étude pour la première fois? Avez-vous l'habitude de collaborer? Y avait-il une communication déjà bien établie? 	
	entendu parler		<ul style="list-style-type: none"> La qualité de l'eau était-elle un sujet pertinent pour vous au moment des ateliers/ quand vous avez entendu parler de l'étude pour la première fois? Avez-vous travaillé sur des questions liées à l'occupation des sols? 	
	entendu parler		<ul style="list-style-type: none"> Par rapport à la qualité de la recherche, pensez-vous que cela a constitué un obstacle? Pensez-vous que le chercheur était capable de mener efficacement la recherche? 	

		entendu parler	Avez-vous eu l'impression que la recherche était bien ancrée dans la réalité locale?	
		entendu parler	<ul style="list-style-type: none"> Pensez-vous que toutes les variables pertinentes affectant le changement d'utilisation des terres ont été prises en compte? Sinon, lesquelles devaient être prises en compte? Par rapport aux résultats? Pensez-vous que la compréhension des résultats aurait pu être un obstacle? <p>A quel point avez-vous trouvé les résultats compréhensibles? Si ce n'est pas complètement, quelle en était la raison? Était-ce dû à un manque de connaissance? Quelle partie des résultats était difficile à comprendre? (Cartes, format texte, graphiques, impact sur la qualité de l'eau)</p>	
		Oui ateliers	<p>Les résultats ont-ils été différents de ce que vous attendiez? Ont-ils contredit certaines connaissances antérieures?</p>	
		entendu parler	<ul style="list-style-type: none"> Dans quelle mesure pensez-vous qu'il aurait été utile de faire un pas en avant et de discuter des options politiques avec les chercheurs? Les options politiques liées à l'étude étaient-elles trop difficiles à mettre en œuvre? <p>Pensez-vous que le fait de contraster les futurs envisagés aurait été contraire à l'intérêt des acteurs importants? Pouvez-vous me donner quelques exemples? Pensez-vous que le fait de contraster les futurs envisagés aurait signifié des changements majeurs dans les arrangements institutionnels? De quelle manière?</p>	
		Oui ateliers	<ul style="list-style-type: none"> Pensez-vous que la communication des résultats a été efficace? Comment les résultats des projets ont-ils été bien diffusés auprès des planificateurs? 	
		Oui ateliers	<ul style="list-style-type: none"> Ont-ils atteint les personnes qui n'ont pas participé aux ateliers? Est-ce que l'étude aurait pu être plus efficace si les aménageurs avaient plus d'influence directe sur les variables considérées? Les participants à l'atelier avaient-ils suffisamment d'influence sur la prise de décision? 	
Fermeture (5 min)	Tous		<p>Merci pour votre temps, vos réponses sont vraiment utiles pour mes recherches. Voulez-vous que je vous envoie l'article final lorsqu'il sera prêt ? N'hésitez pas à me contacter à tout moment si vous souhaitez me faire part de quelque chose qui ne vous est pas venu à l'esprit aujourd'hui.</p>	

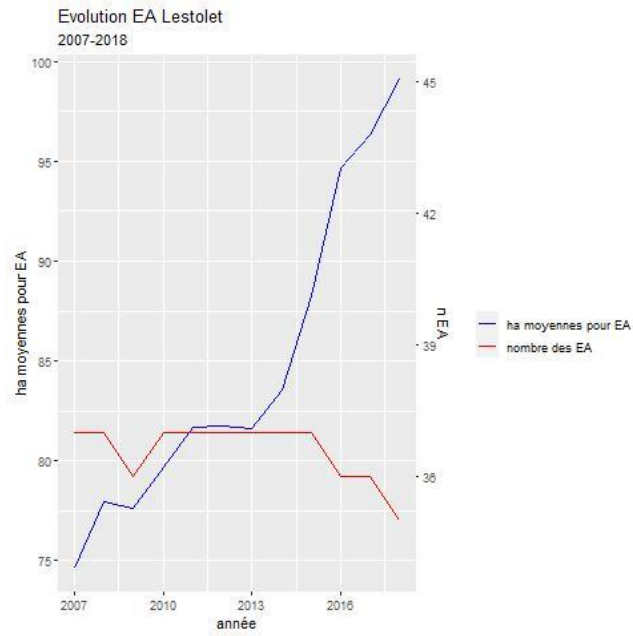


Figure 1: ha moyennes par EA de 2007 à 2018 (analyse des chercheurs à partir des données de la RPG)

figures

Lestolet land use 2019

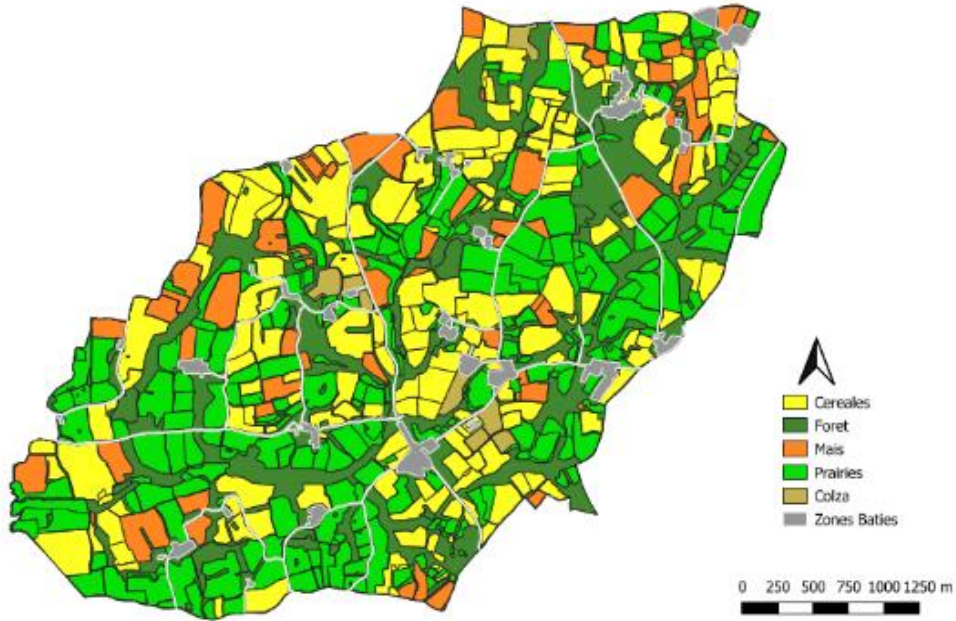


Figure 2: couverture des terres du Lestolet en 2019 (analyse du chercheur à partir des données de Sentinel2)

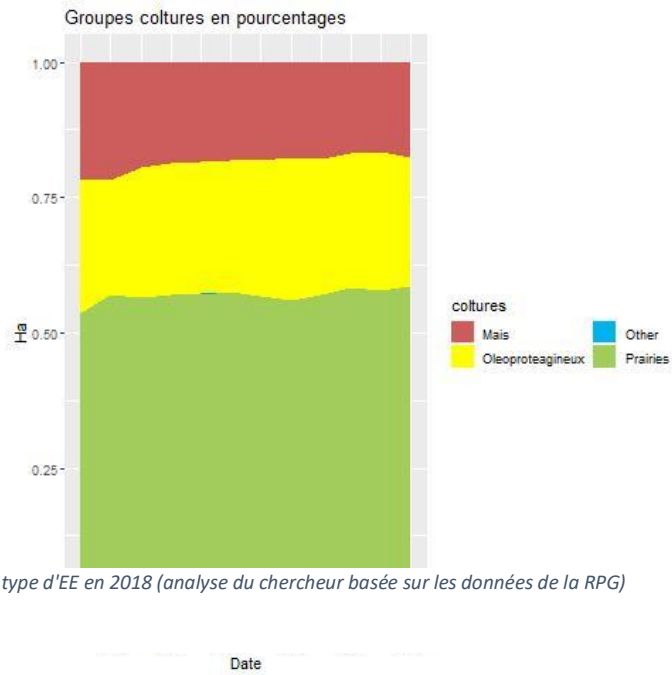


Figure 3: type d'EE en 2018 (analyse du chercheur basée sur les données de la RPG)

4.2 Interview themes and extracts

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.
	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 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.	LA6 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. 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.	LA6 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

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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. 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 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. [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.	LA5 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. 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.	LA4 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	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.	LA1

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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.	LA8
Landowners' low interest in scientific research	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. 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

Table A.4 – Interview themes (mode of scenarios use; relevant features of scenarios; and external features influencing scenarios outcomes) and extracts from Lestolet's local actors.

4.3 Kappa indexes

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

Table A.5 – Similarity indexes between observed and scenario-predicted land-use cover (means of 2018, 2019 and 2020).

4.4 Evolution of crops trajectories

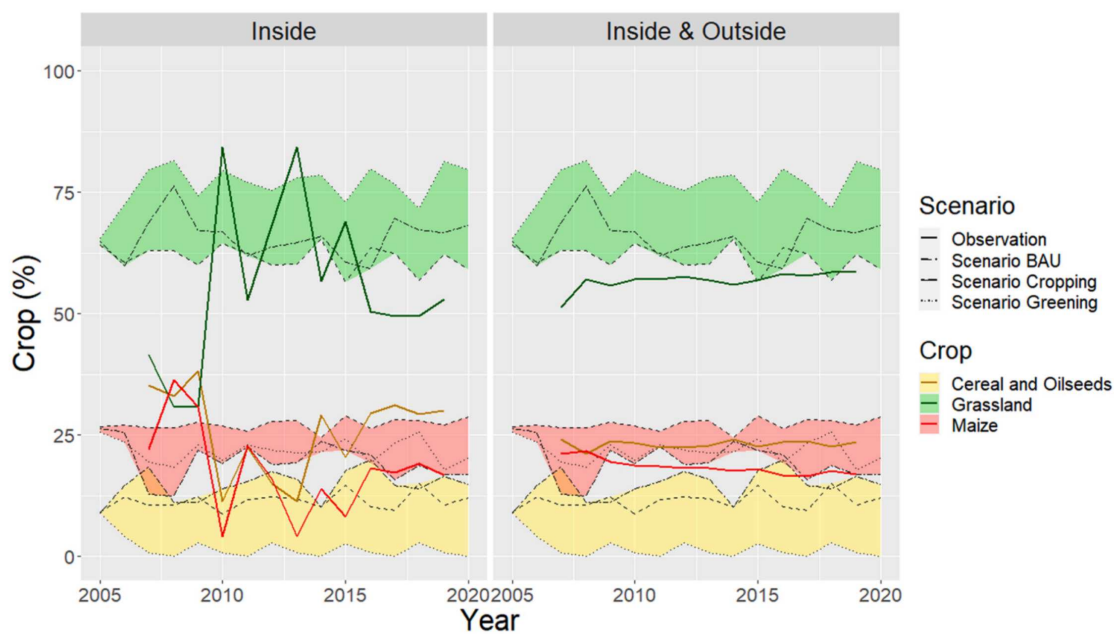


Figure A.8 – Comparison of observed (LPIS data, solid lines) and predicted (scenarios, dotted lines) trajectories of crop percentages for the parcels inside the Lestolet watershed (“Inside”) and for all farms that had at least one field inside the Lestolet watershed (“Inside & Outside”). Ribbons highlight 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).

4.5 Strategies followed by farms

Production system	Land use strategies													
	No change		Greening		Cropping		Not defined							
	In line	Extreme	In line	Extreme	In line	Extreme	In line	Extreme	In line	Extreme				
Change	No change	Pork	85.92											
		Dairy and pork	Ha n	1										
	Dairy and poultry	Dairy and poultry	Ha	93.07		73.36		157.96						
		Dairy	Ha n	1		1		1						
	Dairy bio	Dairy bio	Ha	142.31		159.19								
		Dairy bio	Ha n	2		1		1						
	Total	Total	Ha	321.30		106.76		42.32						
		Total	Ha n	4		1		1						
	Specialization & bio	Specialization & bio	Ha	73.36		62.14		157.96						
		Specialization & bio	Ha n	1		2		1						
Diversification	Diversification	Ha	401.45		80.35		155.50							
	Diversification	Ha n	4		1		2							
Others	Others	Ha	58.08		130.04		34.13							
	Others	Ha n	1		2		1							
Total	Total	Ha	130.04		130.04		189.63							
	Total	Ha n	2		2		3							
Total	Total	Ha	58.08		400.02		495.52							
	Total	Ha n	1		6		7							
Total	Total	Ha	203.40		346.30		251.77							
	Total	Ha n	3		3		4							
Total	Total	Ha	379.38		464.83		415.62							
	Total	Ha n	5		13		13							

Table A.6 – Number of hectares (Ha) and farms (n) that followed a land use strategy.

5 Other contributions

The research part of this thesis is based on a total of 28 interviews and 13 workshops. The contributions of those research activities being integrated as a thesis chapter (Chapter 1 to 3). In this appendix we provide a list of ancillary contributions directly related to the thesis subject, or more in general with the science - society interface that have been made during the period of the thesis.

5.1 Scientific reports

- C., Fayet, L., Felix, L. C, Quintero Uribe, R., Rigo, T., Houet, Thomas, K., Lindholm, & J. S., Kluiving (2021). TERRANOVA White Paper 2. An explorative opinion paper: 'why do we need stakeholders' engagement in knowledge production: TERRANOVA's vision on landscape transformation'. <https://doi.org/10.5281/zenodo.5763214>
- R. Rigo, C. Fayet, R. Capper, L.C. Quintero-Urbe, N. Fernández, H. M. Pereira (2021). TERRANOVA Deliverable 4. 2. Scenarios for land management

5.2 Conference posters & presentations

- Rigo Roberta "A Long Term View Of Nature And Culture In Decision Making: Are Spatially Explicit Scenarios Effective For Land Management?". On Sustainability 2021 : Seventeenth International Conference on Environmental, Cultural, Economic & Social Sustainability; February 24 - 26, 2021; Vrije Universiteit Amsterdam, Amsterdam, Netherlands (Held online). Poster
- Rigo Roberta "Évaluer l'utilité de scénarios du changement du paysage sur le processus décisionnel." « Réinventer les territoires ? » : Journées doctorales de l'Association de Science Régionale De Langue Française; February 24 - 26, 2021; Université de Poitiers, Poitiers, France (Held online).
- Rigo Roberta "Envisioning future LUCS for water management: lessons learned from an ex-post evaluation". Shifting Landscapes 2022 : PhD Conference; June 16 - 17, 2022; Department of Geography & Environment, London School of Economics & Political Science, London, United Kingdom.

5.3 Other scientific communication activities

- Coordination of Chapter 5: Integrated Landscape Analysis (ILA), addressing the biodiversity and climate crises MOOC & Production of Module 6 lesson 2: Towards integrated landscape management: developing tools for adapting to change MOOC
- Member of the ComSciCon France 2022 & 2023 organising team: <https://france.comscicon.com>
- Production of podcast Women In Copernicus: <https://www.c-lab.fr/emission/women-in-copernicus.html>
- Participation in the MT180 contest 2022: <https://www.youtube.com/watch?v=z76xVhtah4Q>
- Organisation du projet Erasmus + KA152-YOU-77FA5B82 "Inform.Action". 15 - 24 June 2022, Guipry-Messac, 35480 France

RÉSUMÉ ÉTENDU

1 Introduction

1.1 Évaluation d'impacts et science de la durabilité

Au cours des dernières décennies les études en science de l'environnement ont considérablement évolué. Tout d'abord, dans les années 1960 et 1970, les spécialistes de l'environnement ont plaidé pour un développement durable fondé sur des études multidisciplinaires. Puis, dans les années 1990, face à l'urgence de lutter contre le réchauffement climatique et à la perte de biodiversité, une partie des études environnementales s'est orientée vers une approche transdisciplinaire plus axée vers l'action. Dans ce mouvement, la science de la durabilité a commencé à se structurer jusqu'à son établissement en tant que domaine autonome caractérisé par l'ambition de produire une science orientée vers l'action et qui aide à comprendre les systèmes socio-écologiques en utilisant des approches locales et transdisciplinaires.

En parallèle de la mise en place de la science de la durabilité, la question de savoir si les acteurs locaux utilisaient effectivement les connaissances scientifiques se posait. Les travaux sur l'évaluation des programmes publics ont alors été mobilisés pour évaluer les impacts de la recherche entendus comme "des changements de valeurs, d'attitudes et de comportements dans le monde au-delà des instituts de recherche" (Matthews et al., 2011, p. 247). Cette définition large des impacts de la recherche reflète la restructuration du contrat social entre la science et la société qui s'est produite au cours des mêmes décennies. En effet, si historiquement le contrat social était basé sur l'idée d'une application linéaire et directe de la science dans l'arène politique, la croissance de la recherche transdisciplinaire porte à concevoir la contribution de la science à la société comme plus nuancée et indirecte (European Commission, 2009, p. 7).

Les impacts de la connaissances scientifiques prouvent être classés comme suit:

- **impacts conceptuels (ou cognitifs)** qui surviennent lorsque les connaissances scientifiques soutiennent la conceptualisation d'un problème et suscitent de nouvelles idées;
- **impacts politiques (ou stratégiques, symboliques)** qui surviennent lorsque les connaissances scientifiques sont utilisées pour soutenir des positions préconçues;

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- **et impacts instrumentaux**, qui surviennent lorsque les connaissances scientifiques sont directement utilisées pour éclairer une prise de décision.

Le dépassement de l'idée d'une science produite par des scientifiques et directement appliquée à l'élaboration des politiques va de pair avec la pleine reconnaissance des impacts politiques et cognitifs tant au niveau personnel que collectif, ainsi que des impacts instrumentaux qui découlent de l'utilisation d'une étude par des acteurs locaux. À cet égard, une étude crédible, légitime et pertinente est considérée comme utilisable et peut produire des impacts si son utilisation n'est pas entravée par des obstacles fonctionnels, structurels et sociaux.

Pour évaluer l'utilisabilité d'une recherche, il est nécessaire de considérer le contexte géopolitique dans lequel elle se déroule ainsi que son processus de production et diffusion. Pour faciliter l'utilisation d'une étude, aligner la méthode de construction et de diffusion de cette dernière avec les impacts attendus est essentiel. Dans cette optique les méthodes participatives de coproduction de connaissances ont été largement reconnues comme des stratégies efficaces pour accroître l'utilisabilité d'une étude. Pour classer les méthodes de construction et de diffusion, différents chemins d'impact ont été reconnus et classés en trois classes (*science-push*, *demand-pull* et *co-construction*) selon le degré de suprématie des utilisateurs ou producteurs de l'étude dans le processus de création de connaissances. Ce cadre théorique peut être davantage détaillé selon les multiples formes d'interaction entre la science et la société.

Enfin, le moment auquel l'évaluation est effectuée détermine de manière significative les impacts détectés. En effet, les impacts évoluent continuellement et peuvent être indirectement liés au processus de production de connaissances. En outre, des événements externes et sur lesquels les actrices et acteurs impliqués dans la construction de la connaissance n'ont pas de contrôle, tels que l'évolution des conditions géopolitiques et du contexte institutionnel, peuvent entraver ou favoriser les impacts.

1.2 Les scénarios comme outil efficace pour la science de la durabilité?

Les scénarios sont "des descriptions plausibles de la manière dont l'avenir peut évoluer, fondées sur un ensemble cohérent d'hypothèses d'évolution des principaux facteurs du changement et leurs relations" (IPCC, 2000, p. 594). Constamment utilisés dans la pratique de la prospective, les scénarios ont été reconnus comme des outils qui s'inscrivent dans les sciences de la durabilité, car ils permettent une réflexion sur la coévolution à long-terme des systèmes sociaux, économiques et naturels (Swart et al., 2004) ce qui est essentiel pour la résilience des systèmes socio-écologiques.

Dans l'histoire des scénarios, les États-Unis et la France sont les principales « écoles » dans lesquels différentes approches prospectives ont été développées. Bien que l'on puisse trouver certaines différences entre les approches d'élaboration de scénarios, une caractéristique commune est la combinaison de récits décrivant l'évolution des tendances futures et de leurs représentations visuelles (par exemple sous forme de cartes, de vidéos, d'images 3D et de dessins). Pour élaborer ces récits, les prospectivistes font souvent appel à des experts et à des approches participatives. D'autre part, les représentations spatialement explicites sont davantage produites par les prospectivistes à travers des modèles mathématiques qui aident à visualiser et évaluer les impacts des changements envisagés.

Si nous nous concentrons sur le contexte agricole, focus de cette thèse, les décisions sont prises au niveau de l'exploitation et sont déterminées par des préférences personnelles et des facteurs à plus grande échelle telles que les pressions climatiques, les mécanismes économiques et financiers ou encore les limites/capacités biogéochimiques du sol. En outre, les pratiques agricoles déterminent des schémas paysagers à différentes échelles spatiales et ont un impact sur les ressources naturelles au-delà des limites de l'exploitation. Si les modèles à échelle fine sont généralement développés pour des étendues spatiales restreintes, l'un des principaux avantages de ce type de modèles est d'utiliser la parcelle comme unité de base. La modélisation prospective à une échelle fine permet donc de quantifier les impacts des décisions de gestion agricole sur des variables environnementales telles que la qualité et la quantité d'eau ou la biodiversité et donner ainsi des indications utiles pour la gestion du territoire.

Enfin, au-delà de l'échelle spatiale utilisée pour développer les scénarios, d'autres classifications sont possibles. En effet, on peut distinguer les scénarios du type *forecasting* et *backcasting* (selon le point de départ - le présent ou le futur - utilisé pour développer les scénarios) et les scénarios normatifs et exploratoires (basés sur la présence/absence de la notion de désirabilité).

1.3 Appliquer l'évaluation d'impacts aux scénarios

Malgré l'ambition des scénarios de fournir un support à la prise de décision (Harrison et al., 2019), la vérification des impacts réels des études prospectives est encore loin d'être une pratique courante (Oteros-Rozas et al., 2015; Von Wirth et al., 2014). Ainsi, les connaissances produites dans le champ de l'évaluation de programmes publiques ne sont pas complètement explorées dans leur application aux scénarios. Cependant, certaines évaluations ont été réalisées et ont permis de clarifier le panel des impacts potentiels des scénarios (par exemple, Millenium Ecosystem Assessment (MA), 2005; Sitas et al., 2019).

Les trois caractéristiques d'une connaissance utilisable (crédibilité, légitimité et pertinence), prennent des nuances particulières dans le contexte des scénarios. Un scénario crédible rapporte des visions plausibles du futur avec des récits qui commencent ou atteignent un présent reconnaissable (Mitter et al., 2019) tout en étant capable d'apporter de la nouveauté. En outre, les hypothèses qui sous-tendent les récits doivent être cohérentes entre elles. La légitimité est, quant à elle, liée à la transparence des résultats, des conclusions et des méthodes utilisées, y compris l'accessibilité du modèle mathématique utilisé pour la spatialisation (Durance and Godet, 2010; Hamilton et al., 2019). En outre, elle dépend de l'intégration des différents points de vue des acteurs locaux dans les récits et de la capacité des scénarios à représenter clairement les futurs (Mitter et al., 2019; Xiang and Clarke, 2003). Enfin, un scénario pertinent est un scénario orienté vers un objectif clair, comme par exemple, apporter des éléments de soutien à une prise de décision spécifique (Mitter et al., 2019; Wilson, 1998).

Lorsque les scénarios sont perçus comme utilisables, envisager différents futurs déclenche potentiellement plusieurs impacts qui émergent à court ou long terme (Saritas, 2006) au niveau de l'individu, du groupe et du système.

Du côté cognitif, les scénarios peuvent stimuler l'apprentissage par l'apport de nouvelles informations et l'aide à la structuration de celles déjà acquises. Xiang and Clarke (2003) qualifient ce double impact cognitif des scénarios des fonctions de rapprochement et d'étirement. Du côté du rapprochement, les scénarios couplent de multiples éléments d'information et les structurent en une vision systémique et cohérente. Du côté de l'étirement, les scénarios peuvent élargir l'éventail des éléments, des facteurs de changement et des futurs possibles considérés par les actrices et acteurs locaux. En ce sens, les scénarios peuvent aider à prendre en compte les incertitudes (Cook et al., 2014; Pereira et al., 2019), à détecter les variables clés du changement (Godet and Lesourne, 1977) et à anticiper les défis de gestion (Van der Voorn et al., 2012). Les changements cognitifs peuvent également se refléter dans une dynamique de groupe, par exemple via l'introduction de nouvelles informations dans les discussions collectives et par le partage des connaissances. En outre, favoriser une pensée créative et une compréhension partagée des dynamiques socio-écologiques (Butler et al., 2015; Priess and Hauck, 2014), ou encore permettre de détecter des problèmes dans le raisonnement et dans les modes de gestion établis peuvent être considérés comme un possible impact cognitif des scénarios (Da Costa et al., 2008).

Du point de vue des impacts politiques, les scénarios peuvent être utilisés pour promouvoir les préférences personnelles et collectives par rapport aux futurs souhaitables. Enfin, du côté instrumental, des changements substantiels peuvent se produire dans les comportements à niveau personnel, conduisant

à des décisions de gestion privée et à un changement dans le degré d'ouverture envers les autres actrices et acteurs locaux. Au niveau du groupe, les impacts instrumentaux concernent plutôt l'utilisation directe des scénarios dans la sélection des options politiques et le développement de stratégies d'intervention consensuelles. Les scénarios peuvent également être utilisés de manière instrumentale pour améliorer les mécanismes de gestion à travers la création de collaborations structurées entre différents actrices et acteurs locaux ou la modification des outils de gestion pour surmonter les incompatibilités institutionnelles (Hauck et al., 2019; Lumbroso, 2019; Ruckelshaus et al., 2015; Wimmer et al., 2012).

Enfin, les impacts au niveau du système surviennent indirectement à long terme et regroupent les changements dans la compréhension générale d'un problème, et dans le fonctionnement d'un système (Hamilton et al., 2019). Le Tableau R.71 reprend les impacts potentiels des scénarios, qui doivent être considérés comme des impacts en constante évolution, de sorte que les impacts cognitifs peuvent conduire à des impacts politiques et instrumentaux, et les impacts personnels peuvent soutenir les impacts de groupe et systémiques (Ghazinoory et al., 2015).

1.4 La nécessité d'une recherche transformatrice

Avec une population croissante et une crise sociale et environnementale exacerbée, l'appel à une transformation économique et sociétale radicale se fait de plus en plus pressant (McCrorry et al., 2020; Schneidewind, Singer-Brodowski, et al., 2016). Les scientifiques et les praticien · ne · s impliqué · e · s dans la science de la durabilité plaident pour une science transformatrice conçue comme "un type spécifique de science qui ne se contente pas d'observer et de décrire les processus de transformation sociétale, mais qui les initie et les catalyse" (Schneidewind, Singer-Brodowski, Mandy Augenstein, et al., 2016, p. 6). Plus qu'un champ d'étude distinct, la science transformatrice est une approche qui peut nourrir les études en science de la durabilité (Horlings et al., 2020) et qui se concentre sur les interactions homme-environnement dans des contextes de transformation. Dans la recherche transformatrice, la science et la société se chevauchent, et l'utilisabilité des connaissances produites par la recherche n'est pas le résultat d'une négociation entre des personnes qui produisent des connaissances et celles qui les utilisent (Schneidewind, Singer-Brodowski, Mandy Augenstein, et al., 2016). En revanche elle découle d'un processus dans lequel les scientifiques ne sont qu'un des producteur · ice · s de connaissances aidant à comprendre et à faciliter la transférabilité des solutions. En effet, ancrée dans l'idée que l'expérimentation sur le terrain conduit à une meilleure compréhension des transformations, la science transformatrice veut donner les moyens et créer le changement (Kok et al., 2023) en testant et produisant des solutions acceptables pour des problèmes concrets et les transférer plus largement (McCrorry et al., 2020; Parodi et al., 2018). Dans ce processus de compréhension et de transfert, les personnes qui affrontent et traitent un problème con-

	individual	group	System
	Acquire new information (instrumental learning) Consider uncertainty; Detect key variables; Anticipate challenges	Consider new information in collective discussions Knowledge sharing; Shared understanding of socio-economic systems and dynamics; Create shared values; Creative thinking	Shift in community understanding
Cognitive	Reinterpret previous information (Communicative learning) Stimulate causal thinking about effects of today's choices, trade offs, small/large scale drivers and effects; Highlight pattern of changes	Identify issues in established reasoning/management Detect institutional incompatibilities	
Political	Reinforce personal political opinion/preference	Support group political opinion/preference Mediate conflicts	Shift in community priorities
Instrumental	Change in personal behaviour (transformative learning) Change in private management; Change in attitudes towards other stakeholders	Develop of new policies Develop of management strategies; Support choices between options Modify management mechanisms Improve collaboration mechanisms between institutions/groups; Improve management tools	Shift in community practices

Table R.7 – Impacts attendus des scénarios à niveau individuel, du groupe et du système et selon le type d'impact.

cret (*frontrunners*) sont considérées comme celles qui se sont "appropriées le problème", dépassant les approches de type "*knowledge-first*" qui considèrent la société comme le propriétaire du problème et la science comme un résolveur qui façonne et répond aux questions de recherche (Wittmayer and Schöpke, 2014, p. 485; Miller, 2013).

Cette thèse se concentre sur les impacts sociétaux des scénarios de type *science-pushed* visant un changement transformateur. Dans ce contexte, l'activité de plaidoyer des scientifiques intrinsèque à l'approche de la recherche transformatrice pourrait intervenir dans la phase de présentation des impacts des scénarios. Néanmoins, l'activité de plaidoyer est limitée dans la phase de réalisation. En effet, lors de la réalisation des scénarios, les scientifiques recueillent les visions des personnes participantes sur les évolutions territoriales, et la légitimité des scénarios repose sur l'inclusion de ces visions dans les récits sans imposer celle du ou de la prospectiviste.

1.5 Objectifs et matériaux

Alors que les scénarios ont été appliqués à une multiplicité de domaines, cette thèse se concentre sur les scénarios de changement d'occupation et d'usage du sol (LUCC) développés pour des contextes agricoles français. Elle utilise une approche de géoprospective (Gourmelon et al., 2012; Houet and Gourmelon, 2014) qui combine les récits, les méthodes participatives et la modélisation (à échelle fine). Un élément du contexte à considérer est l'approche intégrée qui caractérise la gestion de l'eau en France et qui implique des préoccupations et des décisions de gestion transversales. En outre, le système de gestion de l'eau demande une phase prospective et est imbriqué dans la gestion agricole et urbaine par le biais de mécanismes financiers et juridiques. La présence d'un certain niveau de gouvernance anticipative et d'interconnexions entre différents secteurs de la gestion environnementale fait de la gestion de l'eau en France un contexte riche pour étudier les impacts de scénarios à échelle fine.

L'objectif de cette thèse est d'évaluer les impacts personnels et collectifs de deux études de géoprospective participative, fondées sur des scénarios de changements d'occupation et d'usage du sol, survenant à différents moments et qui résultent de différents chemins d'impact. À cet égard, nous avons interrogé des actrices et acteurs locaux qui ont participé à la phase de co-construction, puis nous avons organisé des ateliers de diffusion nous permettant de présenter ces scénarios et de débattre de leurs implications avec un large public. Cette approche nous a permis d'introduire une variable supplémentaire dans notre analyse (se rajoutant à la temporalité de l'évaluation et au chemin d'impact) : le profil du répondant en termes d'activité professionnelle. En suivant Muhonen et al. (2020), les chemins d'impact que nous analysons sont la collaboration et la diffusion interactive.

Les questions de recherche qui guident notre travail sont les suivantes :

3 Quels sont les impacts des scénarios LUCC au fil du temps ?

3a) Comment les scénarios modifient-ils la façon dont les dynamiques territoriales sont comprises en dehors du processus décisionnel de gestion des territoires ?

3b) Est-ce que les scénarios entrent-ils dans le processus de prise de décision en matière de gestion des territoires et si oui, de quelle manière ?

4 Quels sont les principaux facteurs qui influencent les impacts ?

4a) La temporalité : la perception des impacts des scénarios par les actrices et acteurs locaux évolue-t-elle avec le temps ? Pour quel type d'actrices et acteurs et pour quel type d'impacts ?

4b) La complémentarité entre les chemins d'impact : quelle est la contribution des chemins plus ou moins chronophages sur les impacts ?

4c) Existe-t-il d'autres facteurs d'influence que le temps et les chemins d'impact ?

La thèse se structure en trois chapitres et le choix des études de cas reflètent la volonté d'étudier l'effet de différents chemins d'impact dans le temps (voir Figure R.9). En effet, la première étude de géo-prospective a été développée pour le bassin versant du Couesnon dans le cadre du projet ALICE Interreg (2016-2022). La seconde a été développée pour le bassin versant du Lestolet dans le cadre de la thèse de Thomas Houet (2003-2006) (voir Figure R.10). Lorsque cette thèse a débuté, le projet ALICE entrait dans son dernier semestre, ce qui nous a permis d'étudier ses impacts à court (chapitre 1) et moyen terme (chapitre 2). D'autre part, avec le projet Lestolet, nous évaluons les impacts à long terme des scénarios produits il y a plus de 15 ans (chapitre 3).

Les critères de sélection des scénarios étaient également l'échelle fine et le focus sur des questions environnementales. En outre, l'accès aux données constituant la base des scénarios et les contacts avec les actrices et acteurs locaux constituaient également un préalable. Les scénarios sélectionnés se concentrent sur les changements d'utilisation des sols agricoles et leur influence sur la gestion de l'eau et/ou la biodiversité. Les récits des scénarios ont été élaborés conjointement avec les actrices et acteurs locaux impliqués dans la gestion de l'eau et l'agriculture. Les scénarios spatialement explicites sont composés de récits envisageant les effets des facteurs socio-économiques et environnementaux sur le paysage et de cartes LUCC.

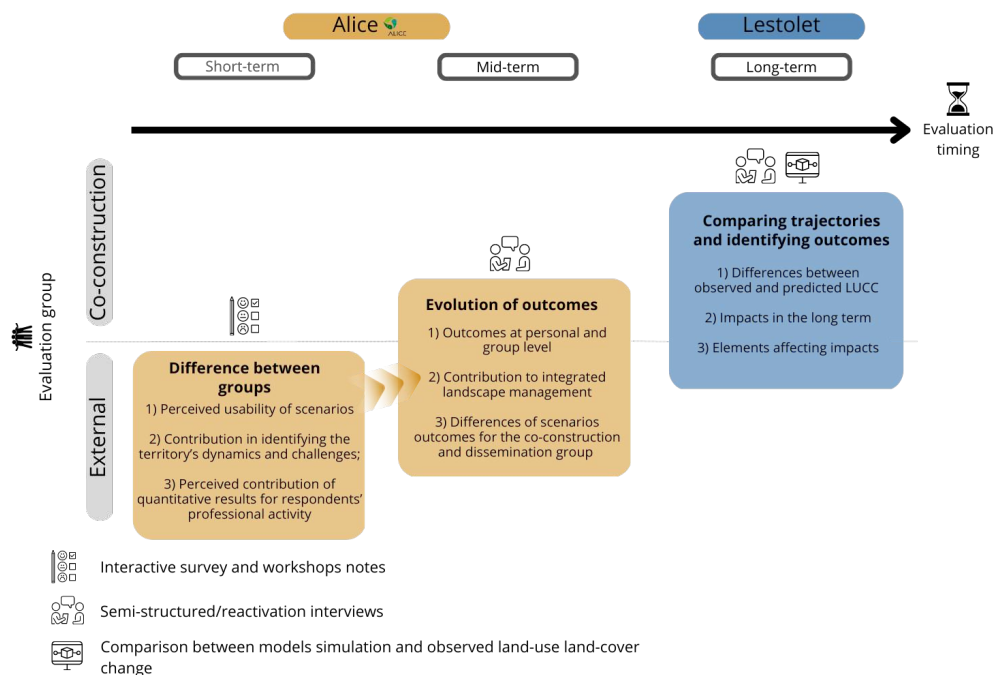


Figure R.9 – Schéma des trois chapitres constituant la partie de recherche de cette thèse en fonction des actrices et acteurs locaux inclus dans l'étude et du moment de leur évaluation.

Par ailleurs, les scénarios sélectionnés diffèrent par leur type et leur étendue spatiale, et ont été développés à 15 ans d'intervalle. L'étude de cas du Couesnon (1130 km²) comprend cinq scénarios *forecasting*, tandis que des scénarios *backcasting* sont également représentés pour le Lestolet (1320 ha) (3 scénarios *forecasting* et 3 *backcasting*). La place la plus importante accordée aux scénarios *forecasting* s'explique par le rôle qu'ils jouent dans le processus de décision. Reconnus comme particulièrement adaptés à la définition de la problématique de gestion et à l'établissement de du programme d'action, ils peuvent produire à la fois des impacts cognitifs et instrumentaux dans un contexte institutionnel.

Ce travail de recherche a été réalisé dans le cadre du projet international de formation (ITN) Terra-nova, l'initiative européenne d'apprentissage du paysage, qui a bénéficié d'un financement du programme de recherche et d'innovation Horizon 2020 de l'Union européenne du programme Marie Skłodowska-Curie [convention de subvention n° 813904]. Ce travail a été réalisé au laboratoire LETG-UMR 6554 (Littoral Télédétection Environnement Géomatique) de l'Université de Rennes 2 (France). Les impacts reflètent uniquement les opinions des auteurs, et l'Union européenne ne peut être tenue responsable de l'usage qui

pourrait être fait des informations qu'ils contiennent.

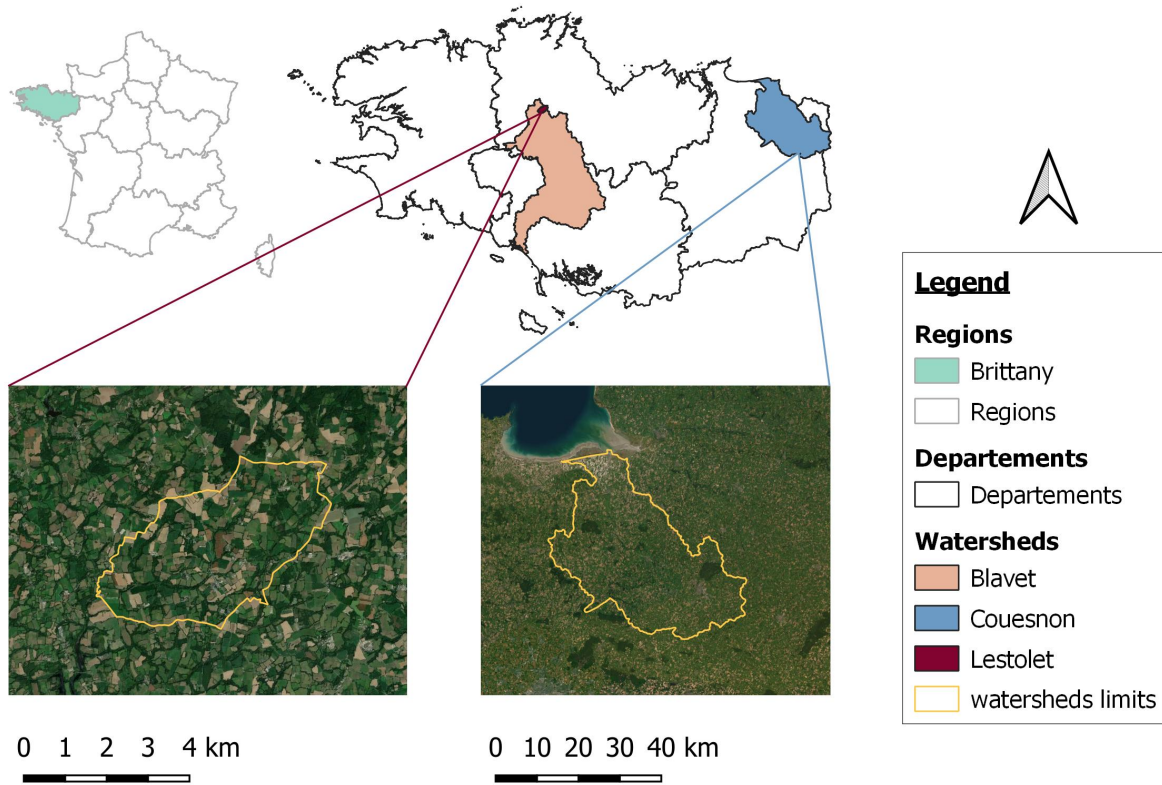


Figure R.10 – Localisation des deux sites d'étude (lignes jaunes). Le bassin versant du Lestolet (zone rouge) est situé au centre de la Bretagne (France), à la limite nord du bassin versant du Blavet (zone rougeâtre). Le bassin versant du Couesnon (zone bleuâtre) est situé au nord-ouest de la Bretagne.

Chapitre 1. Impacts des scénarios à court terme

Dans ce premier chapitre, nous recueillons la réaction à court terme vis-à-vis des scénarios ALICE, de la part d'un public qui a pris connaissance des scénarios grâce aux ateliers de diffusion sans avoir participé à la phase de coproduction.

Comme souligné dans l'introduction de cette thèse, la co-construction est l'un des piliers des études de la durabilité dans lequel s'inscrivent les scénarios ALICE. Cependant, la co-construction est accessible à un nombre limité d'actrices et acteurs locaux. C'est pourquoi nous avons choisi de nous concentrer dans ce chapitre sur la diffusion en tant que chemin d'impact complémentaire à la co-production.

L'objectif principal est de déterminer si les scénarios ALICE sont perçus comme utilisables, compris comme applicables dans les activités professionnelles respectives et résultant d'un processus de recherche crédible. De plus, nous avons analysé comment les groupes d'actrices et acteurs locaux perçoivent l'évolution du LUCC futur, leur conscience des défis attendus en matière de gestion de l'eau et leur connaissance de certains concepts techniques. Enfin, des impacts émergents à court terme sont également examinés. Par conséquent, ce chapitre abordera plus souvent la "perception" des impacts plutôt que les impacts en eux-mêmes en mettant l'accent sur la question suivante : "les répondants perçoivent-ils les scénarios comme utilisables ?" plutôt que "les scénarios ont-ils été utilisés ?" abordée dans les chapitres suivants.

Pour vérifier le rôle de la diffusion des scénarios dans la promotion des impacts, nous avons diffusé les scénarios à différents groupes uniformes d'actrices et acteurs locaux, en sélectionnant des technicien·ne·s, des représentant·e·s et des agriculteur·ice·s comme étant les plus représentatifs des parties prenantes dans la gestion des paysages agricoles. Compte tenu de la nécessité d'avoir un nombre suffisant des personnes répondantes par groupe et dans un temps limité, nous avons choisi une méthode d'évaluation quantitative enrichie par des notes sur les discussions collectives tenue lors des ateliers. Une vérification plus approfondie est laissée pour l'évaluation à moyen et long terme. Cependant, l'approche statistique que nous avons adoptée ne présente pas que des avantages. L'un des revers est l'impossibilité de prendre en compte les profils complexes des répondants. Par ailleurs, pour ce chapitre, nous excluons les personnes participant à la phase de co-construction car elles n'étaient pas suffisantes pour constituer une catégorie à part entière. Dans le chapitre suivant, nous remédierons à ces limites en réintroduisant au sein de l'échantillon les participants à la phase de co-production, et en ajoutant quelques informations générales concernant les personnes interrogées.

Les résultats du questionnaire interactif et les notes de discussion ont permis de mettre en évi-

dence les impacts suivants. Concernant la connaissance des concepts techniques, nous avons enregistré une différence significative entre les groupes d'actrices et acteurs locaux. En effet, les agriculteurs étaient moins familiers avec le concept de trame vertes et bleues (TVB) sur lequel le projet ALICE se base et accordaient moins d'importance à ce réseau d'éléments paysagers que les deux autres groupes. De plus, les agriculteur·ice·s ont déclaré être moins conscient·e·s des défis attendus en matière de gestion de l'eau. Inversement, les LUCC attendus varient de manière significative entre les groupes et au sein de ceux-ci, ce qui montre l'absence de visions homogènes sur le futur du paysage agricole.

En ce qui concerne l'utilité instrumentale des scénarios, tous les groupes ont évalué positivement la recherche (au-dessus de la valeur médiane), et les représentant·e·s ont considéré les résultats des scénarios sur la ressource en eau comme plus utilisables par rapport aux agriculteur·ice·s. Néanmoins, une plus grande variabilité dans les réponses a été enregistrée entre les agriculteur·ice·s et les technicien·ne·s qu'entre les représentant·e·s. D'une manière générale, les scénarios ont été perçus comme pertinents et crédibles, et le processus de coproduction a été considéré comme ayant un impact positif sur leur légitimité.

Une partie des débats ayant eu cours durant les ateliers tournait autour du rôle central des haies dans la qualité de l'eau et les services écosystémiques. Néanmoins, les différents acteur·ice·s n'avaient pas une connaissance équivalente des pratiques liées à l'entretien des haies. Par exemple, les agriculteur·ice·s reconnaissent la pratique courante consistant à rendre les arbres malades pour contourner la loi interdisant la suppression des haies. Cependant, alors que les représentants semblaient au courant de cette pratique, les technicien·ne·s régionaux se sont dit surpris d'entendre de telles méthodes. Bien que notre protocole n'ait pas permis de vérifier statistiquement la connaissance de cette pratique dans les différents groupes, notre observation souligne que certains tabous dans la gestion du territoire ne sont pas discutés ouvertement, et empêchent une discussion fructueuse sur les politiques à mettre en place pour favoriser une durabilité économique et environnementale.

Outre l'évaluation de l'utilisabilité des scénarios, nous avons détecté quelques premiers impacts. En effet, les ateliers ont permis de niveler les connaissances sur les défis environnementaux attendus et les pratiques agricoles.

En résumé, cet article d'évaluation à court terme nous a permis de :

- Vérifier l'exploitabilité des scénarios : les répondants ont exprimé leur confiance dans les résultats de la recherche, indépendamment de leur activité professionnelle et de leur familiarité avec la zone

d'étude. La phase de co-création a été perçue comme essentielle pour asseoir la légitimité de l'étude montrant une première complémentarité entre les chemins d'impact. Du côté de la pertinence, les actrices et acteurs locaux considèrent que les résultats sur l'eau sont plus pertinents que ceux sur la biodiversité, reflétant les tensions sur les ressources en eau présentes sur le territoire. De plus, les résultats des scénarios sont plus susceptibles d'aider les représentants dans leurs activités professionnelles que les techniciens.

- Détecter une incohérence entre les attentes et l'utilité perçue des scénarios par les répondants : les scénarios ont été développés en partenariat avec une structure technique visant à aider les gestionnaires du territoire à définir les TVB et à les intégrer dans les plans de gestion locaux. Néanmoins, les scénarios semblent plus pertinents pour les représentants que pour les techniciens.
- Détecter les impacts à court terme : certains impacts personnels et cognitifs ont été détectés à court terme. En effet, les scénarios ont permis d'améliorer les connaissances sur les défis attendus et les pratiques agricoles, et ont apporté de nouvelles connaissances dans les secteurs d'activités dans lesquels les personnes qui ont répondu ne sont pas spécialisées (c'est-à-dire le concept de TVB pour les agriculteurs et les pratiques qui contournent les restrictions légales pour les techniciens travaillant à des niveaux organisationnels plus larges).

Si le cadre d'évaluation est facilement reproductible, l'organisation et la mise en pratique des ateliers demande du temps. Cependant, cette première évaluation permet de poser les bases de l'évaluation des impacts pour les différents types d'actrices et acteurs locaux, ce qui permettra de mieux cibler le public par rapport aux impacts attendus.

Ce chapitre a été soumis comme un article de recherche original à la revue *Environmental Science and Policy* (en cours de révision).

Rigo R., T Houet, Gonthier C. (Under review) Evaluating and maximising the outcomes of LUCC scenarios: strategies for an effective dissemination, *Environmental Science and Policy*

Chapitre 2. Impacts des scénarios à moyen terme

Dans ce deuxième chapitre, nous passons de l'évaluation de l'utilisabilité des scénarios à l'évaluation des impacts à moyen terme. L'approche d'une évaluation dynamique permet de différencier les impacts en fonction du moment de leur apparition. Cela est important afin de pouvoir planifier efficacement le moment d'évaluation approprié pour détecter la présence/absence d'impacts spécifiques. Alors que ce deuxième chapitre analyse l'émergence de différents types de résultats, nous avons décidé d'observer principalement l'impact des scénarios dans une intégration majeure des politiques de gestion du territoire. En effet, en montrant les interdépendances entre les éléments du paysage et les services écosystémiques, nous émettons l'hypothèse que les scénarios peuvent mettre en évidence les limites du secteur public divisé en silos et fonctionner comme un outil de soutien pour une gestion plus intégrée des territoires. Tout au long du processus de diffusion, nous avons rencontré plusieurs actrices et acteurs locaux impliqués dans différents aspects de la gestion des territoires. Cela nous a permis d'examiner si et comment les scénarios ont engendré les impacts attendus dans différentes communautés de pratiques. En outre, les scénarios sont développés à une échelle spatiale pertinente, car la zone couverte par les scénarios coïncide avec le niveau de l'organisation de la gestion de l'eau et se chevauche avec le niveau d'organisation de la gestion urbaine.

Dans cette analyse, nous utilisons le concept d'objet-frontière comme des objets physiques permettant le transfert de connaissances et la coopération entre différents groupes. En effet, différentes actrices et acteurs locaux ont travaillé ensemble dans la phase de co-construction et ont échangé des expériences, des connaissances et des pratiques de leur communauté pour co-construire les scénarios (notamment les technicien·ne·s du SAGE Couesnon et du SCOT du Pays de Fougères, les conseiller·e·s agricoles et les scientifiques). A l'inverse, les personnes participant aux ateliers de diffusion provenaient de communautés relativement homogènes. Néanmoins, à quelques occasions, une certaine hétérogénéité était présente. En particulier, lors d'une session au sein de la Zone Atelier (ZA) Armorique, des habitant.e.s, des représentant.e.s et des agriculteur.ice.s étaient réunis. De plus un atelier mené à la Région Bretagne a rassemblé des technicien.ne.s de la même structure mais de services différents. Sur une base plus faible par rapport à la coproduction, les répondants ont alors pu échanger des points de vue et des pratiques en réponse aux scénarios. En outre, la mobilisation de ce concept est particulièrement pertinente dans ce chapitre car le délai d'évaluation relativement court (de 7 à 11 mois) permet aux répondants de se référer à des impacts cognitifs personnels (tels que des connaissances accrues). Également, suffisamment de temps s'est écoulé pour permettre l'évocation d'impacts de groupe tels qu'une coopération accrue.

Du point de vue méthodologique, nous basons ce chapitre sur des entretiens, et nous incluons dans l'échantillon certains actrices et acteurs locaux précédemment exclus en raison des contraintes imposées

par l'analyse quantitative. Notamment, l'inclusion des personnes ayant participé à la co-construction permet de différencier les impacts en fonction du chemin d'impact par laquelle les personnes participantes sont entrées en contact avec les scénarios de la différence de temps investi dans le projet qui en découle. L'approche qualitative nous permet également de prendre en compte les profils des répondants d'une façon plus nuancée. Par ailleurs, lors de la restitution des scénarios à l'équipe de coproduction et des ateliers de diffusion, certaines personnes interrogées ont accepté de lever l'anonymat de l'enquête. L'accès aux réponses nominales nous a permis de rediscuter la vision à court terme des scénarios. Parmi les 20 personnes interrogées dans le cadre de ce document, 16 ont accepté de lever l'anonymat.

Il faut aussi noter que les conditions sociopolitiques ont changé considérablement entre l'évaluation à court terme (juin - décembre 2021) et le moment des entretiens (avril - juin 2022) avec une influence importante sur les impacts relevés. En particulier, la guerre en Ukraine a commencé en février 2022 et a provoqué une flambée des prix des céréales en France (Neveu, 2022). Ainsi, le débat public, auparavant marqué par les sujets liés à COVID-19, s'est centré sur le conflit russo-ukrainien en cours.

Les résultats des entretiens menés dans le cadre de ce chapitre soulignent que, alors que les impacts cognitifs sont toujours majoritaires, certains acquis d'apprentissage ont bénéficié d'un large consensus lors de l'évaluation à court terme. En particulier l'acquisition des connaissances plus approfondies sur les défis environnementaux à venir et sur les pratiques agricoles ont perdu leur consensus au fil des mois. En effet, parmi les 16 personnes interrogées qui ont acceptées de lever l'anonymat des réponses au questionnaire, 14 avaient déclaré que les scénarios soutenaient certains impacts d'apprentissage ; cependant, seules 6 personnes ont maintenu la même opinion dans l'entretien à mi-parcours. D'autre part, la seule personne qui a utilisé cette étude comme base pour un travail supplémentaire avait déclaré à l'origine que les résultats des scénarios n'étaient pas utilisables dans son activité professionnelle.

De plus, nous mettons en évidence comment les scénarios ont été utilisés de manière instrumentale conduisant à la citation des résultats des scénarios dans un avis rédigé par la Commission Locale de l'Eau (CLE) Couesnon mettant en garde sur les conséquences à long terme sur la ressource en eau de l'installation d'une usine. Néanmoins, il est essentiel de préciser que l'avis n'a pas empêché l'usine d'obtenir le permis d'installation. Au contraire, ce qui entrave le projet de se réaliser est un mouvement civil, actuellement en cours.

Les scénarios ont augmenté la collaboration entre différentes communautés de pratique dans trois cas (SCOT et SAGE; techniciens de la Région Bretagne; et agriculteurs et habitants de la ZA Armorique).

En ce qui concerne les participants à l'atelier sur la ZA, les scénarios ont permis d'augmenter l'empathie des riverains envers les agriculteurs qui vivent à côté et l'apprentissage s'est produit par la formation d'un vocabulaire partagé. Dans les deux autres exemples de coopération, un vocabulaire partagé était déjà présent et l'apprentissage est passé par le biais des réflexions dans lequel les différentes actrices et acteurs ont pensé à comment coordonner leurs pratiques.

Enfin, il faut noter que le discours sur les futures pratiques agricoles a radicalement changé entre l'évaluation à court et moyen terme. En effet, dans le cadre de la première évaluation, les agriculteurs ont souligné l'hétérogénéité entre leurs pratiques et opinions. À l'inverse, dans les entretiens à moyen terme, la plupart des personnes interrogées ont fait référence à une croissance attendue de la surface en blé. Dans ce sens, les conditions géopolitiques renouvelées ont changé la perception des trajectoires paysagères et ont poussé les gens à avoir une vision plus homogène de l'avenir. Néanmoins, certains ont pu faire le lien entre un paysage changeant et les risques environnementaux, montrant ainsi une capacité accrue à analyser le système socio-écologique dans sa complexité.

En résumé, ce chapitre d'évaluation à moyen terme nous a permis de :

- Vérifier les impacts à moyen terme des scénarios : alors que les impacts à court terme étaient principalement personnels et cognitifs, nous avons détecté certains impacts de groupe lorsque la présence de frontières était la plus explicite. En effet, la collaboration a été favorisée entre des techniciens de différentes structures de gestion du territoire qui ont participé à la phase de co-construction et entre des techniciens de différents services d'une même structure qui ont sollicités un atelier de diffusion.
- Souligner que les scénarios ont agi comme catalyseur d'une forte volonté politique déjà présente d'aller vers une gestion intégrée. Néanmoins, ils ont permis d'impulser une initiative de gestion intégrée menée par un public qui a participé uniquement à la phase de dissémination et qui ne travaille pas à la même échelle des scénarios.
- Reconnaître que les scénarios sont entrés dans le processus décisionnel d'une manière qui n'avait pas été envisagée par l'équipe scientifique : le cas de l'installation d'une usine sur le territoire. En effet, nous avons détecté une utilisation directe de l'information scientifique par un organisme de gestion de l'eau appelé à donner un avis sur une décision ayant un impact sur le développement économique de la région. Des scénarios ont alors été mobilisés pour guider une décision collective basée sur un raisonnement des effets à long terme.

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- Détecter une boucle de rétroaction positive entre la co-production et la diffusion des scénarios : la co-production était essentielle pour que les actrices et acteurs locaux reconnaissent l'étude comme utilisable. En retour, la diffusion a été cruciale pour qu'ils et elles puissent exprimer leurs inquiétudes concernant l'implantation de l'usine. En effet, comme de nombreux représentants connaissaient l'étude et la considéraient utilisable, certains d'entre eux ont pu utiliser les scénarios de manière politique et parvenir à la décision finale du groupe.
 - Souligner les changements d'opinion des personnes répondantes entre le court et le moyen terme et le rôle des événements de réactivation dans la perception des impacts des scénarios. En effet, l'opinion initialement partagée sur l'impact des scénarios dans la mise à niveau des connaissances par rapport aux défis environnementaux et aux pratiques agricoles a perdu son consensus au fil des mois entre les personnes qui n'ont pas rediscuté/repris en mains les scénarios ou des sujets connexes. D'un autre côté, l'utilité des scénarios a été reconsidérée par la personne qui a utilisé les scénarios comme base pour un travail supplémentaire.

Ce chapitre a été soumis en tant qu'article de recherche original à la revue *Land* (en cours de révision)..

Rigo R. and Houet T. (submitted) Do land use and land cover scenarios support more integrated land-use management? *Land*

Chapitre 3. Reconstructing the past: Outcomes of scenarios in the long term

Dans les deux premiers chapitres, nous avons évalué les impacts des scénarios à un moment spécifique. Ce chapitre adopte une approche à long terme qui nous permet de retracer l'évolution des impacts dans un temps long. Pour ce faire, nous analysons les scénarios élaborés il y a 15 ans en interrogeant à la fois des actrices et acteurs locaux qui avaient participé à la co-construction et des personnes ayant un rôle clé dans la gestion actuelle du territoire. En utilisant une approche mixte de données qualitatives (entretiens semi-directifs) et quantitatives (Analyse des données RPG et satellitaires Sentinel-2), nous comparons les LUCC observés avec ceux envisagés par les scénarios en considérant les changements sociaux survenus sur le territoire au fil des ans. Dans ce chapitre, les aspects de modélisation des scénarios prennent une place plus importante par rapport aux deux chapitres précédents, et les notions de plausibilité et de précision des futurs envisagés sont discutées.

Les résultats indiquent que les scénarios ont indirectement atteint leur objectif initial : soutenir

la définition de la stratégie locale de gestion de l'eau. En effet, le SAGE Blavet a mandaté un bureau d'études (ASCA) pour élaborer des scénarios dans le but spécifique d'éclairer la définition du SAGE Blavet en 2007. Les scénarios proposés par le bureau d'études reprenaient et complétaient les scénarios proposés par Houet (2006). Néanmoins, la technicienne du SAGE interrogée a identifié le bureau d'études comme étant le principal fournisseur de connaissances. En ce sens, le principal outil d'appui à la définition du plan de gestion de l'eau (les scénarios proposés par le bureau d'étude) a été une recherche de type *policy-pull* partiellement basée sur les scénarios que nous avons évalués.

En outre, les scénarios ont favorisé une perspective multidisciplinaire au sein des gestionnaires du territoire et ont facilité la reconnaissance des défis et des opportunités auxquels sont confrontés les agriculteur·ice·s locaux. Néanmoins, ils n'ont pas réussi à créer une vision commune de l'avenir au sein de groupes différents. L'analyse a aussi permis de montrer que certains impacts des scénarios ont émergés des années après le projet en réponse à des événements extérieurs. Un processus de dissémination des scénarios avait été réalisé par une participante à la phase de co-construction (membre de la Chambre d'Agriculture) qui a présenté les scénarios aux agriculteur.ice.s. Des années plus tard, ce groupe d'agriculteur·ice·s, suivie par la même conseillère agricole, a re-évoqué les scénarios lors de réunions ayant finalement porté à la création d'un Groupement d'Intérêt Économique et Environnemental (GIEE). En effet, le groupe a reconnu dans l'arrivée des personnes qui exploitaient économiquement le bois local la concrétisation d'une des hypothèses considérées dans les scénarios et reconnu des conséquences sociales négatives pour les habitants du bassin versant.

Du point de vue de la modélisation, nous avons constaté que les trajectoires du LUCC issues des différents scénarios envisagés, ne correspondaient pas à ce qui c'était réellement passé en termes de LUCC. Une partie de l'explication peut se retrouver dans une modélisation faite sur les parcelles uniquement situées à l'intérieur du bassin versant, au lieu de considérer toutes les parcelles appartenant aux exploitations qui possèdent au moins une parcelle dans le bassin versant. Cette dernière option reflèterait mieux l'échelle sur laquelle les impacts des décisions prises par les agriculteur·ice·s se manifestent. Néanmoins, le manque de données peut considérablement limiter l'intégration des décisions des exploitant·e·s agricoles dans les modèles. En outre, les personnes interviewées n'ont jamais cité la modélisation à l'échelle du bassin versant comme une limite de l'étude. Par conséquent, la prise en compte de la dynamique interne d'une exploitation peut améliorer la précision de la modélisation et de la spatialisation des pratiques agricoles, tandis que le fait de se conformer aux limites administratives est bénéfique pour l'intégration des scénarios dans la prise de décisions institutionnelles.

Les leçons tirées de ces études sont synthétisées dans des lignes directrices qui pourront être utilisées pour améliorer les impacts de tout scénario futur.

En résumé, cet article d'évaluation à long terme nous a permis de :

- Contribuer à la définition des facteurs influençant la plausibilité des scénarios et, par conséquent, la définition des impacts environnementaux. Notamment il peut s'avérer utile de considérer dans la modélisation: 1) une échelle spatiale qui correspond à l'échelle à laquelle les facteurs des LUCC produisent leurs effets ; 2) la différence de rendement des sols à l'intérieur et à l'extérieur des limites du bassin versant; 3) les possibles changements des systèmes de production.
- Détecter les résultats à long terme. Nous avons notamment observé que les scénarios concourraient à l'élaboration de décisions politiques. En effet, les scénarios du Lestolet ont servi de base pour des études plus complètes commandées par le SAGE Blavet et fournies par un bureau d'études. Ensuite cette étude du type *policy-pull* a été utilisée de manière instrumentale pour définir un document officiel de planification. De plus, nous avons observé que des événements extérieurs survenant des années après la réalisation des scénarios en ont réactivé la mémoire, ils ont ensuite été réemployés lors du processus de constitution d'un GIEE.
- Identifier des facteurs influençant les résultats à long terme. Par exemple, les étendues spatiales qui conduisent à une modélisation plus proche des LUCC observés pourraient ne pas être les plus appropriées pour induire des résultats instrumentaux car elles ne correspondent pas aux limites organisationnelles. Enfin, les aspects institutionnels (tels que la collaboration limitée entre les institutions et la retranscription des résultats via des bureaux d'études) ont considérablement conditionné les impacts des scénarios.

Ce chapitre a été publié en tant qu'article de recherche original dans la revue *Futures*.

Rigo R., Martin P., Verburg P., Houet T. (2022) Contributions of local LUCC spatially explicit scenarios for water management: Lessons learned from an ex-post evaluation, *Futures*, <https://doi.org/10.1016/j.futures.2022.102937>

2 Conclusions générales

2.1 Structurer les résultats des études d'aménagement du territoire

Dans ce chapitre, nous nous éloignons des classifications qui divisent dans un premier temps les impacts personnels, de groupe et systémiques (Hamilton et al., 2019) et dans un second temps les impacts cognitifs, politiques et instrumentaux (McKenzie et al., 2014). Les résultats sont synthétisés en fonction des conditions nécessaires à l'apparition des impacts tels qu'observés dans nos cas d'études. La figure R.11 reprend les résultats des scénarios obtenus dans les deux études de cas, ainsi que leurs processus et les conditions nécessaires pour leur apparition.

Comme indiqué dans la littérature, l'utilisabilité des scénarios est la première condition pour en permettre l'utilisation et, en conséquence, l'émergence d'impacts. Si cette première condition est remplie, certains résultats personnels peuvent survenir. Tout d'abord, les actrices et acteurs locaux qui prennent connaissance des scénarios reçoivent ou structurent des informations sur la dynamique du paysage et les défis en lien avec la gestion attendu. Il leur est possible de formaliser des connaissances non formelles acquises précédemment et remettre en question les pratiques traditionnelles au regard de ces nouvelles données/informations. Le fait que les actrices et acteurs locaux reçoivent ou structurent les informations dépend de la voie de diffusion par laquelle ils entrent en contact avec les scénarios (diffusion ou co-construction dans notre cas).

Après la première exposition aux scénarios, un processus de réactivation peut faciliter l'émergence d'impacts supplémentaires. Celui-ci peut conduire à plusieurs impacts personnels : une nouvelle considération des problèmes environnementaux, une reconsidération des pratiques traditionnelles, un mode de raisonnement différent et, enfin, l'utilisation des scénarios pour soutenir des opinions personnelles.

Dans un second temps, des résultats collectifs peuvent émerger, directement ou indirectement. Par le biais de la reconnaissance collective, des scénarios de type *science-pushed* peuvent entrer directement dans le processus décisionnel institutionnel en soutenant les décisions basées sur des considérations à long terme. Les scénarios exploratoires de type *science-pushed* soutiennent également de manière indirecte la prise de décision en suivant un processus de détachement. Dans les cas d'étude de cette thèse, le processus de détachement vient d'un besoin de connaissances plus adaptées pour la prise de décision ou par une volonté de collaboration déjà forte. Dans ce dernier cas, les scénarios ont joué le rôle de catalyseur d'une volonté préexistante de collaborer pour formuler une proposition politique commune.

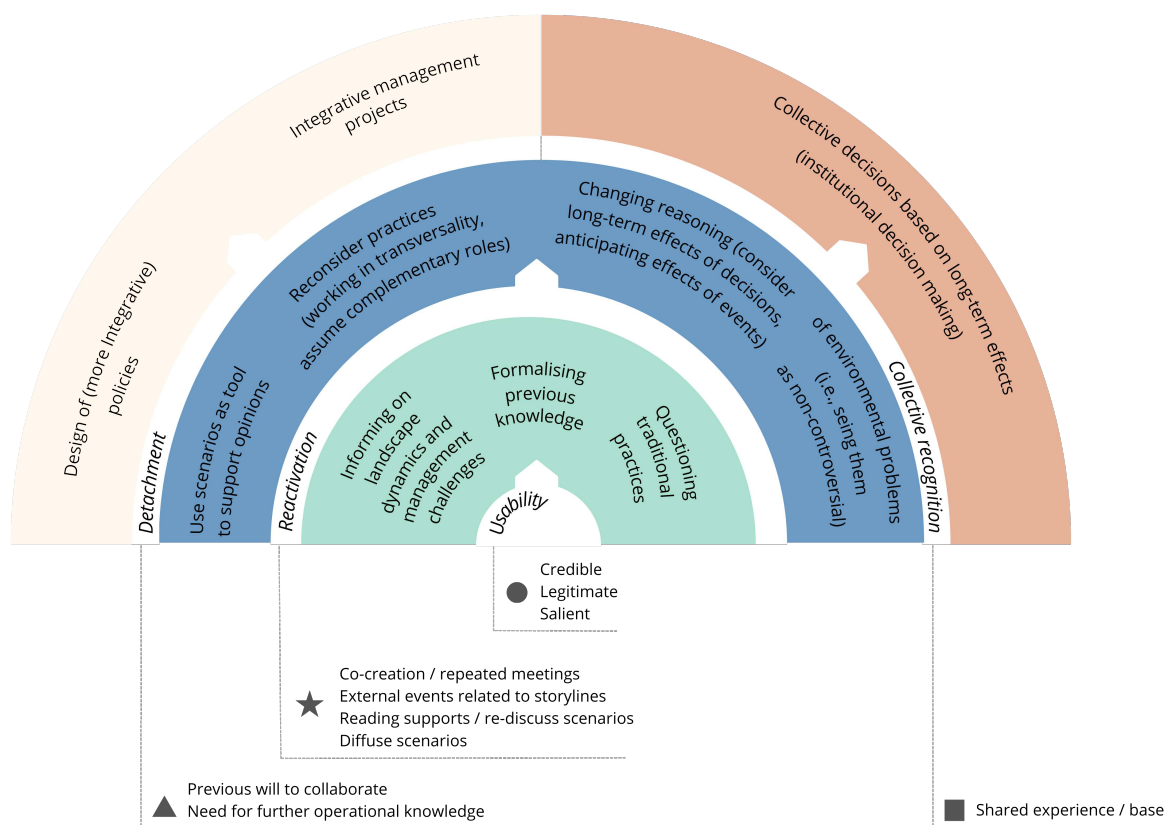


Figure R.11 – Impacts des scénarios (en demi-cercles colorés) selon un degré croissant de conditionnalité (du centre vers l'extérieur). Les conditions d'émergence des impacts (dans les demi-cercles blancs) sont détaillées sous le demi-cercle.

Des scénarios LUCC utilisables (qui présentent les caractéristiques ●) peuvent donner lieu à des impacts bleu clair. Si un processus de réactivation se produit sous l'effet d'événements★, ils peuvent donner lieu à des impacts bleu foncé. Ensuite, si un processus de reconnaissance collective se produit lorsque les conditions ■ sont réunies, les impacts peuvent être de couleur pêche. Enfin, les conditions ▲ peuvent entraîner un processus de détachement et des impacts de couleur pêche claire.

Savoir quelles conditions de la figure R.11 sont présentes au moment de l'interaction science-société (et lesquelles pourraient être facilitées) aide les prospectivistes. Cela permet également aux actrices et acteurs locaux à prédéfinir des objectifs réalisables et permet d'adapter la stratégie d'intervention.

Pour résumer le processus des résultats, nous empruntons le concept de "divergence, émergence et convergence" développé par Sirr and Ratcliffe (2003). En effet, un scénario peut conduire à l'émergence de nouvelles questions, perspectives et idées, créant une divergence par rapport à l'état initial (résultat cognitif personnel). Ensuite, le débat autour des défis futurs et des implications des différentes possibilités peut laisser émerger des opinions/objectifs collectifs (résultats cognitifs et politiques de groupe). Enfin, des résultats instrumentaux de groupe peuvent apparaître par la reconnaissance collective de nouvelles idées et la convergence d'opinions.

2.2 Principaux facteurs influençant les impacts

La phase de co-création a été essentielle pour favoriser la collaboration et la transversalité dans un secteur public organisé en silos (services). Bien que l'implication directe des résultats des scénarios dans la prise de décision soit limitée et puisse passer par un processus de détachement, les scénarios de type *science-pushed* ont le mérite de rassembler différents actrices et acteurs ayant une légitimité sur des aspects distincts de la gestion du territoire. De plus, comme pour tout autre outil, la contribution des scénarios à la gestion de l'environnement dépend non seulement des aspects techniques des scénarios, mais aussi de la personne qui les utilise. La grande hétérogénéité des motivations qui poussent les actrices et acteurs locaux à se confronter aux scénarios et aux impacts qui en découlent nous ont poussé à représenter les résultats des scénarios sur la base d'une conditionnalité croissante plutôt que sur un décalage temporel. En effet, même s'il existe une conséquence temporelle dans certains impacts, l'effet du temps est controversé et le fait de se concentrer sur celui-ci suggère que des impacts plus complexes ou tangibles ont besoin de plus de temps pour apparaître. Cependant, pour certains actrices et acteurs locaux, les résultats peuvent "stagner" longtemps à un stade, éventuellement sans atteindre le stade suivant, alors que pour d'autres, ils peuvent atteindre des niveaux plus élevés très rapidement lorsque les conditions requises sont réunies. Le concept de "fenêtre d'opportunité", emprunté à la politique publique et à l'entrepreneuriat (Kingdon and Stano, 1984; Wickham, 2006), peut être relié aux impacts des scénarios. Nous nous référons ici à la fenêtre d'opportunité comme le moment où les résultats peuvent être produits, déterminé par la stabilité des personnes impliqués dans la gestion locale du territoire et par la présence d'un contexte institutionnel et géopolitique cohérent avec les hypothèses des scénarios.

Le chemin d'impact joue également un rôle crucial dans l'émergence des impacts. Tout d'abord, la relation entre la co-création et la légitimité peut être rediscutée en prenant en compte le caractère *science-pushed*, *policy-pulled* ou de co-création des recherches. En effet, bien qu'il soit généralement admis qu'une phase de co-création favorise l'appropriation (même d'un projet *science-pushed*), la recherche *science-pushed* laisse peu de place aux partenaires institutionnels pour façonner le format des résultats attendus (Sterk et al., 2009). Néanmoins, nous avons observé d'importantes rétroactions positives entre la co-création et la diffusion, en termes d'émergence des impacts. Le meilleur exemple de complémentarité est présenté au chapitre 3. Lorsque nous avons interagi avec les organes politiques locaux, les scénarios ont été perçus comme utilisables grâce à la phase de co-création et ont favorisé une meilleure prise en compte des problèmes locaux de quantité d'eau. La sensibilisation accrue des représentants locaux résultant de la phase de diffusion a ensuite conduit à une décision collective qui n'avait pas été envisagée au début du projet, élargissant ainsi le spectre des occasions dans lesquelles les résultats des scénarios ont trouvé leur pertinence et leur utilisabilité.

2.3 Limites de l'étude et perspectives scientifiques pour les scénarios LUCC

Le choix d'adopter une approche par étude de cas a ses avantages et ses inconvénients. D'une part, elle permet une analyse en profondeur et une compréhension fine des processus étudiés prenant en compte le contexte social et institutionnel. De plus, cela nous a permis de mettre en place une évaluation temporelle et de travailler sur la diffusion des scénarios ALICE. D'autre part, ce choix nous a empêché d'analyser davantage d'études de cas, par exemple en introduisant certains *policy-pulled* scénarios. Bien que nous estimions que le délai choisi pour l'entretien à moyen terme était approprié pour mettre en évidence les résultats de groupe, nous avons potentiellement manqué certains résultats instrumentaux. En effet, en raison du décalage entre le calendrier de la recherche et celui de l'administration nous n'avons pas pu évaluer les impacts des scénarios au terme d'une phase de révision des documents de gestion du territoire (SCoT du Pays de Fougères). Enfin, nous n'avons pas été en mesure d'interviewer un technicien qui critiquait les résultats de la recherche et qui aurait pu apporter des opinions et des perspectives supplémentaires en enrichissant ainsi les résultats de l'étude.

Cette étude nous a permis d'identifier des pistes d'amélioration pour optimiser les impacts des scénarios. Dans ce sens, malgré les évolutions passées des LUCC intégrées dans l'élaboration des scénarios, il peut s'avérer utile de montrer comment des décisions administratives ou politiques passées ont influencé l'évolution du territoire et accroître ainsi la prise en compte des effets à long terme des décisions actuelles

et favoriser la réflexion sur les leviers d'action.

En ce qui concerne la structure des ateliers, il serait intéressant d'explorer les effets d'une présentation adaptée à des groupes de parties prenantes spécifiques, et l'intégration d'évaluateurs externes pourraient être abordée. De plus, alors que certains leviers d'action pour une gestion plus durable des sols ont été identifiés (un foncier agricole regroupé selon certaines caractéristiques par exemple), proposer un atelier spécifique pour l'identification, l'analyse de faisabilité et l'implication des parties prenantes dans le développement et la mise en œuvre de ces leviers pourrait considérablement favoriser l'émergence d'impacts instrumentaux.

Un autre élément à explorer est la possible synergie entre les scénarios *science-pushed* et *policy-pulled*. En effet, si notre recherche s'est concentrée sur des études initiées par des scientifiques, il existe également des scénarios *policy-pulled* ou des projets co-pilotés par des partenaires scientifiques et privés/institutionnels. L'étude des synergies entre les différents types des scénarios peut aider à combler le manque des résultats cognitifs des scénarios *policy-pull* et des impacts instrumentaux des scénarios *science-push*.

Enfin, cette thèse clarifie les impacts potentiels des scénarios et les conditions qui leur permettent de se produire. Il reste à déterminer au cas par cas si l'équilibre entre les coûts nécessaires au développement des scénarios et leurs avantages en termes de impacts attendus est viable.

2.4 Contributions et perspectives pour des études durables

La science de la durabilité est intrinsèquement liée à la science-action et à l'idée d'un savoir local visant à atténuer les problèmes socio-écologiques. Néanmoins, l'introduction de phases participatives dans la production de connaissances ne suffit pas à enclencher des changements transformatifs (Beier et al., 2017; Díaz et al., 2019; Pelling et al., 2015; Van Bruggen et al., 2019). En effet, bien que nous ayons observé une véritable tentative de dépasser l'approche qui voit la science et les institutions comme "deux communautés" complètement séparées, les phases de co-production des études de cas que nous avons étudiées avaient principalement un but extractif visant à soutenir la création de connaissances/outils conçus principalement pour atteindre des objectifs scientifiques. Si les projets *science-pushed* restent importants en eux-mêmes et peuvent produire des impacts, y compris instrumentaux, nous mettons en garde contre le fait de mettre en permanence l'accent sur les ambitions transformatives de ces projets. En fait, nous pensons que l'utilisation d'étiquettes telles que "recherche-action" et "recherche transformative" lorsque la recherche n'est pas principalement motivée par des "problèmes du monde réel", participe à

vider de son sens un champs d'études qui trouve toute sa légitimité dans ce moment historique.

Par ailleurs, les définitions et applications récentes du concept de science-action véhiculent l'idée que l'action est déterminée au niveau institutionnel (voir par exemple la définition de Pearman and Cravens, 2022). Néanmoins, nous constatons une augmentation générale des mouvements civils ascendants (Hayes, 2006; Thackeray et al., 2020), y compris des actions de désobéissance civique qui peuvent entraîner des changements concrets plus radicaux et plus rapides que les tentatives portées par des institutions. Dans ce contexte, on peut se demander s'il est approprié de lier explicitement (et presque exclusivement) la science-action au contexte institutionnel ?

En regardant nos cas d'étude rétrospectivement, nous avons constaté qu'ils étaient fondés sur l'idée que de nouvelles connaissances co-construites conduiraient à une transformation vers des pratiques plus durables. Cependant, nous devons reconnaître que cette approche a conduit à peu de changements transformatifs. La littérature sur la connaissance transformative, qui la définit comme le résultat des pratiques de transformation plutôt que comme une condition préalable à la transformation, offre des perspectives intéressantes pour interpréter cette capacité transformative limitée des études durables (Bennett et al., 2016; Colloff et al., 2017; Shrivastava et al., 2020).

Enfin, en parallèle des ambitions et de la volonté personnelle des scientifiques, les structures de recherche et les systèmes de financement peuvent considérablement encourager les études sur le développement durable à produire des connaissances transformatives. En effet, à la lumière de nos observations, produire une recherche orientée vers l'action dans le cadre d'un projet *science-pushed*, si n'est pas une contradiction, dépend des compétences et volontés des scientifiques. Pour surmonter ce problème, les critères de financement de la recherche devraient aller au-delà de l'évaluation des impacts attendus et exiger une cohérence entre les impacts attendus et les chemins d'impact et la définition d'un agenda commun entre les partenaires académiques et non académiques (Schneider et al., 2019). De plus, exiger des équipes interdisciplinaires comprenant des experts en philosophie des sciences, en sciences politiques, en sociologie et en économie semble être une prérogative pour dépasser la primauté des aspects environnementaux sur les aspects sociaux et économiques (Schoolman et al., 2012), et répondre à la nécessité de mieux définir (Alvarez et al., 2010) et atteindre les impacts attendus. En ce sens, il pourrait être intéressant pour les structures de recherche d'avoir des personnes travaillant de manière transversale sur plusieurs projets et ayant une expertise dans l'interface science-société.

En conclusion, cette thèse contribue à la réflexion sur la détermination des impacts attendus et

atteignables des projets de type *science-pushed* visant à impacter positivement la société par la production d'une science-action. En se basant sur des études de cas de scénarios participatifs LUCC, elle propose une perspective pour la production et la diffusion de connaissances scientifiques en fonction des résultats souhaités et des conditions existantes. Les résultats obtenus, grâce à une combinaison de méthodes quantitatives et qualitatives, ont permis de mettre en évidence les impacts personnels et collectifs des scénarios, ainsi que le rôle ambigu du temps dans l'émergence des impacts.

Alors que l'analyse des impacts était auparavant quasi exclusivement limitée aux processus de co-construction, cette thèse a élargi le champ en mettant en évidence les synergies entre les pratiques de diffusion et les processus de co-construction pour maximiser l'impact des études en science de la durabilité. Les résultats soulignent la nécessité d'aligner les stratégies de méthodes participatives sur les finalités des études de type *science-pushed*, inscrites dans les sciences de la durabilité. Enfin, la thèse souligne l'importance d'adapter les mécanismes de financement, le fonctionnement des structures scientifiques et l'expertise des équipes pour atteindre les ambitions de la science de la durabilité.

Contents

Introduction	1
1 Program evaluation in sustainable studies	2
1.1 A brief history of science and socio-ecological issues: from multidisciplinary approaches to sustainable studies	2
1.2 Evaluating societal impacts	4
1.3 Partial Conclusion	14
2 The (LUCC) scenarios as a tool for sustainable studies?	16
2.1 Different approaches and categorisation of scenarios	17
2.2 Case of LUCC scenarios in intensive agricultural landscapes: practice at the crossing of multiple disciplines and methods	21
2.3 Partial Conclusion	24
3 Applying evaluation frameworks to LUCC scenarios	25
4 The need for transformative science	30
5 The national context	32
5.1 The Zone Atelier research network: A french socio-ecological initiative	32
5.2 The water management: a regulatory context requiring foresight studies	33
6 Partial conclusions	34
7 Objectives and structure of the thesis	36
7.1 Identifying the knowledge gap	36
7.2 Defining the research questions	37
7.3 Thesis structure	38
Materials	43
1 Scenarios for the Couesnon study area	46
1.1 Overview of the methodology	46
1.2 Study area and LUCC trajectory	47
1.3 Scenario assumptions	49
1.4 LUCC and Landscape connectivity model	51
1.5 Scenarios results	52
2 Scenarios for the Lestolet study area	57
2.1 Overview of the methodology	57
2.2 Study area and LUCC trajectory	59

2.3	Scenario assumptions	59
2.4	Modelling LUCC and impacts on the water resource	60
2.5	Scenarios results	62
3	Partial conclusion	65
Chapter 1 Outcomes of scenarios in the short term		67
1	Introduction: dissemination pathways as multipliers of outcomes	68
2	Article: Evaluating and maximising the outcomes of LUCC scenarios: strategies for an effective dissemination	70
2.1	Introduction	70
2.2	Materials and Methods	73
2.3	Results	78
2.4	Discussion	90
2.5	Conclusion	95
3	Additional results and conclusion of Chapter 1	96
Chapter 2 Outcomes of scenarios in the mid-term		99
1	Introduction: scenarios as boundary objects?	100
2	Article: Do land use and land cover scenarios support more integrated land-use management?	102
2.1	Introduction	103
2.2	Literature review	104
2.3	Context and Matherials	107
2.4	Methods	109
2.5	Results	111
2.6	Discussion	120
2.7	Conclusions	124
3	Additional results and conclusion of Chapter 2	126
Chapter 3 Outcomes of scenarios in the long term		131
1	Introduction: reconstructing the past	132
2	Article: Contributions of local LUCC spatially explicit scenarios for water management: lessons learned from an ex-post evaluation	133
2.1	Introduction	133
2.2	Materials	138

2.3	Methods	141
2.4	Results	144
2.5	Discussion	153
2.6	Conclusions	157
3	Additional results and conclusion of Chapter 3	157
General Conclusions		161
1	Theoretical contribution	162
1.1	Structuring the outcomes of land use studies	162
1.2	Main factors influencing outcomes	166
2	Limits of the study and scientific perspectives for LUCC scenarios	170
3	Contributions and perspectives for sustainable studies	174
Bibliography		177
Appendices		221
1	Appendix Materials	221
1.1	Couenson 2050 dissemination booklet	221
1.2	Norois and Houet's article describing the socio-demographic and geographical context of the Lestolet	250
2	Appendix Chapter 1	268
2.1	Printed version of the workshop survey	268
2.2	Structure and analysis of the workshop survey	273
3	Appendix Chapter 2	277
3.1	List of dissemination workshops	277
3.2	Anonymised data from respondents	278
3.3	Main actors implied in water management for the Couesnon watershed and relations between them	279
4	Appendix Chapter 3	285
4.1	Interview protocol	285
4.2	Interview themes and extracts	293
4.3	Kappa indexes	296
4.4	Evolution of crops trajectories	296
4.5	Strategies followed by farms	297
5	Other contributions	298

5.1	Scientific reports	298
5.2	Conference posters & presentations	298
5.3	Other scientific communication activities	298
	Résumé étendu	299
	Table of Content	325
	List of Figures	329
	List of Tables	331

List of Figures

Introduction	1
1 Hoppe’s interaction models between research and policy	13
2 Building scenarios within the policy cycle context	20
3 Participatory LUCC scenarios as part of the geopropective and sustainable studies . . .	24
4 Thesis structure scheme	38
5 Scheme of the three research articles according to stakeholders groups and the evaluation time	40
6 Contribution of the central chapters in answering the thesis questions	41
Materials	43
7 Location of the study sites	45
8 Method overview for the Couesnon scenarios	46
9 Couesnon watershed LUCC and key geographical features	48
10 Observed (2018) and predicted (2050) land-cover maps for the Couesnon watershed . . .	53
11 Example of the esteemed evolution of crops and landscape elements for one Couesnon scenario	54
12 Landscape connectivity maps for the Couesnon scenarios	55
13 Method overview for the Lestolet scenarios	58
14 Estimated change in farm size for the Lestolet watershed between 1998 and 2020	61
15 Observed (2006) and envisioned (2020) land-cover maps for the Lestolet watershed . . .	64
16 Envisioned (2050) land-cover maps for the Lestolet watershed according to the backcast- ing scenarios	64
Outcomes of scenarios in the short term	67
1.1 Most probable scenario according to respondents’ professional activity	84

Outcomes of scenarios in the mid-term	99
2.1 Areas covered by the principal land management institutions in the Couesnon	109
2.2 Actors involved in the Couesnon water management and their relations with urban management and agriculture actor	112
2.3 Lexicometric analysis results	114
Outcomes of scenarios in the long term	131
3.1 Lestolet study area	138
3.2 Observed and forecasted crop percentages evolution for the Lestolet watershed	150
3.3 Observed distribution of farm production systems in 2006 and 2020 in the Lestolet watershed.	152
3.4 Observed farm production systems in 2006 and 2020 in the Lestolet watershed.	152
General Conclusions	161
3.5 Outcomes of scenarios according to an increasing degree of conditionality	163
3.6 Concise answers to research questions	170
Appendices	221
A.7 Actors involved in the Couesnon water management and their relations with urban management and agriculture actors: details	284
A.8 Comparison of observed and predicted trajectories of crop percentages for the Lestolet	296

List of Tables

Introduction	1
1 Summary of concepts and associated references	11
2 Characteristics of usable scenarios	26
3 Expected outcomes of scenarios according to the individual, group and system level and to the type of outcome	29
Materials	43
4 The five Couesnon scenarios	49
5 Landscape connectivity change in area and quality for the Couesnon scenarios	56
6 Observed (2018) and estimated (2050) water quantity and quality for the Couesnon scenarios	56
7 Evolution of the agricultural production systems and farm size	65
Outcomes of scenarios in the short term	67
1.1 Research topics and correspondent survey sections	78
1.2 Differences in previous ideas on BGINs and evaluation of research quality by professional activity	79
1.3 Spearman’s non-parametric correlations between questions.	81
1.4 Median value, average rank, Kruskal-Wallis and Dunn test relatively to the familiarity with the study area	82
1.5 Median value, average rank, Kruskal-Wallis and Dunn test relatively to the professional activity	83
Outcomes of scenarios in the mid-term	99
2.1 Mid term outcomes resulting from thematic analysis	116

Outcomes of scenarios in the long term	131
3.1 Scenario outcomes and influencing factors in the long term	148
3.2 Elements to consider during the stages of the scenario-building process to enhance scenario outcomes.	153
Appendices	221
A.3 Dissemination workshops	277
A.4 Interview themes and extracts from Lestolet’s local actors	295
A.5 Similarity indexes between observed and scenario-predicted land-use cover for the Lestolet	296
A.6 Number of hectares and farms that followed a land use strategy in the Lestolet	297

Titre : Apports des scénarios de changement d'occupation et d'usages des sols pour les acteurs locaux: une évaluation temporelle appliquée à la gestion de l'eau et de l'environnement à des échelles fines

Mots clés : scénarios de changement d'occupation et d'usage du sol, évaluation des impacts, gestion intégrée, chemins d'impact, science de la durabilité

Résumé : Avec l'ambition d'orienter la recherche vers l'action, caractéristique des dernières décennies, la question d'évaluer les bénéfices sociétaux de ce type de recherche se pose. À travers l'analyse de deux cas d'étude, cette thèse évalue les impacts des scénarios de changement d'occupation et d'usage du sol (LUCC) qui visent à soutenir la gestion locale de l'eau en Bretagne, ainsi que le processus et les conditions qui permettent leur apparition. Pour le premier cas d'étude (bassin versant du Couesnon), nous avons organisé des ateliers de dissémination des scénarios et évalué les impacts à court et moyen terme via des enquêtes interactives et des entretiens semi-directifs. Pour le deuxième (bassin versant du Lestolet), les impacts à

long terme ont été évalués en menant des entretiens semi-directifs, couplés à une comparaison quantitative entre le LUCC observé et simulé. Les résultats montrent la dominance des impacts cognitifs. Des impacts instrumentaux ont également été enregistrés lorsque les scénarios agissent comme catalyseurs d'une volonté préexistante d'améliorer la gestion intégrée du territoire. En outre, nous montrons l'effet controversé du temps sur les impacts et la complémentarité entre la co-production et de diffusion des scénarios. Cependant, le rôle transformant des scénarios reste limité, ouvrant ainsi de nouvelles perspectives quant au développement de scénarios ancrés dans une approche transformative.

Title : Outcomes of fine scales land use and land cover change scenarios: a temporal assessment applied to water and environmental management

Keywords : LUCC scenarios, outcomes evaluation, integrated management, impact pathways, sustainable studies

Abstract : With the growing ambition for producing action-oriented research, the question of evaluating the societal benefits of this type of research arises. This thesis evaluates the outcomes of two study cases of land use and land cover change (LUCC) scenarios developed to support local water management in Brittany. For the first case study (Couesnon watershed), we organised several dissemination workshops and evaluated short- and mid-term outcomes via interactive surveys and semi-structured. For the second case study (Lestolet watershed), we evaluated long-term outcomes by conducting semi-structured interviews coupled with a quantitative comparison between observed and simulated LUCC.

The results highlight the cognitive, political, and instrumental outcomes of the scenarios and the process and conditions that allowed them to arise. Despite the dominance of cognitive outcomes in the short term, scenarios produced instrumental outcomes by working as catalysts of a pre-existing will to enhance integrated management. Moreover, we highlight time's controversial effect on outcomes and show that feedback between scenarios dissemination and co-production positively affects outcomes. Nevertheless, the transformative impact of scenarios is limited, opening new perspectives for developing scenarios rooted in a transformative study approach.