UNIVERSITÉ DU LUXEMBOURG

PhD-FHSE-2021-045
The Faculty of Humanities, Education and Social Sciences

DISSERTATION

Defence held on 16/12/2021 in Esch-sur-Alzette, Luxembourg

to obtain the degree of

DOCTEUR DE L'UNIVERSITÉ DU LUXEMBOURG

EN SCIENCES SOCIALES

by

Karl PICKAR
Born on 1 February 1993 in the City of Luxembourg, Luxembourg

EXPLORING THE POTENTIAL OF CITIZEN SCIENCE FOR MORE ADAPTIVE AND SUSTAINABLE SURFACE WATER GOVERNANCE IN LUXEMBOURG

Dissertation defence committee

Dr Ariane König, dissertation supervisor
Sr Research Scientist, Université du Luxembourg

Dr Christian Schulz, Chairman
Professor, Université du Luxembourg

Dr Muki Haklay
Professor, University College London

Dr Joachim Hansen
Professor, Université du Luxembourg

Dr Kerry Waylen
Sr Researcher, James Hutton Institute

The following Ph.D. thesis describes a research project, which aimed to explore the potential of environmental citizen science to contribute to more adaptive surface water governance in Luxembourg and beyond. Citizen science projects are research projects, which are marked by the active engagement of members of the public. Adaptive governance refers to a type of governance, which is based on the engagement of diverse types of knowledge, perspectives, and stakeholders, and on building adaptive capacity in the face of unforeseen change and coordination across levels and scales. The research contributes to the conceptual development of citizen science in the context of adaptive governance and provides an example of a co-design process with a focus on building a citizen science tool for the exploration of social-ecological systems. In addition, the thesis contributes to practical development by identifying a set of opportunities for change of current data collection and meaning-making towards more adaptive surface water governance in Luxembourg and by making first experiences with surface water citizen science in Luxembourg, while engaging multiple place-based, regional, and national partners.

Towards the above-mentioned goal, the research project, first, examined the current data collection programmes and meaning-making approaches for the governance of surface water bodies in Luxembourg. Prevailing practices are discussed based on key criteria for adaptive governance based on relevant academic literature. The research project, then, examined different approaches to environmental citizen science as alternative and complementary data collection programmes and meaning-making approaches in view of their potential to contribute to more adaptive surface water governance.

The research project set out to do so by taking a transdisciplinary sustainability science research approach. The methodology encompassed (1) semi-structured qualitative interviews with specialists in the water domain and documentary review to

gain insights into the current data collection programmes and meaning-making approaches in Luxembourg, (2) the trialling of two contributory surface water citizen science projects based on the Freshwater Watch citizen science tool by Earthwatch, an approach, in which volunteers are called upon to engage in data collection designed by scientists, and (3) the co-creation of surface water citizen science projects with interested groups based in Luxembourg centred around co-design workshops, in which the co-design partners were invited to explore changes and challenges and to develop sets of parameters for investigating the state of surface water bodies based on their research interests.

In line with other studies, the findings show that citizen science can, indeed, constitute new sources of data on surface water bodies and, thus, increase data availability. Citizen science can lead to datasets on multiple temporal and spatial levels, and may increase overall transparency (of, for example, data on water quality). It can also contribute to more transparency in the meaning of data and increase the capacity for individual meaning-making.

The findings show, in particular, that citizen science can increase the diversity of approaches to data collection and meaning-making, as projects constitute channels for the engagement of different knowledge types and can utilise new funding sources with alternative funding criteria. In addition, the case studies have shown that citizen science is particularly useful for complementing current official data collection, in particular, with respect to data from smaller water bodies, and for linking ecological data with social and technological data for a faster detection of changes in the system and a better grasp of the evolution of drivers of change.

Interestingly, the study suggests that contributory citizen science may be better suited for the initial engagement of those, who are not specialised or professionally engaged in the water domain. Specialists and professionals, in turn, showed a bigger interest in engaging in co-design.

This research project has been funded by the University of Luxembourg under the project acronym WATGOV.

I would like to thank my PhD supervisor Ariane König for her support and guidance.

My gratitude also goes to

Muki Haklay, Christian Schulz, Joachim Hansen, and Kerry Waylen,

Kristina Hondrila, Bo Raber, the other members of the Sustainability Science Research Group, and all other colleagues at the university,

Alexandra Arendt, Birgit Kausch, Rose Scharfe, and Stephan Müllenborn,

The members of the NEXUS FUTURES Reference Group,

All those, who took part in the interviews, co-design workshops, in WaterBlitz’19 and ’21, and the Citizen Science Project at the Syr,

All those, who shared Project Waterblitz and workshop invitations, and

Earthwatch Europe and the Royal Bank of Canada.

A special thanks also goes to Tea, Eric, Gilles, and Patrick and to Tiina and Alwin.

Table of Contents

List of Text Boxes

Chapter 1. Introduction

The state of freshwater bodies around the globe is a topic of continuous concern. Although anthropogenic pressures have been evolving, social factors have been directly and indirectly impacting their state over the past millennia (United Nations Environment Programme, 2021). Today, nutrients and chemicals are two of the major substances affecting freshwater quality (European Environment Agency, 2018). Nutrients may lead to accelerated eutrophication, which can have many adverse consequences for nature and humans. Fish and other aquatic organisms may die, as the dissolved oxygen is used up by decomposing algae (European Environment Agency, 2016). The occurrence of blue algae may cause serious health problems for humans and, therefore, require a discontinuation of cultural and leisure activities. Anthropogenic nutrient emissions can originate from agricultural activity as run-off or leaching from fields and from treated and untreated wastewater from households and industry. Even though the issue has been known for decades, it is still very much a concern today (European Environment Agency, 2018). Many directives, laws, and regulations have been passed in relation to nutrient concentrations in surface water bodies in the European Union and in Luxembourg (*Council Directive 91/271/EEC of 21 May 1991 Concerning Urban Waste-Water Treatment*, 1991; *Council Directive of 12 December 1991 Concerning the Protection of Water against Pollution Caused by Nitrates from Agricultural Sources (91/676/EEC)*, 1991; *Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 Establishing a Framework for Community Action in the Field of Water Policy*, 2000; *Loi Du 19 Décembre 2008 Relative à l'eau*, 2008; *Règlement Grand-Ducal Du 13 Mai 1994 Relatif Au Traitement Des Eaux Urbaines Résiduaires*, 1994; *Règlement Grand-Ducal Du 24 Novembre 2000 Concernant l'utilisation de Fertilisants Azotés Dans l'agriculture*, 2000). In general, technological advancement has been known to come with implications for freshwater quality, even in areas which may not seem directly connected. Similar to nutrients, pesticides and their degradation products may be found in freshwater bodies due to run-off or leaching. Even pharmaceuticals and their degradation products, when consumed and excreted, mostly end up in freshwater bodies after passing through wastewater treatment plants, which, as of now, are generally not suited to address them. Talks about adopting additional stages of wastewater treatment are on-going in many places, but, without coordination across sectors, it will not be long until new substances find their way to the market (European Environment Agency, 2018).

Not only freshwater quality, however, is an important challenge today. The related hydromorphological properties of water courses also play a key role in the quality of the aquatic ecosystems, of which freshwater quality is one aspect, including habitats, and in the protection of settlements against floods (European Environment Agency, 2018). The straightening of water courses and bank reinforcements of the past centuries, for example, still dominate much of the landscapes today (European Environment Agency, 2018).

Due to population and economic growth, the pressure on freshwater bodies are intensifying and consequences are far from passing by society (Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services, 2019b). The degradation of ecosystems reduces their ability to provide services that humans rely on. Aquatic ecosystems, for example, provide water for drinking, fish for eating, a series of regulation services, such as the natural ability of freshwater ecosystems to cope with certain amounts of pollution, and cultural services (United Nations Environment Programme, 2021). In Luxembourg, for example, several freshwater sources cannot be used for drinking water production due to nutrient levels exceeding thresholds associated with adverse effects on human health (Bingenheimer, 2019). The threshold set by the World Health Organisation and adopted by the European Union for nitrate concentrations in drinking water is at 50 mg/L (Eurostat, 2012; World Health Organization, 2011). In addition, multiple lakes in the country are subject to summerly access bans due to toxic algal blooms (Oé, 2017; Tageblatt Lëtzebuerg, 2021).

Hydromorphological alterations to water courses, such as bank reinforcements and the reduction in the size of spaces for waterbodies to extend beyond the normal beds, also played a role in one of the worst floods in Luxembourg and many other nearby places in July 2021.

This thesis conceives of freshwater bodies as components within intricate social-ecological systems. The state of freshwater systems changes interdependently with social and technological systems and other ecological factors. Biodiversity, for example, is one such factor. Biodiversity loss is a major concern today, of which the reduction in fish species forms a significant part. Among other pressures, such as over-fishing, declining ecosystem quality is a key cause (United Nations Environment Programme, 2021). Climate change, one of the biggest challenges for society of current times, also shares many links with freshwater. Changing weather patterns - in particular, increasing temperatures and changing rainfall patterns - are prone to affect surface water quantity. They may lead to changing surface water volumes in time and place (United Nations Environment Programme, 2021). Even though the concrete form of the impacts of climate change on freshwater bodies are highly uncertain (Whitehead et al., 2009), changes in seasonal precipitation and temperature patterns, including heatwaves and exceptionally low volumes of rainfall, may impact the effect of emitted, treated wastewater on water quality due to the reduction of the dilution of pollutants, and excessive rainfall may overwhelm wastewater treatment systems and, thus, render them ineffective (United Nations Environment Programme, 2021). In addition, higher pollution levels of freshwater bodies may lead to increased greenhouse gas emissions by aquatic organisms leading to higher greenhouse gas concentrations in the atmosphere (L. Ho et al., 2020), and anthropogenic changes, in turn, may have an effect on aquatic plant diversity due to changing concentrations in bicarbonate and carbon dioxide, on which many aquatic plants rely for photosynthesis (United Nations Environment Programme, 2020).

Arguably, attaining a good state of our freshwater bodies is one of the most important sustainability challenges of our time. The sustainable governance of freshwater bodies faces many obstacles, which can be generally linked with two key properties of sustainability challenges, namely complexity and uncertainty. Complexity relates to such challenges being embedded in social-ecological systems, in which components are tightly intertwined and change interdependently, as the previous paragraphs exemplify. As a result, change can hardly be predicted and our understanding of system processes is limited. Uncertainty is generally classified into reducible and irreducible uncertainty. This entails that some of it can be reduced, for example, by further research, and that some of it cannot be eliminated, which requires arrangements for building preparedness for unforeseen changes and the capacity to adapt in the fact of it (Ascough et al., 2008; Hasselman, 2017).

Engaging diverse stakeholders into governance processes promises to reduce uncertainty by gathering available information from diverse sources on the system (scientifically produced or otherwise) for a more comprehensive understanding of system processes. This is based on the assumption that stakeholders, who frequently interact with a certain social-ecological system, have insights into its functioning based on experience and observation that are valuable in governance. It is acknowledged that local communities and indigenous groups have found ways to govern natural resources in sustainable ways, also, in the context of freshwater, based on local knowledge that is valuable for governance (Dietz et al., 2003; Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services, 2019a). Stakeholder engagement is also essential in making the necessary value-choices that come with decision-making in the research and governance of sustainability challenges.

The values that humans credit to freshwater ecosystems may be related to the services that they provide, as described in a previous paragraph, or to their intrinsic value. The choices are necessarily based on trade-offs between different interests and values and depend on the kind of future that is sought (United Nations, 2021).

Sustainability challenges, therefore, require a kind of governance that is capable of adequately addressing their complexity and uncertainty. Accordingly, multiple channels demand a shift towards more networked and adaptive governance practices (United Nations, 2021). Adaptive governance is specifically designed for these circumstances, and it is, therefore, a key concept of this thesis. As Chapter 2 outlines in more detail, adaptive governance is based on the engagement of diverse types of knowledge, perspectives, and stakeholders, on building adaptive capacity in the face of unforeseen change, and on coordination across levels and scales.

An approach to research - in particular, data collection and meaning-making - that is increasingly put forward in the context of the governance of sustainability challenges is citizen science. Citizen science in general terms refers to the meaningful and active engagement of volunteers in research projects. It is often linked with a number of benefits in this context. It has, for example, proven to be a viable data source for governance purposes, also in the context of freshwater (United Nations, 2021; United Nations Environment Programme, 2021). It is also seen as a channel for the engagement of stakeholders (in the context of sustainability challenges, this also refers to citizens) in research processes and paves the way for more participatory decision-making in governance (United Nations, 2021; United Nations Environment Programme, 2021). Through stakeholder engagement, citizen science promises to support the ground-truthing of data and information - that is, the checking for correctness of remote sensing data using information collected by site visits (United Nations, 2021).

1.1 Main Research Question

While the literature on the concept of citizen science has been expanding exponentially in recent years and citizen science is often positioned as a helpful approach in the context of the governance of sustainability challenges, such as attaining a good state of freshwater bodies, it has only been rarely studied in an adaptive governance framework. Adaptive governance is a key approach for addressing sustainability challenges, as discussed in a previous paragraph, and research in this area is long due. Citizen science is a promising approach for data collection and meaning-making in adaptive governance, in particular, because it is based on the engagement of stakeholders in research processes and may provide opportunities for the engagement of diverse knowledge types and perspectives in research design and data collection. The thesis centres on one main research question: *What role can citizen science play in data collection and meaning-making for the adaptive governance of social-ecological systems?* The main research question is divided into three sub-questions, which are introduced in detail in section 2.3:

A. In how far are current data collection programmes and meaning-making approaches compatible with key principles of adaptive governance of social-ecological systems? What are opportunities for change?

B. How can contributory citizen science contribute to the adaptive governance of social-ecological systems? How can it address the opportunities for change identified in Research Question A?

C. How can co-created citizen science contribute to the adaptive governance of social-ecological systems? How can it address the opportunities for change identified in Research Question A?

The research sets out to answer these questions by exploring the case of surface water in Luxembourg and the ways, in which surface water citizen science may contribute to current data collection and meaning-making by four case studies of surface water citizen science in Luxembourg, which are based on projects that were undertaken as part of the research project. Another distinction criterion of this thesis is the comparison of two common approaches to environmental citizen science, namely contributory and co-created citizen science (two case studies each).

1.2 Research Context

The research was concerned with the case of surface water governance in Luxembourg. The selection of Luxembourg was dependent on multiple factors. The Grand Duchy of Luxembourg is a relatively small country (2586.4 km^2) in north-western Europe. It has two major administrative units: the communal and national administrations. As result, the paths to decision-makers are relatively short. Due to the small size of the country and its administrational structure, key organisations and individuals are few compared to larger countries, such as Germany. Luxembourg is landlocked and shares borders with Belgium, Germany, and France. It has four major surface water bodies, namely the rivers Moselle, Sure, Alzette and Our, all of which are part of the International Rhine River Basin District. Only the Chiers in the South-West drains into the Meuse. The North-West of the country is marked by the dammed Upper-Sure lake, which extends over 3.8 km^2. It is also the main source of drinking water in Luxembourg. Water governance on national level is mainly a responsibility of the Water Management Agency, which underlies the Ministry of the Environment, Climate and Sustainable Development. Among others, the Water Management Agency is charged with the technical implementation of the governmental monitoring programmes and with the implementation of measures, whereas the Ministry steers the general political direction of governmental action, for example, seeking to attain the goals stated in the governmental programme in relation to the state of freshwater bodies. On regional and communal level, communal administrations and intercommunal syndicates also participate in and undertake the implementation of measures. Chapter 4 describes in detail the actors engaged in data collection and meaning-making for water governance in Luxembourg as well as the data collection programmes and meaning-making approaches themselves. The major law in relation to surface water governance is the Loi du 19 Décembre 2008 Relative à l'Eau, which is the national transposition of the Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 Establishing a Framework for Community Action in the Field of Water Policy.

1.3 Structure of the Thesis

Figure 1 shows the structure, in which the thesis sets out to answer the main research question. The conceptual chapter (Chapter 2) is based on extensive reviews of the academic literature on the key concepts of the thesis, namely adaptive governance and citizen science. In particular, the chapter discusses the role of data collection and meaning-making in adaptive governance and the ways, in which citizen science can contribute. Based on the literature, two evaluation frameworks are developed as a basis for the discussion of the empirical results: one framework for the evaluation of the compatibility of data collection programmes and meaning-making approaches with key principles of adaptive governance and another for the evaluation of the contributions of citizen science to adaptive governance. The methodology chapter (Chapter 3) describes transdisciplinary sustainability science as the adopted research approach and the methods for data collection and analysis. Chapter 4 to 7 are based on the results of the data collection and analysis carried out as part of the research project. Chapter 4 presents the current data collection programmes and meaning-making approaches for the governance of surface water bodies in Luxembourg and discusses their compatibility with key criteria of adaptive governance using the appropriate framework presented in Chapter 2. Based on this, it outlines a number of opportunities for change. Chapters 5 and 6 examine the four case studies of surface water citizen science undertaken as part of the research project. After their presentation, a discussion is provided in a very similar manner as in Chapter 4 to explore the compatibility of the case studies with the key criteria of adaptive governance using the appropriate framework. Building on this, a discussion is provided, which focuses on the contributions that citizen science could make to current practices for more adaptive governance based on the opportunities for change identified in Chapter 4. While Chapters 5 and 6 focus on contributory and co-created citizen science approaches respectively, Chapter 7 brings the insights together. It is designated to a comparison of the two approaches in terms of findings and experiences. It discusses the contributions of citizen science identified by means of the empirical inquiry by comparing those presented in the academic literature and identifying differences. Chapter 8 offers a conclusion to the thesis. It recapitulates the key insights by research question, provides an outlook on the case studies, and proposes further research avenues.

Figure 1

Thesis Structure

Chapter 1. Introduction

Chapter 2. Key Concepts

Data Collection and Meaning-Making in Adaptive Governance and the Contribution of Citizen Science

Chapter 3. Methodology

Chapter 4. Surface Water Governance in Luxembourg

The Compatibility of Current Data Collection and Meaning-Making with Key Principles of Adaptive Governance, and Opportunities for Change

Chapter 5. Case Studies Streams-Corporate Partnership and Waterblitz

Contributory Surface Water Citizen Science in Luxembourg and Contributions to Adaptive Governance

Chapter 6. Case Studies Sources-Mullerthal and Streams-Syre

Co-Created Surface Water Citizen Science in Luxembourg and Contributions to Adaptive Governance

Chapter 7. Contributory and Co-Created Surface Water Citizen Science

A Comparison of Findings and Experiences

Chapter 8. Conclusions

Note. The empirical chapters are highlighted in dark green.

Chapter 2. Data Collection and Meaning-Making in Adaptive Governance and the Contribution of Citizen Science

Chapter 2 is a conceptual chapter and it is based on extensive reviews of the literature related to adaptive governance and citizen science. In particular, chapter 2 focuses on the form and role of data collection and meaning-making in adaptive governance and on the ways in which citizen science can contribute to this role. The goal of the literature review was to develop two frameworks, which provide the basis for the discussion of the results of the empirical study. Accordingly, Chapter 2 encompasses three main sections. Section 2.1 introduces the key concept of adaptive governance in the context of sustainability challenges and identifies the engagement of diverse perspectives, experimentation and flexibility, and coordination across levels and scales as key features of data collection and meaning-making in adaptive governance. Section 2.2 describes the practices of citizen science and its evolution, before delving into the key contributions of citizen science to adaptive governance identified from existing literature, while distinguishing between quantitative and qualitative contributions. Section 2.3 presents research areas identified based on the literature reviews, to which the research aims to contribute, and the research questions. Section 2.4 outlines the research scope. Section 2.5 is based on the two previous sections and describes two frameworks: one framework for the evaluation of the compatibility of data collection programmes and meaning-making approaches with key principles of adaptive governance and another for the evaluation of the contributions of citizen science to adaptive governance. Later in the thesis, the two frameworks are used as a basis for the reflexive discussion of the empirical results.

2.1 Data Collection and Meaning-Making in Adaptive Governance and Practical Recommendations

This first section is concerned with introducing adaptive governance as a main concept of the thesis and, in particular, with identifying and discussing key features of data collection and meaning-making in adaptive governance. Towards this goal, section 2.1.1 puts adaptive governance in the context of sustainability challenges and, thus, social-ecological systems to provide an argument for the suitability of the adaptive governance approaches with the governance of water. To frame the discussion of the role and form of data collection and meaning-making in adaptive governance, section 2.1.2 describes the role of science in adaptive governance in general terms, while pointing out how this role of science attempts to address the features of sustainability challenges identified in the previous section. To situate the approach to adaptive governance deployed in this thesis, the concept is introduced in section 2.1.3 by outlining its conceptual origins in different literature fields, while also defining the related concepts of adaptive management and adaptive co-management to avoid any confusion among terms. The following sections 2.1.4-2.1.7, then, focus on the features of data collection programmes and meaning-making approaches in adaptive governance identified as key by a literature review: the engagement of diverse perspectives, experimentation and flexibility, and coordination across levels and scales as a basis for the later evaluation frameworks.

2.1.1 Adaptive Governance and Sustainability Challenges

Adaptive governance is a form of governance, which is often presented as particularly suited in the context of sustainability challenges. It acknowledges the complexity and uncertainty inherent to such challenges and seeks to address them. The unique attributes of sustainability challenges are well-summarised in Rittel and Webber’s account of so-called wicked problems originally developed in the face of social problems in urban planning (Jerneck et al., 2011; Miller, 2013; Rittel & Webber, 1973; Skaburskis, 2008). Since its initial formulation, the concept has received increasing attention throughout numerous scientific fields, including sustainability science (Jerneck et al., 2011; Miller, 2013). It is generally described by ten attributes: wicked problems

- are unique,
- cannot be clearly defined,
- are multi-scalar and interconnected,
- affect multiple stakeholders with often conflicting agendas,
- surpass organisational and disciplinary boundaries, and
- cannot be solved.

  Any attempts at addressing wicked problems

- create intended and unintended consequences,
- are not right or wrong, but better or worse, and
- cannot be easily evaluated (see, for example, Potter et al. 2019; Skaburskis 2008).

Sustainability challenges can, therefore, be seen as complex and uncertain. They are complex in that they are embedded in social-ecological systems, in which components are tightly intertwined and change interdependently. As a result, change can hardly be predicted and our understanding of system processes is limited. These two features are referred to by uncertainty. The uncertainty related to sustainability challenges is often characterised as reducible and irreducible. Reducible uncertainty is related to imperfect knowledge, which can be further reduced by scientific research. It is also related to incomplete knowledge, which requires the engagement of diverse stakeholders for gathering all available information to further our understanding of system processes. Irreducible uncertainty, in turn, is related to the inherent unpredictability of social and natural systems. The only arrangement humans can make in the face of irreducible uncertainty is to be prepared for unforeseen changes and build the capacity to adapt (Ascough et al., 2008; Hasselman, 2017; W. E. Walker et al., 2003). As the later sections will show, the approach to adaptive governance adopted by this thesis acknowledges these features of sustainability challenges and has provisions to address them. As the following section demonstrates, the role of science for adaptive governance in the context of sustainability challenges is also different from established approaches.

2.1.2 The Role of Science in the Face of Sustainability Challenges

The role of science in governance, in general, is to develop evidence drawn upon in decision-making processes. High system uncertainties and high decision stakes are key components of the argument for a "post-normal science" as defined by Silvio Funtowicz and Jerome Ravetz (1993). Ravetz argues that "normal" science is not adequate to address such contexts. Normal science is described as

- Assuming that every problem has only one solution,
- Being conducted by disinterested scientists, who produce value-free, objective facts,
- Aiming to attain the truth or, at least, certain factual knowledge,
- Studying standardised versions of the natural world in artificially set pure and stable conditions of laboratory experiments (at least in the natural sciences),
- Assuming expertise is the only form of knowledge that is admissible (Ravetz, 1999).

On the other hand, the position and role of science has changed, arguably from the state of existing independent of society in the so-called ivory tower to being embedded in society (Dedeurwaerdere, 2014; Ravetz, 1999). For science in social contexts, of which sustainability challenges are part, in which "facts are uncertain, values in dispute, stakes high, and decision urgent", the above-mentioned characteristics of normal science do not hold up anymore (Ravetz 1999: 649). In these context, all “too often, we must make hard policy decisions where our only scientific inputs are irremediably soft” (that is, in the form of subjective value-judgements) (Ravetz 1999: 649). Key features are:

- Scientists are not disinterested, but stakeholders, as career aspiration and prestige and power as well as other commitments may influence research. Increasingly competitive funding opportunities may influence research into the direction of funding strategies.
- Problems in practice often have more than one answer or none at all.
- In these new contexts, scientists have to directly interact with nature, that is it cannot be tamed, and they have to deal with it in its disturbed and reactive state leading to high uncertainties, some of which are irreducible through further research.
- In these new contexts, other non-scientific institutions are capable of challenging scientific findings (e.g. environmental organisations). As management involves value-choices, considering all stakeholders in policy-making is essential. Public participation in policy-making is embodied by the concept of extended peer communities, which go beyond stakeholder participation to include everyone interested to working towards policy. Extended facts, as a result, become increasingly important. These are based on types of knowledge, which may not comply with normal scientific quality standards, but can be useful in evaluating policy proposals or making own proposals (Ravetz, 1999).

These features of a science for adaptive governance can be closely linked to the description of sustainability challenges provided in the previous section and represent ways, in which traditional scientific enterprise may be revised to better serve in these situations.

2.1.3 Origins of Adaptive Governance

The origins of adaptive governance can be traced back to at least four bodies of literature, which each have contributed aspects to the stance of adaptive governance adopted in this thesis. These are adaptive management, (adaptive) co-management, the sustainable and effective management of common pool resources, and natural resource governance. Adaptive management has developed largely based on the work of Holling. Stemming from the field of ecology, Holling was concerned with, in his words, "adaptive environmental management and assessment" (Holling, 1978). The approaches to adaptive management were later classified into two broad camps - that is, active and passive forms. Active adaptive management, which has been rather linked to positivist approaches to scientific inquiry, is based on the belief that scientific knowledge is absolute and that uncertainty is something to be reduced. It is rather based on the participation of diverse "experts" with limited room for non-specialists, and it uses experimentation and hypothesis testing to pre-trial different approaches, generate new knowledge, and find the optimal approach (Hasselman, 2017; Huitema et al., 2009). Passive adaptive management, in contrast, is rather based on the belief that "the production of knowledge (…) [is] always and inevitably in part a social (…) process" (Cooney & Lang, 2007, p. 538). Here, management itself is seen as experimentation. One of its goals is to build responsiveness in the face of unpredictability. Passive adaptive management is more open to socially-held knowledge (Hasselman, 2017; Huitema et al., 2009; see also Walters & Hilborn, 1978). The stance to adaptive governance adopted in this thesis incorporates the concept of adaptive management in its passive form as it sees all governance and management interventions as experiments and uncertainty as prevailing.

Co-Management refers to the participation of a local community user group in the management of a local resource (Berkes, 1989). On this basis, the concept of adaptive co-management has developed, integrating features of adaptive management and co-management (Berkes, 2009). As a result, adaptive co-management is presented as a form of adaptive management, which focuses on the engagement of resource citizen scientists and local communities in management processes. In addition, it often comes with an institutional dimension as it is based on links between and learning among diverse actors (Berkes, 2009; Hasselman, 2017; Plummer et al., 2013). Common features of different approaches to adaptive co-management are that it is described as a "dynamic, multilevel, and polycentric [process] [that] (…) seeks to find some balance between decentralised and centralised control" (Djalante et al., 2011, p. 2). In the stance of adaptive governance adopted by this thesis as the following section will show, the engagement of stakeholders, including place-based communities, is seen as a key feature as well as an approach that involves coordination across multiple levels and scales.

The literature on the sustainable and effective management of common pool resources has been another carrier of the concept of adaptive governance. In fact, Dietz et al. (2003) discussed the struggle of governing the commons and ways to do so more effectively by describing a kind of adaptive governance based on dialogue among diverse parties, institutional diversity, and experimentation, learning, and change. This stream of literature is largely based on the work of Oström and associates and has treated topics, such as institutions (Ostrom, 1990) and polycentric governance arrangements (Ostrom, 2010) further discussed in section 2.1.6. Experimentation, adaptation and learning as well as polycentric arrangements are a key component of the argument of this thesis.

From the perspective of natural resource governance, Brunner et al. (2005) link adaptive governance with community-based approaches. They put forward three pillars of their practice of adaptive governance. (1) It is based on a rather integrative than reductive science, considering multiple kinds of knowledge. (2) In policy-making, multiple interests are considered and a balance is sought and (3) community-based decision-making is favourable as it can, for example, overcome gridlock situations. In essence, according to Brunner et al. (2005) policy needs to take into account the specific application contexts by acknowledging differences and changes and having appropriate provisions for flexibility. It needs to build on the common interest of a community and adapt to the "experience[s] on the ground as real people interact with each other and the soils, waters, plants, and animals in specific contexts" (Brunner et al., 2005, p. 19). Traditional reductionist science alone "is not sufficient as a foundation for sound policies and decision-making structures, even though science can make important contributions." (Brunner et al., 2005, p. 20). The stance adopted in this thesis is based on the assumption that the taking account of the social and other application contexts is essential for sustainability. The following three sections focus on further discussing the stance to adaptive governance adopted by this thesis, while outlining key criteria of data collection and meaning-making in adaptive governance as a basis for developing the frameworks presented in section 2.5.

2.1.4 Diverse Knowledge Types and Perspectives

In the governance of social-ecological systems, input from multiple and diverse stakeholders is essential for democratising the necessary value-choices (e.g. related to decision of the desirable future system states to pursue). In situations marked by multiple, diverse, and often contradicting perspectives, this is essential for the legitimacy of decisions and action. Sustainability challenges as wicked problems, involve multiple and often conflicting perspectives (see the definition of sustainability challenges and wicked problems in the introduction) and decision-making entails value-choices (Cooney & Lang, 2007). As such, stakeholders define the challenge according to their particular perspective and in line with their values and corresponding interests. In the same way, stakeholders have diverging criteria for evaluating desirable system states and desirable approaches to attain them. In the context of sustainability challenges, decisions and actions are considered legitimate and efficient, if they take account of the multiple and diverse values and interests of the stakeholders within the realm of possibilities (Cooney & Lang, 2007). Legitimacy of decisions and actions in essential for collective action.

This has many implications for data collection and meaning-making in adaptive governance. In general, it is argued that scientific knowledge production is always a social process (Cooney & Lang, 2007) (which is also in line with the paradigmatic perspective of this thesis), as the reality that exists independent of humans is experienced, thought of, and expressed inter-subjectively - that is, mediated by the person, who is experiencing, thinking of, expressing, and theorising as well as the cultural context that he or she is part of (Heron & Reason, 1997). Scientific research, therefore, especially when applied in social contexts, such as sustainability challenges, involves value-choices, for example, in the definition of the research questions, the approach for developing empirical evidence, and analysis. In such a context, it may be argued that, if science is to serve "rather than dictate the information needs of policy makers and resource citizen scientists", then it needs to take account of the multiple and diverse perspectives, values, and interests of the stakeholders (Cooney & Lang, 2007; Nelson et al., 2008, p. 591).

Alongside taking account of the perspectives of multiple and diverse stakeholders in governance and management, it is considered important to build on scientific place-based and non-scientific forms of knowledge for adaptive governance. In the context of the governance and management of social-ecological challenges, uncertainty related to our understanding of system processes is high (Ascough et al., 2008; Hasselman, 2017; Ravetz, 1999). This means that evidence for decision-making is limited and predictions are difficult (for example, regarding the impacts of interventions). Especially in situations like these, it is important to consider all available information, either scientifically produced information or information held by nonscientists, for example, by experience and observation (Folke et al., 2005). This need was brought forward by Funtowicz and Ravetz (1993) under the name “extended facts”. Social-Ecological systems may be understood in the best way possible by engaging different points of view in the research processes - that is, the points of view of different scientific disciplines as well as from practice and relevant communities. In this way, scientific perspectives are one of many. In addition, there are no one-size-fits-all solutions (Nelson et al., 2008). Social-ecological challenges take different forms depending on time and place. Approaches, therefore, have to be also tailored to the particular social-ecological setting (Nelson et al., 2008). As a result, considering not only abstract scientific knowledge but also place-based scientific and place-based non-scientific knowledge is essential (Folke et al., 2005). In the words of Brunner et al. (2005, p. 25), considering “the best available science” is important in adaptive governance alongside “applied science” to account for the uniqueness of specific application contexts and “local knowledge”, which encompasses knowledge produced by experience and observation without adhering to rules of scientific inquiry. Stakeholder engagement in data collection and meaning-making can lead to an improved evidence base that is also more relevant to management questions and contribute to the transparency and legitimacy of decisions (Cundill & Fabricius, 2009).

As regards the approach to engaging stakeholder perspectives and non-scientific knowledge in governance and management, negotiation among the stakeholders is put forward as key to build common understanding and to increase legitimacy of decisions and action (Cooney & Lang, 2007; Dietz et al., 2003; Pereira & Ruysenaar, 2012). Negotiation is understood as deliberation with the aim to produce a common output. Due to the fact that there are not only multiple and diverse, but also often conflicting perspectives, conflict resolution is a topic with increasing importance (Nelson et al., 2008).

Closely connected to stakeholder engagement are the concepts of legitimacy and transparency. Stakeholder engagement is largely seen as a promising way to increase the legitimacy and transparency of decision-making in governance and management and to contribute to more legitimate measures that are broadly supported across society (Curtin & Meijer, 2006; Van Assche et al., 2017). They are two features of good governance (Lockwood et al., 2010) and are seen to contribute to adaptive governance (Chaffin et al., 2014). Transparency is defined as "(a) the visibility of decision-making processes; (b) the clarity with which the reasoning behind decisions is communicated; and (c) the ready availability of relevant information about governance and performance in an organization" (Lockwood et al., 2010, p. 993). Data that is used as evidence in decision-making, therefore, needs to be publicly accessible as well as the way in which it is used (Waylen et al., 2019).

Legitimacy, social legitimacy in particular, is closely connected to transparency in this context. Social legitimacy is an indicator for the 'affective loyalty' of those affected, which can be grounded in common interests and/or identity (Curtin & Meijer, 2006). In the context of sustainability challenges, socially legitimate decisions and actions are essential for collective support and essentially their success. Social acceptance is key. Social acceptance can be a result of a wide agreement on the benefits something will bring (output legitimacy) or a result of processes of meaningful stakeholders engagement in influencing the output (input legitimacy) (Curtin & Meijer, 2006). Transparency is not only essential for legitimacy, but also for increased accountability - that is, accountability of decision-makers (Herrfahrdt-Pähle, 2013). Transparency and accountability are essential for quality control (Ravetz, 1999).

2.1.5 Adaptation to Changing Circumstances

Data collection and meaning-making plays an important role in experimentation as it is charged with producing evidence on the effects and for adaptation and learning

(Hasselman, 2017; Huitema et al., 2009). In the context of social-ecological challenges the knowledge used as evidence for decision-making and action as well as predictions are subject to high uncertainty. As a consequence, decisions and action have to be taken in situations, in which uncertainty is high. As it is uncertain, if a management intervention will lead to the expected results, policy and management interventions essentially represent experiments, which needs to be acknowledged in their design. These experiments are then adapted, when new information (e.g. about unforeseen impacts) becomes available after their implementation. This position is most closely related to the passive adaptive management practice (Hasselman, 2017; Huitema et al., 2009). Experimentation involves judgements and normative choices about the future that is sought and about the things that need changing. Similarly to research, therefore, it is a value-laden activity (Huitema et al., 2009).

Experimentation is closely linked to learning. That is, learning from the results of the experiment. This kind of learning can give rise to a feedback loop, which allows to improve our understanding of system processes as well as to adapt the experiment to better lead to the desired outcomes. In adaptive governance, this is seen as a continuous process of experimentation and learning (Cooney & Lang, 2007). This continuous process of experimentation and learning strongly relies on data collection and meaning-making for tracking the impacts of experiments (Cooney & Lang, 2007; Hasselman, 2017; Waylen et al., 2019). For this, one needs to be able to identify the cumulative effects on the system of interest (Waylen et al., 2019). This involves three different aspects, for which data collection and meaning-making is important. (1) Data collection and meaning-making needs to further our understanding of system processes (Cundill & Fabricius, 2009). (2) It needs to incorporate social factors alongside ecological factors for an understanding of the social-ecological system (Chapman, 2014), and (3) it needs to account for external drivers of change in the system of interest. Developing an idea of the cumulative effects on a system allows to single out the effects of interventions in the best way possible, which can then be used for learning and adapting the current approaches (Waylen et al., 2019). Two forms of meaning-making are described in the literature: individual and collective or social meaning-making (Hochachka, 2021). Individual meaning-making is a personal process, where perceptions are pre-structured by cognitive conceptual representations, often referred to as mental models or schemas (Abel et al., 1998; Jones et al., 2011; König, 2018). Even though individual meaning-making is a personal process, it is argued that it occurs inter-subjectively - that is, mediated by the person, who is experiencing, thinking of, expressing, and theorising as well as the cultural context that he or she is part of (Heron & Reason, 1997). In the context of the qualitative state of freshwater bodies, two forms of meaning-making can be identified. The more technical kind is based on the current scientific understanding and consists of analysing and interpreting data for insights into the state of freshwater bodies according to proven scientific methods. The other kind is based on long-term observation and experience and does not adher to scientific standards. It is applied by frequent interaction with the subject. The focus in this thesis lies more on the technical kind, which is due to a number of design choices. Among others, it seemed important to position the thesis closer to the existing views of governmental officials to pick them up where they stand (as based on the interviews conducted as part of the thesis). This comes with a number of implications, such as a higher obstacle for non-professional and non-specialist involvement in meaning-making due to lacking background information, such as of specific ecological processes and the evolution of different parameters in varying scenarios.

Cundill and Fabricius (2009) discuss the various benefits that collaboration in data collection and meaning-making is associated with. A collaborative approach may foster deliberate learning processes among collaborators, which may help in building common understanding. This, in turn, may give rise to common decisions and action. Learning can lead to changing perspectives. Collaboration may lead to increased social capital, transparency and legitimacy of decisions. Social capital is associated with an increased capacity to adapt in the face of changes. In addition, it increases the likelihood of producing data that is valid, broadly understood and used in decision-making.

An important feature of the experiments is their provisional character. This means that the policy and management intervention experiments need to be flexible to allow for adaptation. In addition, they need to be designed in a way that they avoid irreversible impacts as far as possible (Cooney & Lang, 2007). Smaller-scale experiments have been seen as well-suited in the context of adaptive governance. They, for example, limit the costs of failures (Huitema et al., 2009; Nelson et al., 2008). In addition, if they are part of a regime of multiple smaller-scale experiments, they may lead to redundancy, which can increase resilience (Nelson et al., 2008).

2.1.6 Coordination Across Levels and Scales

The coordination of governance efforts across levels and scales has been described as a key component of adaptive governance. For clarification, "scale" is used to refer to "a graduated range of values forming a standard system for measuring or grading something" (Google Dictionary, 2021b), whereas "level" is used to refer to "a position on a scale" (Google Dictionary, 2021a). This is due to the nature of sustainability challenges. They usually occur and/or produce effects on multiple levels of, for example, bio-physical, spatial, and time scales. How society organises to approach sustainability challenges and their effects is, therefore, seen as a key factor in adaptive governance. Not only cross-level interactions, however, have to be considered, but also cross-scale interactions. An often-mentioned example is the scale of social organisation and the bio-physical scale, where mismatches lead to difficulties in addressing sustainability challenges (Termeer et al., 2010). The concept of polycentric governance addresses some of the related challenges. Polycentric governance systems are marked by multiple governing authorities at different levels. These systems centre around inter- and intra-level collaboration, learning, and adaptation, and aim to do produce positive outcomes at multiple scales (Ostrom, 2010). Based on this idea, the idea of polycentric monitoring emerged. In line with polycentric governance, polycentric monitoring is characterised by multiple centres of data collection and analysis (Buytaert et al., 2016). Polycentric monitoring that involves people traditionally not involved in data collection and meaning-making, such as non-professionals and non-specialists, may contribute towards are more dynamic, decentralised, and diverse network of data collectors. It holds the potential to not only increase the availability of and access to data, but also to empower actors to collect data as evidence for specific purposes and agendas, which can contribute to a data collection that is better tailored towards place-specific management questions (Buytaert et al., 2016).

The level of place is of particular importance in adaptive governance. In line with the paradigmatic stance adopted in this thesis (see section 3.1.5), which sees the reality that exists independent of human as experienced, thought of, and expressed inter-subjectively (Heron & Reason, 1997), place is seen as “a phenomenological event, an intersubjective interaction among places themselves and the humans that intermingle with them” (Haywood, 2014, p. 69). As a result, both the social and the material dimensions are important. In the thesis, “place-based” is used as a qualifier. In the case of “place-based knowledge”, it refers to the kind of knowledge that is meant - in this case, knowledge, which has emerged from the interaction of places and humans. “Place-based” is used in academic literature, which puts emphasis on the role of places, also in relation to citizen science (see, for example, Charles et al., 2020; Haywood, 2014; G. Newman et al., 2017; Toomey et al., 2020). In the context of sustainability challenges, particular places are also important, as challenges are place-dependent and may take different forms in different places. By extension, there are no panaceas. Approaches always have to be adapted to the specific social and material application settings. This applies to both governance and management interventions. While policies usually refer to higher levels (such as regional, national, and international), management interventions are always implemented in particular places. Nelson, Howden, and Smith (2008) propose an approach to governance that is marked by experiments at multiple and diverse places. The insights of the experiments can provide a basis of understanding that allows to adapt them to other settings, and when considered in combination they can be essential for understanding the complexity at larger scales. Following this approach is also seen to increase redundancy, which protects against failure (Nelson et al., 2008). Social networks are considered essential in adaptive governance. Social networks involving both vertical and horizontal collaboration may enhance social capital and innovation. In addition, social networks across scales are important to generate and transfer knowledge (Folke et al., 2005).

2.1.7 How can adaptive governance be implemented in practice?

In line with the key features of adaptive governance discussed above, a number of studies have put forward important factors, which can support change towards more adaptive governance in a social-ecological system. For example, it has been found that, for a change towards more adaptive governance, it is important that stakeholders meet and exchange embedded in flexible processes, and develop a shared vision (Olsson et al., 2005; Österblom & Folke, 2013). For a change towards more adaptive governance, it is also considered important that policies support learning and adaptation, deal with conflict among stakeholders and foster transparency (Österblom & Folke, 2013). Data collection and meaning-making plays a vital role in adaptive governance, as it supports the detection and tracking of effects of interventions and learning for adaptation in practice. For change towards more adaptive governance, an approach that encourages smaller-scale experiments is favourable to foster learning and adaptation at the same time as reducing costs of failure (Olsson et al., 2005).

2.2 Citizen Science for Adaptive Governance

As mentioned in the introduction to Chapter 2, the goal of this section is twofold. First, it aims to describe the practices of citizen science and its conceptual evolution to situate the approach to citizen science taken by this thesis, and, second, it aims to explore the key contributions of citizen science to adaptive governance identified based on existing research, while distinguishing between contributions that are based on the collection of data and stakeholder engagement. This distinction is relevant in the case of this thesis, as it focuses on contributory and co-created citizen science, which come with varying intensities of stakeholder engagement. Towards the above-mentioned goal, section 2.2.1 explores the emergence of citizen science and key approaches identified based on an extensive literature review, while highlighting the aspects of the different approaches most relevant to this thesis. Section 2.2.1 also discusses key typologies of citizen science put forward in existing literature. Sections 2.2.2 and 2.2.3 are concerned with exploring features and effects of environmental citizen science practices, which have already been presented or can be seen as contributory to adaptive governance practices. This exploration uses the key features of data collection and meaning-making in adaptive governance identified in section 2.1 as a basis for discussion. Section 2.2.2 focuses on contributions of citizen science to adaptive governance that rather based on the collection of data, referred to as quantitative contributions. Section 2.2.3, in turn, focuses on contributions, which rather based on the engagement of stakeholders, referred to as qualitative contributions.

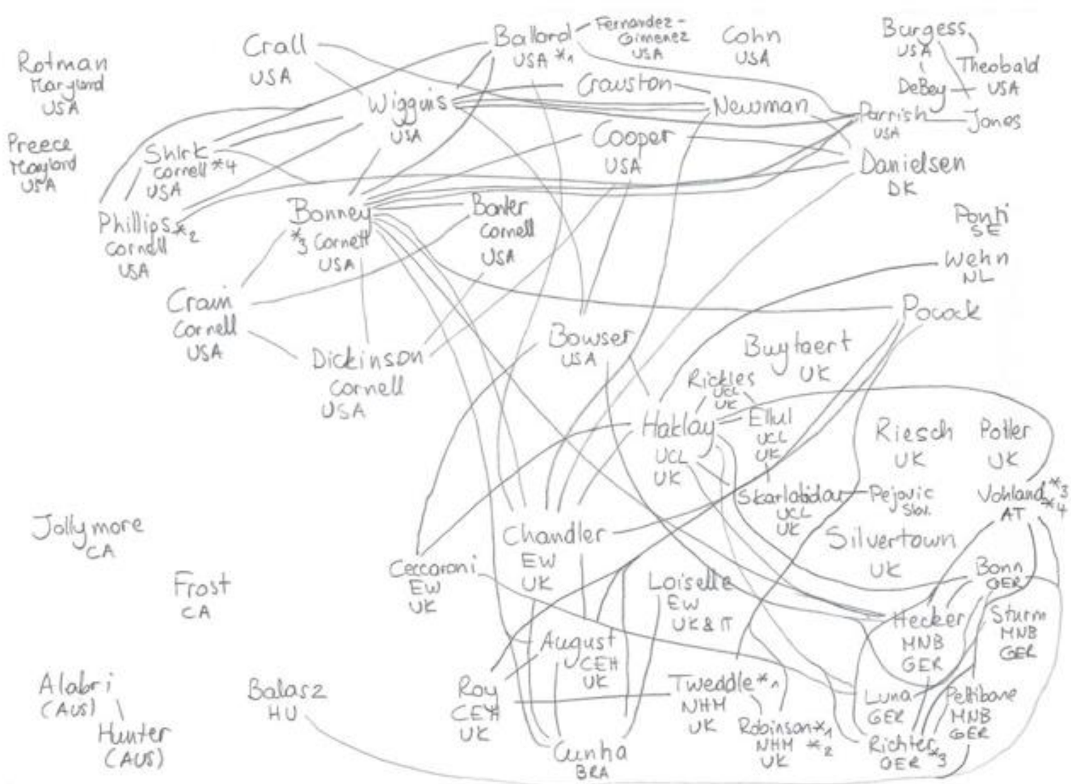
2.2.1 Overview and Evolution of the Concept of Citizen Science

The literature related to citizen science is varied. A key reason is that citizen science is a practice, which can be adopted across scientific fields, and it comes in multiple formats. Citizen science, for example, has engaged citizen scientists in collecting data on bird populations (FeederWatch, 2021), in the morphological classification of photos of galaxies (Lintott et al., 2008), and the transcription of manuscripts (University College London, 2017). Citizen science can be both the primary subject of concern and an approach to collecting data to study another phenomenon. Before a targeted overview of the field is provided, however, the following briefly outlines the commonly acknowledged origins of the term “citizen science” dating back to the 1990s. Two channels are generally credited with being among the first to contribute to the now diverse body of literature specifically on citizen science, while, however, adopting distinct stances. On the one hand, sociologist Alan Irwin positioned citizen science as a means to rethink the relationship between science and society in the face of environmental issues in his well-known book *Citizen Science a Study of People, Expertise and Sustainable Development* (Irwin, 1995). On the other hand, the term “citizen science” was used in the context of project FeederWatch (Bonney, 1996; Trumbull et al., 2000). It is an early example of a citizen science project with roots dating back to the 1970s concerned with monitoring the distribution and abundance of winter bird populations across the U.S.A. and Canada (FeederWatch, 2021). Here, “citizen science” was positioned as a practice, which allows citizens - that is, anyone interested - to make contributions to often large-scale datasets used in scientific inquiry by scientists. A particular benefit of citizen science was often put into focus: tasking volunteers with collecting data makes large-scale datasets attainable and relatively low-cost (Bonney et al., 2009). FeederWatch was and still is organised yearly by the Cornell Lab of Ornithology (Ithaca, U.S.A.) and has given rise to numerous scientific publications. One of the earlier cases of public participation in research can be traced to the early 20th century with the annual Christmas Bird Count, which was originally organised by the American Museum of Natural History and, later, by the National Audubon Society and started off as an alternative to Christmas bird shooting contests (Audubon, 2021; Dickinson et al., 2010).

Since the 1990s, contributions to the field have continuously increased. An overview of key authors contributing to the field of citizen science can be found in Figure 2. As it displays, a majority of the mapped authors are based in the United States of America, the United Kingdom, and Germany. The map is marked by clusters of collaboration by country, by organisation and international collaboration platforms (e.g. the citizen science associations), among others. In the U.S., the Cornell Lab of Ornithology is a key player. In the U.K., Earthwatch Europe and University College London may be considered as such, while, in Germany, a significant role is taken by the Natural History Museum in Berlin.

Figure 2

Map of Authors in the Field of Citizen Science



Cornell	Cornell Lab of Ornithology
Maryland	University of Maryland
EW	Earthwatch
CEH	UK Centre for Ecology and Hydrology
UCL	University College London
MNB	Museum for Natural History Berlin

Note. This is a hand-drawn map of key authors in the field of citizen science including country of work (official country codes are used) and important co-authorships (connecting lines and numbered stars). It also includes organisational affiliation for some authors (when considered relevant). It seeks to provide an overview and does not make claims to comprehensiveness.

As this thesis is concerned with exploring citizen science as an approach to data collection and meaning-making in the context of adaptive surface water governance, the following presentation of different strands in the literature focuses on the sub-practice of environmental citizen science. A unifying criterion of such practices is the application of citizen science to study environmental phenomena. The practices of concern in this thesis aim to explore the state of surface water bodies with varying approaches. As adaptive governance is seen as way of self-organisation in social-ecological systems, environment in the case of this thesis does not only refer to the ecological environment, but also to the linked social and technological environments.

Environmental citizen science has been applied for large-scale ecological research and monitoring (Burgess et al. 2017; Pocock et al. 2017; Roy et al. 2012; Theobald et al. 2015), much like project FeederWatch discussed above, and as community-based environmental monitoring, linked to community-based natural resource management (Danielsen et al., 2005, 2009, 2014; Fernandez-Gimenez et al., 2008). While large-scale ecological monitoring projects tend to be designed and driven by a group of researchers and citizen scientists are often engaged as data collectors, community-based environmental monitoring projects for natural resource management tend to also engage citizen scientists in design processes driven together with community members and involve benefits to the community beyond mere participation (see also distinction between contributory and co-created approaches to citizen science on page 31).

Large-scale ecological research and monitoring is a costly endeavour. Especially the monetary costs associated with the salaries of professionals for data collection often constitute a significant barrier. This barrier may be overcome by engaging citizen scientists as free labour in data collection instead of professionals or using automated sensors (Aceves-Bueno et al., 2015; Gardiner et al., 2012). This change, of course, has many implications for such projects, which need to be carefully considered, for example, in project design. Often-mentioned aspects are the potential for lower data quality due to the engagement of non-specialists and due to less precise and accurate data collection methods (Cohn, 2008). Alongside saving costs on salaries, citizen scientists may be recruited in different locations across a defined geographic area, which, for example, removes costs for travel. This approach to citizen science is particularly relevant for this thesis, as elements of it are applied across the case studies, in particular, data collection in defined geographic areas from place-based and regional to national, and the engagement of citizen scientists for data collection in research projects that are rather researcher-driven.

Citizen science as community-based environmental monitoring has been described as an approach to building evidence and understanding of important phenomena relevant to local management questions, and to social learning (Fernandez-Gimenez et al., 2008). Evidence suggests that citizen science as community-based environmental monitoring can also overcome monetary restrictions on professional monitoring especially in developing countries and empower local communities in decision-making (Danielsen et al., 2005). Community-based monitoring is generally linked with community-based natural resource management, where local communities are engaged in the management of a local natural resource. Often, it aims to combine benefits for the community, for example, in the form of ecosystem goods and services with more sustainable management (Fernandez-Gimenez et al., 2008). This stance is particularly relevant for this thesis as the organised co-design process, especially, was also designed to engage place-based communities and to empower them to collect data for their purposes. This approach is also based on the premise that place-based communities have special insights into place-based social-ecological systems, which can be useful for research and governance, and that their engagement in governance processes has a number of benefits.

Citizen science has also been linked with geographic information science and, in particular, with the field of volunteered geographic information. From this perspective, the focus lies on a particular subset of citizen science practices, namely geographic citizen science. For citizen science to be considered geographic, data collected by citizens has to be linked with accurate geographic locations (Haklay, 2013). A key author here is Muki Haklay at the University College London. He has been involved in OpenStreetMap, an illustrative example of a geographic citizen science project with the aim to create user-generated street maps that are free to use and editable (Haklay and Weber 2008) and has co-founded Mapping for Change, a company that focuses on working with individuals and groups to map local areas for positive change (Mapping for Change, 2021). The ExCiteS Research Centre at the University College London has a long experience in working "with broad networks of people to design and build new devices and knowledge creation processes that can transform the world" (University College London, 2021a). In particular, ExCiteS aims to further the broad field of geographic citizen science and develop tools and methodologies that allow communities to implement their individual citizen science project. The associated publications date back to 2012 and earlier (University College London, 2021b). The most recent publication associated with geographic citizen science and the field of volunteered geographic information is the book entitled *Geographic Citizen Science Design: No One Left Behind* edited by Skarlatidou and Haklay (2021). The book takes a "human-computer interaction" and anthropological perspective and discusses the evolution of geographic citizen science with a particular emphasis on the use of technologies. In the case studies, the geographic location of data collection sites takes a pivotal role. It is generally, part of the mandatory sets of parameters and the representation of data depends for a large part on the use of maps.

The debate on data quality in citizen science datasets has been the origin of numerous publications, especially related to the field of ecological monitoring (Barratt et al., 2003; Bloniarz & Ryan, 1996; Crall et al., 2011; Danielsen et al., 2014; Darwall & Dulvy, 1996; Engel & Voshell, 2002; Gardiner et al., 2012; Kremen et al., 2011; Munson et al., 2010; C. Newman et al., 2003; D. Walker et al., 2016). Many studies approached the topic via a comparison of data collected by volunteers and scientists. As section 2.2.2 lays out in more detail, the success of citizen science projects depends on the adequate consideration of the linked challenges, uncertainties, and objectives in project design and use of the data, and on the adequate design of sampling protocols and citizen scientists' training requirements (Aceves-Bueno et al., 2015; Balázs et al., 2021; Buytaert et al., 2016; Cohn, 2008; Crall et al., 2011; Danielsen et al., 2005).

Over the years, many other aspects of citizen science have been put under the microscope. For example, the motivations of citizens to participate in ecological citizen science projects have been explored (Buytaert et al., 2014; Rotman et al., 2012, 2014). Studies have shown that personal interest plays a key role (Buytaert et al., 2014; Rotman et al., 2014). People may be interested in citizen science as leisure activity, for self-enhancement or as a way to take part in science. Especially in the context of researcher-driven projects, the acknowledgement of the citizen scientists' contributions by the researchers is key for continued engagement, and a close citizen scientist-researcher relationship (Rotman et al., 2014). These insights were considered in the design and implementation of the case studies of this thesis, however, subject to a number of limitations (such as person working hours). For example, the results and findings of case studies were communicated in the form of reports to the citizen scientists in regular intervals.

Technological aspects of citizen science projects, such as gamification (Bowser et al., 2014) and the design of mobile applications and web platforms (Sturm et al., 2018) have also received considerable attention. Since the case studies are based on the use of existing technologies due to a number of limitations (such as limited funds and time), only limited influence exists over the design of mobile applications and standard protocols. The design of a web platform is a marginal subject of this thesis, in which the representation of the multiple dimensions of uncertainties linked with citizen science datasets played a key role for adequate interpretations. Alongside data quality in citizen science, learning effects for volunteers engaged in citizen science can probably be considered one of the largest research areas within the citizen science field (Jordan et al., 2012). The aspect of learning, however, remained outside the scope of this thesis, also due to time limitations.

An often-mentioned scale for categorising citizen science projects broadly distinguishes between projects in function of the degree of empowerment of citizens in the individual project phases. The two forms of citizen science that are used for characterisation purposes in this thesis are contributory and co-created citizen science. These terms have been used by Shirk et al. (2012), whose definitions are applied for the purposes of this thesis. They define contributory citizen science as projects, "which are generally designed by scientists and for which members of the public primarily contribute data" (p. 4), and co-created citizen science as projects, "which are designed by scientists and members of the public working together and for which at least some of the public participants are actively involved in most or all aspects of the research process" (p. 4). Although projects covering the spectrum of that scale have always existed in concurrence, it can be said that the beginnings of citizen science were rather marked by contributory forms of citizen science, whereas, in recent times, contributory and co-created forms of citizen science have reached similar popularity. This shift is well-illustrated by two recent landmark publications, which are strongly based on the cooperation in the frameworks of the European Citizen Science Association (formed in 2014) and the European Union programme Cooperation in Science and Technology Action CA15212 *Citizen Science to Promote Creativity, Scientific Literacy, and Innovation throughout Europe* (kick-off in 2016) - that is, the book *Citizen Science: Innovation in Open Science, Society and Policy* edited by Hecker et al. (2018) and the book *The Science of Citizen Science* edited by Vohland et al. (2021b). The books equally focus on "citizen science as science" and "citizen science in society" (Vohland et al., 2021a).

Multiple attempts have been made at categorising the various activities encompassed by the term citizen science with varying approaches to classification. Some of the criteria for classification have been the roles of citizen scientists and scientists in the research projects (Bonney et al., 2015; Cooper et al., 2007; Danielsen et al., 2009; Haklay, 2013; Shirk et al., 2012), the number of citizen scientists involved and their relationship (Bonney et al., 2015; Haklay, 2013), and the wider settings of the citizen science activity and its purpose (Bonney et al., 2015; Cooper et al., 2007; Wiggins & Crowston, 2011). A single typology may use multiple of these criteria.

The roles of the citizen scientists engaged in a project are varied. Citizen scientists may be engaged as environmental data collectors (Bonney et al., 2015; Danielsen et al., 2009; Shirk et al., 2012) and as data processors (Bonney et al., 2015; Haklay, 2013). The latter role engages citizen scientists by building on their cognitive ability to complete data processing tasks (from simple to more advanced), such as the digital transcription of manuscripts (University College London, 2017) and the classification of galaxies (Lintott et al., 2008).The origins and purpose of a citizen science project also define the project phases, at which citizen scientist and researcher engagement is foreseen (Haklay, 2013; Shirk et al., 2012). In researcher-driven environmental projects, citizen scientists can be engaged in all project phases from design and data collection to interpretation. In citizen scientist-driven environmental projects, researchers may be engaged as consultants (Cooper et al., 2007; Danielsen et al., 2009). The number of citizen scientists engaged by a project largely depends on its design. Large-scale environmental data collection projects may attempt to engage as many volunteers as possible in the defined geographic area (Shirk et al., 2012). Distributed-intelligence projects may even allow anyone interested and capable of completing the task at hand to participate, independent of a geographical location (Haklay, 2013; Wiggins & Crowston, 2011). Smaller-scale projects may focus on the engagement of local communities, for example, in community-based monitoring. Citizen scientist-driven projects tend to be smaller-scale and tend to address social issues of direct relevance to a particular community (Danielsen et al., 2009).

2.2.2 Potential Quantitative Contributions of Citizen Science to Adaptive Governance

A number of studies have discussed various features of environmental citizen science and effects, which have already been or can be seen as contributing to adaptive governance. In the following, such features and effects are explored using the key features of data collection and meaning-making in adaptive governance identified in section 2.1 as a basis. This section 2.2.2 starts the exploration focusing on contributions of citizen science to adaptive governance that rather based on the collection of data, referred to as quantitative contributions. It discusses environmental citizen science

(1) as a way to produce datasets of adequate quality, if challenges and uncertainties are adequately taken into account,
(2) as an additional, potentially cost-effective data source,
(3) as a way for increased data availability, transparency, and capacity for meaning-making,
(4) as a way to increase the accountability of existing data collectors and decision-makers,
(5) as a well-suited approach for social-ecological system research, including a data collection frequency that is well-suited for unexpected insights into the system, and
(6) an approach that can produce datasets on various time and spatial levels.

Environmental citizen science has been described as an approach to overcoming insufficient monitoring in adaptive management in space and time - an issue that is often associated with the relatively high monetary costs of professional monitoring arising from, for example, the high salaries of specialists and expensive measurement instruments (Aceves-Bueno et al., 2015). Environmental citizen science has proven to be a cost-effective approach to data collection and meaning-making compared to traditional approaches (Aceves-Bueno et al., 2015; Gardiner et al., 2012), and an approach for overcoming data shortages related to water quality (Capdevila et al., 2020; S. Y.-F. Ho et al., 2020; Quinlivan et al., 2020). The amount and intricacy of the training that is required have been highlighted as crucial factors impacting the overall costs of citizen science projects, in addition to the costs of equipment. Of course, no universal statement can be made here; the cost-effectiveness is always project-dependent. It has also been questioned by recent publications (e.g. Capdevila et al., 2020). In addition, citizen science may bring benefits, which cannot be easily put in monetary terms (see, for example, section 2.2.3; Aceves-Bueno et al. (2015)).

The cost-effectiveness of environmental citizen science, however, is only relevant, if it is suitable for producing data that is of adequate quality for use in adaptive governance. “Adequate”, as is later put forward, is dependent on the purpose, for which the dataset is intended to be used. Environmental citizen science has been linked with data quality concerns, since it is usually based on the engagement of volunteers, who are in the majority of the cases charged with data collection, and generally simpler data collection methods are used compared to professional data collection (Balázs et al., 2021; Cohn, 2008). Many studies, however, have demonstrated that citizen science approaches have been able to produce datasets of appropriate quality for use for different purposes, if challenges, uncertainties and objectives are adequately taken account of in project design and use of the data (Aceves-Bueno et al., 2015; Buytaert et al., 2016; Crall et al., 2011), also in the context of water quality (S. Y.-F. Ho et al., 2020). Well-designed sampling protocols and adequate training of the citizen scientists have shown to be a key factor (Balázs et al., 2021; Cohn, 2008; Crall et al., 2011; Danielsen et al., 2005) as well as being realistic about what citizen science data can offer (Buytaert et al., 2014).

Not only can citizen science projects constitute additional data sources, but they can also lead to improved availability and access to data (Buytaert et al., 2016). This is particularly important for transparency (and legitimacy) in adaptive governance, which requires that data, which is used for evidence in decision-making needs to be publicly available (Waylen et al., 2019). Citizen science data may also contribute to increased transparency, for example, of the state of surface water bodies. For the communication of citizen science data to non-specialists, it is essential that data is represented in ways, which are accessible for them, thus, requiring little to no specialist knowledge and to try to avoid representations, which may lead to misinterpretations as much as possible (Buytaert et al., 2014). Learning among non-specialist citizen scientists about the topic complex and scientific methodologies may also contribute to an increased ability to make meaning from existing published datasets.

The improved availability and access to data may also increase the accountability of existing data collectors and of decision-makers by contributing to breaking up the largely centralised data collection networks with monopolistic traits (Buytaert et al., 2016). This can also be seen as a quality control mechanism (Bäckstrand, 2003). Having multiple centres of data collection, however, comes with a number of challenges. It can decrease overall efficiency, as the effort required for collaboration increases and becomes more important for, for example, avoiding unfruitful duplication of work. Some degree of redundancy in roles has been associated with increased protection against failure. In the case, where one centre breaks down, another one can take over (Buytaert et al., 2016; Nelson et al., 2008).

In addition, citizen science is well-positioned for social-ecological system research. Taking account of both social and ecological factors is considered key in data collection programmes and meaning-making approaches for the adaptive governance of coupled social-ecological systems (Chapman, 2014). Citizen science can provide the opportunity to link social and ecological factors in data collection, for example, by time, date, location, and data collector. This has a number of benefits over, for example, using two separate data sources for social and ecological data. It may, for instance, provide more robust insights into human-nature relationships, which are essential in social-ecological system research and for a more comprehensive picture of the social-ecological system (Crain et al., 2014). In general, citizen science has been credited with the ability to collect data across a heterogeneous set of variables, including social, ecological, and spatial, which is seen as beneficial for studying the complexity of coupled systems (Crain et al., 2014). Another feature also plays an important role here. In fact, if designed appropriately, citizen science may be able to support a data collection frequency that is well-suited for unexpected insights into the system, which can be useful for detecting unexpected change (Crain et al., 2014).

As previously discussed, sustainability challenges usually occur and/or produce effects on multiple levels of a scale, such as bio-physical, geographical, and temporal. It is, therefore, essential that data collection and meaning-making takes account of this multi-level and multi-scalar nature. Many successful citizen science projects have, indeed, demonstrated that citizen science can be used for environmental monitoring at varying time and spatial levels (Aceves-Bueno et al., 2015). Citizen science has been used to map animal and plant species - see, for example, project Protea Atlas, where 377 species of Proteaceae were mapped during a 10-year period producing a database of over 250’000 records (Aceves-Bueno et al., 2015; Midgley et al., 2006; Protea Atlas Project, 2021; Silvertown, 2009) and project eBird, which focuses (on-going) on the mapping of birds and managed to build a database of 140 million observations in 2013 with the majority collected since 2003 in North America (eBird, 2021; Sullivan et al., 2014).

2.2.3 Potential Contributions of Citizen Science to the Quality of Findings for Adaptive Governance

The previous section outlined potential quantitative contributions of citizen science to adaptive governance identified based on a review of relevant literature. This section, in turn, focuses on potential contributions that are rather based on the engagement of stakeholders, referred to as qualitative contributions. The section discusses environmental citizen science

(1) as an approach for the engagement of stakeholders, perspectives, and diverse types of knowledge,
(2) as a way towards more polycentric data collection and meaning-making, empowering diverse stakeholders to collect data as evidence for specific purposes and agendas,
(3) as a way for a better understanding of human-environment interactions and a more comprehensive picture of social-ecological systems,
(4) as a way for increased stakeholder buy-in in adaptive governance and for increased transparency and legitimacy of decisions, and building common understanding,
(5) as a way for increased capacity of self-organisation in social-ecological systems.

Environmental citizen science is, by definition, based on the engagement of citizen scientists in research processes. Even though the types of people that are engaged and the roles that they fulfil are variable across different types of projects (see section 2.2.1, in particular the description of the different typologies), environmental citizen science has proven able to engage diverse people, such as professionals and non-professionals as well as specialists and non-specialists. As section 2.1.4 discusses in more detail, the engagement of diverse stakeholders is seen as crucial in adaptive governance. It allows to take account of multiple and diverse perspectives as well as types of knowledge. It can also increase the quality and legitimacy of knowledge, decisions, and actions.

Also due to the fact that environmental citizen science engages diverse types of people, it has been positioned as a way towards more polycentric data collection and meaning-making with the potential for increased data availability and access (see section 2.2.2) and for empowering stakeholders to collect data as evidence for diverse purposes and agendas potentially contributing to a higher relevance of data to place-specific management questions (Buytaert et al., 2016; Jollymore et al., 2017). In fact, citizen science may give those traditionally not included in data collection and meaning-making the opportunity to participate (e.g. non-specialists). As a result, citizen science may take account of different perspectives with the potential to increase the diversity of purposes and, potentially, agendas that are followed, in the case, where projects are to some degree citizen scientist-driven (Buytaert et al., 2016). This may lead to data collection that is better tailored towards place-specific management questions and to unexpected findings with the potential to help in detecting unexpected changes in the system (Buytaert et al., 2016; Crain et al., 2014). Further, it has the potential to increase accountability of existing data collectors, of decision-makers, and polluters as well as to increase redundancy, which may help protect against system failure (Buytaert et al., 2016).

Engaging place-based communities, in particular, has been credited with a number of positive effects. Such communities may have relevant, often non-scientific understanding about a place, for example, related to the evolution of a place including human-environment interactions, which is considered essential for the governance and management in social-ecological systems, for example, related to changes (including thresholds and time-lags) (Crain et al., 2014). Considering multiple and diverse perspectives as well as different types of knowledge (such as abstract scientific, place-based scientific, and place-based non-scientific knowledge - see section 2.1.4) is seen to support a more complete picture of the complex coupled human-nature system (Crain et al., 2014).

In addition, Aceves-Bueno et al. (2015) have found that citizen science holds the potential to contribute to an increased stakeholder buy-in in adaptive management, which they identified as a key limitation in real-world applications. Stakeholder buy-in was related to "consistent stakeholder engagement throughout the management process" (Aceves-Bueno et al., 2015, p. 2). In case of the engagement of place-based communities, in particular, defining a common set of goals and objectives has shown to be very important. In addition, they put forward that citizen scientists communities can develop a greater sense of responsibility for natural resources and become more invested in governance and management through their participation in citizen science projects. In general, stakeholder participation has been largely credited with the capacity to increase transparency and legitimacy of decisions and actions (Reed, 2008). For this, the design of the process of engagement has been identified as major factor with stakeholder engagement always creating intended and unintended consequences and coming with multiple restrictions (e.g. who participates), which need to be considered (Reed, 2008; Turnhout et al., 2010). Similarly, collaborative monitoring has been connected with fostering social learning and social capital (Cundill & Fabricius, 2009). Social learning, in the context of sustainability challenges, has been defined as being "about bringing people of different backgrounds together. The ensemble of perspectives, knowledge and experiences that is brought about in this way is necessary in order to come to a creative quest for answers to questions for which no ready-made solutions are available" (Wals et al., 2009, p. 6). Social capital refers to the "features of social life, such as networks, bonds, norms, and trust, that enable participants to act together to pursue shared objectives" (Cundill & Fabricius, 2009, p. 3208). This puts the emphasis on the sharing of different types of knowledge and diverse perspectives and the building of a common understanding, which can lead to common action (Cundill & Fabricius, 2009).

It has also been argued that reinforcing the “sense of place” or the human-environment connection can lead to increased self-organisation in social-ecological systems (Crain et al., 2014; Haywood, 2014). Environmental citizen science projects, therefore, which focus on particular places and on the engagement of place-based communities, in particular, have an increased potential to strengthen the sense of place (Toomey et al., 2020) and, by extension, the capacity of self-organisation. The engagement of citizen scientists in research, in general, may build more knowledgeable communities (Bremer et al., 2019), which can be drawn upon in governance and management processes (Crain et al., 2014).

2.3 Identified Research Areas and Questions

Based on the literature reviews of the fields of adaptive governance and citizen science undertaken as part of the research project, two key research areas have been identified, which demonstrated a need for further research. The form of data collection and meaning-making to support adaptive governance has not been explored in detail by many. Research Question A seeks to contribute to its conceptualisation, among other things:

A. In how far are current data collection programmes and meaning-making approaches compatible with key principles of adaptive governance of social-ecological systems? What are opportunities for change?

Research Question A aims to explore the ways, in which current data collection programmes and meaning-making approaches related to surface water governance in Luxembourg are compatible with key principles of the adaptive governance of social-ecological systems. It seeks to do so by drawing on the evaluation framework presented in section 2.5.1 that encompasses a set criteria for an "ideal" form of data collection and meaning-making for adaptive governance identified based on relevant academic literature as presented in section 2.1. As a basis for the evaluation, the key current data collection programmes and meaning-making approaches in Luxembourg related to surface water governance are presented in detail in Chapter 4. Based on the analysis, Research Question A seeks to identify a series of opportunities for change of current data collection and meaning-making towards more adaptive and, thus, sustainable surface water governance in Luxembourg.

The applied evaluation framework of data collection programmes and meaning-making approaches for adaptive governance is a conceptual contribution to the research field of adaptive governance. In addition, the framework provides an opportunity to others to evaluate current practices following the example set by this thesis for change in practice of current data collection and meaning-making towards more adaptive and, thus, sustainable surface water governance. The above-mentioned set of opportunities for change identified based on the analysis of current data collection programmes and meaning-making approaches related to water governance in Luxembourg also provide a series of measures, which could be implemented in practice in view of more adaptive and sustainable surface water governance in Luxembourg.

The other key area for further research identified based on the reviews of relevant literature is the contributions of citizen science to adaptive governance. Citizen science is often mentioned as a promising approach to data collection and meaning-making in adaptive governance, as it has proven to be a viable data source for governance purposes, and has shown to be a channel for stakeholder engagement in research processes. Explorations of citizen science in an adaptive governance framework, however, have not performed by many and more research in this area is needed. Research Questions B and C address this issue. They focus on two common forms of environmental citizen science - that is, contributory and co-created:

B. How can contributory citizen science contribute to the adaptive governance of social-ecological systems? How can it address the opportunities for change identified in Research Question A?

C. How can co-created citizen science contribute to the adaptive governance of social-ecological systems? How can it address the opportunities for change identified in Research Question A?

Research Questions B and C seek to examine the ways in which contributory and co-created citizen science, respectively, can contribute to data collection and meaning-making in adaptive governance. They set out to do so by discussing two case studies of contributory and co-created surface water citizen science implemented as part of the research project in Luxembourg using the evaluation framework of data collection programmes and meaning-making approaches for adaptive governance presented in section 2.5.1. The research questions also each facilitate a discussion of how the particular form of citizen science can contribute to the opportunities of change based on the analysis of current data collection programmes and meaning-making approaches in Luxembourg (as identified in by Research Question A).

Research Questions B and C, therefore, seek to contribute to the conceptualisation of environmental citizen science in an adaptive governance context by exploring how environmental citizen science may look like to support data collection and meaning-making in adaptive governance. The comparison of the two common approaches to environmental citizen science further contributes to this goal. In addition, the implementation and co-design of environmental citizen science projects allowed to make first experiences with citizen science in the field of surface water governance in

Luxembourg and contribute to further developing the practice of citizen science in the country.

2.4 Research Scope

This section 2.4 aims to describe the research scope of this thesis. Of the many aspects of adaptive governance and citizen science presented in sections 2.1 and 2.2 only a limited number can be considered in the thesis due to a number of limitations.

For one, evaluating the compatibility of data collection programmes and meaning-making approaches with key principles of adaptive governance is an ambitious and comprehensive endeavour. Each aspect could be subject of a thesis in its own right. Therefore, due to the number of aspects considered in this thesis, each cannot be explored in the same amount of depth. The legitimacy of decisions and actions, for example, cannot be considered in the evaluation, as it would involve an empirical study design that is too targeted and detailed. In the same way, the use of the results and findings of data collection and meaning-making in governance is not included in the evaluation. Transparency is evaluated in function of the public availability of data sets and interpretations as well as the accessibility of individual meaning-making. In addition, whether diverse perspectives and knowledge types are actually accounted for in the design and implementation of data collection and meaning-making cannot be considered in the evaluation. In this case, the engagement of stakeholders in design and implementation is considered as a related variable. In the same way, the actual parameters used in data collection and meaning-making cannot be examined in detail in view of their potential to contribute to insights for adaptive governance for the same reasons. For the evaluation, the parameters are considered in function of their type - that is, ecological, social, and technological. Furthermore, the specific insights that individual data collection programmes and meaning-making approaches can support, can only be given limited attention. The goals that the data collection programmes and meaning-making approaching purse are considered instead.

As regards the potential contributions of environmental citizen science to data collection and meaning-making in adaptive governance, the focus lies on contributory and co-created citizen science approaches. Learning outcomes of the surface water citizen science case studies could not be included in the evaluation, as the timeline of the case studies did not allow to do so. The co-created citizen science case studies were merely co-designed, but not yet implemented during the research project. In the same way, the role of technology in the case studies could not be included in the evaluation as well as the effects of the case studies on social capital. The following section 2.5 presents a detailed description of the evaluation frameworks and how the different components are considered in the thesis.

2.5 Evaluation Framework for Data Collection and Meaning-Making for Adaptive Governance and the Contribution of Citizen Science

This section 2.5 is based on the previous sections (in Chapter 2) and describes two frameworks: one framework for the evaluation of the compatibility of data collection programmes and meaning-making approaches with key principles of adaptive governance (section 2.5.1) and another for the evaluation of the contributions of citizen science to adaptive governance (section 2.5.2). The frameworks have grown from the reviews of relevant literature related to adaptive governance and citizen science and are based on the discussions of the key features of data collection and meaning-making in adaptive governance (sections 2.1.4 to 2.1.7) and of the key contributions of environmental citizen science to adaptive governance (sections 2.2.2 and 2.2.3). The purpose of the frameworks is to serve as a basis for the reflexive discussion of the empirical results later in the thesis.

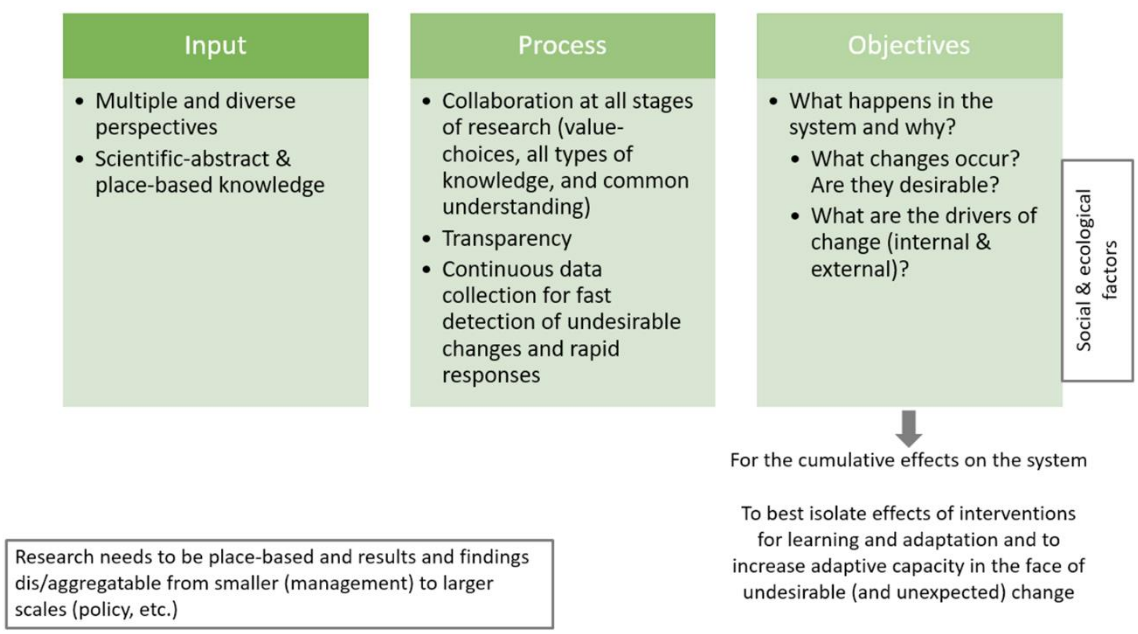
2.5.1 Evaluation Framework for Data Collection and Meaning-Making for Adaptive Governance

The criteria for data collection and meaning-making in adaptive governance presented in section 2.1 were identified from relevant literature. In the following, these criteria are translated into an evaluation framework for data collection programmes and meaning-making approaches for adaptive governance for application in this study. This will be applied to both the current data collection programmes and meaning-making approaches related to water quality in Luxembourg and the case studies of contributory and co-created surface water citizen science.

The evaluation framework can be found in Figure 3. It is divided into three parts: input, process and objectives.

Figure 3

Key Criteria for Data Collection and Meaning-Making in Adaptive Governance



Essential Inputs into the Design of "Ideal" Data Collection and Meaning-Making in Adaptive Governance. Input focuses on elements identified by the literature as important to be considered in the design of data collection programmes and meaning-making approaches: multiple and diverse perspectives, and abstract and place-based types of knowledge developed either scientifically or otherwise. The following summarises the key arguments developed in the previous conceptual sections. A summary is provided for each criteria.

Engaging multiple and diverse perspectives in the design of data collection programmes and meaning-making approaches is crucial as the design involves value-choices (e.g. related to the definition of the research problem and research methodology). In the context of research, which aims to build evidence for use in governance and management and focuses on highly contested topics (e.g. sustainability challenges), taking account of multiple and diverse perspectives is essential for the legitimacy of decisions and actions, and broad support across society and key stakeholders, the support of whom is needed for successful action. Considering place-based types of knowledge in the design of data collection programmes and meaning-making approaches is similarly important. With sustainability challenges, there are no one-size-fits-all solutions and measures always have to be adapted to the concrete application social and ecological contexts. In essence, what may work in one place, may not work at another. Non-scientific types of knowledge can be very valuable for the design of data collection programmes and meaning-making approaches, as place-based communities may have valuable insights, for example, into the evolution of human-nature relationships and system changes.

If multiple and diverse perspectives, and abstract and place-based types of knowledge developed either scientifically or otherwise are considered in the design of data collection programmes and meaning-making approaches is evaluated in two ways: (1) each featured data collection programme and meaning-making approach is discussed based on the degree, to which stakeholders were engaged in the design of the programme. Different forms of engagement point to different degrees of empowerment (e.g. consultation vs. co-design). The evaluation, consequently, combines the Input criteria of Multiple and Diverse Perspectives, and Abstract and Place-Based Types of Knowledge as well as the Process criteria of Engagement of Multiple and Diverse Stakeholders in Collaborations in in the stage of research design. (2) Polycentricity in data collection and meaning-making is used as a guiding concept to evaluate the number and diversity of stakeholders engaged in a data collection and meaning-making network and the degree, to which different perspectives and types of knowledge are considered in a network. The concept of polycentricity is, therefore, also used to evaluate the engagement of multiple and diverse stakeholders in the undertaking of data collection programmes and meaning-making approaches (see Process criteria below).

Essential Process Features of "Ideal" Data Collection and Meaning-Making in Adaptive Governance. Process, in turn, details a series of criteria related to the entire process of the design of data collection programmes and meaning-making approaches and their undertaking. For adaptive governance, it has proven important to engage multiple and diverse stakeholders into the design and undertaking of the programmes. Empowerment of stakeholders is crucial by, for example, using negotiation as a method of interaction and decision-making process, which refers to a discussion with a common output. Collaboration among multiple and diverse stakeholders is considered key for adaptive governance as it provides a platform for sharing and considering different types of knowledge and perspectives, which is related to the inputs and their rationales discussed above. Alongside collaboration, transparent data collection and meaning-making processes are considered as key. This involves transparency about decisions and the associated value-choices as well as about problem definitions and visions. Further, it involves published datasets and transparency about how the findings and conclusion were developed based on the data. Transparency is a feature of good governance and a building stone for the legitimacy of decisions and action. In the adaptive governance of sustainability challenges, societal support for governance and management decisions and interventions is seen as critical for success, especially across key stakeholders. Transparency also allows for quality control of the findings and conclusions of the data collection programmes and meaning-making approaches and the potential future governance and management decisions.

The evaluation of the engagement of multiple and diverse stakeholders in collaborations at all stages of the research process was already discussed above. The criteria Transparency is discussed in three parts: (1) the degree, to which the public has physical access to collected datasets, (2) the degree, to which the public has access to interpretations provided by the issuer alongside the published datasets, and (3) the degree, to which the publications foster individual meaning-making by, for example, providing relevant information on parameters alongside the publication of datasets.

In addition to collaboration and transparency, it is deemed important for data collection programmes and meaning-making approaches for adaptive governance to cater for the detection and tracking of unforeseen changes. This requires data collection that is frequent enough to do so. Sustainability challenges are marked by sometimes rapid and unpredictable changes. Knowledge is incomplete and often provisional. Adaptive governance, therefore, focuses on building the capacity to react to undesirable changes as fast as possible to remedy any associated undesirable consequences. This requires data collection programmes and meaning-making approaches designed to rapidly detect undesirable changes. The evaluation of this Process feature is done in combination with the Essential Objectives below.

Essential Objectives for “Ideal” Data Collection and Meaning-Making in Adaptive Governance. The objectives are concerned with the phenomena, which are seen as important to be subject to data collection and meaning-making in adaptive governance. Knowledge about system processes is considered of primary importance. This entails knowledge about occurring phenomena and cause-effect relationships. In relation to eutrophication, for example, this could take the form of knowledge about the relationships between nitrate concentrations in water bodies and agricultural practices or about nitrate concentrations in water bodies and the increased growth of algae. Changes in the system are of particular concern in adaptive governance. In relation to eutrophication, for example, change could constitute increasing water temperatures or increases in sun exposure of the water body. An evaluation of the changes in the system based on the visions that one is trying to work towards and acceptable pathways to get there, gives insights into the degree, to which a change is desirable. Increasing water temperature, for example, may lead to increases in plant growth and animal reproduction rate until a specific threshold (GLOBE Switzerland, 2019). Increasing water temperature also comes with reducing oxygen content of the water, which can lead to a reduction in animal population sizes, when it falls below a certain threshold (GLOBE Switzerland, 2019). If judged undesirable, actions to steer to desirable pathways can be taken. Knowledge about internal and external drivers of change is also important, in particular, for helping to design interventions in the case of undesirable changes (i.e. where does one need to interfere) as well as for an understanding of the cumulative effects on the system that is as good as possible. In the case of increasing water temperatures, a possible driver of change may be the use of the water body for cooling in industry. Changes in the system may also stem from management interventions, the effects of which need to be isolated in the best way possible for learning and adaptation. Drivers of change in social-ecological systems can come in the form of social, ecological, and technological factors, which makes considering them crucial for a more complete understanding of complex social-ecological systems.

The evaluation of data collection programmes and meaning-making approaches for furthering scientific understanding of system processes is performed by discussing the degree, to which they are aimed at and contribute to informing on cause-effect relationships in the system (e.g. cause-phenomena or driver of change-change).

Whether programmes can support the detecting and tracking of changes in the system is discussed based on their adequacy to contribute to the detecting and tracking of trends and fluctuations. The terms “trends” and “fluctuations” will be used to make a distinction between a general direction, into which, in this case, parameter values are developing, and variations, which do not have a significant effect on the general direction. In relation to the detecting and tracking of changes in the system, it has to be considered that many parameters related to water quality are subject to relatively high natural variations (e.g. nitrate concentrations). This makes the identification of variations that are caused by human activity especially difficult, as it can only be attempted, after natural ranges of variation have been determined. It is also important to note that the terms “trends” and “fluctuations” are relative and can be only defined in relation to a specific time-period. This, of course, also depends on the amount of data that is available as a basis historically. In the same way, a trend identified on a time-scale of a year may be a mere fluctuation when considering a larger time-scale, for example, of 10 years. To operationalise the terms in the following discussion, if a data collection programme and meaning-making approach produces data without a set termination date, it is considered well-suited for the detection and tracking of trends. If a programme is limited in time, as it is, for example, project-based, it is considered less suited for trends. As regards the detection and tracking of fluctuations, data collection frequency is used as the key factor. There is, of course, no universal frequency, which would guarantee the detection of fluctuations or their timely detection, for that matter. Frequencies have to be individually set for each parameter depending on the significance of the implications of fluctuations for nature and humans. In any case, however, the swift detection of changes in the system is important, for example, to increase the accountability of polluters and to reduce the implications of undesirable changes. Therefore, in the discussion, a higher data collection frequency is preferred and, in general, multiple data points per year are seen as favourable as regards the swift detection and tracking of fluctuations.

Whether programmes are considering social, technological, and ecological factors in combination is considered the key factor for evaluating the suitability of the programmes to link internal and external drivers of change with change in the system. Change may be due to natural processes, for example, as precipitation increases the turbidity of a water body. It may, however, also be enhanced or caused by social or technological factors, for example, as the clearing of riverbeds increases soil erosion. It is, of course, in general, a complicated undertaking to identify cause-effect relationships and uncertainty is, generally, high in such contexts.

In adaptive governance, it is considered essential that data collection and meaning-making is relevant for use at multiple levels (e.g. place-based, regional, and national). Higher-level representations of data are important, for example, for overviews and trends of water quality in particular regions and nations. Place-based datasets, in turn, are equally important, for example, for the swift detection of changes in the system and the associated implications for nature and humans, and for an understanding and tracking of drivers of change. This has the potential to increase the accountability of polluters, and the capacity to react to undesirable change. Regarding sustainability challenges, the characteristics of particular places have to be considered in the governance and management of the associated social-ecological systems, as there are no one-size-fits-all solutions. For discussing the suitability of data collection programmes and meaning-making approaches for swiftly detecting place-based changes in the system as well as place-specific context factors important in the design of interventions, sampling site density and the purpose of the programmes are used as a key indicators in combination with the data collection frequency. Similarly to the strategy used for evaluating the capacity of programmes to detect fluctuations, a higher sampling density is considered favourable for the swift detection of place-based changes. For place-based research, in general, multiple data collection sites are needed in or around a particular place.

The location of sampling sites is also important, as it determines the degree, to which samples from a particular site can be taken to represent the respective water body or even the respective stream network. The selection of sites for the different data collection programmes and meaning-making approaches that are subject of this chapter is, generally, performed in function of the overall purpose of the respective programmes. In this way, for example, the five sites of the Water Management Agency's Monitoring Control are strategically selected to represent the entire national surface water network in the best way possible. For the programmes of drinking water syndicates, for example, the determining factor is the location of water extraction for drinking water production and/or provision. As such, the representativeness of these samples in relation to the entire surface water body have to be questioned. In the following discussion, however, the location of sampling sites is not in focus. In general, the results at a sampling site are considered to be able to give insights into state of the segment of the water body that is located upstream of the site. Of course, there may be segmental differences in the state of the water body and, therefore, the topic of representativeness has to be treated carefully.

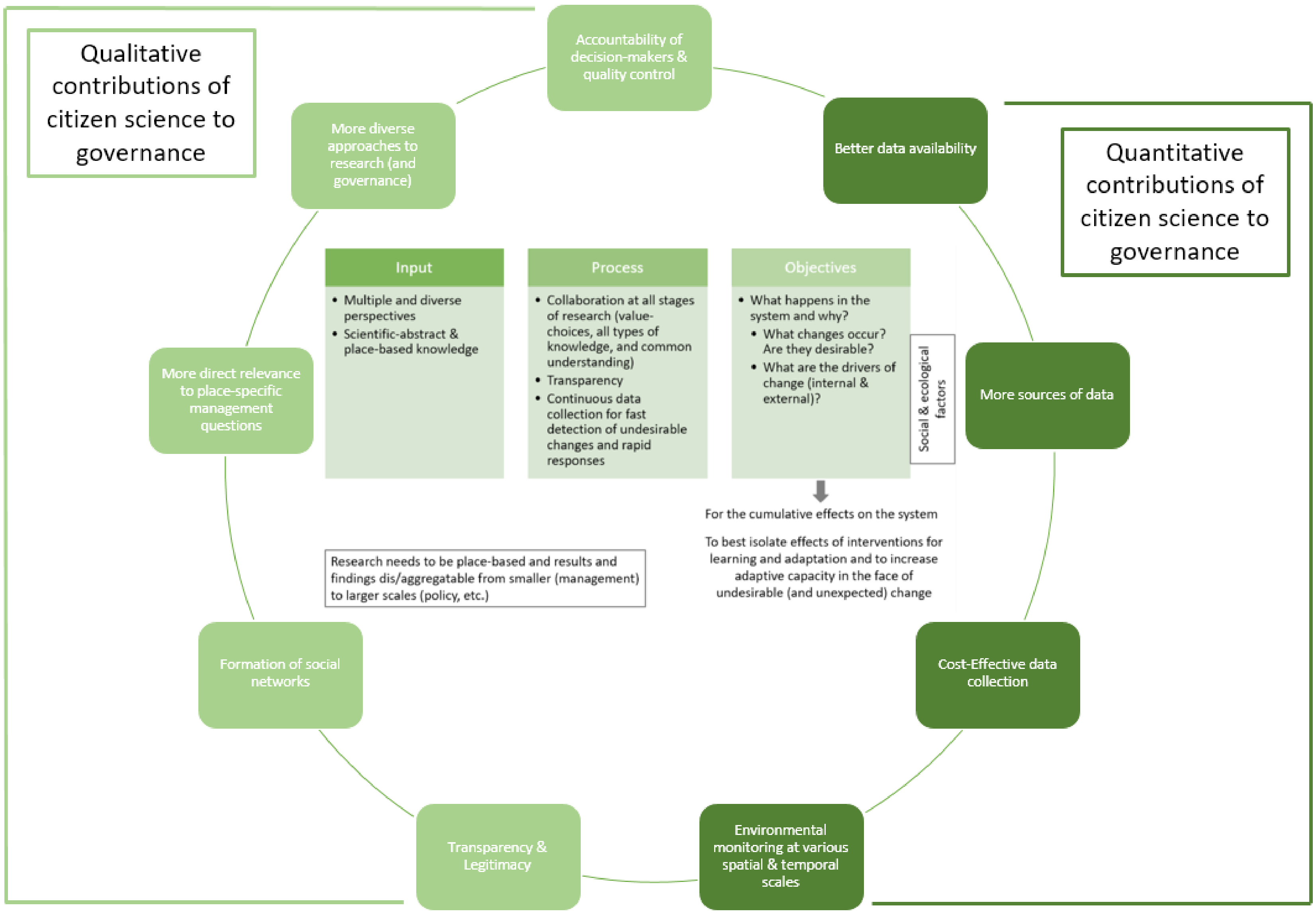
2.5.2 Evaluation Framework for the Contributions of Citizen Science

After the compatibility of citizen science data collection programmes and meaning-making approaches with key principles of adaptive governance has been discussed based on the evaluation framework described above, and the potential contributions of each case study have been discussed, the evaluation framework for the contributions of citizen science is used to discuss the potential contributions identified based on the empirical results with the potential contributions identified from the academic literature. This evaluation framework is presented in

Figure ***4***. The potential contributions identified from the literature are roughly allocated to the categories: quantitative and qualitative contributions. These categories were also used as an structuring criteria in the conceptual section 2.2.

Figure 4

Evaluation Framework of Data Collection and Meaning-Making for Adaptive Governance and the Contribution of Citizen Science


Qualitative contributions of citizen science to governance
Accountability of decision-makers & quality control
More diverse approaches to research (and governance)
Better data availability
Quantitative contributions of citizen science to governance
Input
Multiple and diverse perspectives
Scientific-abstract & place-based knowledge
Process
Collaboration at all stages of research (value-choices, all types of knowledge, and common understanding)
Transparency
Continuous data collection for fast detection of undesirable changes and rapid responses
Objectives
What happens in the system and why?
What changes occur? Are they desirable?
What are the drivers of change (internal & external)?
Social & ecological factors
More direct relevance to place-specific management questions
More sources of data
For the cumulative effects on the system
To best isolate effects of interventions for learning and adaptation and to increase adaptive capacity in the face of undesirable (and unexpected) change
Research needs to be place-based and results and findings dis/aggregatable from smaller (management) to larger scales (policy, etc.)
Formation of social networks
Cost-Effective data collection
Transparency & Legitimacy
Environmental monitoring at various spatial & temporal scales

Chapter 3. Methodology

Chapter 3 describes the methodology used in the research project. It outlines the research approach in section 3.1. It presents transdisciplinary sustainability science as a science of sustainability with its key features of collaboration among scientific disciplines and practice and systemic analyses. In addition, the section briefly characterises the research paradigm of this study using key features of the Participatory Inquiry Paradigm developed by Heron and Reason (1997). It also connects the typical research phases of transdisciplinary sustainability science with the different aspects of the research presented in this thesis and illustrates the influence of the chosen research paradigm on the research project. Section 3.2 gives an overview of the work packages presented in this thesis, which are semi-structured interviews with water specialists on the water quality data landscape and ideas for citizen science (section 3.3), the co-design process and workshops (section 3.4), documentary review (section 3.6), and the undertaking of two contributory surface water citizen science projects (section 3.5). The chapter further describes the process of data triangulation in section 0, the effects of engaging in the Sustainability Science Research Group at the University of Luxembourg on the empirical study (section 3.8), and study limitations (section 3.9).

3.1 Research Approach

As the previous paragraph outlines, the present thesis is rooted in the research approach of transdisciplinary sustainability science. Sustainability science is a new scientific approach, which has emerged as a response to the various sustainability challenges that have become an increasing centre of attention across societal sectors.

In the following, the aim is to introduce the transdisciplinary sustainability science field by the following topics:

1. A brief discussion of sustainability science, in general, and of the two camps that have formed within (section 3.1.1),
2. A discussion of the concept of transdisciplinarity in sustainability science (sections 3.1.2 and 3.1.3), and
3. A discussion of critiques of current practice and future research opportunities (section 3.1.4).

3.1.1 Science for Sustainability and Science of Sustainability

While there is general agreement about the research focus of sustainability science, in general, namely nature-society interactions, the research approach takes different forms depending on the assumptions and methods used in research. Some attempts at describing different camps have been undertaken (see, for example, König 2017; Lang, Wiek, and von Wehrden 2017; Spangenberg 2011). Some of these categorisations use the terms disciplinary, multidisciplinary, interdisciplinary, and transdisciplinary as distinction criteria (for a discussion of the different terms, see, for example, Stock and Burton 2011) contrasting mainly disciplinary and transdisciplinary approaches (see, for example, Lang, Wiek, and von Wehrden 2017; Spangenberg 2011). The following brief rendition of the two camps is largely based on the work of Spangenberg (2011). He puts forward two sub-fields called “science for sustainability” and “science of sustainability”.

Science for sustainability is described as mono- or multidisciplinary (multiple disciplines working in parallel on same issue), but must be “interdisciplinary-ready”, meaning that it is conducted with a broader picture of sustainability in mind and ready for the integration of results from other disciplines. As a result, the sub-field is heterogeneous in scope and practice. A feature of this kind of research is the fact that it focuses on rethinking interactions across domains and scales: mainly nature-society, science-democracy, global-local, and past-present-possible futures (Jerneck et al., 2011). Science for sustainability is aimed at strengthening the dialogue between science and society, with science clearly remaining in the driver's seat. It aims to support the development of "solutions" to sustainability challenges, the assessment of impacts of current decisions, and the identification of future action pathways (Spangenberg, 2011).

Science of sustainability, in contrast, is considered transdisciplinary in that it is based on the integration of different kinds of knowledge (i.e. from scientific and non-scientific sources). This criterion is included into a feature of science of sustainability called "reflexivity". The term encompasses multiple other dimensions: It includes a person's ability to critically reflect on the influences of socialisation and social structures and to act against them. Reflexivity also encompasses critical reflection of research assumptions, such as the objectivity of the observer, the value-neutrality of science, of the kinds of values that are inherited and possible alternatives. Being reflexive requires the acceptance of uncertainty and ignorance and, therefore, the fact that it is impossible to know all the relevant facts in the case of sustainability challenges. Science, therefore, is considered a contributor to science-policy interfaces, where scientists, stakeholders, and decision-makers meet, exchange, and, at best, engage in knowledge co-creation and in building a common understanding of the sustainability challenge. Science of sustainability aims to improve our understanding of the human-environment interactions for change towards more sustainability (Spangenberg, 2011). A more in-depth discussion of transdisciplinary research will follow.

Other categorisations put emphasis on the goal of the research project. As such, one camp might be called descriptive, because it is focused on furthering the scientific understanding about the Earth system to inform prevailing top-down policy-making processes, while another might be called transformative in that it focuses on fundamentally transforming nature-society interactions towards more sustainable pathways (König, 2018). These two ways of dividing the sustainability science field, however, are closely related. Disciplinary science has been concerned with describing phenomena from a single disciplinary perspective, while transdisciplinary research has a bi-fold focus: to transform prevailing ways of acting and doing in practice and scientific development, while integrating different disciplinary perspectives and perspectives of actors from practice. As the thesis is rooted in transdisciplinary sustainability science, it is this strand that the next sections will focus on. A rationale for the need of a new scientific approach to tackling sustainability challenges has already been provided in sections 2.1.1 and 2.1.2.

3.1.2 Transdisciplinarity in Sustainability Science

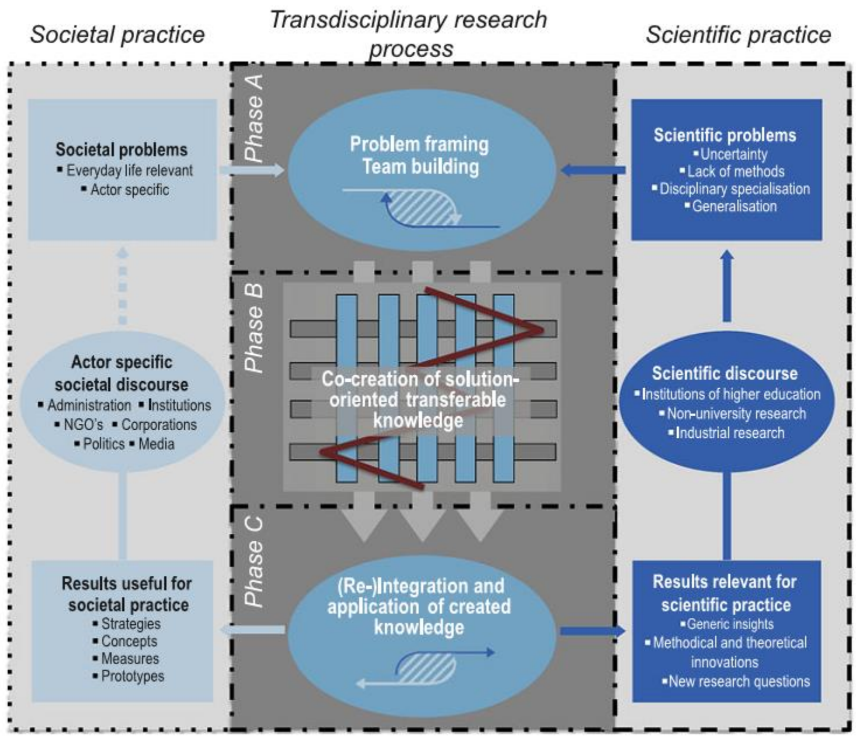
This section briefly introduces the concept of transdisciplinary research, shows its relevance in the context of sustainability challenges, and points out various shortcomings identified from the literature. Transdisciplinary research has been defined as a "research approach that includes multiple scientific disciplines (interdisciplinary) focused on shared problems and the active input of practitioners from outside academia" (Brandt et al., 2013, p. 1). As such, they point out three elements: integration of different disciplinary perspectives and perspectives from practice, and addressing shared problems.

The transdisciplinary research process typically occurs in three phases: the collaborative definition among scientists and practitioners of the scientific and societal problem to be addressed and the formation of a transdisciplinary research team, knowledge co-production through transdisciplinary research, and the integration of results for social change and scientific advancement (Brandt et al., 2013; Dedeurwaerdere, 2014; Lang et al., 2012). The figure featured below depicts the stages and the iterative, recursive cycle. The process occurs on the interface of science and practice. The process has two intertwined pathways (on the right and left of the figure):

one, which is focused on transforming societal practice towards more sustainability and one, which is focused on advancing the scientific field.

Figure 5

Conceptual Model of an Ideal-Typical Transdisciplinary Research Process.



Note. Taken from Lang et al. (2012, p. 28).

Transdisciplinarity is seen as an integral part of science of sustainability. The involvement of non-academics is seen as a means to integrate different knowledge types into the research process, bring different perspectives together and create ownership of both sustainability challenges and possible action pathways. The rationale and origins of collaborative research can be traced back to concepts, such as post-normal science (Funtowicz & Ravetz, 1993; Lang et al., 2012). Transdisciplinarity is considered to (1) hold the potential to integrate various knowledge types (across disciplines and practice), which is essential in the face of complex sustainability challenges, (2) allow to account for divergent goals, norms, and visions across groups essential in the guidance for transitions and interventions, and (3) have the potential to increase legitimacy of scientific findings in society, support ownership and accountability of the issue and possible action pathways (Lang et al., 2012).

3.1.3 Collaboration and Systems Analyses

One of the key pillars of transdisciplinary sustainability science is marked by collaboration across scientific disciplines and practice (Clark & Dickson, 2003; Jerneck et al., 2011; Kaneshiro et al., 2005; Kates et al., 2001; Komiyama & Takeuchi, 2006; König, 2018; Levin & Clark, 2010; Siebenhüner, 2004). Transdisciplinary collaboration or engagement is seen as an important means to the so-called integrated or holistic analyses of sustainability challenges. It helps to elucidate the issue complex from a diverse set of perspectives. In decision-making contexts marked by high uncertainty, collaboration is a way to account for uncertainty by collaboratively defining the issue complex at hand and collaboratively determining and evaluating possible future action pathways and their consequences (Kates et al., 2001; Komiyama & Takeuchi, 2006). The high urgency of such issues as well as their embeddedness in society (and their direct impact on the lives within society) makes the involvement of non-scientific actors imperative (Ravetz, 1999; Siebenhüner, 2004). Collaboration is associated with social learning among the groups involved and, at best, it should support it (Kates et al., 2001; Siebenhüner, 2004). Alongside these claims, Siebenhüner and colleagues put forward that collaboration (or participation) is required in the face of sustainability challenges, which are not only multi-scalar in nature, but also are being influenced by various actors on multiple levels. Collaboration is also seen as a way to foster commitment across society to support sustainability transitions, to increase legitimacy of decisions based on scientific evidence, and to educate and empower (Siebenhüner, 2004). In sustainability science, the approaches to stakeholder engagement vary, much like the approaches to sustainability science themselves. Mielke et al. (2016), for example, identify four types stakeholder engagement. The technocratic type, for instance, focuses on expert-stakeholders aiming to broaden the set of issue-specific, objective, and falsifiable information. The approach taken in this research project, in turn, is closer to the democratic types, which seeks to integrate stakeholders of societal transformations into the research processes through dialogue mediated by scientists with the aim to produce socially robust knowledge through co-design and the co-production of knowledge.

Next to collaboration, the so-called integrated or holistic analyses play an important role in transdisciplinary sustainability science. They are based on a systems perspective on sustainability challenges (Jerneck et al., 2011; Komiyama & Takeuchi, 2006). They should be performed in consideration of the socio-ecological systems that the challenges are embedded in (Abson et al., 2017; Kaneshiro et al., 2005). It is argued that to perform research on coupled systems, transdisciplinary collaboration is required to deliberate on and co-determine the issue complex and possible future action pathways and their intended and unintended consequences. The transdisciplinary nature of the inquiry does not mean, however, that disciplinary research cannot be utilised to its full potential; It should be integrated into research design as a means to contribute to the co-created project objectives (Lang et al., 2017).

3.1.4 Has Sustainability Science Been Able to Live up to its Promises?

A number of challenges to transdisciplinary sustainability science and sustainability science in general have been identified. It has been put forward, for example, that evidence of impacts in practice are lacking (Dedeurwaerdere, 2014; Mielke et al., 2016; Siebenhüner, 2004) and that stakeholder engagement is often inadequate (Brandt et al., 2013; Dedeurwaerdere, 2014; Lang et al., 2012; Mielke et al., 2016). A key reason seems to be the fact that sustainability science is coordinated by scientists and that traditional incentives focus on achievements related to science (Lang et al., 2017). It has also been argued that sustainability science has been rather focusing on weak leverage points - a critique connected with disciplinary approaches to sustainability science - and that approaches, which take a systems perspective are better suited (Abson et al., 2017).

3.1.5 Participatory Inquiry Paradigm

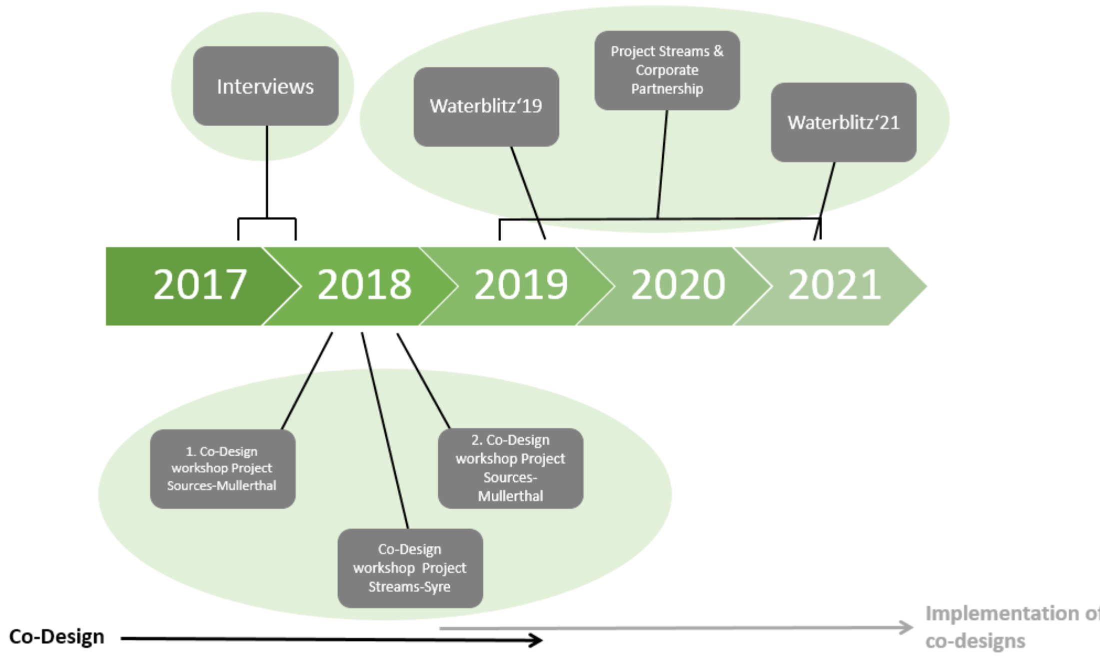
The research ontology that is followed in this research project does not identify with positivism (i.e. assuming a reality independent of us) nor with constructivism (i.e. reality is created by us). It assumes that we participate in a reality that exists independent of us and that we experience, think of, express, and theorise this reality inter-subjectively - that is, mediated by a person and its cultural environment. This is what Heron and Reason (1997) termed subjective-objective. In the subjective-objective ontology, the value of experiential and practical knowing is emphasised. Research that is collaborative is well-suited in such context. Consequently, the value of diverse perspectives and types of knowledge are emphasised in this research project. Section 3.9 gives more details on how stakeholder engagement has been facilitated.

3.2 Overview of Work Packages Part of the Thesis

This thesis encompasses three main work packages, which are (1) semi-structured qualitative interviews with specialists in the water quality domain, (2) workshops for the co-design of citizen science projects including tools for data collection and meaning-making related to the state of surface water bodies in Luxembourg with interested Luxembourgish groups, and (3) the undertaking of citizen science data collection programmes and meaning-making approaches with the Freshwater Watch citizen science methods developed by Earthwatch. For a graphical representation, please see Figure 6. In the following each of the work packages is presented in more detail.

Figure 6

Timeline Detailing Major Work Packages: Interviews, Co-Design Workshops, and Citizen Science Activities using the Freshwater Watch Methods by Earthwatch



3.3 Semi-Structured Interviews with Water Specialists on the Water Quality Data Landscape and Ideas for Citizen Science

In this study, semi-structured qualitative interviews were conducted with specialists in the water quality domain. Interviews are a very common method for data collection in qualitative research (Mason, 2002). In particular, in research using a subjective-objective ontology, "human experiences, understandings, meanings, and practices" are considered important (Anderson et al., 2015, p. 29). Interviews are particularly suited in this context (Stringer, 2014). The interviews were also exploratory in nature, which is common practice for getting insights into experiences (Stringer, 2014), and centred around the key themes of actors, roles, relationships, and data flows as well as other important themes in the data landscape on water and water quality in Luxembourg. The purpose of the interviews was multi-fold. The interviews were aimed at building an overview of the data landscape on water and water quality in Luxembourg from various perspectives. At the same time, the interviews aimed at identifying opportunities in the data landscape with the potential for more sustainable water governance, potential roles and contributions of citizen science from the perspectives of the interviewees.

3.3.1 Interviewees and Selection Criteria

The selection criteria for the interviewees was their engagement in data collection and meaning-making and/or relevant experience in the water quality domain. It followed the purposeful sampling strategy, in which interviewees are selected based on having a stake in or influence over a particular issue or process (Collins et al., 2004; Reed et al., 2009; Stringer, 2014). Table 1 lists all the interviewees with a brief description including relevant information, such as profession or professional affiliation and the particular field of experience.

Interviewee selection was based on understanding of the Luxembourgish data landscape on water and water quality developed previously in the overarching NEXUS FUTURES project from interviews and documentary review and developed in an on-going manner based on the interviews as they were conducted. For more information on the NEXUS FUTURES project, please see section 3.8.

Table 1

List of Interviewees

Interviewee	Description	Month and year of interview
1	Governmental professional in the water quality domain	November 2017
2	Governmental professional in the water quality domain	November 2017
3	Researcher in the water quality domain, in particular wastewater treatment	November 2017
4	Researcher in the water quality domain	December 2017
5	Person with relevant professional experience in the water quality domain and former researcher	December 2017
6	Governmental professional in the water quality domain	December 2017
7	Person with relevant experience in the water quality domain, in particular ichtyofauna	December 2017
8	Researcher in the water quality domain, in particular wastewater treatment	January 2018
9	Professional in the water quality domain, in particular wastewater treatment	January 2018
10	Professional in the water quality domain, in particular wastewater treatment	January 2018
11	Professional in the water quality domain, in particular drinking water production	January 2018

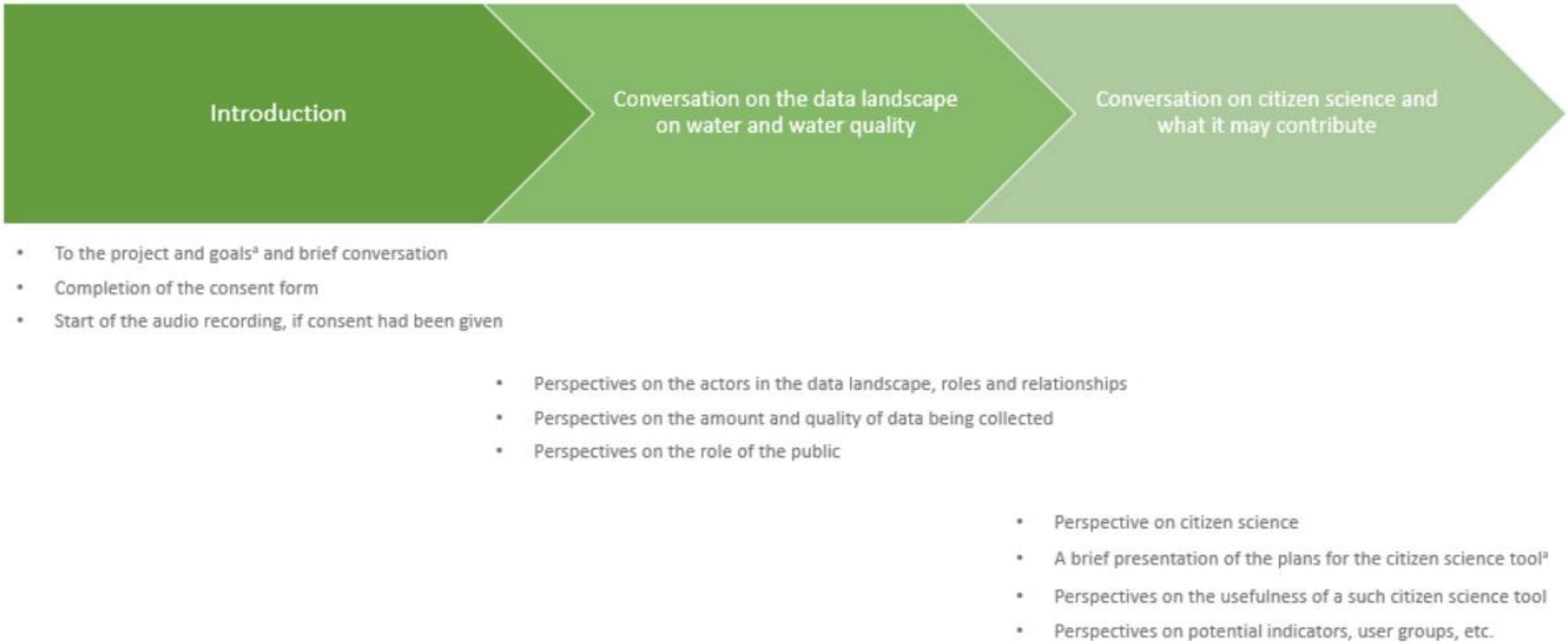
Note. To guarantee the anonymity of the interviewees, the descriptions are intentionally as broad as possible.

3.3.2 Interview Procedure: Consent Forms, Interview Questions, and Recording

Figure 7 depicts the interview procedure as applied in this study. The introductory part of the interviews encompassed a brief presentation of the goals of the research project and a brief subsequent conversation on the project. It also included the completion of the prepared consent form, which detailed questions and information about the use of the data, about anonymisation and the recording of data (see Annex 2). The consent form was established as part of the ethics approval of the research project by the ethics committee of the University of Luxembourg. If consent was given, the interview would be audio recorded for later transcription or the composition of a summary. The interview procedure roughly follows the procedure set out by Stringer (2014).

Figure 7

Interview Procedure



Notes. [a] These activities were performed by the interviewer.

The list of guiding questions for exploring the three main themes can be found in Annex 1. The interviews were designed in a way to provide some degree of freedom for the exploration of important themes not listed as part of the guiding questions. In the same way, the structure of the interviews was flexible to allow for a more natural flow in function of the conversations and interviewees. In general, the interview duration ranged from about 90 to about 120 minutes.

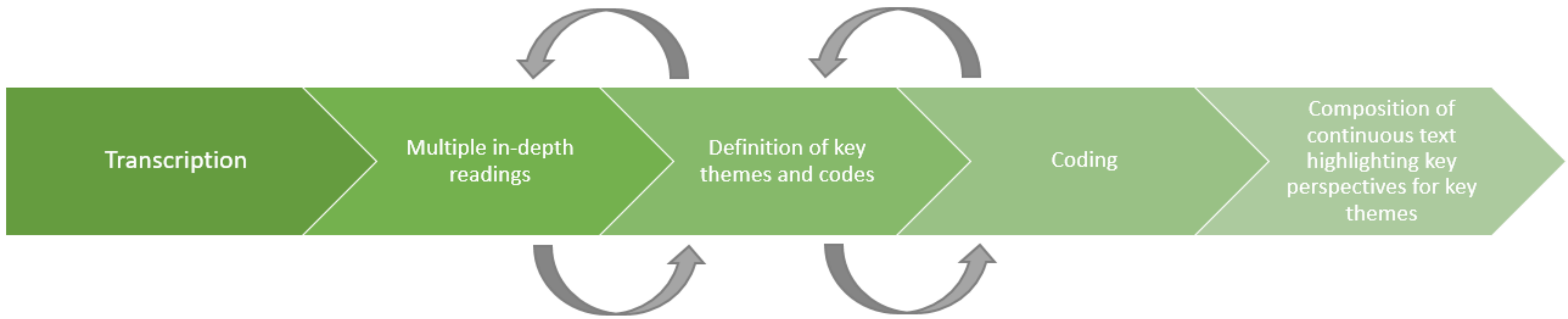
3.3.3 Interview Data Analysis

As all interviews were audio recorded, many interviews were also transcribed. The transcriptions were performed by the doctoral researcher and a company offering transcription services in an about 50:50 ratio. The transcription format followed the rules of “edited” (Penguin Transcription, 2021; Summa Linguae, 2021) or “denaturalised” (Oliver et al., 2005) transcription, where, in short, the speech is edited to remove certain characteristics of non-rehearsed speech, such as filler words and repetitions, while focussing on preserving the speech and its meaning as much as possible (Oliver et al., 2005). The interviews that were not transcribed (two interviews), were summarised instead. To save time, summaries of interviews were also considered appropriate, as the focus in the analysis was on informational content rather than the conversation itself.

After the transcripts and summaries were made, they were subject to multiple in-depth readings to identify the key themes. For a graphical display of the interview analysis procedure, please see Figure 8. The themes were partly determined by the guiding questions and partly a result of the exploratory character of the interviews. The key themes were used to determine a set of codes for qualitative interview analysis using MAXQDA software. The reading of the interviews, the definition of key themes and codes, and the coding of the interviews were part of an iterative process of refinement. The fact that some interviews were summarised did not cause any issues in the coding and further analysis, as coding was not dependent on the exact wording of a statement. Time stamps in the summaries also allowed for quick re-listening of the audio recording.

Figure 8

Interview Analysis Procedure



The codes that were the result of this process were the following:

- Perspectives on citizens as data producers,
- Citizen responsibility to water quality,
- More and better quality data,
- Citizen science and data quality,
- Joining scattered databases,
- Change for more sustainable water governance,
- Sharing information or data with citizens?,
- Uncertainties in the interpretation of water quality data,
- Ideas for applications of citizen science,
- Data landscape: actors, roles, relationships, and data flows.

The codes served as “bins”, into which related statements could be collected. A goal was to develop collections of statements relevant to a certain topic containing the different perspectives. This facilitated the analysis of the different statements and perspectives per topic.

3.4 Co-Design Process and Workshops

Alongside the interviews, this study was based on the results of a co-design process including multiple co-design workshops. The aim of the co-design process and workshops was to co-create one or multiple citizen science projects for research on the topic of the state of Luxembourgish surface water bodies with relevance for governance and management. An early objective was to find groups in Luxembourg, which were interested in the topic area and in co-designing a citizen science project and tool for their purposes. A description of the co-design process is presented in the following.

A diversity of groups was contacted in the first phase of the co-design. They can be roughly divided into the following categories: clubs (e.g. active in sportive activities), environmental organisations (amateur and professional), organisations active in promoting sustainable development (amateur and professional) and organisations related to tourism. In total, 16 organisations in the above categories were contacted. First contact was established by email. A phone call was issued to the respective organisations in case of no reply or in case of interest. 4 groups were not reached.

Exploratory meetings were held with 5 groups: the later co-design partners Natur- & Geopark Mëllerdall and the Committee for Sustainable Development of the Commune of Niederanven as well as one regional amateur environmental organisation, one regional professional organisation active in promoting sustainable development and one club active in sportive activities related to surface water. In the next step, the co-design workshops were organised with the above-mentioned partners as well as the club.

A detailed description of the co-design methods used in the co-design workshops is presented in the subsequent sections per workshop in chronological order per project. Table 2 provides an overview of the co-design workshops including information on methods, number of participants, and duration. As Table 2 displays, there is a significant difference in the number and duration of the co-design workshops between Projects Sources-Mullerthal and Streams-Syr. Consequently, there are also significant differences in the number of insights that can be drawn from the workshop results, which can be witnessed in the following chapters.

The procedure and methods adopted in the co-design workshops were inspired by the participatory design framework developed by Sanders, Brandt, and Binder (2010). They propose a series of methods for participatory design by form (i.e. making, telling, and enacting), purpose (i.e. probe, prime, understand, and generate) and context (i.e. individual, group, face-to-face, and online). Sections 3.4.1 - 3.4.3 demonstrate the application of the framework in this context.

Table 2

Overview of Co-Design Workshops Including Number of Participants, Duration and Methods

Workshops	Participants	Methods	Duration (hours)
1 Sources-Mullerthal	6	• Mapping and discussion of relevant actors to the project in function of their potential interest level and their potential level of influence over the project with links, roles, and motivations • Mapping and discussion of relevant experiences (impressions, circumstances, and changes) with surface water bodies and of (corresponding) indicators • Discussion of selected indicators based on a number of characteristics, such as data collection method and effort • Identification and discussion of potential data collectors and their motivations, among others • Identification and discussion of potential data users and their motivations	4
2 Sources-Mullerthal	5	• Classification and discussion of the indicators according to their potential for awareness raising, learning, improvement of the state of the streams, and science • Classification and discussion of user groups according to their potential interest, data collection frequency, potential for awareness raising, and effort of engagement • Design and discussion of the way, in which the project is introduced to potential user groups and the kit is provided, if applicable • Identification and discussion of important contextual information for meaning-making in function of the selected indicators • Identification and discussion of important indicator values: e.g. values for the "natural" range and for thresholds • Identification and discussion of important relationships among indicators • Brainstorming and discussion on approaches to data visualisation	4
1 Streams-Syre	5	Mapping and discussion of relevant experiences (impressions, circumstances, and changes) with surface water bodies and of (corresponding) indicators	2

3.4.1 Co-Design Workshop 1: Sources-Mullerthal

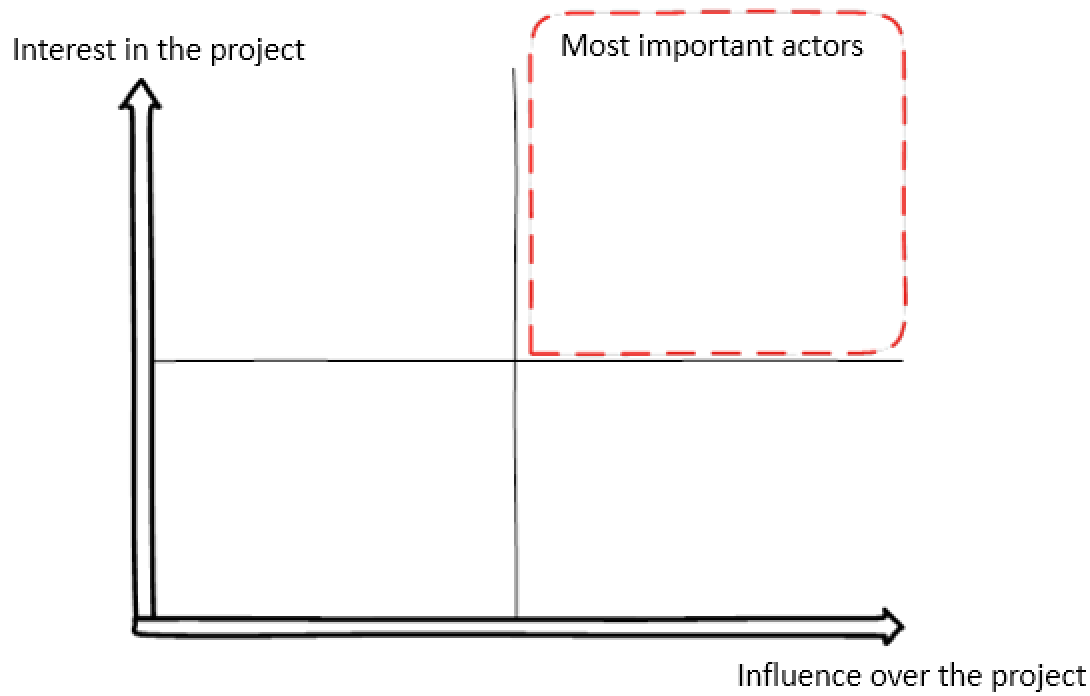
Each of the activities on the different topics was started as an individual task. A short silent reflection was followed by an individual collection of ideas. This intended to give each individual the opportunity to think about a topic and to come up with an individual stance and ideas. These were, then, brought into the subsequent group discussion, which was to be enriched by the different perspectives. During or after the discussion phase, the templates were filled out collectively based on the previous insights. This four-step process aimed at giving all participants the opportunity to meet and exchange on one level as far as possible.

Templates and sticky notes played an important role in all activities. All participants worked on a common product and sticky notes could easily be moved around on the template during the process. In addition, the visual representation and the associated physical activity were intended to stimulate discussion and creativity. According to Sanders, Brandt, and Binder (2010, p. 2), 2-D collages are well-suited “for probing participants, (…) for priming participants in order to immerse them in the domain of interest, (…) to get a better understanding of their current experience [and/]or the generation of ideas or design concepts for the future (…)”. The use of sticky notes rested on the suggested method of cards, which is described as helpful for “organis[ing], categoris[ing], and prioritis[ing] ideas” (Sanders et al., 2010, p. 2).

Method 1: Actor Mapping. The template in Activity 1 "Actors" aimed to classify the identified and relevant actors visually, on a grid with the axes of interest (Y) and influence (X). As displayed on Figure 9, the grid was divided into four rectangles. The actors placed in the same rectangle share a similar level of interest and influence. Thus, the most important actors were placed in the rectangle furthest from both axes. Here the actors had a relatively high level of interest and influence. The actors in the rectangle that was located below the one previously discussed had a great influence on the project, but relatively little interest. Due to their higher influence level, the needs of these actors should be considered in the project and the actors should be "on board". The rectangle located at the top left of the grid indicated great interest in the project but little influence. Stakeholders placed in this rectangle should be well informed about the project and news. Attempts should be made to engage them in cooperation. The actors placed in the rectangle closest to the two axes had the least interest and influence. They should be marginally informed about the project and news. In addition, the roles and motivations of the respective actors were listed in a table.

Figure 9

Template for Activity 1 "Actor Mapping" (and Activity 3 "User Groups" and 4 "Data Citizen Scientists") of Co-Design Workshop 1 Sources-Mullerthal

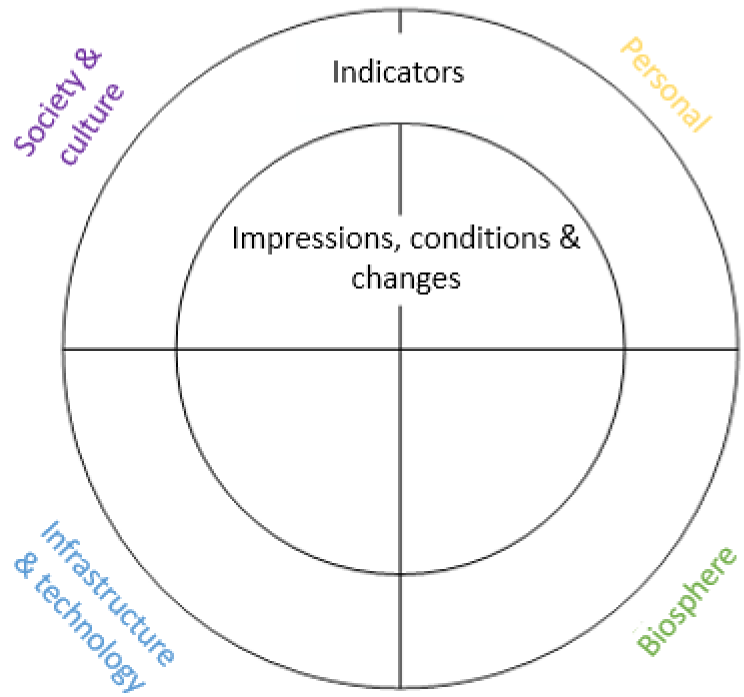


Method 2: Indicator Mapping. The template in Activity 2 "Indicators" as shown in Figure 10 served to infer relevant indicators for the monitoring activities from the actors' experiences with the water bodies in question and water issues in general. Here, impressions, conditions and changes were first arranged in the inner area of a circle,

which were then linked to indicators. The indicators, in turn, were arranged in the outer part of the circle. The areas represented (Society and Culture / Personal / Biosphere / Infrastructure and Technology) were intended to encourage creativity in the collection of ideas, to serve as inspiration and to assist in the interpretation (and definition) of the ideas listed. In the case where impressions and indicators could not be clearly assigned to the areas, they could, for example, be placed between the areas under consideration or in the middle of the template. The experiences of the participants were taken as a starting point in order to establish a wider range of ideas (greater variety of ideas / unexpectedness). The template is based on Material Engagement Template developed by Ariane König (manuscript in preparation). It aimed at supporting the identification and discussion of indicators from the different spheres of the social-ecological-technological system and their interconnections and feedbacks. The Material Engagement Template supports inquiries into social-ecological systems considering feedbacks between the society, culture, the personal sphere, ecosystems, technologies, and infrastructure.

Figure 10

Template for Activity 2 "Indicator Mapping" of Co-Design Workshops 1 Sources-Mullerthal and Streams-Syr



To create a selection with the most relevant indicators, another template was available. Here the groups were asked to answer a series of questions relevant to the later implementation and to generate more details on the selected indicators. The question can be found Text Box 1.

Text Box 1

Guiding Questions for the Selection of Indicators and the Generation of Additional Information

Guiding Questions for the Selection of Indicators and the Generation of Additional Information

- What is the indicator an indicator for?
- How could the indicator be recorded?
- How high would the effort be for a recording (e.g. very low, low, medium, high, very high)?
- Are fixed data collection sites of benefit or even necessary for meaning-making?
- Is a specific minimum data collection frequency necessary for meaning-making? If so, what would it be?
- What could citizen scientists learn by recording the indicator and by making meaning from the recording?
- Which other indicators would fit well?

Methods 3 and 4: Potential Data Collectors and Data Citizen Scientists.

Methods 3 and 4 dealt with potential data collectors and data citizen scientists respectively. A template with questions was provided for the user groups to generate more detail and help with selection (see Text Box 2). All relevant user groups were arranged on the 'actor' template (see Figure 9) and their motivations determined. The data citizen scientists were arranged/labelled on the 'actor' template and their motivations written down.

Text Box 2

Questions Regarding Potential Data Collectors for More Detail and Help With Selection

Questions Regarding Potential Data Collectors for More Detail and Help With Selection

- What would be the group's motivation to participate?
- Is the relationship of the value of participation for the group and the associated required effort adequate?
- What would be the estimated supported data collection frequency by the user group?
- Does the user group fulfil any other conditions (e.g. Is any specific know-how required for data collection)?

3.4.2 Co-Design Workshop 2: Sources-Mullerthal

Method 1: Classification of Indicators. Step one of Method 1 consisted of assigning 3-5 indicators to each motivation of the relevant actors, i.e.

- awareness raising,
- learning,
- state improvement, and
- science,

that appeared to be particularly relevant, writing the indicators in the appropriate boxes on the corresponding template. Afterwards, the indicators were numbered according to their degree of relevance. Based on this, a set of indicators was created that included the most important indicators based on, among others, the frequency of mention and the noted degree of relevance.

Method 2: Refinement of the Selection of Data Collectors. A template was also provided for Method 2. The previously identified user groups were listed in the boxes provided and classified in relation to the factors:

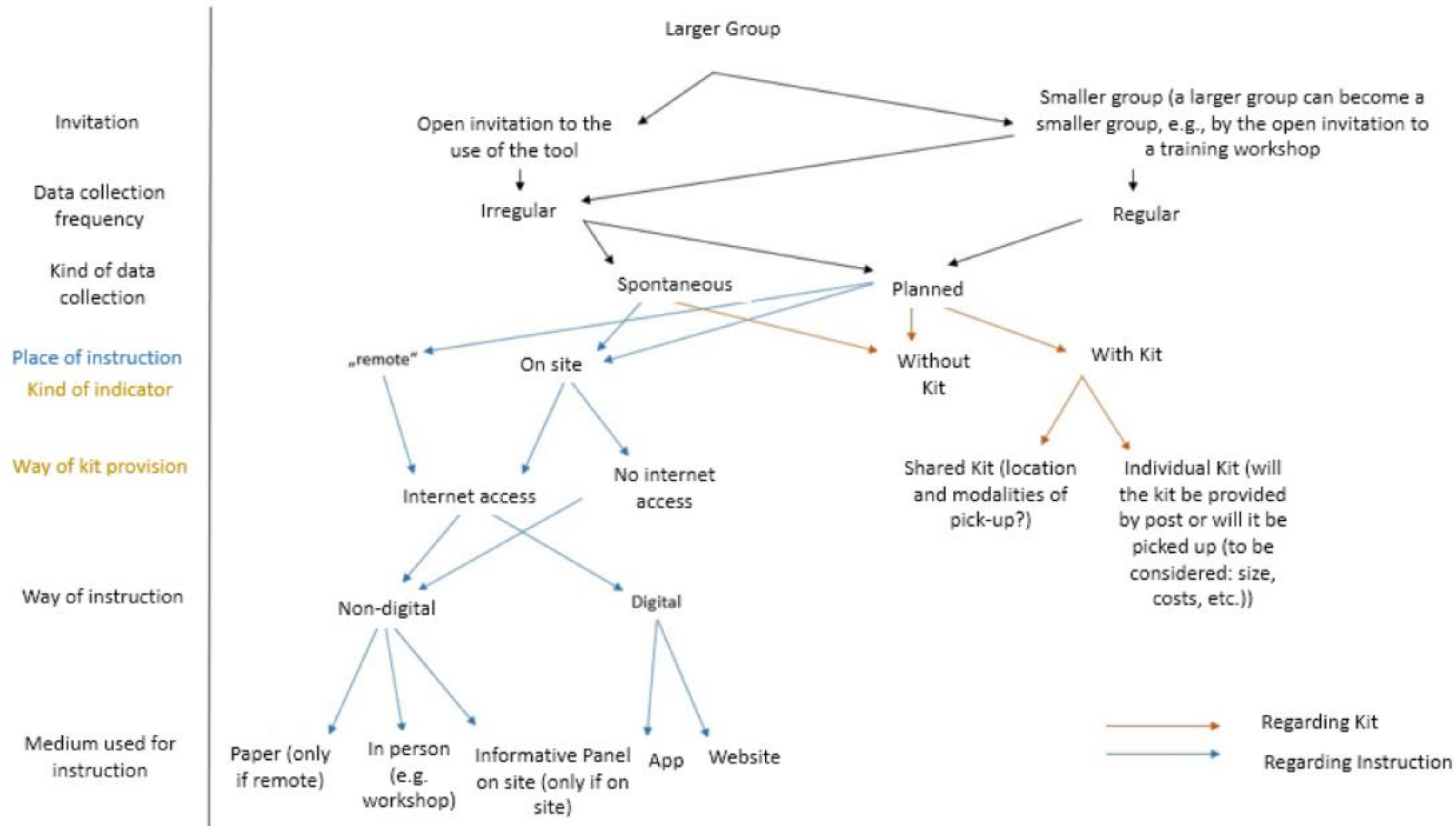
- potential interest in using the tool,
- the number of data points per year that the group of data collectors is estimated to collect,
- potential for motivation "awareness raising", and
- organisational effort to involve the data collectors in the project.

It should be noted that this activity was designed to be thought-provoking and to provide a basis for discussion to compare the different characteristics of the groups of data collectors. The final step was to identify a group of data collectors that emerged from the discussion as the most important in relation to the factors listed above.

Method 3: Design of Project Introduction and Kit Provision. Method 3 was designed in the form of a “decision tree” also provided as a template (see Figure 11), on which the decisions were also marked. The tree acted as guidance for important decisions and pointed out compatibilities in them. The starting point was a specific group of data collectors identified beforehand. This method rests on the method of participatory envisioning and enactment, which is seen as well-suited for “setting user in future situations” put forward by Sanders, Brandt, and Binder (2010, p. 3).

Figure 11

Decision Tree: Project Introduction and Kit Provision



2021 Karl Pickar

Method 4: Contextual Information for Meaning-Making. On the template for Method 4, relevant contextual information for interpreting the selected parameters were listed in a table. The rationale for the relevance of each sort of contextual information (e.g. geological information of the Mullerthal Region) was included as well as known sources (e.g. Geoportal.lu). In the second step, relevant thresholds related to the indicators were listed in a table (if applicable) along with an explanation of the meaning of each threshold in the interpretation. In addition, the threshold values for the "natural" range were added, if possible. In the following table, relevant relationships between the parameters were inserted, accompanied by a short description of the relationship and its relevance in the context.

Method 5: Collection of Ideas in Relation to the Visualisation of Data. Method 5 took the form of a collection of ideas in relation to the visualisation of data for the selected parameters. At this stage, also building on the previous activity, graphical as well as written modes of presentation for the different indicators were discussed and represented on a blank sheet of paper. The following questions were provided for guidance:

- What should be obvious at first glance?
- Should it be possible to compare indicators among each other? If so, which ones?
- Should it be possible to display time series? For which indicators would this be interesting?

Method 6: Role and task allocation. Method 6 consisted of an open exchange about preferences and concessions regarding role allocation and possible involvement in the elaboration of tasks in project development.

3.4.3 Co-Design Workshop: Streams-Syr

Due to the considerably shorter duration of the only co-design workshop for Project Streams-Syr, method Indicator Mapping was mainly used. For a description of the method, please see section Co-Design Workshop 1: Sources-Mullerthal .

3.4.4 Co-Design Workshop Procedure: Consent Forms and Recording

Before the methods were used as presented above, each workshop started with the distribution of the consent forms that were established as part of the ethics approval of the research project by the ethics committee of the University of Luxembourg. Among other things, the consent forms included questions and information on the use of the collected data, anonymisation, and the recording of data. If consent had been given by all attendees, the audio recording was started. Subsequently, an introductory presentation was held including information, such as project goals and schedule for the day.

3.4.5 Co-Design Workshop Follow-Up

A report was written as follow-up on all the co-design workshops. The reports included information on the methods used as well as a detailed description of the results and suggestions for follow-up actions. The content was based on the material products of the workshops, namely the maps and tables that were filled in as part of the different methods, if applicable. In addition, the audio recordings were used to complement the results noted on the material products in case there was a need for additional information on the results noted on the material products and for information on other prominent topics of discussion. The reports were sent to the attendees for feedback and quality control.

3.5 Contributory Citizen Science Projects

As section 3.2 outlines, another work package of the research project described in this thesis was the design and implementation of two contributory citizen science projects, namely project Streams & Corporate Partnership and Waterblitz. Since the two projects also constitute case studies in this thesis, an entire chapter (Chapter 5) is dedicated to their description. For more detail on them, such as actors involved and data collection methods, therefore, see Chapter 5.

3.6 Documentary Review

As a basis of the presentation of results in the empirical chapters of this thesis, a series of documents were reviewed to complement the data from the work packages. Table 3 displays the key documents, mainly including Luxembourgish laws and regulations as well as governmental websites for the publication of data. Alongside these key documents, other documents were also reviewed. These include organisational websites for information about the organisations (e.g. missions) and reports/ publications for information, such as activity reports, and data collection programmes, results, and findings (examples are the websites of the actors represented in Chapter 4, Chapter 5, and Chapter 6).

Table 3

List of Key Documents Reviewed

Thesis Chapter	Document type	Issuer	Document Name (Original Language)	Document Name (English), if applicable	Purpose of Review
Chapter 4	Luxembourgish law	Luxembourgish Government	Loi du 19 Décembre 2008 Relative à l'Eau 2008	Luxembourgish Water Law	Water data collection programme of the Luxembourg Government (e.g. parameters, data collection frequencies, sites, etc.)
Chapter 4	Luxembourgish regulation	Luxembourgish Government	Règlement Grand-Ducal du 13 Mai 1994 Relatif au Traitement des Eaux Urbaines Résiduaires 1994	Luxembourgish Wastewater Treatment Regulation	Water data collection programme related to wastewater treatment (e.g. parameters, data collection frequencies, sites, etc.)
Chapter 4	Luxembourgish regulation	Luxembourgish Government	Règlement Grand-Ducal du 7 Octobre 2002 Relatif à la Qualité des Eaux Destinées à la Consommation Humaine 2002	Luxembourgish Drinking Water Regulation	Water data collection programme related to drinking water (e.g. parameters, data collection frequencies, sites, etc.)
Chapter 4	Management plan	Luxembourgish Water Management Agency	Plan de Gestion Pour Les Parties Des Districts Hydrographiques Internationaux Rhin et Meuse Situées Sur Territoire Luxembourgeois (2015-2021)	Management Plan for the Parts of the International Hydrographical Districts Rhine and Meuse on Luxembourgish Territory (2015-2021)	Water data collection programme of the Luxembourg Government (e.g. parameters, data collection frequencies, sites, etc.)

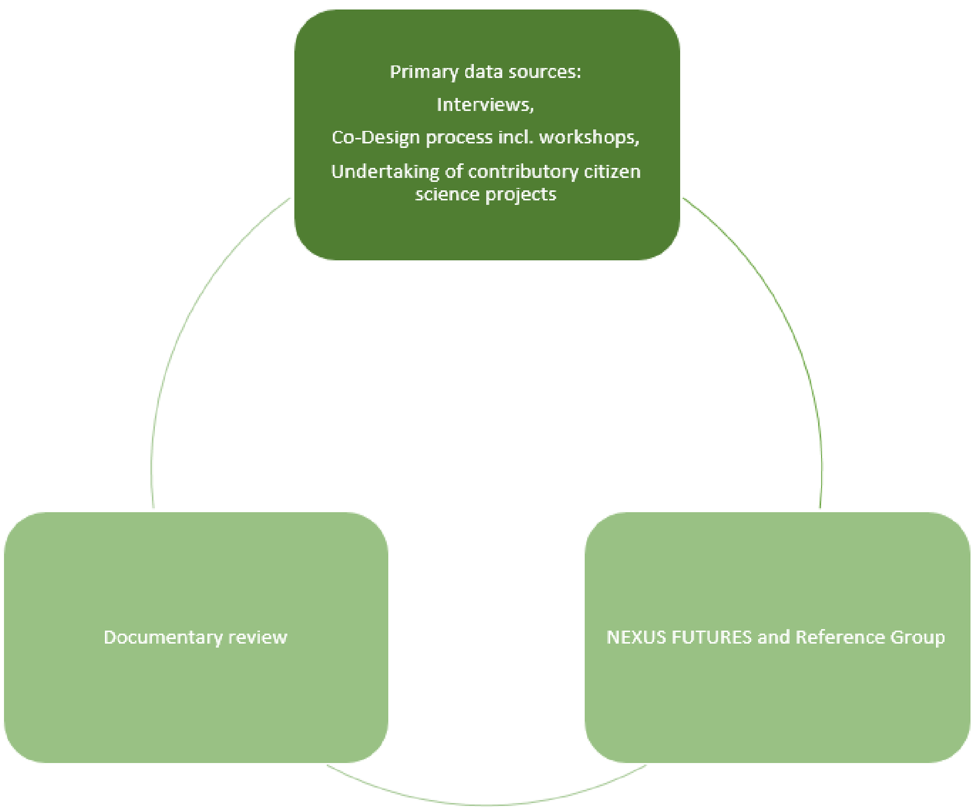
Chapter 4	Website	Luxembourgish Government	Geoportal.lu	Geospatial water data in Luxembourg (e.g. related to the governmental water data collection programme, such as results and sites, locations of wastewater treatment plants, location of surface water bodies, etc.)
Chapter 4	Website	Luxembourgish Government	Inondation.lu	Geospatial water quantity data in Luxembourg (e.g. water level measurements across Luxembourg)
Chapter 4	Website	Luxembourgish Government	Data.public.lu	Water Data in Luxembourg (e.g. related to the governmental water data collection programme, such as results and sites, locations of wastewater treatment plants, location of surface water bodies, etc.)
Chapter 5	Citizen science project supporting documents	Earthwatch	Freshwater Watch Supporting Documents (e.g. data collection form, help section on mobile application, user guide)	Freshwater Watch data collection programme (e.g. data collection protocols, guiding information)

3.7 Method Triangulation

Method triangulation is common in qualitative research. It can include multiple methodological practices, empirical materials, perspectives, and observers and is seen "as a strategy that adds rigor, breath, complexity, richness, and depth to any inquiry" (Denzin & Lincoln, 2011, p. 5). Since the subjective-objective research paradigm posits that the objective reality cannot be captured, it is important to consider multiple sources of data on a phenomenon. Method triangulation was, therefore, applied in this research project and the different sources of data are displayed in Figure 12.

Figure 12

Method Triangulation in the Research Project



The primary data sources, which correspond to the work packages described in sections 3.3 and 3.4, were complemented with documentary review (section 3.6) and with information gathered through the engagement in the Sustainability Science Research Group in the framework of project NEXUS FUTURES, and presentations and discussions in Reference Group meetings of the NEXUS FUTURES research project (see section 3.8 for a detailed description of its role). Documentary review, in general, aimed to provide more detail to the primary data sources. The description of actors in the empirical chapters, for example, was based both on the primary data sources as well as on documentary review for more detail. In the same way, the description of the current data collection and meaning-making in Luxembourg (Chapter 4) is both based on the interviews and the review of relevant laws and organisational documents.

3.8 The Sustainability Science Research Group at the University of Luxembourg and the Reference Group

The aim of this section is to describe the ways, in which the engagement in the Sustainability Science Research Group at the University of Luxembourg and the NEXUS FUTURES Reference Group have contributed to the empirical study presented in this thesis. For a presentation of the Research Group and NEXUS FUTURES, see section 5.1.1. The Reference Group of NEXUS FUTURES was composed of multiple stakeholders in Luxembourg mainly from practice (a couple also from academia). Its aim was to provide regular feedback and guidance on project developments, results, and findings. As such, the Reference Group meetings constituted an opportunity for gathering information on additional perspectives of key stakeholders. In addition, the meetings constituted an opportunity for all to catch up on recent developments in the field of water governance.

The engagement in the Sustainability Science Research Group at the University of Luxembourg contributed to the empirical study in multiple ways. For example,

- A lot of additional data was available due to the overall very high number of interviews and workshops conducted as part of NEXUS FUTURES, which, for example, provided a lot of background information and contributed to the "common understanding" of related phenomena throughout Research Group,
- The engagement of the PhD researcher and author of this thesis in discussions at NEXUS FUTURES workshops and interviews also contributed contextual information and to the above-mentioned "common understanding", and
- The engagement of the PhD researcher and author of this thesis in regular meetings of the Sustainability Science Research Group provided room for feedback on research project developments, results, and findings and for discussion.

The engagement in the NEXUS FUTURES Reference Group meetings also contributed to the empirical study in multiple ways. For example,

- It constituted a place for feedback and discussion by key stakeholders in Luxembourg on research project developments, results, and findings and discussion, and
- It made available a lot of contextual information and informed on relevant current developments in water governance in Luxembourg and beyond.

3.9 Application of the Research Approach in the Research Project

After the research approach has been discussed in the previous sections, this section 3.9 aims to show how it was applied in the research project. To do so, the phases of the typical transdisciplinary research process are used as structural elements (see Figure 5; based on Lang et al. (2012)).

1. *Collaborative Problem Framing and Collaborative Team Building*
2. *Co-Creation of Solution-Oriented and Transferable Knowledge Through Collaborative Research*
3. *(Re-)integrating and applying the co-created knowledge*

Phase 1 encompasses the design of the research project. In transdisciplinary research, the research project is typically designed with input from actors from academia and practice aiming to further scientific knowledge and for changes in practice. Methods are designed to allow for the engagement of multiple knowledge types in the research processes, and research is performed by a collaborative research team. Phase 2 focuses on the actual implementation of the research project. Transdisciplinary sustainability science, typically, engages multiple knowledge types in the research process (e.g. specialist academic or practical knowledge, non-specialist knowledge). It is also built on the collaboration between actors from practice and academia in the research process. Phase 3 entails the use, application, and implementation of the research results and findings in societal and scientific practice.

The research project engaged the perspectives of actors from academia and practice in research design and process in the form of engaging actors

- as members of the Reference Group in meetings for feedback and steering,
- in qualitative interviews,
- in the co-design and implementation of surface water citizen science projects, and

- as citizen scientists in data collection and meaning-making on surface water.

The PhD research project was, from the very start, closely followed and influenced by the NEXUS FUTURES Reference Group composed of key actors from academia and practice, as section 3.8 describes in more detail. Meetings provided occasions for voicing ideas, feedback on project developments, and, as such, for the collective steering of the project. As meetings were held regularly (i.e. annually or bi-annually), the group members were involved in the design of the project as well as in its implementation.

The semi-structured qualitative interviews conducted at the start of the research project also allowed specialists in the water domain to shape the project by, for example, identifying areas in the data landscape on water quality in need for improvement and by making suggestions for ways, in which citizen science could be relevant for more sustainable surface water governance (see section 3.3 for more detail).

The co-design process of the co-created surface water citizen science projects was specifically designed to engage actors in the design of the research projects aiming to result in a project that is relevant for those involved. As such, the process facilitated the collaborative design of the citizen science projects and the building of collaborative research teams (see, in particular, project Sources-Mullerthal). The research was also particularly aimed at providing insights into social-ecological systems relevant for change in practice. The contributory citizen science projects also facilitated stakeholder engagement in the design, albeit in lesser form (see, in particular, project Streams-Syr).

Stakeholder engagement in the research process was demonstrated by the two contributory citizen science projects, in which citizen scientists collected data using a citizen science tool for surface water monitoring. It involved not only the use of measurement equipment, but also provided room for the engagement of diverse types of knowledge, for example, by using the comment function as well as determining the location of sampling sites.

The relevance of the research project for academia and practice is discussed in section 2.3. Phase 3, (re-)integrating and applying the co-created knowledge, could not be implemented in the framework of this research project due to time restrictions. It is, however, foreseen as part of future activities.

3.10 Study Limitations

This section is dedicated to describing the most pertinent limitations of the study in relation to the data collection and analysis methods presented in the previous sections. This section starts with overarching limitations, before presenting limitations related to the interviews and the co-design process in that order.

First of all, it has to be remarked that the interviews and the co-design process were conducted by the PhD researcher and author of this thesis with little to no experience in the use of the respective methods. The lack of experience can cause a number of issues in interviewing and co-design, impacting the amount and usefulness of the obtained data. Both practices are demanding and full mastery requires a lot of practice. For this reason, the thesis supervisor co-facilitated the co-design workshops.

The approach to recruitment related to the co-design process turned out not adequate for engaging non-specialists. Although engaging non-specialists and potential citizen scientists was initially considered a main goal of the process, they chose not to engage, even if non-specialists groups had shown interest after initial contact. A key reason for not engaging beyond first contact, which was stated, was that the co-design process seemed too demanding in terms of specialised understanding of surface water system processes. As a result, the co-created citizen science projects are missing important perspectives. The lack of non-specialist and potential citizen science tool user perspectives in the co-design processes has to be considered in the evaluation of the results. In general, the co-design workshops were held with a very limited number of co-design partners due to a number of reasons. The co-design workshops for project Sources-Mullerthal, for example, were only held with the stakeholders of a source renaturation project, as the plan was to integrate the citizen science project. The co-design workshop for project Streams-Syr, in contrast, was aimed at the broader public. The open invitation, however, was only met by a handful of people, most of whom could be considered specialists in the water domain due to their profession. A suspected reason for this small turnout and incapability to reach non-specialists was the rather impersonal approach to taken to advertising the workshop with only publishing invitation letters in organisational newsletters and on websites. A more personal approach to recruitment by, for example, holding presentations in schools and communal meetings could have been more successful. In addition, the invitation letters were rather long and used complicated language. This was also remarked by a co-organiser from practice. In the future, adaptations of the language and format of open invitations seem like a worthwhile avenue to explore.

In addition, the duration of the co-design workshops was rather short in comparison with the intricacy and number of the tasks to be performed. It has to be noted that workshop duration was set in consultation with the co-organisers (i.e. the Committee for Sustainable Development of the Commune of Niederanven and the Natur- and Geopark Mëllerdall). A duration had to be determined, which provided enough room for the co-design process, and, at the same time, which did not deter stakeholders from engaging. At multiple occasions during the workshops, the present co-design partners gave the impression of being rather rushed than at ease. This issue can have multiple effects on the gathered data in the workshops, for example, resulting in a lack of detail as well as dissatisfied co-design partners. It also caused some deviations from the initial workshop schedules, for example, in the form of leaving out certain steps of a method possibly resulting in less detailed data. In the future, adaptations of the number and intricacy of the tasks to be performed in the co-design workshops could be worthwhile for more detailed data and more comfort during the workshops. Of course, co-creating a citizen science tool is also a complicated endeavour and a balance has to be reached.

Chapter 4. Surface Water Governance in Luxembourg: The Compatibility of Current Data Collection and Meaning-Making With key Principles of Adaptive Governance and Opportunities for Change

The goal of this first empirical chapter is to develop an answer to Research Question A: *"In how far are current data collection programmes and meaning-making approaches compatible with key principles of adaptive governance of social-ecological systems? What are opportunities for change?*". To arrive at an answer to this question, this chapter, first, presents the results of the empirical inquiry on current data collection programmes and meaning-making approaches oriented towards the governance and management of surface water bodies in Luxembourg. The results are based on data from semi-structured interviews with professionals in the water quality domain on the topic of the national "data landscape". The interviews (incl. questions about important actors, relationships, the role of the public, data publication practices, and gaps and opportunities for more sustainability) on water (see section 3.3) as well as extensive and in-depth documentary review of relevant legal texts and organisational reports, among others (see section 3.6).

Second, these results assessing the suitability of the current data collection programmes and meaning-making approaches for contributing to the adaptive governance of social-ecological systems are discussed in connection with the criteria identified in the conceptual framework (see section 2.5).

4.1 Actors, and Roles and Motivations

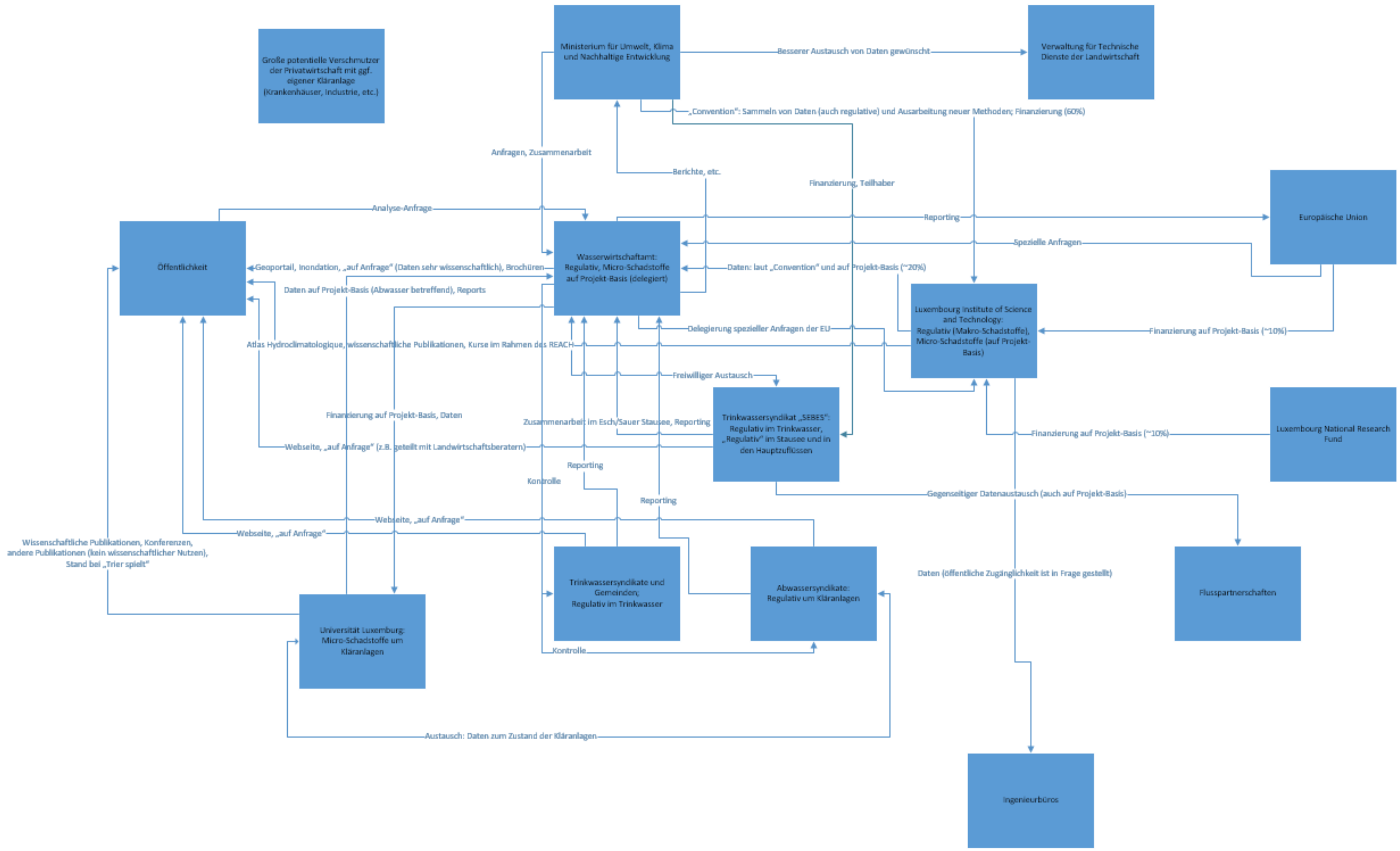
To begin the presentation of the results, the following focuses on the presentation of important actors more generally as well as on the presentation of the roles and motivations of each actor to participate in data collection and meaning-making on water quality more specifically. The actors and their motivations were largely identified by the interviewees. Actor descriptions, including organisational nature, if applicable, as well as exact roles for each actor are mainly based on documentary review. For ease of reading, first, an overview of the network of actors is presented, based on the interview results, including information about important roles, motivations, and connections.

4.1.1 Overview of Important Actors, and Important Roles, Motivations, and Connections

A relational map of important actors, and important roles, motivations, and connections identified based on the interviews can be found in Figure 13.

Figure 13

Relational Map of Important Actors, Important Roles, Motivations and Connections



2021 Karl Pickar

As can be observed, a majority of the arrows, representing relationships and flows, point to or originate from the national Water Management Agency, which is, arguably, the focal point of the network of important actors. It is in charge of the governmental data collection programmes and meaning-making approaches, which is set by, arguably, the most important piece of national legislation in the context of surface water quality, the Water Law of 2008 (*Loi Du 19 Décembre 2008 Relative à l'eau*, 2008; *Loi Du 28 Mai 2004 Portant Création d'une Administration de La Gestion de l'Eau*, 2004). It is the national transposition of the European Water Framework Directive (*Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 Establishing a Framework for Community Action in the Field of Water Policy*, 2000). The Water Management Agency is assisted in its mission by the Luxembourg Institute of Science and Technology, a public research centre. The Institute represents the most important contractor of the Water Management Agency in this context (Interviewee 4, personal interview, personal communication, 2017).

Other important actors include the syndicates for the decontamination of wastewater and the syndicates for the provision of drinking water. The former is tasked with data collection on the quality of the efficiency of the treatment and the quality of the treated wastewater that is emitted to the nearby watercourses. The data collection programme is defined by the Wastewater Treatment Regulation (*Règlement Grand-Ducal Du 13 Mai 1994 Relatif Au Traitement Des Eaux Urbaines Résiduaires*, 1994). The syndicates for the provision of drinking water, in turn, are in charge of ensuring the provision of drinking water that complies with the relevant standards as defined by the Drinking Water Regulation (*Règlement Grand-Ducal Du 7 Octobre 2002 Relatif à La Qualité Des Eaux Destinées à La Consommation Humaine*, 2002). Other important actors are the Wastewater Treatment Research Group at the University of Luxembourg, the river partnerships, and Natur&Emwelt. The most important actors are also listed in

Table 4, which acts as a summary of the following sections introducing each actor separately.

Table 4

Most Important Actors Engaged in Data Collection and Meaning-Making Related to Surface Water Governance and Management in Luxembourg Including Information on Roles, Legal Bases, and Motivations

Actor	Role of the actor in the data collection and meaning-making network	Legal basis of the actor and/or for data collection and meaning-making	Motivation for engaging in data collection and meaning-making directly or indirectly
Ministry of Environment, Climate and Sustainable development	Information recipient	N/A	Governance
Water Management Agency	Data collector, data orderer, supervisor, data reporter, funder	*Loi du 28 mai 2004 portant création d'une Administration de la gestion de l'Eau* (2004)	Governance, change in practice
Luxembourg Institute of Science and Technology	Data collector, data reporter, funding recipient	*Loi du 3 décembre 2014 ayant pour objet l'organisation des centres de recherche publics* (2014)	Science and innovation, contractor for public and private institutions
Wastewater Treatment Research Group	Data collector, sample collector, data reporter, funding recipient	N/A	Science and innovation
Syndicates for the provision of drinking water	Data collector, sample collector, data reporter	*Règlement grand-ducal du 7 octobre 2002 relatif à la qualité des eaux destinées à la consommation humaine* (2002)	Track product or service quality
Syndicates for the decontamination of wastewater	Data collector, sample collector, data reporter	*Règlement grand-ducal du 13 mai 1994 relatif au traitement des eaux urbaines résiduaires*, 1994)	Track product or service quality
Syndicate of Water from the Dammed Lake Esch-sur-Sûre	Data collector, sample collector, data reporter	*Arrêté grand-ducal du 8 juillet 1963 portent institution du Syndicat des Eaux du Barrage d'Esch-sur-Sûre* (1963)	Track product or service quality, contractor for AGE for samples in Esch-sur-Sûre lake
Communes (semi-autonomous and autonomous in drinking water provision)	Sample collector, data reporter	*Règlement grand-ducal du 7 octobre 2002 relatif à la qualité des eaux destinées à la consommation humaine*, (2002)	Track product or service quality
River partnerships	Sample collector, data reporter, funding recipient	*Loi du 19 décembre 2008 relative à l'eau* (2008) and Flusspartnerschaft Syr (2011)	Change in practice
Natur&ëmwelt	Sample collector, data reporter, funding recipient	natur&ëmwelt (2012)	Change in practice

4.1.2 The Water Management Agency

The Water Management Agency exists since its legal and practical establishment in 2004 (*Loi Du 28 Mai 2004 Portant Création d'une Administration de La Gestion de l'Eau*, 2004), and it is one of three agencies supporting the Ministry of the Environment, Climate, and Sustainable Development in its mission (The Luxembourg Government, 2018). The mission of the Agency is to research and analyse, coordinate, plan and implement, review, grant and enforce, define best available technologies, encourage sustainability initiatives as well as to inform the public in the domains of water quality and quantity (Administration de la Gestion de l'Eau, 2014; *Loi Du 28 Mai 2004 Portant Création d'une Administration de La Gestion de l'Eau*, 2004). It is also tasked with the monitoring of the quality of the national surface and underground water bodies and with the related reporting to the European Union (Administration de la Gestion de l'Eau, 2014; Interviewee 1, group interview, personal communication, 2017; *Loi Du 28 Mai 2004 Portant Création d'une Administration de La Gestion de l'Eau*, 2004).

The Water Management Agency is the focal point in the data collection and meaning-making network. Its role is the technical implementation of the governmental monitoring programmes (i.e. sample collection and analysis by itself or commissioned), to conduct further research (when necessary), and to provide funding for relevant research endeavours (Administration de la Gestion de l'Eau, 2014; *Loi Du 28 Mai 2004 Portant Création d'une Administration de La Gestion de l'Eau*, 2004). In addition, it is recipient of the data that needs to be reported to the national government and to the EU, the latter of which it also undertakes, and it maintains the most central and largest database on water and water quality nationally (Interviewee 1, group interview, personal communication, 2017; Interviewee 4, personal interview, personal communication, 2017). It also supervises and undertakes regular checks, for example, at wastewater treatment stations (*Loi Du 28 Mai 2004 Portant Création d'une*

Administration de La Gestion de l'Eau, 2004). Its motivations are to ensure the compliance with European and national law regarding water and water quality, and to achieve good status of the national freshwater network.

4.1.3 The Ministry of the Environment, Climate and Sustainable Development

Although not directly involved in data collection and meaning-making, the Ministry of the Environment, Climate and Sustainable Development is important, as it steers the general political direction of the governmental action in relation to environmental protection and sustainable development (Interviewee 6, personal interview, personal communication, 2017; The Luxembourg Government, 2018).

The Ministry of the Environment, Climate, and Sustainable Development was formed as part of the coalition agreement of 2018 at the time of installation of the current (2020) government (*Arrêté Grand-Ducal Du 5 Décembre 2018 Portant Énumération Des Ministéres*, 2018). It is headed by Minister Carole Dieschbourg, a green party politician. It is concerned with sustainable development, energetic efficiency, and the protection of climate, and natural and human environments. Its main tasks are to implement the governmental programme, to take measures for the protection of climate, and natural and human environments as well as the coordination of the work regarding sustainable development (The Luxembourg Government, 2018).

The Ministry's role in relation to data collection and meaning-making on water quality is to determine the general political direction of governmental action in support of the goals stated in the governmental programme and to undertake and supervise the fulfilment of reporting obligations towards the EU (Interviewee 6, personal interview, personal communication, 2017; The Luxembourg Government, 2018). In more specific terms, the Ministry is consumer of official data on water and water quality mainly in consolidated form (e.g. reports by the Water Management Agency) (Interviewee 6, personal interview, personal communication, 2017). The Ministry's motivation to pursue the activities stated above is to attain the goals stated in the governmental programme in relation to water and water quality (e.g. improvement of the status of water quality in Luxembourg and to guarantee access to clean water for the country's population) (Interviewee 6, personal interview, personal communication, 2017).

4.1.4 The Luxembourg Institute of Science and Technology

The Luxembourg Institute of Science and Technology is the most important contractor of the Water Management Agency in this context. Alongside this function, it conducts other data collection and meaning-making activities in the boundaries of original research and of private partnerships.

The Institute is a public research centre as defined by the relevant national law (*Loi Du 3 Décembre 2014 Ayant Pour Objet l'organisation Des Centres de Recherche Publics*, 2014). Its board, the members of which are appointed by the relevant minister, is tasked with the adoption of the general policy, strategic choices, and with the definition of activities according to the multi-annual agreement negotiated every four years between the board and the minister. This agreement also sets out the financial contribution by the government (Interviewee 4, personal interview, personal communication, 2017; *Loi Du 3 Décembre 2014 Ayant Pour Objet l'organisation Des Centres de Recherche Publics*, 2014).

The mission statement of the Institute includes objectives more general to public research centres, such as undertaking and support of research, development, and innovation activities in the form of contract research for (inter)national research, development, and innovation organisations and through funding from competitive research, development, and innovation programmes, the undertaking of expert studies and consulting for research, development, and innovation, as well as to promote knowledge transfer to public and private sectors, (doctoral) training of researchers, life-long learning, and conducting research to support the definition, implementation, and evaluation of national policies (*Loi Du 3 Décembre 2014 Ayant Pour Objet l'organisation Des Centres de Recherche Publics*, 2014). Alongside these more general objectives, the Institute aims to conduct research, development, and innovation activities tailored to the needs of public and private socio-economic actors and to develop useful and sustainable innovation for the economy and society. In addition, an objective is to assist public sector partners in their missions. The stated research fields of the Institute range from the environment and advanced material sciences, to health and organisational sciences (*Loi Du 3 Décembre 2014 Ayant Pour Objet l'organisation Des Centres de Recherche Publics*, 2014; Luxembourg Institute of Science and Technology, 2019, 2020).

Defined by its different functions, the Institute's role as regards data collection and meaning-making on surface water bodies is also diverse. Its most well-defined role is the one of contractor for the Luxembourgish government for the collection of regulatory data (i.e. data that is collected based on legislation, e.g. the Water Law) based on the formal convention between the Water Management Agency and the Institute. In 2017, it contributed approximately 20 % of the regulatory data defined by the Water Law (Interviewee 4, personal interview, personal communication, 2017). It also collaborates with the Water Management Agency and the Ministry on assignments to collect extraordinary (i.e. other than what is required by legislation) data and analysis. In addition, in the framework of independent original research, the Institute engages in the data collection on water quality and quantity. In total, the Institute is the actor, which collects the most data on water nationally (Interviewee 4, personal interview, personal communication, 2017).

4.1.5 Syndicates for the Decontamination of Wastewater

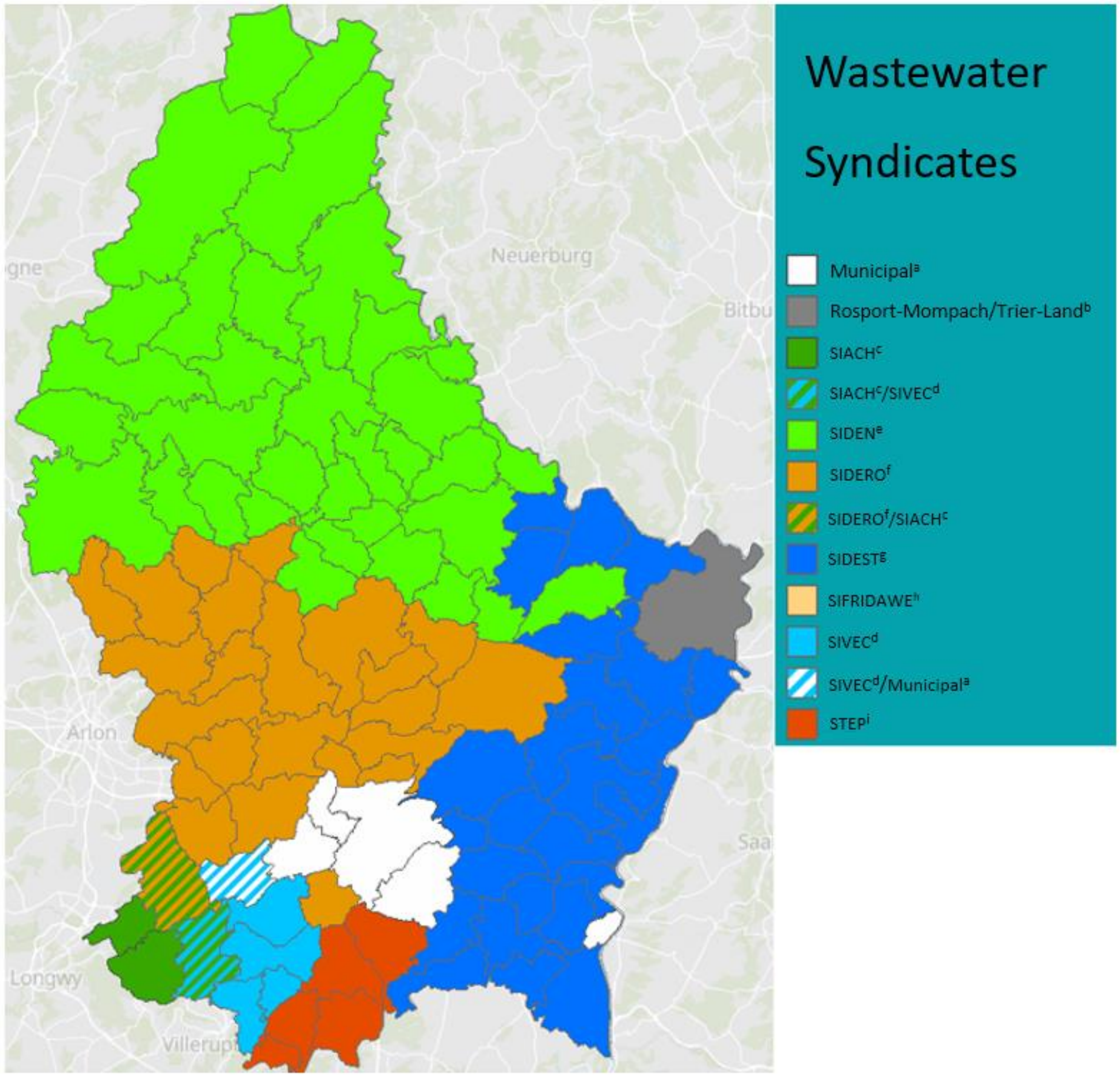
Another important actor regarding data collection and meaning-making related to surface water bodies are the syndicates for the decontamination of wastewater. They are in charge of wastewater treatment and, consequently, need to prove adequate efficiency of treatment or adequate quality of treated wastewater.

There are six intercommunal syndicates for the decontamination of wastewater:

- The Intercommunal Syndicate for the Decontamination of Wastewater from the North,
- The Intercommunal Syndicate for the Decontamination of Wastewater from the East,
- The Intercommunal Syndicate for the Decontamination of Wastewater from the West,
- The Intercommunal Syndicate for the Operation of the Wastewater Treatment Plant Bettembourg,
- The Intercommunal Syndicate for the Sanitation of the Chiers basin,
- The Intercommunal Syndicate of Ecological Mission,
- The Intercommunal Syndicate for the Sanitation of the Commune of Frisange and of the Parts of the Communes of Dalheim and Weiler-la-Tour, Served by the Construction, Maintenance and Operation of a Biological Wastewater Treatment Plant Downstream of Aspelt (Syndicats des Villes et Communes Luxembourgeoises, 2020).

Figure 14

Geographical Visualisation of the Syndicates for the Decontamination of Wastewater in Luxembourg.



Notes. Adapted from Syndicat Intercommunal pour l'Assainissement du Bassin de la Chiers (2020). [a] The denomination “Municipal” refers to communes separately organising wastewater treatment. [b] The syndicate “Rosport-Mompach/ Trier-Land” is an international cooperation and, therefore, not listed under national syndicates. [c] SIACH is the abbreviation of the French denomination of the Intercommunal Syndicate for the Sanitation of the Chiers basin. [d] SIVEC is the abbreviation of the French denomination of the Intercommunal Syndicate of Ecological Mission. [e] SIDEN is the abbreviation of the French denomination of the Intercommunal Syndicate for the Decontamination of

Wastewater from the North. [f] SIDERO is the abbreviation of the French denomination of the Intercommunal Syndicate for the Decontamination of Wastewater from the West. [g] SIDEST is the abbreviation of the French denomination of the Intercommunal Syndicate for the Decontamination of Wastewater from the East. [h] SIFRIDAWE is the abbreviation of the French denomination of the Intercommunal Syndicate for the Sanitation of the Commune of Frisange and of the parts of the Communes of Dalheim and Weiler-la-Tour, served by the Construction, Maintenance and Operation of a Biological Wastewater Treatment Plant downstream of Aspelt. [i] STEP is the abbreviation of the French denomination of the Intercommunal Syndicate for the Operation of the Wastewater Treatment Plant Bettembourg.

The mission of the wastewater syndicates is described as including the evacuation and purification of wastewater, the treatment of sewage sludge and its disposal, and the management (operation, maintenance, and acquisition) of the related infrastructure (see, for example, Syndicat Intercommunal pour l'Assainissement du Bassin de la Chiers, 2020).

As their main mission is to provide the adequate treatment of wastewater, they are also tasked with the monitoring of the water quality of the plant outflow as well as the efficiency of the treatment process. The syndicates also underlie a reporting obligation to the Water Management Agency (*Règlement Grand-Ducal Du 13 Mai 1994 Relatif Au Traitement Des Eaux Urbaines Résiduaires*, 1994). From the above can be derived that their main motivation in relation to data collection and meaning-making is to provide adequate treatment of wastewater.

4.1.6 Syndicates for the Provision of Drinking Water

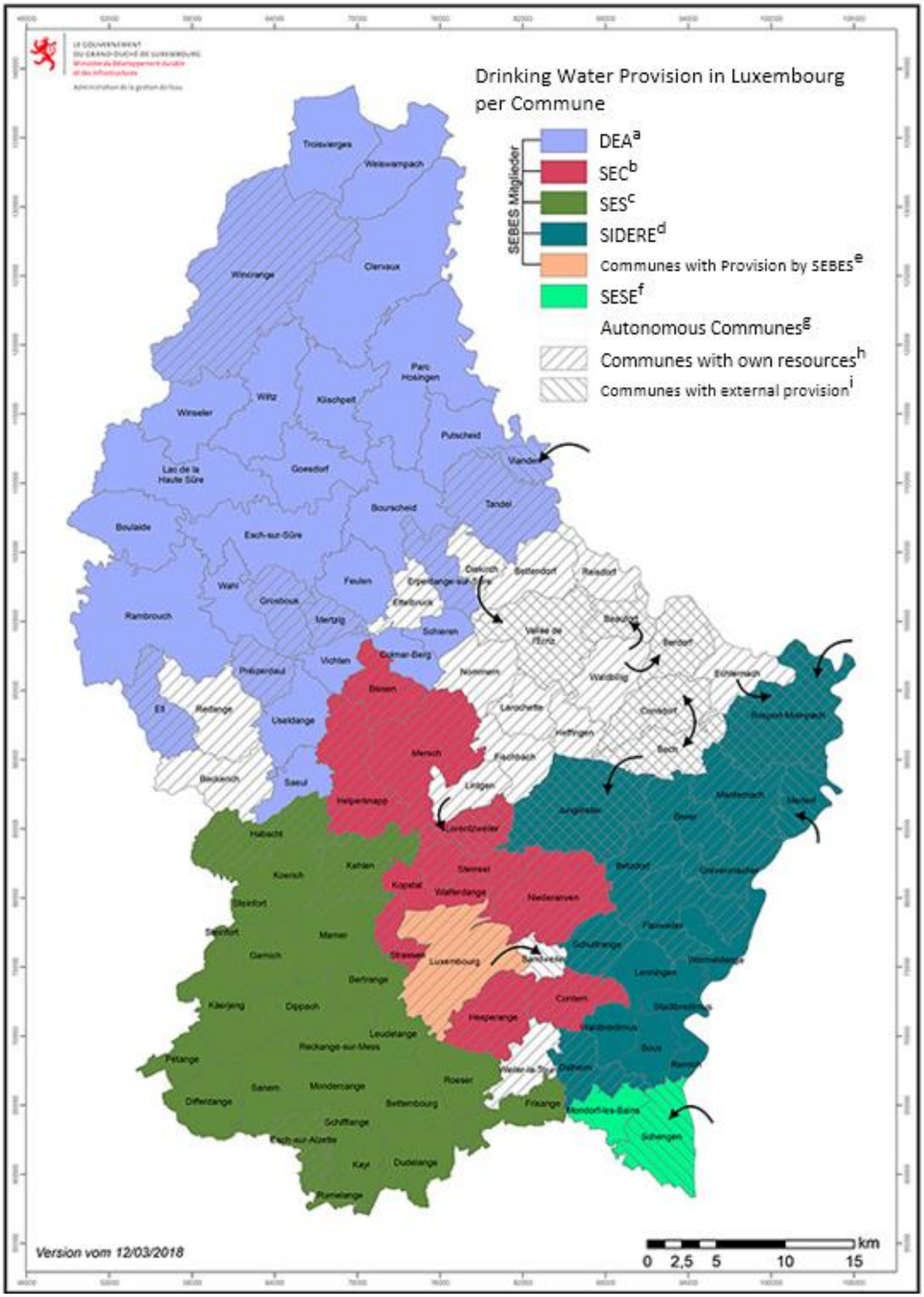
A similar role is ascribed to the syndicates for the provision of drinking water. They are in charge of providing drinking water, which complies with the relevant standards as set in the Drinking Water Regulation (*Règlement Grand-Ducal Du 7 Octobre 2002 Relatif à La Qualité Des Eaux Destinées à La Consommation Humaine*, 2002). In addition, they are obliged to prove the adequate quality of the provided drinking water.

There are six syndicates for the provision of drinking water in Luxembourg, five of which are intercommunal syndicates:

- Distribution of Water from the Ardennes,
- Intercommunal Syndicate for the Construction, the Operation and the Maintenance of the water pipes of the South-East,
- Syndicate of Water from the Centre,
- Syndicate of Water from the South
- Intercommunal Syndicate for the Distribution of Water in the Western Region (Geoportal, 2021b).

Figure 15

Geographical Representation of the Syndicates for the Provision of Drinking Water in Luxembourg.


Drinking Water Provision in Luxembourg per Commune
SEBES Mitglieder
DEA[a]
SEC[b]
SES[c]
SIDERE[d]
Communes with Provision by SEBES[e]
SESE[f]
Autonomous Communes[g]
Communes with own resources[h]
Communes with external provision[i]
Version vom 12/03/2018
0 2,5 5 10 15 km

Notes. Adapted from Syndicat des Eaux du Sud (2018). [a] DEA is the abbreviation of the French denomination of the syndicate Distribution of Water from the Ardennes. [b] SEC is the abbreviation of the French denomination of the Syndicate of Water from the Centre. [c] SES is the abbreviation of the French denomination of the Syndicate of Water from the South. [d] SIDERE is the abbreviation of the French denomination of the Intercommunal Syndicate for the Distribution of Water in the Western Region. [e] The denomination "Communes with provision by SEBES" (i.e. Syndicate of Water from the Dammed Lake Esch-sur-Sure) refers to the communes, which receive drinking water by SEBES directly without the interference of another syndicate. [f] SESE is the abbreviation of the French denomination of the Intercommunal Syndicate for the Construction, the Operation and the Maintenance of the water pipes of the South-East. [g] The denomination "Autonomous Communes" refers to the communes, which organise the provision of drinking water individually without the interference of a syndicate by means of own sources. [h] The denomination "Communes with own resources" refers to communes, which have own sources of drinking water. [i] The denomination "Communes with external provision" refers to communes, which receive drinking water from external sources other than syndicates from Luxembourg, such as a from a commune with own resources or abroad (this relationship is also represented by an arrow on the map).

Each member commune of a syndicate is represented on its board, which is tasked with the overall management of the organisation. Everyday business is performed by a group of employees, headed by the director (see, for example, *Arrêté Grand-Ducal Du 8 Juillet 1963 Portent Institution Du Syndicat Des Eaux Du Barrage d'Esch-Sur-Sûre*, 1963).

The institutional framework of the Syndicate of Water from the Dammed Lake Esch-sur-Sure is particular in the way that only the City of Luxembourg is represented as a commune on its board. The other members are from the Government of Luxembourg (which holds 50 % of the Syndicate), the Syndicate of Water from the South and the Distribution of Water from the Ardennes. As such, the Syndicate of Water from the Dammed Lake Esch-sur-Sure does not qualify as an intercommunal syndicate, which is also underlined by its mission to provide drinking water not only to communes (here the City of Luxembourg), but to intercommunal syndicates in function of need to supplement other sources (*Arrêté Grand-Ducal Du 8 Juillet 1963 Portent Institution Du Syndicat Des Eaux Du Barrage d'Esch-Sur-Sûre*, 1963).

Alongside the provision of drinking water to the reservoirs of the communes (or, in the case of Syndicate of Water from the Dammed Lake Esch-sur-Sure, also to other syndicates) and the management of drinking water sources, treatment plants and all related infrastructure, drinking water providers are tasked with the monitoring of the quality of their water as defined in the Drinking Water Regulation (*Règlement Grand-Ducal Du 7 Octobre 2002 Relatif à La Qualité Des Eaux Destinées à La Consommation Humaine*, 2002)**.**

4.1.7 Communes

Communes are also engaged in data collection and meaning-making in relation to the provision of drinking water. Similarly to the syndicates for the provision of drinking water, all communes are tasked with the provision of the designated drinking water to the end consumers (e.g. households). As a result, they are obliged to ensure the good quality of the water, while it is located in their pipe networks, which involves data collection on the quality of the water. More importantly, however, some communes are sourcing drinking water autonomously (i.e. without the interference of a syndicate; see Figure 15 and "communes with own resources", from German "Gemeinde mit Eigenressourcen") from sources from within the surface area of their commune. As these communes act as drinking water producers, they underlie the same data collection obligations as the syndicates, defined in the Drinking Water Regulation.

Communes are the smallest administrative entities in Luxembourg. They manage their assets and interests, however, controlled by the Government, in particular the Ministry of Home Affairs, which holds administrative supervision (Guichet, 2019). Each commune has a communal council, a communal board, and a mayor to assist in the management of the commune. A commune's general roles are administrative: for example, to keep the register of births, marriages, and deaths, to issue identity documents, to keep the population register, to organise consensuses, and to draw up electoral lists. Some communes, however, also have a technical service, which is responsible for maintaining all public areas of the commune, such as green areas, communal buildings, and sports facilities (Guichet, 2019).

Another relevant task of the communes in the context of water and water quality is the provision of drinking water to the households. In this context, one can distinguish between three categories of communes: (1) the autonomous communes, which extract their own drinking water from local sources (or other), (2) the semi-autonomous communes, which extract their own drinking water, but also receive drinking water from a syndicate, and (3) the affiliate communes, which depend on a syndicate for their drinking water (Administration de la Gestion de l'Eau, 2018).

The role of the communes regarding data collection and meaning-making on water quality is to commission the analysis of drinking water samples from their distribution network as to ensure the compliance with the standards applicable to drinking water. The communes underlie a reporting obligation to the Water Management Agency and the results must be, in theory, publicly accessible (*Règlement Grand-Ducal Du 7 Octobre 2002 Relatif à La Qualité Des Eaux Destinées à La Consommation Humaine*, 2002).

4.1.8 Wastewater Treatment Research Group at the University of Luxembourg

In the previous sections, actors were discussed, which are part of legally prescribed and regular data collection programmes and meaning-making approaches. In the following, the focus is oriented towards important actors, which engage in project-based data collection activities that are not based on legal prescriptions.

The Wastewater Treatment Research Group at the University of Luxembourg, for example, is involved in project-based data collection in and around wastewater treatment plants for research and innovation purposes. The Research Group is conducting research on three pathways:

- Research on the filtration of micro-pollutants in wastewater treatment plants (see EmiSure, 2021),
- Research on producing energy from wastewater and wastewater treatment, and
- Research on the valorisation of substances from wastewater and wastewater treatment (Interviewee 8, personal interview, personal communication, 2018).

The main role of the Research Group is the one of data collector regarding micro-pollutants in and around wastewater treatment plants, and the one of consumer of data and information to support the three research pathways mentioned above. Its main motivation is scientific knowledge development and innovation in their area of expertise (Interviewee 8, personal interview, personal communication, 2018).

4.1.9 The River Partnerships

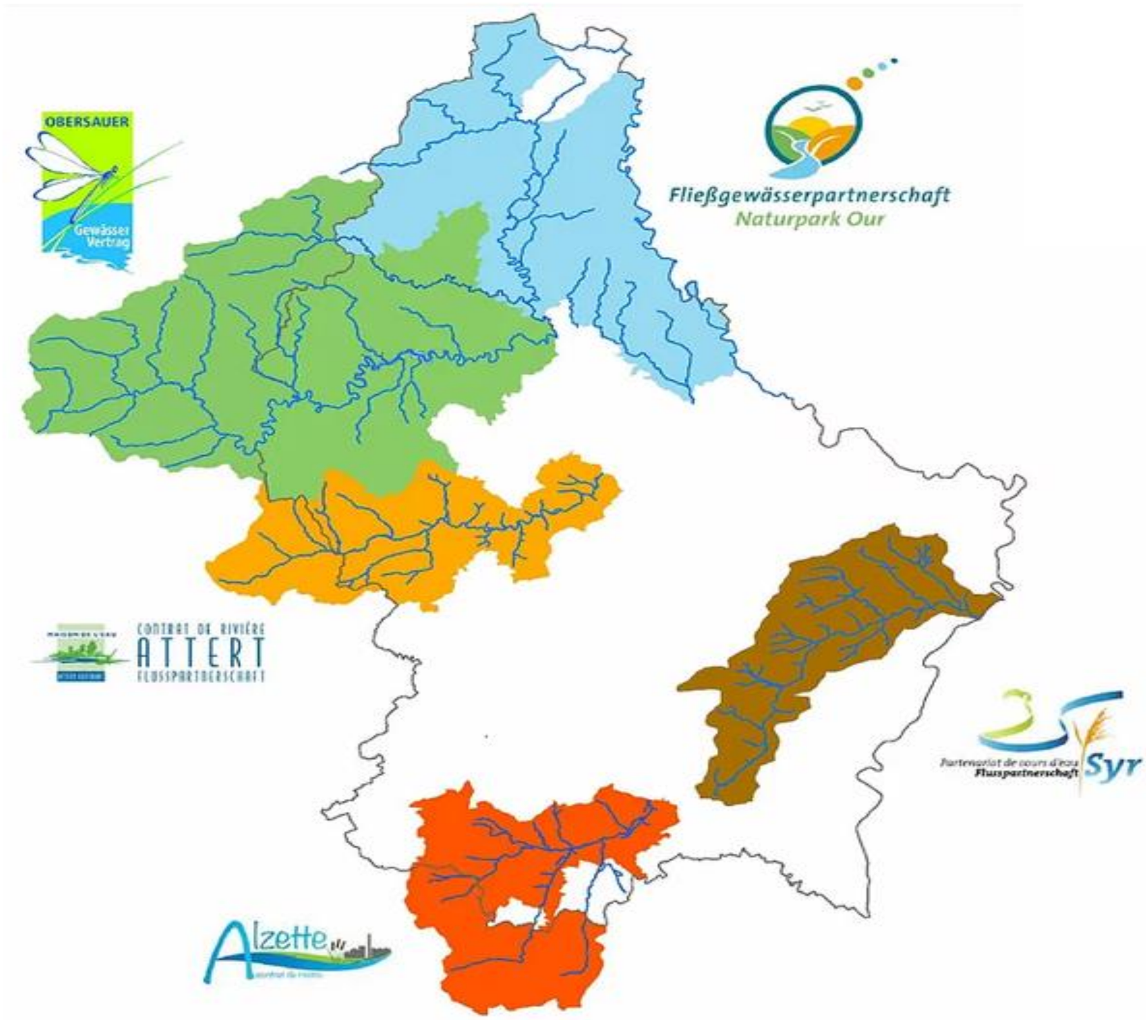
In addition to project-based data collection and meaning-making for research and innovation purposes, the river partnerships and Natur&Emwelt engage in data collection for management purposes.

The river partnerships are defined in Article 55 of the National Water Law (*Loi Du 19 Décembre 2008 Relative à l'eau*, 2008). In 2021, there are six river partnerships in

Luxembourg: the River Partnerships Attert, Upper Sure, Syr, Our, Alzette, and Chiers (Flusspartnerschaften, 2019).

Figure 16

Geographical Representation of the River Partnerships in Luxembourg.



Notes. From Flusspartnerschaften (2019). As the River Partnership Chiers has only been recently founded, it is not yet represented on official documentation.

Defined as initiatives based on the collaboration between communes, intercommunal syndicates, and associations from the water domain, and on a joint formal convention, the river partnerships are tasked with bringing the actors in the water domain and the public together to inform and raise awareness on the integral and global management of the water cycle. The river partnerships can, further, plan and implement technical measures with or without collaboration with the Water Management Agency. Any measures implemented in the boundaries of the initiatives are, at least, co-financed by the Government with 50 % (see, for example, Flusspartnerschaft Syr, 2011; *Loi Du 19 Décembre 2008 Relative à l'eau*, 2008). Their roles related to data collection and meaning-making on water quality is project-based data collection in the context of planning and implementation of technical measures (Interviewee 1, group interview, personal communication, 2017).

4.1.10 Natur&Emwelt

Natur&Emwelt a.s.b.l. is a non-profit organisation in Luxembourg, which campaigns for the protection of the biodiversity of a diverse natural and cultural landscape. Their mission is to raise awareness, to give advice, to conduct practical, scientific, and political work on local, national, and international level. It counts around 11,000 members, divided into member organisations and 40 partner associations (natur&ëmwelt, 2020a).

The Foundation Hëllef fir d'Natur is concerned with the acquisition and maintenance of nature conservation land, informing and raising awareness on nature and biodiversity protection, scientific work, the protection of forests, and the implementation of national, interregional, and European projects for nature protection. Currently, the foundation owns around 1500 ha of nature conservation land and their maintenance is organised in close collaboration with farmers, volunteers, and social organisations (natur&ëmwelt, 2020b). As both organisations are part of the organisational complex of Natur&Emwelt, they are discussed together.

Their main role in the data processing network is the collection of data as part of their missions of practical and scientific work on a project-basis (see, for example, Natur- & Geopark Mëllerdall, 2018b).

4.1.11 The Public

In the previous, many of the most important actors either directly engaged in or otherwise important for data collection and meaning-making for governance and management of surface water bodies in Luxembourg have been presented. One important actor, especially in the adaptive governance of social-ecological systems and in the context of citizen science, however, is still missing - that is, the public. The word “public”, here, refers to one of its general definitions, “the people as a whole” (Merriam-Webster, 2021). As such, it refers to people, groups of people, organisations, and any other organisational form of groups of people. Different roles of the public were pinpointed mainly based on interview results. Details about the roles stem from documentary review (where possible).

Three different roles were identified. Arguably the role of the public that is closest to data collection and meaning-making is its role of “warning system” for water pollution incidents. People are contributing to identifying and reporting pollution incidents, which triggers appropriate governmental action, often involving data collection. The reports are made by a call to “112”, which is the national emergency call number. As Interviewee 2 (2017) put it: “Gleichzeitig helfen die Bürger aber auch im Falle einer Verschmutzung, die sie (…) melden. (…) Dann geht jemand (...) auf die Stelle und schaut was gemacht werden muss und welche Proben genommen werden müssen” (Interviewee 2, group interview, personal communication, 2017).

The public has also been given the opportunity to participate in the development of management plans. In fact, the Water Framework Directive of the European Union and the Water Law set out the framework for public participation in the development of management plans and in relation to the implementation of specific measures (*Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 Establishing a Framework for Community Action in the Field of Water Policy*, 2000 article 14; *Loi Du 19 Décembre 2008 Relative à l'eau*, 2008, article 56). For the second management plan (2015-2021) of the Water Management Agency the participatory processes took three different formats: (1) formal consultations, (2) plenary meetings, and (3) working groups.

(1) Formal consultations

A formal consultation of the public took place concerning the schedule and work programme in combination with the consultation on the most important topics in water management. Statements could be sent per Post or per Email (for a period of six months for the public and seven for communes). The most important topics that were put forward included non-point source pollution, settlement pressure, and structure and water balance of surface water bodies (Administration de la Gestion de l'Eau, 2015: chapter 12).

A second formal consultation of the public was organised concerning the draft of the second management plan and of the second programme of measures. Again, reactions could be posted or emailed to the authorities during six to seven months. In total 59 statements were received, of which 42 were issued by communes and less than 5 each by communal syndicates, river partnerships, actors specialised in the agricultural sector, private people, and other. The remarks by the communes mainly concerned the programme of measures, in particular concerning specific measures for specific water bodies (Administration de la Gestion de l'Eau, 2015: chapter 12).

(2) Plenary meetings

Two plenary meetings were organised, during which the two drafts were presented with time allocated for open discussion. Anyone interested could take part (Administration de la Gestion de l'Eau, 2015: chapter 12).

(3) Working groups

Two working groups were founded: one on the topic of settlement management and settlement pressures and one on the topic of non-point source pollution and water body structure. The task of the groups was to work through the catalogue of measures in detail to assess its comprehensiveness. The former working group focused on the catalogue regarding settlement water management, while the latter was primarily concerned with the catalogue regarding agriculture and hydromorphology. In addition, both groups were engaged in a round of discussion focusing on how the implementation of measures could be improved in the second management cycle. The members of working groups were associated with a number of different public and private organisations in the categories of communal syndicates, the agricultural sector, the Luxembourg government, environmental organisations, and other. For each working group, one session was organised (Administration de la Gestion de l'Eau, 2015: chapter 12).

Alongside the role of the public as "warning system" and as participant in developing national management plans, the public generally acts as a requester of data and information from public organisations. In general, an increasing interest of the public, in particular citizens, in being informed, in taking part in discussions and in forming own views has been observed.

> [Der Bürger] will informiert werden, er will mitreden, er will mitdenken können und nachher macht er sich sein eigenes Bild. An uns ist es, ihm so viele Informationen zu liefern, damit der sich auch wirklich ein komplettes Bild macht und da gehören auch Daten dazu, dass er im Vorfeld mehr an Daten bekommt, dass er wahrscheinlich auch dezidierter Fragen stellt. (Interviewee 9, group interview, personal communication, 2018).

4.2 Data Flows Among Actors and Other Important Relationships

As has been described above, various actors are engaged in data collection and meaning-making on water quality. To continue this presentation of results, the focus now shifts from the important actors, separately, to the important relationships among them with particular attention to data flows on water quality. Data publication as a particular “data flow” between an actor and the public (the word “public” encompasses any of the important actors presented in the previous) is also presented by actor (in function of the availability of information). The results presented here are largely drawn from the interviews. Documentary review was used to confirm and complement, where possible. For ease of reading, first, a summary of the data flows and other important relationships presented in more detail in the subsequent sections is provided (see Table 5).

Table 5

Data Flows and Other Important Relationships Among the Actors Identified as Important in Data Collection and Meaning-Making on Water Quality in Luxembourg

From \ To	Ministry of Environment, Climate and Sustainable Development	Water Management Agency	Luxembourg Institute of Science and Technology	Wastewater Treatment Research Group	Wastewater syndicates	Drinking water syndicates	River partnerships & Natur&Emwelt
Ministry of Environment, Climate and Sustainable Development		Order	Order, funding				
Water Management Agency	Information		Order, funding	Funding	Supervision	Supervision	Funding
Luxembourg Institute of Science and Technology	Data, information	Data, information		Collaboration, data			
Wastewater Treatment Research Group		Data, information	Collaboration, order				
Wastewater syndicates		Reporting		Data			
Drinking water syndicates & communes		Reporting					
River partnerships & Natur&Emwelt		Data					

Note. This table includes the relationships that could be identified based on the interviews.

The following presentation of data flows and important relationships among the important actors starts with the focal point in the network, the Water Management Agency, and its various links with other actors.

4.2.1 Data Flows and Other Important Relationships Linked with the Water Management Agency

The Water Management Agency is linked with the Ministry of Environment, Climate and Sustainable Development, the Luxembourg Institute of Science and Technology, the syndicates for the decontamination of wastewater and for the provision of drinking water, communes, the Wastewater Treatment Research Group at the University of Luxembourg, and the river partnerships and Natur&Emwelt.

The connections of the Agency are marked by its role of implementing body of the governmental data collection programme and meaning-making approach, of supervisory body for public service providers, and of funding body for relevant projects.

In the boundaries of its role as implementing body of the governmental data collection programme and meaning-making approach, and generally, the Agency is linked with the Ministry. While the Ministry sets the general political direction governmental action and issues special requests, for example, in the form of projects addressed at the Agency, the Agency delivers briefing documents to the Ministry, which may be based on the results of data collection programmes and meaning-making approaches. In general, their relationship is transparent (Interviewee 6, personal interview, personal communication, 2017).

In addition, the Luxembourg Institute of Science and Technology supports the Agency in the governmental data collection programme and meaning-making approach as most important contractor. Their relationship is largely based on a formal convention. In the frameworks of this relationship, the Institute undertakes data collection and meaning-making and shares datasets as well as reports with the Agency. Extraordinary data collection and meaning-making requests by the Agency (or the Ministry) may also be fulfilled by the Institute on a need-basis (Interviewee 4, personal interview, personal communication, 2017).

In the boundaries of the Agency's role of supervising body of public service providers, it is connected with the syndicates for the decontamination of wastewater and for the provision of drinking water as well as communes. The Agency, therefore, receives collected data from the syndicates and communes in regular intervals in the framework of the legal reporting obligations and undertakes regular checks at the different facilities.

The Agency holds a special relationship with the Syndicate of Water from the Dammed Lake Esch-sur-Sure (a syndicate for the provision of drinking water). Alongside the regular relationship marked by reporting and supervision the Syndicate is collecting samples in the dammed lake Esch-sur-Sure and in some of its tributaries for analysis in the Agency's lab. This is not a formalised connection and it was instated for pragmatic reasons of the geographical proximity of the Syndicate to the lake (Interviewee 1, group interview, personal communication, 2017; Interviewee 11, personal interview, personal communication, 2018).

As part of the Agency's role of funder for and supporter of relevant projects, it has connections with the Wastewater Treatment Research Group at the University of Luxembourg and Natur&Emwelt. Between the Agency and the Research Group, for example, exists an agreement, allowing the latter to request funding for projects of mutual relevance. In return, the collected data is shared with the Agency (Interviewee 8, personal interview, personal communication, 2018). In addition, Natur&Emwelt is known to collaborate on projects of mutual relevance as part of scientific or practical works (see, for example, Natur- & Geopark Mëllerdall, 2018b).

The role of the Water Management Agency and the river partnerships is somewhat different. It is noted in Article 55 of the Water Law that the river partnerships receive 100 % of governmental funding for technical projects, which are undertaking in collaboration with the Agency. For all other project undertaken by the river partnerships, governmental funding is fixed at 50 % (*Loi Du 19 Décembre 2008 Relative à l'eau*, 2008).

4.2.2 Data Flows and Other Important Relationships Between the Other Important Actors

There are some connections between the other important actors as well. The Wastewater Treatment Research Group, for example, often orders sample analysis in external labs, due to the smaller size and capacity of its internal lab. One of the external labs is at the Luxembourg Institute of Science and Technology, which receives compensation for its services (Interviewee 8, personal interview, personal communication, 2018). Due to the similar domains of interest, the Research Group also receives data from syndicates for the decontamination of wastewater (Interviewee 8, personal interview, personal communication, 2018).

In addition, the actors characterised by project-based involvement, Natur&Emwelt and the river partnerships, receive funding from other organisations for their projects, since funding is seldom sourced internally. This may constitute funding from competitive EU programmes or national organisations, such as communes.

4.2.3 Data Publication Practices, and Public Meaning-Making

After the data flows and other important relationship between the actor organisations have been presented above, the following section focuses on the publication and public access to data. First, data publication practices are presented by actor, which draws on the interviews for the identification and characterisation of the practices and on documentary review for more detail including information on the format of the publications. Second, comments from the interviews are presented related to facilitation of public meaning-making based on the published datasets.

Data Publication Practices. Before the presentation of the data publication practices by actor, an overview is provided in Table 6. As one can see, not all important actors presented above are represented. For the actors that are not represented, no information about data publication practices was available (also meaning that no instances of data publication were detected by a thorough web search).

Table 6

Data Publication Practices by Actor Including Information on Format and Public Meaning-Making.

Actor	Platforms for data publication	Format	Public access to meaning
Water Management Agency (& the Ministry[a])	"Geoportal.lu"	Geospatial; lab reports; tables	Technical
	"Data.public.lu"	Geojson-files; shp-files; xml-files	Technical
	"Inondation.lu"	Figures; tables	"Information section"[b]
Wastewater syndicates	Management reports and/or websites	Figures; tables	Technical (sometimes with key definitions)
Drinking water syndicates and communes	Websites	Lab reports	Technical

Notes. [a] The denomination "the Ministry" refers to the Ministry of Environment, Climate and Sustainable Development. [b] "Information section" refers to the "information" section of the "Inondation.lu" web page, which contains information on hydrometry (e.g. definition, measurement methods, statistical analysis) and on floods (e.g. causes and hydrological models).

To start, the data publication practices of the Ministry of Environment, Climate and Sustainable Development and the Water Management Agency are presented in combination (i.e. no difference is made between who is in charge).

Data Publication Practices of the Ministry of Environment, Climate and Sustainable Development and the Water Management Agency. The three main routes for data publication in relation to surface water bodies by the Ministry and the Agency are the websites: “geoportail.lu”, “inondation.lu”, and “data.public.lu”.

> Für die Hochwasserprävention, da werden die Daten zu Verfügung gestellt für Rettungsdienste, die Personen, die in den Hochwasserrisikozonen wohnen (…) die Verwaltung ist ganz proaktiv, was die Bereitstellung der Daten angeht, sowohl auf dem Geoportal als interaktive Karten, als auch auf dem Open-Data-Portal, wo wir nach dem STATEC die meisten Datensätze zur Verfügung stellen. Das heißt die Informationen nach außen zu bekommen, ist auch ein großer Teil der Verantwortung der Verwaltung. (Interviewee 2, group interview, personal communication, 2017)

The Geoportal is the national repository for geospatial data, including a lot of data related to the environment and water, in particular (see Geoportal, 2021a). In relation to surface water, the Geoportal provides access to the results of the governmental data collection programme and meaning-making approach as set out by the EU Water Framework Directive and the Water Law. The data is represented per data collection site and per year. The dataset includes all parameters measured and per parameter an average of the year, a threshold for a “good ecological state” (if applicable), the maximum measured throughout the year, the maximum concentration acceptable (if applicable), the unit of measurement, and the number of samples per year (see Geoportal, 2021c). For the data collection sites, which are part of Monitoring Control, datasets per data collection site are available for three years, 2015-2017. For other sites, data sets are available for one or two years, depending. The presentation of data on the Geoportal is rather technical and more aimed at specialists (Interviewee 2, group interview, personal communication, 2017). As such, even though the data might be physically accessible, meaning-making is only possible with background knowledge or additional research.

> Auf dem Geoportal und auf dem Open-Data-Portal ist es eher technisch gehalten. Das heißt das sind kurze Erklärungen, was die einzelnen Wörter an sich bedeuten, muss man dann eher selber wissen oder selber nachschlagen. (Interviewee 2, group interview, personal communication, 2017)

The Open Data Portal is a Luxembourgish data platform by the Luxembourgish government in the boundaries of the governmental initiative “Digital Lëtzebuerg”. Its mission is to assist in the publication of data by the state and the administrations. In general, the aim is to give datasets a second life-time after their primary use by the state or the administrations (Data.public.lu, 2021a). Digital Lëtzebuerg is a collaborative government initiative by the Ministry of the State’s Department of Media, Telecommunications & Digital Policy. It is the “uniting force behind Luxembourg’s digitalisation movement” (Digital Luxembourg, 2021).

As regards data on surface water, the Open Data Portal offers datasets, for example, in the form of GEOJSON, SHP, and XML files. In general, the GEOJSON and SHP files can be viewed on Geoportal. A search of “water” on the Portal shows, for example, data sets regarding the assessment of the continuity of surface water bodies in 2015, the assessment of the chemical status of surface water bodies in 2015, and the yearly results of the data collection programmes and meaning-making approaches as defined by the EU Water Framework Directive and the Water Law from 2014 to 2017 (Data.public.lu, 2021b). Similarly to Geoportal, the Open Data Portal is rather technical and more aimed at specialists (Interviewee 2, group interview, personal communication, 2017).

Inondation.lu is a governmental website dedicated to informing about the current water level of surface water bodies in Luxembourg and precipitations, and to generate alerts in case of flood incidents or high risk of floods. Current measurements can also be found on the Open Data Portal. Historical data can be requested at the

Department of Hydrometry of the Water Management Agency. Inondation.lu includes an "information" section, which gives background information in relation to, for example, hydrometry and floods. These sections include detailed information, including definitions and descriptions of data collection and meaning-making methods (Inondations, 2017).

> Das Erklären der Daten passiert eher auf Inondation.lu, wo dann die verschiedenen Messmethoden erklärt werden, wo die Werte erklärt werden mit den verschiedenen Schwellenwerten und was die bedeuten. (Interviewee 2, group interview, personal communication, 2017)

Data Publication Practices of the Syndicates for the Decontamination of Wastewater. To continue the presentation of data publication practices by public organisations, the following focuses on the syndicates for the decontamination of wastewater. Data publication on the quality of wastewater, treated wastewater, and wastewater treatment is not as common practice. If data is publicised, it is usually in yearly averages concerning either the efficiency of treatment or the quality of outflow (as only one or the other needs to comply with the applicable standards according to the legislation). Data publication may take place within published management reports (see Syndicat Intercommunal de Dépollution des Eaux Résiduaires de l'Ouest, 2014; Syndicat Intercommunal de Dépollution des Eaux Résiduaires du Nord, 2019; Syndicat Intercommunal pour l'Assainissement du Bassin de la Chiers, 2017). The Intercommunal Syndicate for the Decontamination of Wastewater from the North also publishes current data on the organisational website (Syndicat Intercommunal de Dépollution des Eaux Résiduaires du Nord, 2021).The presentation of data is usually fairly technical, although definitions for the most important terms may be provided (see, for example, Syndicat Intercommunal de Dépollution des Eaux Résiduaires du Nord, 2021).

As regards wastewater treatment, some data can also be found on Geoportal. In fact, one can find data on the quality of the inflow and quality of the outflow for the larger treatment plants in Luxembourg. The data sets contain data for one year only and a variable number of data points per year per wastewater treatment plant. No explanations are provided (Geoportal, 2021d).

Data Publication Practices by the Syndicates for the Provision of Drinking Water and the Communes. Access to data concerning the quality of drinking water provided by the communes to the households is a legal obligation (*Règlement Grand-Ducal Du 7 Octobre 2002 Relatif à La Qualité Des Eaux Destinées à La Consommation Humaine*, 2002). Many communes chose to provide at least the latest results on their website, whereas others operate on a request-basis (see Drénkwaasser, 2021 for an overview of drinking water quality per commune).

Three of the five intercommunal drinking water syndicates are publishing data on the quality of drinking water on their websites (see Syndicat des Eaux du Barrage d'Esch-sur-Sûre, 2021a; Syndicat des Eaux du Sud Koerich, 2021; Syndicat Intercommunal pour la Distribution d'Eau dans la Région de l'Est, 2021). The amount of data published depends on the syndicate. The Syndicate of Water from the South offers the data of the last data collection date, while the Intercommunal Syndicate for the Distribution of Water in the Western Region offers data of the data collection dates for the past year. The Syndicate of Water from the Dammed Lake Esch-sur-Sure even offers data of samples taken for the past years.

In the framework of the development of the new drinking water protection zones around the dammed lake Esch-sur-Sure, the Syndicate of Water from the Dammed Lake Esch-sur-Sure is collaborating with the Water Management Agency in collecting and analysing samples of the lake and its tributaries on a monthly basis. The results are also provided on the website (Syndicat des Eaux du Barrage d'Esch-sur-Sûre, 2021b).

Public Access to Environmental Data of Public Institutions. As regards environmental data collected by public institutions, physical access by the public is regulated by the *Convention on Access to Information, Public Participation in Decision-Making and Access to Justice in Environmental Matters* (1998) also known as the Århus Convention, which was approved by the European Commission in 2005 (*Council Decision 2005/370/EC of 17 February 2005 on the Conclusion, on Behalf of the European Community, of the Convention on Access to Information, Public Participation in Decision-Making and Access to Justice in Environmental Matters*, 2005) and was first adopted into European Union legislation by the *Directive 2003/4/EC* (*Directive 2003/4/EC of the European Parliament and of the Council of 28 January 2003 on Public Access to Environmental Information and Repealing Council Directive 90/313/EEC*, 2003) and the *Directive 2003/35/EC* (*Directive 2003/35/EC of the European Parliament and of the Council of 26 May 2003 Providing for Public Participation in Respect of the Drawing up of Certain Plans and Programmes Relating to the Environment and Amending with Regard to Public Participation and Access to Justice*, 2003) (see European Commission (2021) for a more detailed description of the adoption process). The Luxembourgish implementation is the *"Loi du 25 novembre 2005 concernant l'accès du public à l'information en matière d'environnement"* (*Loi Du 25 Novembre 2005 Concernant l'accès Du Public à l'information En Matière d'environnement*, 2005). The Århus Convention sets out, for example, that any environmental information held by a public authority must be provided upon request of a member of the public. Only in exceptional cases are public authorities allowed to withhold, for example, in the case, where the datasets contain personal information.

> Es gibt die Århus Direktive, die besagt, dass umweltrelevante Daten dem Publikum gehören (…) die Daten selbst, ja, die Daten sind meisten georeferenziert und mit persönlichen Daten versehen. Wenn jemand Daten

> anfragt, dann bekommt er die, falls die in den Bereich fallen, aber die Daten werden dann schon anonymisiert oder aggregiert (…). (Interviewee 1, group interview, personal communication, 2017)

Access to Project-Based Datasets. In this context, it seems relevant to mention a topic, which came up multiple times during the interviews. In contrast to access to datasets based on regular data collection and meaning-making activities by public organisations, it is more difficult to get access to project-based datasets by public organisations. In fact, water quality data in Luxembourg, in particular project-based datasets, are rather scattered across organisations in Luxembourg. Identifying relevant project-based datasets is difficult and even when such datasets are identified, it may take a while to get access, which is often a consequence of a lack of workforce (Interviewee 8, personal interview, personal communication, 2018). This is due to the fact that there is no central national database for water quality data (Interviewee 4, personal interview, personal communication, 2017; Interviewee 8, personal interview, personal communication, 2018).

This is not only relevant for the access by the public, but also more specifically by organisations. The public may not be aware of project-based datasets and, therefore, cannot request access to them. Organisations may not be aware of project-based datasets, which may lead to inefficiencies, for example, in the form of duplication of work.

Public Meaning-Making. Access to data collected by public organisations is mandated by the *Convention on Access to Information, Public Participation in Decision-Making and Access to Justice in Environmental Matters* (1998). However, whether publicly accessible representations of data and accompanying explanatory information are adequate to be meaningful to non-specialists is another question. A lot of the dataset are presented in technical context, and without specialised knowledge about the parameters and approaches to their measurement, they may not be very meaningful to non-specialists (except for the website "Inondation.lu" by the Government, for example, where a lot of information is provided for meaning-making). In fact, to make meaning of current datasets is not an easy undertaking. On the one hand, information is needed on the individual parameters: for example, effects of different concentrations on the environment and for humans, and relevant thresholds. In addition, information is needed on the processes between parameters: for example, how they influence each other. The added challenge is that to interpret data points, for example on nutrient levels or the presence of absence of indicator species, place-based information on surrounding land use or whether there is a wastewater treatment plant upstream is required to understand the specific circumstances that lead to the observed phenomenon and to understand the situational meaning of a data point or a time series of measurements. On the other hand, even specialists in the field often struggle to, for example, explain certain fluctuations in the dataset, and to provide satisfactory interpretative depth.

> Diese Informationen haben wir bis jetzt noch nicht drin, aber da sind wir auch...wir diskutieren auch regelmäßig über diese Dinge, aber wir haben noch nicht das Optimum gefunden, wie man erklären kann, was das heißt, wenn da 50 Nanogramm „Ampa" drin sind. Wir können sagen, das ist über dem Grenzwert für Trinkwasser. Mehr kann man eigentlich dazu nicht sagen. Aber das sollte schon einen Schritt in die Richtung gehen, dass man zumindest sensibilisiert und den Leuten sagt: Da sind positive Befunde. Da ist was los in dem Bach. (Interviewee 11, personal interview, personal communication, 2018)

> (…) dann müsste ich sagen, ich muss mir die ganzen Daten mal angucken. Eventuell muss ich noch ein paar Messungen machen von anderen Parametern, die wir nicht standardmäßig bemessen, dann muss ich mir noch die Biozönose im

Gewässer angucken und dann kann ich vielleicht sagen, wieso der Wert jetzt mal hoch ist, aber wahrscheinlich würde ich sagen, gucken wir doch mal wie es morgen aussieht. (Interviewee 9, group interview, personal communication, 2018)

4.3 Phenomena, Data Collection Frequencies, and Sites

In the previous sections, the focus was on important actors and relationships. In the following, the actual data collection programmes and meaning-making approaches by the actors will be described. This includes the phenomena subject to data collection, the data collection frequencies, and the sites of data collection. The available information on the data collection programmes and meaning-making approaches that are not legally defined was limited. As a result, their presentation mainly draws on interview data. For the legally prescribed programmes, the documentary review is the main source of information (such as the programmes by the Water Management Agency - see(2015b)). Another consequence of the differences in the availability of information is the differences in detail provided in the presentations of the different programmes.

As the lists of phenomena included in the data collection programmes and meaning-making approaches are quite long and much too detailed for the purposes here, the phenomena are presented in the form of clusters. Cluster 1 is composed of quantifiable properties of a water body, for which different quantities can be associated with particular states of the water or a water body. These include physical chemical, biological, and hydromorphological attributes. The physical chemical attributes include temperature, conductivity, and the oxygen balance. The biological include the composition and biomass of aquatic flora (including phytoplankton), of benthic invertebrates, and the composition, abundance, and age structure of the ichtyofauna.

The hydromorphological properties include the quantity and dynamics of water flow, the continuity of the river, and the structure and substrate of the bed. Cluster 2 is composed of quantifiable substances in a water body, which naturally occur in water, but which have been released by people in harmful quantities, such as substances associated with salinity, for example sulphate, chloride, and magnesium, as well as metals and nutrients, for instance phosphorus and nitrogen. Cluster 3 is related to other pollutants, in particular, substances, which, naturally, do not occur in the water, among which pesticides, pharmaceuticals, other chemicals and their metabolites.

The phenomena of focus depend on the circumstances and purpose of data collection. Naturally, there are differences in them and in the standards (the same phenomena can be subject to data collection, but with differing applicable thresholds) between data collection in surface water and, for example, data collection in drinking water. Drinking water must comply with other standards specifically designed to make sure the water we consume is not making us ill and also to guarantee the aesthetics of the water. Examples of properties in drinking water are Escherichia coli and turbidity.

The before-mentioned properties are part of routine data collection as well as foreseen occasional (or regular, but limited in time) extended data collection activities. In case of special circumstances, in which other pollutants need to be subject to data collection in case of, for example, accidental pollution, or pollutants on the described list need to be subject to data collection more intensively in time and/or space, the data collection activities can be adapted.

Table 7 shows the phenomena subject to data collection by the actors of the data collection and meaning-making network represented in the before-mentioned clusters. In most cases, the phenomena described refer to the regular data collection programmes and meaning-making approaches of the actors. The phenomena part of project-based data collection are variable, as set on a need-basis. Only for the

Wastewater Treatment Research Group, the phenomena of focus have been noted in Table 7, as their interest is with a particular group of pollutants.

Table 7

Summary of Phenomena Subject to Data Collection by Actor and in Clusters.

Actor	Physical chemical	Biological	Hydromorphological	Naturally occurring substances associated with pollution	Other pollutants
Water Management Agency	Temperature, several indicators relating to oxygen in the water, turbidity, and pH	Several indicators relating to the populations of aquatic plants (in particular phytoplankton) and living organisms (i.e. benthic invertebrates and fish)	Several indicators related to water flow, river continuity, depth and width of a river, river bed, and bank	Salinity and nutrients, chlorophyll (eutrophication), metals	Pesticides, pharmaceuticals, and other chemicals
Luxembourg Institute of Science and Technology	On-going assistance with the governmental monitoring programme	On-going assistance with the governmental monitoring programme	On-going assistance with the governmental monitoring programme	On-going assistance with the governmental monitoring programme	On-going assistance with the governmental monitoring programme
Wastewater Treatment Research Group					Micro-pollutants, generally including pharmaceuticals, pesticides, other chemicals, washing detergents and cleaning agents
Drinking water syndicates and communes	Turbidity, taste, smell, colour, hydrogen ions	Several indicators linked to health-threatening bacteria		Nutrients, metals	Pesticides, other chemicals
Wastewater syndicates	Several indicators related to oxygen in the water, total suspended solids (turbidity)			Nutrients	

Notes. Information from Administration de la Gestion de l'Eau (Administration de la Gestion de l'Eau, 2015b), Règlement grand-ducal du 7 octobre 2002 relatif à la qualité des eaux destinées à la consommation humaine (*Règlement Grand-Ducal Du 7 Octobre 2002 Relatif à La Qualité Des Eaux Destinées à La Consommation Humaine*, 2002), Règlement grand-ducal du 13 mai 1994 relatif au traitement des eaux urbaines résiduaires (*Règlement Grand-Ducal Du 13 Mai 1994 Relatif Au Traitement Des Eaux Urbaines Résiduaires*, 1994), and Interviewee 8 (personal interview, personal communication, 2018). The table only includes data collection programmes and meaning-making approaches that are on-going, as the parameter-sets for project-based programmes are put together on a need-basis, except for the Wastewater Treatment Research Group, as it is concerned with a particular set of parameters.

The data collection frequencies by the different actors can be found in Table 8.

Table 8

Data Collection Frequencies and Sites per Actor and Phenomena Cluster.

Actor		Physical chemical	Biological	Hydromorphological	Naturally occurring substances associated with pollution	Other pollutants
Water Management Agency and Luxembourg Institute of Science and Technology	Major rivers (long-term)	Once every month	Every 3 years, phytoplankton bi-monthly, others once	Hydrology continuously, others once every 6 years	Once every month	After screening, monthly (?) every 3 years
	Smaller rivers and streams (minimum)	Every 3 years (quarterly or monthly)	Once every 3 years		Every 3 or 6 years (quarterly or monthly)	Every 3 years (monthly, if at all), except for metals every 3 years (quarterly or monthly)
Drinking water syndicates and communes	Routine control	2-4 times per year (depending on m^3/day distributed)	2-4 times per year (depending on m^3/day distributed)		2-4 times per year (depending on m^3/day distributed)	2-4 times per year (depending on m^3/day distributed)
	Full control	1-10 times per year (depending on m^3/day distributed)	1-10 times per year (depending on m^3/day distributed)		1-10 times per year (depending on m^3/day distributed)	1-10 times per year (depending on m^3/day distributed)
Wastewater syndicates		4, 12 or 24 times per year (depending on the capacity of the plant and previous findings)			4, 12 or 24 times per year (depending on the capacity of the plant and previous findings)	

Notes. Information from Administration de la Gestion de l'Eau (2015b), Règlement grand-ducal du 7 octobre 2002 relatif à la qualité des eaux destinées à la consommation humaine (*Règlement Grand-Ducal Du 7 Octobre 2002 Relatif à La Qualité Des Eaux Destinées à La Consommation Humaine*, 2002), Règlement grand-ducal du 13 mai 1994 relatif au traitement des eaux urbaines résiduaires (*Règlement Grand-Ducal Du 13 Mai 1994 Relatif Au Traitement Des Eaux Urbaines Résiduaires*, 1994). This table only includes information about the data collection programmes and meaning-making approaches that are on-going.

4.3.1 The Governmental Data Collection Programme and Meaning-Making Approach

As has been noted, the Water Management Agency is in charge of the implementation of the governmental data collection programme and meaning-making approach as set out by the EU Water Framework Directive and the national Water Law. The programme consists of three types of data collection activities (the following is based on Administration de la Gestion de l'Eau, 2015b): Monitoring Control, Operational Control, and Investigative Control.

Monitoring Control designates the baseline monitoring activities that take place on a regular and on-going basis. In summary, its main objective is to provide a broad picture of the state of the national surface water bodies. For this, there are five active monitoring stations (Erpeldange/Sure, Ettelbruck/Alzette, Wasserbillig/Sure, and Rodange/Chiers), strategically positioned to represent the entire surface water network in Luxembourg. The set of parameters, which are monitored, varies yearly: The general physico-chemical parameters are tracked every year. The priority substances, the specific pollutants identified for each watershed area and the biological parameters are monitored every three years, alternating between stations. Only at the station 'Rodange', more intensive monitoring is taking place: The general physico-chemical parameters, the priority substances and the specific pollutants for the watershed area are monitored yearly, while the biological parameters remain monitored in three-year-cycles.

As Monitoring Control is designed to gain an overview of the state of the main Luxembourgish surface water bodies, it is not detailed enough to provide insights into the state of each surface water body, less so to identify pollution sources. For this reason, Operational Control is in place. This kind of monitoring takes place during a specific time-frame and generally, at stations of surface water bodies that have been identified as at risk of not complying with environmental standards. This classification is based on longitudinal profiles carried out before. Operational Control is also used to track the impact of implemented measures, and to get a picture of the state of every surface water body of the Luxembourgish surface water network in regular intervals. Logically, the list of parameters, which are monitored, is variable and is determined on a need-basis (for example, based on previously detected pollutants). Currently, Operational Control is also used to monitor the watershed areas of the main surface water bodies, which are the focus of Monitoring Control. For this, samples are taken at strategically selected stations. The parameters that are monitored are in accordance with the cycles of Monitoring Control, such that every watershed area is monitored completely, every three years.

Investigative Monitoring is performed, when the reasons for non-compliance with environmental standards are unknown and to research the impacts of accidental pollution incidents. Accordingly, parameters and monitoring frequencies are set on a need-basis. In the past, Investigative Monitoring has been often used to create longitudinal profiles. They are useful to identify the status of a surface water body as a whole, and they help with detecting pollution sources.

4.3.2 The Data Collection Programmes and Meaning-Making Approaches of the Syndicates

The data collection programmes and meaning-making approaches by the syndicates for the decontamination of wastewater and for the provision of drinking water are set out in the respective regulations (*Règlement Grand-Ducal Du 7 Octobre 2002 Relatif à La Qualité Des Eaux Destinées à La Consommation Humaine*, 2002; *Règlement Grand-Ducal Du 13 Mai 1994 Relatif Au Traitement Des Eaux Urbaines Résiduaires*, 1994).

The Syndicates for the Decontamination of Wastewater. According to the Wastewater Treatment Regulation, the syndicates for the decontamination of wastewater underlie the obligation to make sure that wastewater treatment complies with the set standards and to report the results in regular intervals to the appropriate administration (in this case, the Water Management Agency) (*Règlement Grand-Ducal Du 13 Mai 1994 Relatif Au Traitement Des Eaux Urbaines Résiduaires*, 1994, Art. 10). The standards come in two formats and a single wastewater treatment plant has to comply with only one of the two formats. They are presented in the form of thresholds per parameter and in the form of a percentage per parameter, which represents the minimal reduction required during treatment. As such, a wastewater treatment plant has to either prove that the emitted treated wastewater complies with the set thresholds per parameter or that the values for the measured parameters have reduced by the given minimal percentages during treatment (*Règlement Grand-Ducal Du 13 Mai 1994 Relatif Au Traitement Des Eaux Urbaines Résiduaires*, 1994, Annexe I). The minimum number of samples taken are defined in function of the size of the wastewater treatment plant: the number ranges from 4 for the smaller plants to 24 for the larger ones. The limits for samples that do not comply with the standards is also set in the Regulation and it is expressed in function of the number of samples taken at the plant. For example, in the case, where 4 samples are taken within a year, 1 is allowed to be non-compliant. In the case of 24 samples per year, 3 can be non-compliant. Samples have to be taken at the end point of the wastewater treatment plant before the emission into the water body, and, if applicable, at the entry of the plant (*Règlement Grand-Ducal Du 13 Mai 1994 Relatif Au Traitement Des Eaux Urbaines Résiduaires*, 1994, Annexe I). In addition, the water body that is the host of the emitted treated wastewater has to be sampled in the case, where the impact of the treated wastewater in the water ecosystem is expected to be of significant character. This sampling, however, is undertaken by the Water Management Agency (*Règlement Grand-Ducal Du 13 Mai 1994 Relatif Au Traitement Des Eaux Urbaines Résiduaires*, 1994, Art. 10).

The Syndicates for the Provision of Drinking Water. According to the Drinking Water Regulation, points for sampling have to be set up in every distribution zone (defined as a geographical zone, in which the water quality can be considered more or less the same) and at every water extraction point (*Règlement Grand-Ducal Du 7 Octobre 2002 Relatif à La Qualité Des Eaux Destinées à La Consommation Humaine*, 2002, Art. 9). The standards are noted as thresholds. There are two different formats of sampling: the routine checks and the full checks. The number of parameters that have to considered in full checks is higher than in the routine checks. In addition, the number of each format that has to be performed per year is defined in function of the volume of distributed water per day in a particular distribution zone. For the routine checks, it ranges from 2 for the lower volumes to 4 for the higher volumes. There is no limit of routine checks, as it increases in function of the volume of distributed water per day. For the full checks, the number ranges between 1 to 10 and it is, again, open-ended (*Règlement Grand-Ducal Du 7 Octobre 2002 Relatif à La Qualité Des Eaux Destinées à La Consommation Humaine*, 2002, Annexe II).

4.4 The Suitability of Current Data Collection Programmes and Meaning-Making Approaches for Adaptive Governance

Following the presentation of the results based on the interviews and documentary review, a discussion is offered. The discussion attempts to contribute to developing an answer to research question A " In how far are current data collection programmes and meaning-making approaches compatible with key principles of adaptive governance of social-ecological systems? What are opportunities for change?". The structure of the discussion is displayed in Table 9.

Table 9

Structure of the Discussion, Guiding Questions, and Key Factors

Order of Appearance in the Discussion	Input, Process and/or Objectives	Criterion	Guiding Question and Key Factor
1	Objectives	Furthering the scientific understanding of system processes	Is the data collection programme aimed at studying cause-effect relationships?
2	Objectives	Detecting and tracking changes in the system	a) Is the data collection programme well-suited for detecting and tracking trends, i.e. is it open-ended? b) Is the data collection programme well-suited for detecting and tracking of fluctuations? The suitability is considered in a positive relationship with the data collection frequency with a guiding threshold of multiple data points per site per year.
3	Objectives	Detecting and tracking of drivers of change	Does the data collection programme consider social, ecological, and technological factors in combination?
4	Objectives	Swift detection of place-based changes and place-specific context factors	a) Is the data collection programme aimed at studying place-based changes in the system and/or place-based factors? b) Is the data collection site density of the programme well-suited for studying place-based changes and factors? The suitability is considered in a positive relationship with the data collection site density. c) Is the data collection frequency suitable for the swift detection of place-based changes? This was already discussed as part of question b) under 2.
5	Process	Transparency	a) Is the data of the data collection programme physically accessible to the public? b) Is the data of the programme presented with meaning (i.e. interpretations)? c) Are tools for individual meaning-making accessible in combination with the data?
6	Input/Process	Stakeholder engagement in design and implementation of the programmes	a) In how far are stakeholders engaged in the design and implementation of the data collection programme? b) In how far can the data landscape be characterised as polycentric?

The guiding questions and key factors are based on the evaluation framework for data collection and meaning-making for adaptive governance presented in section 2.5.1.

4.4.1 The Suitability of Current Data Collection Programmes and Meaning-Making Approaches for the Objectives of Ideal Data Collection and Meaning-Making in Adaptive Governance

Table 10 gives a summary of the discussion in relation to the objectives of ideal data collection and meaning-making in adaptive governance (building on the ideal type presented above in Table 9, 1-4).

Table 10

Summary of the Discussion of the Criteria Related to Objectives of Data Collection and Meaning-Making in Adaptive Governance

Criterion	Guiding Question and Key Factor	Water Management Agency	Drinking Water Syndicates and Communes	Wastewater Syndicates	Wastewater Treatment Research Group	Luxembourg Institute of Science and Technology	River Partnerships and Natur&Emwelt
Furthering the scientific understanding of system processes	Is the data collection programme aimed at studying cause-effect relationships?	+ Investigative Control: cause-pollution + Operational Control: intervention-effect	-	-	+ scientific research	+ scientific research	+ scientific research, intervention-effect
Detecting and tracking changes in the system	a) Is the data collection programme well-suited for detecting and tracking trends, i.e. is it open-ended? b) Is the data collection programme well-suited for detecting and tracking of fluctuations? The suitability is considered in a positive relationship with the data collection frequency with a guiding threshold of multiple data points per site per year.	+ Monitoring Control (a - yes, b - dependent on parameter group) + Operational Control (a - yes, b - intermittently)	+ a) open-ended b) rather suited	+ a) open-ended b) rather suited	- a) no (project-based) b) occasionally rather suited (project-dependent)	- a) no (project-based) b) occasionally rather suited (project-dependent)	- a) no (project-based) b) occasionally rather suited (project-dependent)
Detecting and tracking of effects of interventions	Is the data collection programme aimed at studying the effects of interventions?	+ Operational Control - The identification of the cumulative effects on the system may be difficult, as little consideration is given to social and technological factors	-	-	- rather aimed at scientific research	- rather aimed at scientific research	+ yes, but project-dependent

Detecting and tracking of drivers of change	Does the data collection programme consider social, ecological, and technological factors in combination?	- Little considerations for social, ecological, and technological factors in combination	-	-	No evidence	No evidence	No evidence
Swift detection of place-based changes and place-specific context factors	a) Is the data collection programme aimed at studying place-based changes in the system and/or place-based factors? b) Is the data collection site density of the programme well-suited for studying place-based changes and factors? The suitability is considered in a positive relationship with the data collection site density. c) Is the data collection frequency suitable for the swift detection of place-based changes? This was already discussed as part of question b) under 2.	+ Operational Control: change, intervention-effect (a - yes, b - yes, c: intermittently) + Investigative Control: cause-pollution (a - yes, b - yes, c - on occasion) - Swift detection only occasionally (Operational and Investigative Control) and in three year intervals (Operational Control)	+/- a) yes b) rather unsuited c) rather suited	+/- a) yes b) rather unsuited c) rather suited	+/- a) yes (changes in treated wastewater quality) b) project-dependent c) occasionally rather suited (assumption)	+/- a) project-dependent b) project-dependent c) project-dependent	+ a) yes, but project-dependent b) yes, but project-dependent c) yes, but project-dependent

Furthering the scientific understanding of system processes, detecting and tracking changes in the system, and detecting and tracking the effects of interventions. In the following, the current data collection programmes and meaning-making approaches and organisations are discussed separately in function of their suitability to further the scientific understanding of system processes, detecting and tracking changes in the system, and detecting and tracking the effects of interventions.

The Water Management Agency. Arguably the most detailed data collection programme and meaning-making approach is conducted by the Water Management Agency. The three distinct programmes, (1) Monitoring Control, (2) Operational Control, and (3) Investigative Control, are discussed separately.

(1) Monitoring Control

Monitoring Control is aimed at providing qualitative overviews of the national surface water network and data is collected at five stations. It is, therefore, not designed to develop explanations of general system processes and to study cause-effect relationships.

Data collection is on-going. Monitoring Control, thus, supports the development of long-term datasets, which are a good basis for the detection and tracking of qualitative trends in the national surface water network. Trends are important for an overall direction, in which quality is developing and to act as a basis for action, in the case, where developments are undesirable. As regards the detection and tracking of fluctuations, the potential of Monitoring Control depends on the parameter group, as the data collection frequencies are highly variable, ranging from monthly every year for the general physical-chemical parameters and the naturally occurring substances associated with pollution to data collection in three year intervals for the biological parameters and other pollutants (see Table 7 and Table 8).

As Monitoring Control is set up to track the evolution of the quality of the entire national surface water network, it is not designed to detect and track the effects of specific interventions.

(2) Operational Control

Operational Control is used in two scenarios: (a) to track the impacts of management interventions and (b) to provide a picture of the state of every surface water body in Luxembourg in regular intervals.

(a) Tracking the impact of management interventions

Operational Control is used to track the impacts of management interventions. Tracking the impacts of management interventions qualifies as a kind of explanatory research, as it entails research into the intervention-effect relationship. For an idea of this relationships, at the very least, one would need to detect and track other changes in the system as well as other drivers of change internal and external to the system to have an idea of the cumulative effects and, therefore, to consider the effects that other drivers of change may have in the observed changes (Waylen et al., 2019). Even though no clear evidence was found on the kind of parameters included in this form of Operational Control, it seems that it would be rather focused on ecological system factors, as is Monitoring Control, which makes the identification of other internal and external drivers of change in the system difficult.

In this case, Operational Control is time-limited. Time-limited endeavours cannot guarantee the detection of changes in the system in the long-term and have only a very limited potential for the detection and tracking of trends. As regards fluctuations, in contrast, the potential of Operational Control is higher, however, dependent on the design of the data collection programme and meaning-making approach. Little data has been found on concrete application cases and, as the design is logically done on a case-by-case basis, no other statements can be made of the potential to detect and track fluctuations.

(b) Providing a picture of the state of every surface water body in Luxembourg in regular intervals

Operational control is also used to provide a picture of the state of every surface water body in Luxembourg in regular intervals. In essence, this form of Operational Control is targeted towards adding detail to the results of Monitoring Control in the form of more place-based data. Similarly to Monitoring Control, this kind of Operational Control is not designed for explanatory research.

It is on-going and regular. It, therefore, supports the development of long-term datasets, which are a foundation for the detection and tracking of trends. Its intermittent character, however, - that is, in three year intervals, monthly or quarterly - significantly limits its potential for swiftly detecting and tracking fluctuations.

While this form of Operational Control can help detect and track changes, it is not designed to detect and track the effects of specific interventions.

(3) Investigative control

Investigative Control is performed, when the reasons for non-compliance with environmental standards are unknown and to research the impacts of accidental pollution incidents. As the name already suggests, Investigative Control is designed for investigative purposes. In particular, it attempts to research the relationship of a driver of change (e.g. an accidental pollution incident) and change in the system (e.g. pollution) in either direction. As such, it is designed to support explanatory research.

Similarly to Operational Control used to track the effects of interventions, Investigative Control is a time-limited activity and, thus, holds only limited potential for the detection and tracking of trends. In addition, its potential concerning fluctuations is higher, but dependent on the design of the programme - in particular, on the data collection frequency and length of the programme. As it is the case with Operational Control, Investigate Control cannot guarantee the detection of changes in the long-term, as it is a limited endeavour.

The Syndicates for the Provision of Drinking Water and Communes. The datasets produced by syndicates for the provision of drinking water and communes have the main purpose of tracking product quality. Even though the purpose of data collection does not suggest importance for the governance and management of surface water bodies, the datasets have potential, as they include ecological parameters, such as turbidity, nutrients, metals, pesticides, and other chemicals, and drinking water producers are charged with data collection at the water extraction points. Obviously, the produced datasets are not designed for explanatory research nor for detecting and tracking the effects of a specific intervention.

Their long-term and open-ended character, however, represent a good basis for trend detection. Depending on the parameter, data collection frequency ranges between 2 and 10 times (or more) per year. As a result, it holds some potential regarding fluctuations.

The Syndicates for the Decontamination of Wastewater. The datasets produced by wastewater syndicates are directly relevant to the governance and management of surface water bodies, as they give insights into the quality of emitted, treated wastewater, which constitutes an important pollution source in modern societies. The data collection programmes and meaning-making approaches are based on legally required parameters - that is, several parameters related to the oxygen in the water, total suspended solids, and nutrients. In contrast to the case of drinking water syndicates, however, the data of wastewater syndicates are not directly applicable to surface water bodies that are hosting the emissions from the wastewater treatment plant. To get an idea of the effect on the hosting surface water bodies, data collection in the surface water bodies would be needed (this happens by the Water Management Agency, when significant effects on the water body are suspected, see *Règlement grand-ducal du 13 mai 1994 relatif au traitement des eaux urbaines résiduaires*, 1994).

As the data collection programmes and meaning-making approaches by wastewater syndicates are on-going and regular, they are well-suited to contribute to the detection and tracking of trends, for example, to get an idea of the evolution of the pressure from treated wastewater. The data collection frequency is variable as dependent on the capacity of the treatment plant and on previous findings. The legal minimum requirement ranges from 4 to 24 times per year. As a result, the programmes allow for multiple data points per year, which was defined as favourable for the detection of fluctuations in section 2.5.1.

As with the drinking water syndicates, the data collection programmes by the wastewater syndicates are not designed for explanatory research related to the quality of surface water bodies. The datasets are crucial, however, in assessing the efficiency of current wastewater treatment, and, thus, can be used as evidence for innovation or the application of new technologies.

The Wastewater Treatment Research Group. The datasets by the Wastewater Treatment Research Group are produced mainly for research and innovation purposes. They, therefore, have the potential to contribute to explanatory research. Alongside, the datasets by the Research Group are also relevant for governance and management. The Research Group collects data, in particular, on micro-pollutants in wastewater with the aim to contribute to research on their filtration at treatment plants. This type of research can lead to technological innovation for more sustainability. In addition, data on micro-pollutants (a term generally encompassing pharmaceuticals, pesticides, other chemicals, and washing detergents and cleaning agents) in wastewater and treated wastewater can contribute to an improved understanding of the pressures on hosting water bodies. The pool of empirical data considered in this thesis, which was based on the interviews conducted as well as the review of documents that could be found by a thorough web search, did not include data related to the data collection frequency or the length of the data collection programmes and meaning-making approaches, and, therefore, no statements on the potential of the datasets to identify trends and fluctuations can be made. In general, since the programmes are project-based and, therefore, limited in time, the resulting datasets seem better suited for the detection of fluctuations than of trends.

The Luxembourg Institute of Science and Technology. The pool of empirical data considered in this thesis did not include data related to the data collection programmes and meaning-making approaches of the Luxembourg Institute of Science and Technology aside the data available for the programmes aiming to support the Water Management Agency in the data collection as required by the Water Law and the EU Water Framework Directive. Therefore, no statements can be made on the potential of the datasets to identify trends and fluctuations. In general, the evidence suggests that the Institute is contributing to science and innovation for the benefit of socio-economic actors in Luxembourg, and, therefore, contributing to explanatory research. In addition, since data collection rather happens on project-basis, the datasets seem better suited for the identification of fluctuations than of trends.

The River Partnerships and Natur&Emwelt. The river partnerships and Natur&Emwelt are generally engaging in data collection on project-basis for the purpose of management and management related research. The datasets may support the place-specific implementation of management interventions or, in the case of Natur&Emwelt, support a specific research question and, as such, they may be designed for explanatory research and/or the detection and tracking of the effects of specific interventions. As the pool of empirical data considered in this thesis did not include data related to the data collection programmes and meaning-making approaches of the river partnerships and Natur&Emwelt, no statements can be made on the potential of the datasets to help identify trends and fluctuations.

Synthesis*.* Based on the previous discussion, different ways can be identified, in which the current data collection programmes and meaning-making approaches can contribute to adaptive governance. The programmes that are designed to develop regular overviews of the state of surface water bodies and, by extension, their tributaries are, generally, well-suited for the detection and tracking of trends and, depending on the data collection frequency, also for the swift detection of fluctuations. This makes them well-suited for detecting and tracking changes in the system, in general. Most of the time, these programmes are not designed for building scientific understanding of system processes and detecting and tracking the effects of specific interventions (of course, the datasets can be used for purposes that are different of those, for which they were designed).

The programmes that are designed for research into cause-effect relationships and, usually, centre around a particular place for a particular purpose are, generally, time-limited, as they are often resource-intensive. As a result, they are better suited for the detection and tracking of fluctuations than of trends. By design, these programmes aim to build scientific understanding, detect and track effects of specific interventions, and, thus, changes in the system. As noted before, however, they cannot guarantee the detection and tracking of fluctuations in the long-term.

The programmes that are designed for studying pressures (e.g. treated wastewater) can help detect changes in the system, as they are well-suited for the detection and tracking of trends and fluctuations. They may also contribute to studying cause-effect relationships (e.g. Wastewater Treatment Research Group).

As the above demonstrates, the current data collection programmes and meaning-making approaches taken together cover all objectives of ideal data collection and meaning-making in adaptive governance. It also shows, however, that the swift detection of fluctuations can only be supported at a few place across Luxembourg in the long-term, as the more intensive, place-based programmes are generally time-limited.

Detecting and Tracking Drivers of Change. Another objective of ideal data collection and meaning-making in adaptive governance, aside furthering the scientific understanding of system processes, detecting and tracking changes in the system, and detecting and tracking the effects of interventions, is the detection and tracking of drivers of change internal and external to the system. This is important for isolating the effects of specific interventions in the best way possible and for detecting undesirable change. A set requirement for the detection and tracking of drivers of change in social-ecological systems is the consideration of social and technological factors alongside ecological ones. A classification of the phenomena of the current programmes is represented in Table 7. It clearly shows that the focus of current programmes lies on ecosystem factors. The governmental datasets also include some technological factors, such as related to the hydromorphological properties of watercourses (e.g. alterations to the watercourses). Social factors, however, are largely neglected. As a result, the capacity of the current data collection programmes and meaning-making approaches to contribute to the detection and tracking of drivers of change is limited according to the evidence presented before, also limiting their capacity to isolate the effects of specific interventions. In addition, neglecting social and technological factors limits the capacity of current programmes to contribute to furthering the scientific understanding of social-ecological systems.

The Swift Detection of Place-Based Changes and Place-Specific Context Factors. The swift detection of place-based changes and the detection and tracking of place-specific context factors is equally important in adaptive governance. It builds the capacity to identify undesirable changes and to adapt as well as to design interventions adapted to the contexts of particular places. The discussion in relation to the suitability of current data collection programmes and meaning-making approaches for the swift detection of place-based changes rests on the aim of the programmes and in how far they are designed to do so, and, therefore, their data collection site density and the data collection frequency. Table 11 shows the data collection site densities per organisation and programme.

Table 11

Data Collection Site Density per Data Collection Programme and Meaning-Making Approach

Organisation(s)	Main motivation for data collection and meaning-making	Data collection programme and meaning-making approach designation (if applicable)	Description of data collection site density
Syndicates for the provision of drinking water & communes	Track product or service quality		1 site per drinking water source
Syndicates for the decontamination of wastewater	Track product or service quality		Multiple or single site(s) in wastewater treatment plant
Wastewater Treatment Research Group	Research & innovation		Multiple or single site(s) in wastewater treatment plant
River partnerships and Natur&Emwelt	Management		Multiple or single site(s) around intervention/ in water body
The Water Management Agency & Luxembourg Institute of Science and Technology	Governance & management	Monitoring control	5 sites for national overview
		Operational control	Multiple or single site(s) around intervention/ at least one site per water body
		Investigative control	Multiple sites around pollution incident/ multiple sites per water body

As Table 11 displays, some of the presented data collection programmes and meaning-making approaches are aimed at the detection of place-based changes and employ a sampling site density that may be considered rather favourable (i.e. multiple sites around a particular place). Evaluation happens on a continuous scale from a smaller sampling site density to a higher one. A higher sampling site density is, for example, employed by Operational and Investigative Control by the Water Management Agency for studying the effects of specific interventions and for studying the causes and effects of particular pollution incidents. In the same way, the river partnerships and Natur&Emwelt engage in data collection and meaning-making directly relevant for management in the form of data collection to accompany management interventions and for research purposes, such as research into pollution-effect relationships. The unifying criterion of these programmes, however, is that they are all limited in time and, therefore, cannot guarantee the detection of place-based changes in the long-term.

Another dimension is equally important in adaptive governance, which is the timely detection of place-based changes to build the capacity to issue rapid responses to undesirable change. The data collection frequencies were already discussed under the previous heading and, here, the ability of the programmes to identify fluctuations is most important. It is considered in a positive relationship with data collection frequency.

For the purposes of this discussion, it seems appropriate to give an account of the process of data collection and meaning-making for management purposes. It starts with data collection in a watercourse, which is designed to detect and track changes. For this, a few sites in function of the size of the water body that are strategically selected to represent the most important sections of the watercourse are appropriate. Once undesirable change is detected, more intensive place-based data collection is needed with the aim to pinpoint the origin of the change as accurately as possible. For tracing the origin of the undesirable change to a particular cause, data on place-based social and technological factors are essential.

One of the main questions is how to detect undesirable changes. At the moment, it seems this is done by Monitoring Control and Operational Control. Monitoring Control, however, provides a low resolution national overview and, therefore, is hardly able to detect undesirable changes in particular places. Operational Control, in turn, may be able to detect undesirable changes in particular places, but only during one year every three years. What happens in-between the cycles is largely unknown.

A single site, such as of the drinking water syndicates, can contribute to detecting undesirable changes. Its positioning, however, defines the degree, to which the results can represent the entire watercourse. If social and technological data were collected, they could be helpful in identifying causes.

Programmes designed to track the effects of interventions, such as those of the river partnerships and Operational Control, may be able to capture undesirable changes and, if social and technological factors were considered, they could be helpful in identifying causes. These programmes, however, are generally limited in time and, therefore, cannot track changes in the long-term. Investigative Control, similarly, can help in identifying different pressures in different segments of the watercourse, and, if applicable, help in identifying causes, but, as it is also a short-term endeavour, it cannot do so in long-term. It can, therefore, be said that, even though there are mechanisms in place to pinpoint the origins of undesirable changes, the capacity of the programmes to detect changes in a timely manner is limited.

4.4.2 The Suitability of Current Data Collection Programmes and Meaning-Making Approaches for the Input and Process Criteria of Ideal Data Collection and Meaning-Making in Adaptive Governance

In the following, the data publication practices by the actors, as presented in section 4.2.3, are discussed in function of the degree of transparency that they facilitate. The degree of transparency is evaluated using two key factors: public access of the data and the facilitations of public meaning-making.

Transparency. ***Access to Data.*** As section 4.2.3 has demonstrated, access to the data of the current data collection programmes and meaning-making approaches of public organisations is generally given. The majority of data is already available online, and the actors are generally willing (if not even obliged) to meet data requests. Only with programmes funded by private businesses, restrictions may apply. In addition, datasets may not be shared, when there is a situation of competition, for example, in the case of actors engaged in science and innovation (Interviewee 4, personal interview, personal communication, 2017).

Some datasets are published in a modified format, such as aggregated to monthly or even yearly averages for parameter, such as in the case of wastewater syndicates. The modification of datasets in this way has to be seen critically. It may hide important fluctuations in parameters with the potential to cause serious harm to the natural environment. Aggregation is, nevertheless, an important tool in the repertoire for data representation, for example, to provide the level of detail that is relevant for a particular purpose (e.g. national overviews). To be able to disaggregate, however, should be considered an integral component for more transparency.

In the case of project-based datasets, access is not yet ideal. As described before, datasets in general are rather scattered across actors and, in particular, access to project-based datasets are often difficult in, at least, two ways: (1) information about available datasets is not available, up to the point, where even within a single organisation, departments may be unaware of datasets produced by other departments, and (2) to gain access, after a relevant dataset is identified, can take multiple months, in general, not due to an unwillingness to share, but to a lack of human resources. Not only for increased transparency, but also for an improved ability to build on others work, access to project-based datasets needs to be improved, for example, by building a common platform, where datasets can be shared, such as the Open Data Portal, and by the consistent sharing of datasets by all actors.

Public Meaning-Making. In this context, a distinction between public access to data meaningful to non-specialists and public access information for meaning-making seems appropriate. Public access to data meaningful to non-specialists is based on the provision of interpretations by the issuer. Interpretations are generally done from a specific perspective and may hide certain aspects of the results and highlight others. Public access to information for meaning-making, in turn, involves the provision of information and tools for individual meaning-making. This way, the audience is able to use what is provided to make meaning of the dataset in a way that is most relevant for each individual. A reflexive presentation of the assumptions involved is key.

As described in section 4.2.3, meaning-making is generally not provided. Only very few of the publications of datasets by the actors were accompanied by background information aiming to help make meaning. For example, the website "inondation.lu" included a section, which contained key definitions and descriptions concerning the measurement methods. The Syndicate of Water from the South, in turn, offered a separate file, entitled "explanation of an analysis report" (from French: "explication d'un bulletin d'analyse") (Syndicat des Eaux du Sud Koerich, 2021). The document is authored by Water Management Agency and gives descriptions of the parameters, potential sources, and their effects on human health, among others (Administration de la Gestion de l'Eau, 2016a). It can be argued that the cases of flood risk and drinking water quality are of more direct importance to the public than, for example, surface water quality.

A few interviewees also questioned whether people, for whom dealing with water data would be a leisure activity, would have the capacity (e.g. time) to build a basic understanding of system processes and deal with a large amount of data, which is also continuously increasing. Some interviewees also questioned whether it is feasible for non-specialists to become specialists in the water quality domain for individual meaning-making. Alternatively, a more targeted information system was put forward, which would present information in a way that is targeted to the viewers' interests and would justify the information with the adequate data.

Stakeholder Engagement in the Design and Implementation of the Current Data Collection Programmes and Meaning-Making Approaches. This section is dedicated to a discussion of the degree, to which multiple stakeholders are engaged in the design and implementation of each data collection programme and meaning-making approach presented previously. As section 4.1.11 outlined, the public is mainly involved in three functions: as "warning system" for pollution incidents (or anything unusual), as requester of data and information from public organisations, and as participant in the development of national surface water management plans. The role of “warning system” can be considered as stakeholder engagement in the implementation of the data collection programme and meaning-making approach of the Water Management Agency, especially of Investigative Control. In this case, the public provides initial information, which issues further investigation. It takes advantage of certain characteristics of the public, such as its geographical distribution and closeness to “what is actually going on out there”. In addition, it builds on the experience values of individual people of what surface water bodies and their surroundings usually look like and their ability to notice differences. This function of “warning system”, therefore, builds on the knowledge of individual people, gained by experience and observation.

The role of the public as requester of data and information, in turn, can be considered as stakeholder engagement in the implementation of data collection programmes and meaning-making approaches - in particular, in the meaning-making phases of the process. The evidence, however, suggests that, at this point in time, it is not yet supported by adequate processes, such as channels for feedback from the public to the organisations, which undertake data collection, and the provision of meaning and tools for meaning-making.

The role of the public as participant in the development of the management plans is, perhaps, the one that is the best defined. It can be considered stakeholder engagement in the design of data collection programmes and meaning-making approaches - although, only indirectly. Stakeholder engagement primarily happens in the boundaries of the development of governmental management plans. As section 4.1.11 outlines, it is organised by the Water Management Agency in the form of formal consultation, plenary meetings, and working groups.

In Luxembourg, the Water Framework Directive is used as a basis to frame the challenges for the national water system. The challenge is to take action in such a way that all national water bodies can be classified as in “good” state. More specifically, this means that natural surface water bodies should reach good ecological and good chemical state, groundwater bodies should reach a good chemical state and a good state related to the quantity of water, and heavily modified and artificial surface water bodies should reach a good ecological potential and a good chemical state. In addition, the Water Framework Directive sets out that the state of water bodies is not allowed to worsen and that the pollution by priority substances should, at least, continually decrease (Administration de la Gestion de l’Eau, 2015a).

The ecological state (or potential in the case of heavily modified or artificial surface water bodies) of a water body is defined in function of a series of parameters, which can be divided into three categories: biological, physico-chemical, and hydromorphological. The chemical state encompasses the levels of all chemical pollutants not included in the physico-chemical category, which were found in the water bodies by the longitudinal profiles establishing original state (Administration de la Gestion de l’Eau, 2015a).

The legal character of the Water Framework Directive leaves the governments of the EU member states little room for adaptations regarding the objectives. In particular, it defines the set of parameters of interest, which must be taken into account for defining the state of national water bodies and by which any progress is being measured. As a result, the road map is set. Of course, no clause posits that more parameters cannot be monitored. However, as the list of parameters is already fairly long, it can be assumed that most resources of the member state governments will be already assigned with working towards monitoring the “essential” parameters, as set out by the Directive, and reaching the set objectives.

In line with the stipulations of the Water Framework Directive, Article 14, the Luxembourg authorities organised several occasions for public participation in the development phase of the second management plan. Public formal consultations, public plenary meetings, and working groups composed of relevant organisational representatives were organised for feedback on first drafts of the management plan and the programme of measures (Administration de la Gestion de l'Eau, 2015a).

The public formal consultations give anyone interested an opportunity to react to the documents prepared as basis for discussion by the national authorities. To do so, however, requires to work through the fairly technical and detailed texts (which was also presented as a major criticism resulting from the consultations, Administration de la Gestion de l'Eau, 2015a), as they are prepared in such a form to encompass the entire national water network. From the perspective of the national authorities this, of course, makes sense. The public, however, might be most interested in very particular challenges occurring in very particular places. It, therefore, comes as no surprise that private people accounted for only a marginal number of comments and that most comments were received by communes and other specialised organisations (Administration de la Gestion de l'Eau, 2015a).

A similar case can be made for the public plenary meetings. A general presentation of the draft of the second management plan and the programme of measures preceded a round of discussion, during which anyone invited could ask, what can only be assumed to be, any kind of question (Administration de la Gestion de l'Eau, 2015a). It seems that such a setting is not well-suited for such a diverse topic, which affects a high variety of different places. If a private person would like to ask a particular question about a particular challenge or place, it is very likely that there would not be the time nor the right discussion partners to conduct a discussion that would be considered beneficial to all parties - that is, a discussion, which would go into the appropriate amount of depth and lead to results. In addition, it would be also very unlikely that all the people in the room would be interested in the same topics, as every place is different and comes with its own context. As a result, one would have to sit through a round of discussion that is, most likely, not tailored to the specific interests of the individual people.

The two working groups on different essential topics in water management, composed of a variety of representatives from relevant organisations, were formed for a single meeting (Administration de la Gestion de l'Eau, 2015a). While such a setting provides them with an opportunity to influence, in this case, the programme of measures, it does not provide an adequate amount of time to work through the very detailed programme and discuss all the relevant topics in detail. It is merely an occasion to voice the most serious concerns while discussing some topics in varying amount of depth.

In conclusion, a couple of factors can be identified, which limit the potential of the participatory processes: (1) the availability of adequate settings for in-depth discussion on particular and often place-based issues with the relevant actors (specialists in relevant topics, decision-makers, and the public), (2) the mismatch in vocabulary between specialists and the public (hurdles to understanding in-depth technical documents in function of time and interest and to reacting to technical documents in adequate detail), and (3) the time and resources available to engage in participatory processes (by both the authorities and the public).

As the previous discussion on participatory processes demonstrates, mechanisms have been put in place for public participation and consultation. The key feature of stakeholder engagement in adaptive governance, however, is negotiation among diverse stakeholders, and negotiation always entails the pursuit of a common output. In this case, even though one might call the process empowering for the public as, in theory, anyone interested was presented with the opportunity to voice their concerns and opinions, no decision-making power was devolved. The authorities reserved the right to use the comments as they saw fit. Stakeholder engagement in negotiations is essential in adaptive governance of social-ecological systems. It allows stakeholders to be engaged in decision-making processes to be able to advocate their perspectives, experiences, and interests in the pursuit of a common output. This leads to their empowerment and to increased legitimacy of decisions and actions, as well as includes other types of knowledge as well as social factors in the evidence base of decisions.

Discussion of the Current Data Collection Network of Actors in Terms of its Polycentricity. As 0 and Table 4 underline, there are multiple centres of data collection and meaning-making with the Water Management Agency, the drinking and wastewater syndicates, the Luxembourg Institute of Science and Technology, the Wastewater Treatment Research Group at the University of Luxembourg, the river partnerships, and Natur&Emwelt.

Different clusters can be identified. The "public" cluster, composed of the Water Management Agency at the centre and the drinking water and wastewater syndicates as well as the Luxembourg Institute of Science and Technology. This makes up the biggest cluster in function of actors as well as of the size of datasets. The "science and innovation" cluster is composed of the Institute and the Wastewater Treatment Research Group. The "place-based" cluster contains the river partnerships and Natur&Emwelt. As this classification shows, the network is rather dominated by public organisations. The Water Management Agency is a focal point in the network of actors, as it either undertakes data collection by itself, commissions it to other organisations, supervises and collects reports of programmes, or quite often funds them (e.g. at least, in the case of river partnerships and the Wastewater Treatment Research Group). As a result, there are very little overlaps in datasets. The availability of different but overlapping datasets may increase accountability of data collectors (e.g. the government) and increase data availability. In the current set-up, it is difficult to identify polluters (Interviewee 6, personal interview, personal communication, 2017), as datasets are not targeted towards doing so. For an increased accountability of polluters, more intensive place-based monitoring would be essential, such as an increased and regular use of longitudinal profiles of water courses (Interviewee 1, group interview, personal communication, 2017; Interviewee 6, personal interview, personal communication, 2017).

A more dynamic, decentralised, and diverse network of data collectors also including non-professionals could help increase the availability and access to data. Data collection and meaning-making by non-specialists could increase the diversity of purposes and agendas with the potential to lead to data collection better tailored towards place-specific management questions. Increased accountability of government and polluters are important in adaptive governance and for more sustainability.

4.4.3 A Critical Discussion of the Findings and the Evaluation Framework

This section is dedicated to a critical discussion of the findings presented in the previous discussion and of the evaluation framework used as a basis for the discussion and its structure. It begins with an example of a theme from the interviews, which was rather side-lined to point out the fact that the assumptions of the framework play an important role in the discussion. It, then, continues with a critical discussion of aspects of the framework, which proved difficult to operationalise in the analysis, and, finally, it points out a series of opportunities for improvement based on the previous discussions.

The evaluation framework is based on the premise that transparency is an essential criterion in adaptive governance and that it requires the publication of unedited datasets. In the interviews, however, the publication of unedited datasets was often seen critically. One of the main reasons was the fact that interpretation of data related to water quality is a difficult undertaking even for specialists (as discussed in section 4.2.3) and that without a basic understanding of system processes, the publication of datasets may lead to a number of challenges. For example, parameter values may be misinterpreted, which could lead to wrongful negative feelings (in the context of this study, interviewees often used the example of high nitrate readings, which could lead to panic, if their implications for nature and humans were exaggerated). In this way, it cannot be ruled out that the evaluation framework did not side-line other, perhaps, less prominent themes due to built-in assumptions.

In addition, certain aspects of the evaluation framework proved rather challenging to apply. This is mainly due to the lack of general thresholds in the evaluation of the suitability of the programmes for the different criteria. For example, regarding a discussion of the suitability of data collection frequencies for detecting changes in a timely manner, no clear line could be drawn between suitable and not suitable, as drawing a line would require a more differentiated approach in terms of parameters. Consequently, it proved difficult to evaluate a specific data collection frequency in isolation. Evaluation rather took place on a continuous scale, where, generally speaking, a higher data collection frequency was considered favourable. In reality, a number of factors impose limits on the data collection frequency, such as limited financial and human resources. In a similar manner, it proved challenging to evaluate the suitability for detecting fluctuations as a kind of change in the system, as, a priory, the higher the data collection frequency, the higher the chances of detecting even the shortest fluctuations. If these have important implication for nature and humans is, of course, again, parameter-dependent. For an increased accountability of polluters and a rapid response the undesirable changes, a swift detection of changes, however, is important. Another aspect, which proved difficult to operationalise, was to evaluate the suitability of a programme for place-based data collection, as no clear number of required data points per unit of surface area or unit of water body surface area could be identified.

Another point of discussion relates to the approach taken in the discussion of considering the data collection programmes and meaning-making approaches individually, at first. Of course, each individual programme does not need to fulfil all the criteria of the evaluation framework and, oftentimes, cannot do so either. While some criteria are applicable to all programmes, in general, such as transparency, others may not be necessarily compatible, such as the purposes of the detection and tracking of impacts of management interventions and national trend detection. Rather than focusing on the unit of an individual programme, it may be more appropriate to consider the entirety of data considered for a particular purpose and the data collection programmes and meaning-making approaches, which produced it. Since the programmes considered in this study do not necessarily have the same purpose, they also may not be compatible with each other, for example, in terms of the parameters considered and the location of the sampling sites.

Similarly, a statement cannot be made on whether data of social and technological factors sourced by data collection programmes and meaning-making approaches with a primary purpose other than the governance and management of surface water bodies is considered in decision-making processes as this study only considered programmes with the above-mentioned primary purpose.

4.4.4 Opportunities for Change Towards More Adaptive Sustainable Surface Water Governance, Main Insights, and Reflexive Discussion

Based on the above discussions related to the criteria of ideal data collection and meaning-making in adaptive governance, the following lists a series of gaps and opportunities in the structure of the conceptual framework: input and process, and objectives.

Input and Process. As the previous discussion has shown, stakeholder engagement in the design and implementation of single data collection programmes and meaning-making approaches is generally low and the network of actors engaged in data collection and meaning-making in the water quality domain is dominated by the Water Management Agency. Stakeholder engagement in single programmes has been evaluated based on the available information gathered by the interviews conducted with specialists in the water quality domain and documentary review (see Chapter 3). The structure and diversity of the network of actors engaged in data collection and meaning-making in the water quality domain has been evaluated based on the actors involved (see section 4.1) and the links among them (see section 4.2). The actors and links were similarly identified by the interviews and documentary review. The related discussions have been presented in section 4.4.2. In the adaptive governance literature, as presented in more detail in section 2.1, stakeholder engagement in single data collection programmes and meaning-making approaches is considered important for "democratising" to some extent the value choices that come with research in the context of sustainability challenges (Cooney & Lang, 2007). Value-choices are, for example, linked to the definition of the research questions and design. Stakeholder engagement, in addition, facilitates the engagement of diverse types of knowledge in the design and implementation of the research. Diverse knowledge types, including knowledge types that are scientifically and non-scientifically produced, are essential for building the most comprehensive picture of the social-ecological system in the context of sustainability challenges (Folke et al., 2005; Funtowicz & Ravetz, 1993).

In reality, however, there are many obstacles to stakeholder engagement and to the engagement of non-scientifically produced knowledge types. For example, as section 3.10 highlights, the engagement of non-specialists is a difficult undertaking. The co-created surface water citizen science case studies originally also aimed at engaging non-specialists in the co-design, but did not manage to do so. This was due to a number of reasons, among which inadequate design of the co-design process and differences in vocabulary between the researchers and non-specialists (as discussed in section 3.10). Differences in vocabularies (related to technical language) have also been identified as a key reason for the limits of the participatory processes employed in the context of the second management plan in Luxembourg (see section 4.4.2).

Stakeholder engagement is a process that requires many resources. It can be time-intensive for, both, the organisations that are facilitating the engagement as well as for the stakeholders, who are engaging. Stakeholders may have to engage alongside their main function. The public, for example, usually engages as part of their leisure time. The opportunity costs can, therefore, be fairly high, and the benefits of engagement are rather uncertain. The organisations, in turn, which are active in data collection and meaning-making related to water quality and are tasked with facilitating stakeholder engagement, can also face difficulties in the implementation of stakeholder engagement processes. For example, formally defined roles (e.g. in the case of public organisations, the roles are defined by law) may be difficult to change, as processes are rather complex and stakeholder engagement in research for governance is still a fairly new idea. In addition to time, stakeholder engagement also incurs costs and requires adequate expertise.

Many interviewees were also rather reserved in regard to the value of non-scientifically produced knowledge in governance. The concerns were voiced, in particular, in relation to the usefulness of data produced with citizen science, which was often seen as inferior to knowledge produced with state-of-the-art scientific methods (see, for example, Interviewee 1, group interview, personal communication, 2017). Such mind-sets represent a great challenge to the engagement of diverse stakeholders (including non-specialists) in data collection and meaning-making. The example of the role of the public as “warning system” for pollution incidents (see section 4.1.11) shows, however, that knowledge by non-specialists developed by experience and observation can be valuable in governance.

The network of actors engaged in data collection and meaning-making related to surface water governance shows that it is rather dominated by the Water Management Agency in Luxembourg (and other public organisations). Of course, this comes as no surprise, as the state has traditionally been a key actor in the governance of the environment. Even though public engagement has become more prominent in recent years (see, for example, *Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 Establishing a Framework for Community Action in the Field of Water Policy*, 2000; *Loi Du 19 Décembre 2008 Relative à l'eau*, 2008), this approach is ingrained in the current governance system, and change in formalised systems is often complex and slow. Furthermore, the evidence did not show any examples of public engagement in the network of actors in the form of, for instance, conducting own data collection programmes and meaning-making approaches in the water quality domain. This may be due to the high opportunity costs linked with engagement discussed in a previous paragraph as well as a lack of attractive opportunities.

Process. As regards the transparency of the programmes, some gaps and opportunities can also be identified based on the previous discussion. In fact, while, in general, datasets produced by public organisations are available for public access as far as possible, there is a significant barrier to accessing project-based datasets. This insight has been developed largely based on the interview results (see, for example, Interviewee 4, personal interview, personal communication, 2017; Interviewee 8, personal interview, personal communication, 2018), presented in section 4.2.3 and discussed in section 4.4.2. In the adaptive governance literature, transparency is considered a key factor (see section 2.1.4). It is considered a feature of good governance (Lockwood et al., 2010), is seen to contribute to legitimacy of decisions and action (Curtin & Meijer, 2006), to increase accountability of decision-makers (Herrfahrdt-Pähle, 2013), and to facilitate quality control of decisions (Bäckstrand, 2003). In the context of governance, transparency of decisions and actions requires that data that is used as evidence in decision-making is publicly accessible and the way, in which it is used (Waylen et al., 2019). There are a number of challenges to the publication of project-based datasets. One approach to making project-based datasets available that was suggested during the interviews was their publication on a common data sharing platform, such as the Government's Open Data Portal (Interviewee 8, personal interview, personal communication, 2018). Integrating diverse datasets, however, often comes with a number of challenges, such as related to format. Re-formatting datasets is a time-consuming task and can introduce errors (see, for example, Interviewee 2, group interview, personal communication, 2017). In addition, the organisations in charge of uploading datasets may have to do so alongside their main function, which comes with additional costs, such as person-hours, and the benefits for the uploader are rather uncertain.

Another insight developed from the discussion is that, for transparency purposes, original datasets (in disaggregated format) need to be published alongside aggregated forms of data representation (e.g. yearly averages), which at the moment is not always the case (e.g. in the case of wastewater syndicates, see section 4.2.3). This insight is based documentary review, including the review of organisational websites and reports (see section 3.6). Some interviewees were rather reserved in relation to the publication of original datasets in some cases, especially, in the context of wastewater treatment plants (see, for example, Interviewee 8, personal interview, personal communication, 2018). It presents a particular case, as the quality of the treated wastewater closely depends on the quality of the wastewater that is discharged from industry and households, and comparisons of plants are difficult. The publication of original datasets, in this case, may lead non-specialists to believe that one wastewater treatment plant is not working as well as another, even though the differences in the quality of the treated wastewater are down to differences in the quality of the wastewater discharged from households and industry. As in this case, the interpretation of datasets is often complex, even for specialists and non-specialists may, therefore, reach wrong conclusions, if not informed accordingly. Similar fears were also voiced by the interviewees in relation to the publication of data on the quality of surface water bodies. High nitrate readings could, for example, lead to panic, if the consequences for the environment and humans are exaggerated (see, for example, Interviewee 1, group interview, personal communication, 2017). Some interviewees suggested a more targeted approach to data publication in the form of a system, which would provide non-specialists information (e.g. a judgement of the water quality in a surface water body at a particular time) based on original datasets on demand in a format that does not require specialist knowledge. The rationale for the information that is provided by the system could also be presented on demand, for example, by showing the original data used to make the claims for transparency. This also rests on the assumption that the public does not have the capacities (e.g. time) to become specialists in the water quality domain (see, for example, Interviewee 8, personal interview, personal communication, 2018).

As regards meaning-making, another significant gap could be identified. Access to data meaningful to non-specialists and information for meaning-making is, at the moment, rarely given. This insight has been developed based on an examination of the data publication practices of the actors presented in the chapter (see sections 4.2.3 and 4.4.2). Transparency is not only dependent on the mere publication of data. If the goals are to increase the legitimacy of decisions and actions as well as the accountability of decision-makers, it is necessary that the public (i.e. specialists and non-specialists alike) have access to published datasets meaningful to non-specialists. It is only by being able to make meaning from the datasets that legitimacy and accountability can increase (Waylen et al., 2019). As sections 4.2.3 and 4.4.2 have shown, this is not a common practice across the network of actors. A key reason is that producing information also targeted at non-specialists is a difficult endeavour and requires many person-hours and adequate expertise. At the same time, while the public accessibility of datasets produced by public organisations is a legal requirement, public access to data meaningful to non-specialists and information for meaning-making is not. In addition, as has already been discussed before, the interpretation of data is a complex undertaking, often even for specialists. Specialists may not be able to produce satisfactory explanations for high parameter values, and, consequently, cannot share them with the public (see Interviewee 8, personal interview, personal communication, 2018; Interviewee 11, personal interview, personal communication, 2018). It is, however, important to make the public aware of these limits of explanatory power and to showcase system processes (Interviewee 11, personal interview, personal communication, 2018).

Another key insight of this chapter is that the guaranteed data collection frequency of programmes with higher sampling site densities is fairly low, compared to to programmes with lower site densities (see section 4.4.1). This significantly limits the capacity for the swift detection of changes at smaller geographical levels. Project-based programmes have the potential to complement this frequency, but can only do so in short-term and irregularly. This insight has been developed based on documentary review and the examination of the current data collection programmes and meaning-making approaches with their data collection frequencies and sampling site densities (see sections 4.3 and 4.4.1). In adaptive governance, the swift detection of changes in the system is considered important to be prepared to adapt in the case of undesirable changes. Unpredictability is a key characteristic of sustainability challenges. Rapid responses are important to minimise the extend and implications of undesirable changes and to increase accountability of polluters (Hasselman, 2017). Detecting undesirable changes at smaller geographical levels, however, is resource-intensive, depending on the geographical area that is to be covered with a relatively high sampling site density. Not only collecting the samples requires effort, but also their analysis in the laboratory as well as the analysis of the datasets. It is also a key reason, why place-based data collection happens mostly on project-basis. The costs may outweigh the potential findings, especially since environmental degradation can often not be easily put in monetary terms (Interviewee 1, group interview, personal communication, 2017).

Objectives. As the discussion has shown, current data collection and meaning-making includes programmes designed for research into cause-effect relationships, for tracking change, for tracking the effects of interventions, and for identifying possible drivers of change. It has to be noted, however, that the focus is clearly on ecosystem factors, and social and technological factors are more or less neglected. In the adaptive governance literature, the social and ecological are considered tightly intertwined. Drivers of change may be social, technological and ecological in nature, and therefore, it is essential that social, technological and ecological potential drivers of change internal and external to the system are being considered to have the best idea of the cumulative effects on the system. The cumulative effects on the system are important for isolating the effects of interventions in the best way possible for adaptation (Chapman, 2014; Waylen et al., 2019).

Chapter 5. Case Studies 1 and 2: Contributory Surface Water Citizen Science in Luxembourg and Contributions to Adaptive Governance

The goal of this second empirical chapter is to develop an answer to Research Question B: *"How can contributory citizen science support the adaptive governance of social-ecological systems? How can it address the opportunities for change identified in Question A?"*. To arrive at an answer to this question, first, two contributory citizen science projects are presented that were undertaken as part of this thesis. The presented information is based on project documentation, such as published leaflets and reports, other documentary review (where appropriate), the produced datasets of the projects, and experiences gained from the implementation of the projects (see Chapter 3). Second, a discussion is offered based on the presented results assessing the suitability of the two contributory citizen science projects, and of contributory citizen science in general for fostering adaptive governance of social-ecological systems by making connections with the criteria identified in the conceptual framework (see section 2.5.1).

5.1 Case Study 1 - Project Streams & Corporate Partnership: Longer-Term Data Collection and Freshwater Watch

To begin the presentation of the results, the following gives an overview of the project that is the first to be presented, Project Streams & Corporate Partnership, before delving in deeper into the presentation of the specificities of the project starting with the presentation of important actors, and roles and motivations.

The aim of the contributory citizen science Project Streams & Corporate Partnership was twofold. On the one hand, the project was designed to build a database supporting research to learn more about the status of the Aalbaach, Bouneschbaach, and Staflick, three smaller streams located in the commune of Niederanven and tributary to the Syr-river, and to learn more about the effects of social-technological (e.g. presence of pollution sources, such as inlets from industry, and human uses of the water body, such as swimming) and environmental circumstances (e.g. riverside vegetation) on the status of the streams. One the other hand, the project constituted a pilot aiming to lead to insights for the potential of contributory citizen science and citizen science, in general, to contribute to the governance and management of surface water bodies in Luxembourg with a particular focus on the produced dataset and the findings as well as an outlook on the potential for social learning. The focus on three smaller streams was based on the fact that data collection in smaller streams does not take place very often, in particular in the boundaries of the governmental data collection programme (i.e. only every three years as part of Monitoring Control).

The project was designed in collaboration with the River Partnership Syr and Earthwatch. The role of each is discussed in more detail in the following sections. The project involved multiple activities. It involved, for example, data collection by 6 interested employees of the Royal Bank of Canada at 8 data collection sites distributed across the 3 streams. In its initial phases, the project involved presentations at the Bank to excite and recruit employee volunteers for the project, who, in a second phase, were trained at a workshop in the data collection methods and the use of the citizen science software (in particular, the mobile application for data entry).

The Freshwater Watch citizen science tool by Earthwatch Europe, an environmental charity registered in the UK, for data collection on the topic of freshwater quality was used for data collection, entry, and visualisation. The Freshwater Watch tool encompassed a kit, a mobile application, and a web platform. The kit contained all the necessary tools for data collection (e.g. Secchi-disk for turbidity measurements) and was put together based on the selection of parameters from the list of available parameters. The mobile application was used for data entry in the field (data upload via website was also possible and the data could be noted on the available data collection paper sheet prior to upload). The mobile application could be downloaded for both iOS and Android devices. The website was used for project description and data visualisation.

As part of the interest of the Sustainability Science Research Group at the University of Luxembourg in citizen science for more sustainable water governance, interest was high in existing citizen science projects and tools on the subject. As a result, a collaboration with Earthwatch was sounded out in the boundaries of the Freshwater Watch project and with a particular interest in the Freshwater Watch citizen science tool.

The Freshwater Watch project was established in 2012 as part of the HSBC Bank's Water Program. Since then, it had grown and reached global level. Its main objective had been to enable individuals and groups to monitor water bodies by providing them with the Freshwater Watch citizen science tool (Earthwatch, 2018a). The project had resulted in many research publications (e.g., Castilla et al. 2015, Cunha et al. 2016, Loiselle et al. 2017) and diverse local impacts (Earthwatch (2017) as cited in August et al. (2019)).

It was half-way through the PhD-project that Earthwatch came up to the Research Group with a project proposal. It was looking to support selected research projects with its citizen science tool and funding as part of its partnership with the Royal Bank of Canada. The aim of the partnership between Earthwatch and the Bank was to connect local communities to support research into conserving and restoring urban lakes, rivers and streams across Europe. It was active in three European capitals, Luxembourg, Paris, and Dublin. Within this framework, interested employees of the Bank and local volunteers were trained to be equipped with the essential skills to participate in scientific data collection. The research aimed to further the understanding of the state urban water bodies and to contribute to their more sustainable management (Earthwatch, 2018c).

As part of previous work towards this thesis to sound out the interest of groups and organisations in Luxembourg to participate in the co-design of a citizen science project and tool for their purposes (a more detailed account of this process is presented in Chapter 3 and Chapter 5), the Research Group had already been in contact with multiple groups across Luxembourg. As the project proposal constituted an interesting opportunity, it was presented at multiple occasions. The River Partnership Syr and the Commission for Sustainable Development of the Commune of Niederanven showed the most interest. As a result of the above developments, the Project Streams & Corporate Partnership had taken the shape and form that is described here.

5.1.1 Important Actors, and Roles and Motivations

To start the presentation of results, first, the following focuses on the presentation of important actors more generally as well as on the presentation of the roles and motivations of each actor to participate in the citizen science project more specifically. Documentary review was used to deepen the descriptions of important actors, where appropriate and possible. For ease of reading, first, an overview of the network of actors is presented.

Overview of Important Actors, and Important Roles and Motivations.

Table 12 provides an overview of the important actors of Project Streams & Corporate Partnership including information on roles, legal bases, and motivations.

Table 12

Most Important Actors of the Project Streams & Corporate Partnership Including Information on Roles, Legal Bases, and Motivations

Actor	Role	Legal basis	Motivation
Royal Bank of Canada	• Project funder • intermediary for citizen scientist recruitment		Supporting charities with funds and employee volunteers for the benefit of the community (RBC Investor & Treasury Services 2020)
Earthwatch Europe	• Establish Royal Bank of Canada & University of Luxembourg partnerships • Co-Coordinator • Co-Administrator • Provider of Freshwater Watch methods • Funding recipient		More sustainable governance of aquatic ecosystems (also project Freshwater Watch) (Earthwatch 2018)
River Partnership Syr	• Co-Designer of research focus and methodology • Scientific and local expert	Loi du 19 décembre 2008 relative à l'eau (2008) & Flusspartnerschaft Syr (2011)	• More sustainable and integrated governance of the Syr watershed area (Flusspartnerschaft Syr 2011) • Engagement of diverse actors in the region (Flusspartnerschaft Syr 2011)
Committee for Sustainable Development of the Commune of Niederanven	Organisational support	Loi communal (1988)	Sustainable development in the commune and citizen engagement
Citizen scientist community	Data collection		• Sustainability • Engagement in initiatives for sustainability
Sustainability Sience Research Group	• Establish local partnerships • Co-Coordinator • Co-Administrator • Co-Designer of research focus and methodology • Reporter • Funding recipient		More sustainable governance of freshwater bodies in Luxembourg via transdisciplinary research (and citizen science) (Sustainability Science University of Luxembourg 2021)

The River Partnership Syr. For a general presentation of river partnerships, please see section 4.1.9. The River Partnership Syr is concerned with the watershed area of the Syr river, as displayed on Figure 16.

The role of the River Partnership in the Project Streams & Corporate Partnership was diverse. Before implementation, the River Partnership expressed the wish to develop a project in the watershed area of the Syr based on the proposal by Earthwatch (as described in section 5.1). The Partnership was essential for the further project development and implementation. During project design, it selected adequate data collection sites based on its familiarity with the Syr watershed area and related sustainability challenges. Similarly, it also contributed to the selection of most salient parameters for data collection. Due to its expertise and interest in the produced dataset and findings, it provided feedback on project reports.

The motivation of the River Partnership was derived from its general missions. The project coincided with some of them, as it provided a platform for citizen engagement, (social) learning, and it had the potential to contribute to the evidence base for policy-making and management of smaller streams towards more sustainability.

The Commission for Sustainable Development of the Commune of Niederanven. A similar role can be attributed to the Commission for Sustainable Development of the Commune of Niederanven. It was also a crucial place-based partner in the project. The Luxembourgish law on the functioning of the communes sets out that the communal council can form consultative commissions. Their composition, functioning, and their attributes are fixed by internal regulations of the commune (*Loi Communal*, 1988).

In general, these commissions can be permanent or temporary. They do not take decisions, but prepare simple statements of opinion, which the communal council is free to follow or disregard. The statements of opinion, for example, can come in the form of proposals of measures, opinions on measures developed by the communal council or on the general state of the commune in regard to the specific topic area (Ministère de l'Intérieur, 2018). Often, while the communal councils determine and allocate their annual budget, a proportion is foreseen for (some of) the commissions and the implementation of their ideas. The consultative commissions can be composed of municipal councillors and external people in any kind of ratio. In communes, in which voting occurs according to the system of proportional representation, every political group must be represented in function of the number of representatives elected to the communal council (Ministère de l'Intérieur, 2018). The establishment of some consultative commissions is prescribed by law: the commissions regarding education, rent, the supervision of musical education, and integration (Ministère de l'Intérieur, 2018).

These general principles of consultative commissions also apply to the Commission for Sustainable Development of the Commune of Niederanven. A commission for sustainable development, for example, would be concerned with the development of ideas to promote sustainable development in the commune and to assess any communal action plans in relation to their potential for sustainable development. Similarly to the River Partnership Syr, the role of the Commission in the initial phase of project development was to express interest in the implementation of the project and, as such, to offer support in its implementation. During the project activities, the Commission provided organisational support, for example, in the form of offering a venue for the organisation of workshops.

Earthwatch Europe. As outlined in section 5.1, Earthwatch was the initiator of the project. Its offer to the Sustainability Science Research Group at the University of Luxembourg to collaborate on a citizen science project was the factor that led to the design of the project and its implementation.

The Earthwatch Institute (Europe) is a registered charity in England and Wales. It is a non-governmental organisation and focuses on environmental issues. Its website defines its main missions, which can be broadly summarised as working on the topic of environmental impact in the areas of aquatic ecosystems and agriculture, by engaging and working with various groups across society, such as businesses, governments, and communities (Earthwatch, 2018b).

The role of Earthwatch in the citizen science project was to establish the partnership with the Royal Bank of Canada and, thus, secure funding for the project. It, further, initiated the collaboration with Sustainability Science Research Group. Earthwatch representatives were in charge of administering the partnership with the Bank. They had also been involved in organising events, project presentations, and the facilitation of workshops. Its main motivation is derived from its general missions: to extend to the use of their Freshwater Watch citizen science tool and to contribute to missions as stated above.

The Royal Bank of Canada. The collaboration of Earthwatch and the Royal Bank of Canada was the founding stone of the project in that it secured funding as well as defined Luxembourg as one of the locations.

The Royal Bank of Canada is “one of Canada’s largest banks and one of the largest banks in the world, based on market capitalisation” (Royal Bank of Canada, 2020). It employs more than 86’000 people, serving “17 million clients in Canada, the United States of America and 34 other countries” (Royal Bank of Canada, 2020). It provides “personal and commercial banking, wealth management, insurance, investor services, and capital markets products and services a global basis” (Royal Bank of Canada, 2020).

Its branch in Luxembourg with its basis in Esch-sur-Alzette (Belval) is one of its sub-entities, RBC Investor & Treasury Services. It employs over 4’500 people in 16 countries (RBC Investor & Treasury Services, 2020b). Alongside its main missions, it seeks to create “a positive social impact - not just an economic one” as an integral part of their business. “By developing strong relationships with local charitable entities and providing them with both financial support and employee volunteers, (it) can help (its) communities grow and prosper” (RBC Investor & Treasury Services, 2020a).

The role of the Bank was the one of funder of the project and intermediary and encouraging party for building a community of citizen scientists of interested employees.

The Citizen Scientist Community. The citizen scientist community was exclusively composed of employees of the Royal Bank of Canada.

An important characteristic of the community was that many of the individuals were cross-border commuters, which meant that they were resident in neighbouring countries to Luxembourg and commuted to Luxembourg for work. This resulted in a significant difference among the cross-border commuters and the individuals, who lived closer to the data collection sites, in the convenience of participation.

The role of the citizen scientists was to participate in the research process, primarily, in the form of data collection. From the interactions with the citizen scientists, it became clear that to contribute to more sustainability and “doing something meaningful” was a main motivation of many, if not all, of them.

The Sustainability Science Research Group at the University of Luxembourg. The Sustainability Science Research Group at the University of Luxembourg played a key role in the design and implementation of the project. It acted as the project carrier.

The Research Group had been established in 2017 and was composed of four researchers, of which the author of the present thesis formed part, administrative staff, and student assistants (The compositions varied over the course of the years). Since its formation, its research focus had been on three major topic areas: (1) the participative development of a set of scenarios for use in policy- and decision-making (work strand led by the group leader in collaboration with a post-doctoral researcher), (2) the research by the second PhD candidate with the title “Actionable knowledge for sustainability at the water-land nexus: an inquiry into governance and social learning in two river basins in Luxembourg”, and (3) the research that is the subject of the present thesis. The author of this thesis was largely responsible to carry out the work streams related to the projects described in this thesis.

As the practical aim of the third research strand on citizen science was to co-design and initiate citizen science projects for studying the state of surface water bodies in Luxembourg, the Research Group was reaching out to multiple stakeholders and citizen groups aiming to form collaborative partnerships. It also reached out to established research groups or organisations active in citizen science on the topic of water monitoring on the matter of citizen science software, hardware, and protocols in order to build on existing work.

The role of the Research Group was to establish local partnerships, co-develop the research focus, organise meetings and trainings, among others, hold presentations, excite and motivate the development of a group of citizen scientists. It was also tasked with the valorisation of the research and its results in the form of published reports and possible further research. Its motivation was to contribute to more sustainable water governance in Luxembourg and scientific knowledge development in the form of transdisciplinary research along the three described research pathways.

5.1.2 Phenomena, Data Collection Frequencies, and Sites

After the presentation of the important actors in the Project Streams & Corporate Partnership with their roles and motivations, in the following, the focus shifts to the phenomena subject to data collection, standard protocols, data quality mechanisms, and data collection frequencies and sites.

Overview of the Phenomena*.* The parameter-set is geared to giving insights into pollution levels in the sampled water bodies (e.g. floating foam or oil and turbidity) with a focus on nutrients and to identify possible causes (e.g. land use in the immediate surrounding and presence of pollution sources).

Nutrients play a significant role in the quality of surface water around the globe. Increased nutrient contents in surface waters may lead to accelerated eutrophication, which is characterised by excessive plant and algal growth in the water (Chislock et al., 2013). Accelerated eutrophication comes with a number of implications for humans and nature. It leads to unfavourable habitat conditions for aquatic life forms (e.g. fish) and it can come in the form of toxic algal blooms (European Environment Agency, 2016). If ingested in high doses by humans, nitrate can also cause health implications. Different thresholds for the evaluation of water bodies in relation to their nutrient status are available [e.g. for Luxembourg, see Administration de la Gestion de l'Eau (2009)].

Table 13 shows an overview of the parameters used in the Project Streams & Corporate Partnership. In the subsequent sections, each parameter is described in detail. The parameter-set is geared to giving insights into pollution levels in the sampled water bodies (e.g. floating foam or oil and turbidity) with a focus on nutrients and to identify possible causes (e.g. land use in the immediate surrounding and presence of pollution sources).

Nutrients play a significant role in the quality of surface water around the globe. Increased nutrient contents in surface waters may lead to accelerated eutrophication, which is characterised by excessive plant and algal growth in the water (Chislock et al., 2013). Accelerated eutrophication comes with a number of implications for humans and nature. It leads to unfavourable habitat conditions for aquatic life forms (e.g. fish) and it can come in the form of toxic algal blooms (European Environment Agency, 2016). If ingested in high doses by humans, nitrate can also cause health implications. Different thresholds for the evaluation of water bodies in relation to their nutrient status are available [e.g. for Luxembourg, see Administration de la Gestion de l'Eau (2009)].

Table 13

Parameters of Project Streams & Corporate Partnership

Indicator	Physical chemical	Biological	Hydromorphological	Naturally occurring substances associated with pollution	Other pollutants	Social technological contexts
Nitrate				M		
Phosphate				M		
Riverside vegetation		O				O
The appearance of the water body by the presence of foam, floating algae, litter, and oil					O	
The presence and composition of algae in and on the water		O		O		
The presence of aquatic life forms, such as fish, plants, etc.		O				
The presence of pollution sources, such as from industry, residences, etc.					O	O
Turbidity	M					
Type of water body			O			
Uses of the water body, such as fishing, swimming, etc.						O
Water colour	O	O		O		
Water flow			O			
Water level			O			

Notes. The parameters are listed in the order of appearance on the data collection form. The letter “M” stands for measurement and the letter “O” for observation.

Presentation of Phenomena and Standard Protocols. The presentation of phenomena subject to data collection in Project Streams & Corporate Partnership and the associated standard protocols for data collection in Table 14 are largely based on the supporting documentation provided to citizen scientists as part of the Freshwater Watch citizen science tool. The parameters included in Project Streams & Corporate Partnership represent the standard set provided in Project Freshwater Watch by Earthwatch. The use of the standard set of parameters comes with a number of advantages. For example, it allows to compare data from the project with data from many other projects using the Freshwater Watch methodology around the globe. In addition, the selection of parameters was discussed and determined in collaboration with the place-based partners for place-based relevance.

Table 14

Answer Options, Necessary Equipment, and Standard Protocols per Parameter in Project Streams & Corporate Partnership

Parameter	Answer options (if applicable)	Equipment (if applicable)	Standard protocol (Earthwatch 2019b, 2019a)
Nitrate and Phosphate	For nitrate (NO_3-N mg/L): <0.2, 0.2-0.5, 0.5-1, 1-2, 2-5, 5-10, >10 For phosphate (PO_4^{3-} mg/L): <0.02, 0.02-0.05, 0.05-0.1, 0.1-0.2, 0.2-0.5, >1	Test tubes containing a reactant, which would change colour after adding water	1. The citizen scientists should extract a water sample from the water body, while facing upstream (if the subject is a river or stream). During extraction, they should refrain from disturbing the sediments on the bed of the water body, as doing so might impact the test results. The device used for the extraction was self-made. The suggested form by Earthwatch was a cut open plastic milk jug (as common in the United Kingdom) attached to a stick or rope (depending on circumstances at the data collection location) for extended reach. 2. When the extraction device was filled, a smaller plastic container in the form of a cuboid, used as the container, from which the nitrate and phosphate test tubes were filled, should be rinsed twice with the extracted water in order to avoid any contamination by other substances. After rinsing, the cuboid should be filled up to the middle (1.5 millilitres). 3. Now that the water for the test was prepared, the plastic pin should be removed from the test tube to be used, the test tube should be squeezed with fingers to expel about half of the contained air, and, while maintaining the pressure on the test tube, it should be submerged in the water that is contained in the small plastic cuboid in such a way that the side of the test tube with the whole is under water. Then, the pressure should be released for the water to be sucked into the test tube. 4. After the test tube was filled with water, it should be shaken gently several times to ensure that the reagent had completely dissolved. 5. The reagent in the test tube for nitrates needed three minutes times until the test was finished and the colour of the substance in the tube could be compared against the provided colour scale. The test for phosphate took five minutes. When comparing the colour of the substance in the test tubes to the colour scales, the test tubes should be place on the white background of the colour-scale-sheet in order to cancel out any factors from the environment (e.g. background colour or sunlight) (Earthwatch 2019c).
Turbidity	Acceptable answers ranged from 14 to 240 with the extremities of "<14" and ">240"	For collecting data on turbidity levels in the water body, the Secchi-disk method was used. The Secchi-disk was attached to the bottom of a plastic cylinder and the top of the cylinder was open. A scale of Nephelometric Turbidity Units (NTU) was printed along the height of the cylinder.	Water should be gradually poured into the cylinder from the extraction device and the NTU noted at the point, at which the Secchi-disk was first invisible. The test should be performed without wearing sunglasses and out of direct sunlight. It was important to be as exact as possible, even if it meant pouring out some water from the cylinder to find the lowest point, at which the Secchi-disk is invisible (this process could be repeated multiple times if necessary). If the water level reached the top of the cylinder and the Secchi-disk remained visible, the lowest NTU should be noted with "<14" (Earthwatch 2019b) .
Photograph		Smartphone or digital camera (not part of Freshwater Watch kit)	The photograph should include the water level, floating vegetation, and every source of pollution or every sign of use of the land (in function of possibility). In case of photos of moving water bodies, photos should be taken, while facing upstream to capture, where the water was coming from. One should try to take a photo from the same spot and with the same orientation during every visit (Earthwatch 2019b).

Immediate surrounding land use	Urban/ residential, industrial, urban park, agriculture, forest, pasture/ shrub, other with text box (single choice)		
Riverbed vegetation	Trees/ shrubs, grass, no vegetation cover, other with text box (multiple choice)		
The Appearance of the Water Body by the Presence of Foam, Floating Algae, Litter, and Oil	Presence of foam, floating algae, litter, and oil (multiple choice)		The citizen scientists should observe the photograph(s) taken and note all the options that could be detected in the immediate data collection zone on the day, during which the sample was taken (Earthwatch 2019a). It was also remarked that one should pay attention not to mistake other types of plants on the surface of the water for algae.
The Presence of Pollution Sources, such as from Industry and Residences	Effluents from industry, residential areas, urban areas/ roads, other with text box (multiple choice)		Examples of pollution sources were given: pipes, places, where there is a risk of efflux from agriculture or roads (Earthwatch 2019a).
Uses of the Water Body, such as Fishing and Swimming	Fishing, swimming, nautical activities, irrigation, public system of water distribution, other with text box (multiple choice)		It was made clear that only activities should be selected, which could be observed at the moment of data collection. It was, for example, not enough to know that nautical activities were allowed in general (Earthwatch 2019a)
The Presence of Aquatic Life Forms, such as Fish and Plants	Plants growing under the water surface, plants growing across the water surface, plants floating on the water, fish, frogs/ toads, birds, no aquatic life forms found, other with text box (multiple choice)		It was stressed to only select the options, which could be observed at the very moment of data collection. Past sightings of aquatic life forms should not be considered (Earthwatch 2019b).
The Presence and Composition of Algae in and on the Water	No algae, distributed homogenously, floating mat, stationary, and green foam (multiple choice)		It was instructed to consider the photograph(s) taken and to select all options, which could be observed in the immediate data collection zone at the time of data collection. It was also reminded not to mistake other plants for algae (Earthwatch 2019a).
Water Flow	Surging, steady, slow, calm (single choice)	Twig or similar (optional; not part of the Freshwater Watch kit)	A trick was described with the aim to help assess the water flow. One could throw a leaf or a twig into the water body and, at the same time as the object thrown in the water moves downstream, one should walk along the river bed in the same direction. Now, if the water flow speed is slower than normal walking pace - that is, if the object thrown in the water moves slower in the water than normal walking pace - it would be considered "slow". If it is roughly equal, it would be considered "steady", and "surging", if it is faster than normal walking pace (Earthwatch 2019b).
Water Level	High, medium, and low (single choice)		To answer this question correctly, information about the "normal" state of the water body was needed. It, therefore, became easier as one had performed the data collection more often. However, in general, one could look out for signs, which could help make the assessment, such as traces left by the water on the beds, or on trees/ branches (Earthwatch 2019b).
Water Colour	Transparent, yellow, brown, green, other with text box (single choice)		It was suggested to try to assess the colour of the water on the other side of the water body (or further away), instead of directly at the spot, where one was standing, and to try to not be biased by the colour of submerged vegetation or the reflection of the sky (Earthwatch 2019b).

Data Quality. Data quality is a key concern in citizen science projects. Uncertainty may be introduced by technical aspects of the research, such as the accuracy and precision of the data collection methods (e.g. nitrate and phosphate tests as well as observations) or errors in data collection and processing, such as deviations from standard protocols and faults in hardware and software. In Project Streams & Corporate Partnership, in particular, two prime data collection methods were used: observations and measurements.

The data collection method of observation included the identification of the land-use in the immediate surrounding, bank vegetation, the presence of certain items on the water surface, and water colour. Citizen scientist data collectors were asked to select one option (or as many as apply) from a list of possible answers. The identification process was very often intertwined with personal judgements, for example, concerning definitions of the observable phenomena (e.g. what characterises a land-use as agricultural or industrial). In addition, personal judgements were also required in situations, in which multiple answer options were true, but only one option could be selected (e.g. when multiple land-uses coincided). To account for these challenges, visual displays of the answer options were provided in the data collection forms for some of the parameters. This allowed to convey visual definitions of the observable phenomena, which made comparisons possible (as, for example, with the parameter 'water colour').

The data collectors were also asked to perform simple measurements of the nitrate and phosphate concentrations in the surface water body of their choosing. The measurement process included five stages:

1. Taking a water sample,
2. Filling the test tubes with water,
3. Awaiting the colouring of the water,

4. Comparing the colour of the water with colorimetric scale and classification of results, and
5. Input of results and transfer.

The measurement process could introduce a number of limitations, such as

- Disturbances to sediments,
- Use of smaller water quantities for testing,
- Difficulties of comparing the colour of the substance in the test tube with the colorimetric scale and the sub-sequent classification, and
- The inexactness of measurement methods.

Other than the detailed standard protocols for data collection, citizen scientists were also required to participate in a training session and were made aware by the supporting documentation about some of the common sources of errors and how to avoid them (as presented above).

Other mechanisms related to data quality are described in the following. The format of the collected data, for example, for nitrate and phosphate concentrations represented a way to account for the accuracy and precision of the measurement methods. The data was collected in the form intervals to not suggest over-accuracy. Further, a cleaning of the dataset was performed by a researcher before analysis, in the process of which obviously erroneous data was sorted out (e.g. wrong location, impossible turbidity values). During the analysis, two approaches to quality assurance were used, in particular. The “social approach” was used to increase the weight put on individual data entries during analysis (see Haklay, 2015). In other words, other data points from the immediate area were used to, for example, confirm or relativise high nutrient concentrations. If the data points were uploaded by different citizen scientists added another dimension of quality assurance. Further, unusual values or observations for a parameter were triangulated with the results for different parameters of the same entry (see Balázs et al., 2021), for example, photograph for water level, floating vegetation, point-source pollution source and land use. Other triangulation clusters are water colour, the presence and composition of algae and nitrate and phosphate concentrations, and turbidity, water levels (indicating rain events), the presence of point-source pollution sources (effluents), immediate surrounding land use (run-off or soil erosion), and beside vegetation (run-off or soil erosion). It can be noted that, if one of the parameters of the so-called triangulation clusters is not supported by the other parameters, it may suggest an error in data collection.

Data Collection Frequency and Sites. To round off the presentation of the data collection programme of Project Streams & Corporate Partnership, the following presents, first, the data collection sites and, second, the frequencies attained. The data collection sites are represented on Figure 17.

Figure 17

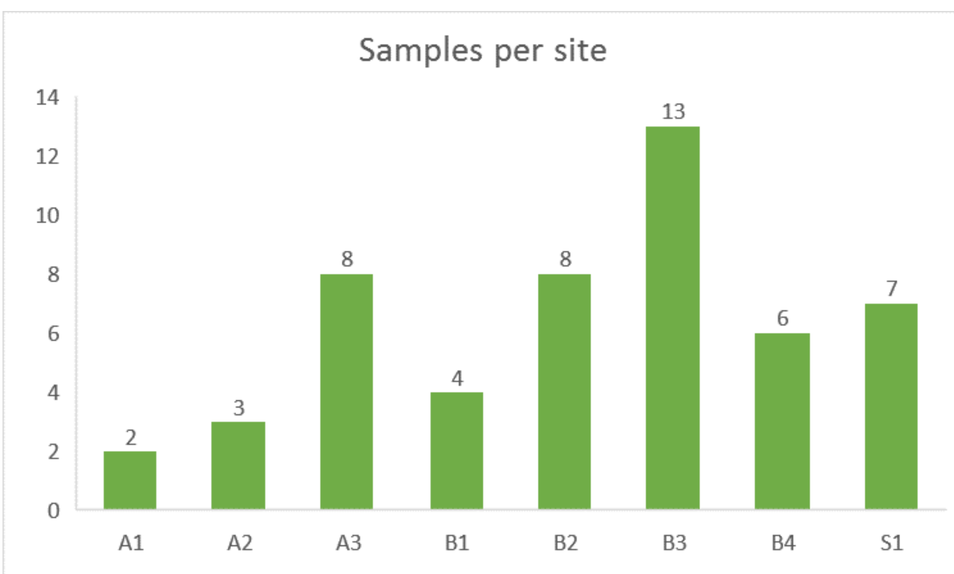
Data Collection Sites in Project Streams & Corporate Partnership

Notes. Map from Google Maps.

Data was collected at 8 sites distributed across the streams Aalbaach (3), Bouneschbaach (4), and Staflick (1) in the Commune of Niederanven. The Aalbaach and Bouneschbaach are tributary to the Syr river, while the Staflick flows into the Bouneschbaach approximately in the middle of its course. The sites were selected by the River Partnership Syr based on considerations linked accessibility and potential insights. In project design, a guideline minimum data collection frequency was set to 1 data point per site per month. After a year, it could be reported that the data collection frequency was more uneven. In fact, since the start of the project in May 2019 (equals 11 months), a total of 51 samples had been taken at the eight pre-determined data collection sites. Most samples had been collected for site B3 with 13 samples, followed by the sites A3 and B2 with 8. For sites A1 and A2, in contrast, only two and three samples had been collected respectively. The numbers for all sites can be viewed in Figure 18.

Figure 18

Number of Data Points Collected per Site for Project Streams & Corporate Partnership from May 2019 to March 2020.



In average, every citizen scientist collected 8.5 data points (6 citizen scientists in total). The most active citizen scientist collected 21 data points, that is almost 2 data points per month and almost half of all data points collected.

As background information to help explain the irregularity of the frequency, one needs to understand the organisation related to site distribution among the citizen scientists. As the citizen scientist community was made up of 6 employees of the Royal Bank of Canada, the group decided to self-organise and assign the sites among themselves to guarantee the guideline minimum frequency. As it turned out, however, some of the citizen scientists were more reliable for regular data collection. As a result, there was less data for some of the sites, which were assigned to citizen scientists, who were less reliable.

5.1.3 Data Publication Practices and Meaning-Making

In the following, the data publication practices by the Project Streams & Corporate Partnership are presented including information of public meaning-making.

Two modes of data publication can be identified: the live publication of data via the Freshwater Watch website and the publication via reports.

Data Publication via the Freshwater Watch Website. The entire dataset produced by the project was accessible by the Freshwater Watch website (FreshWater Watch, 2021). It could be downloaded as a CSV file. Individual entries could also be accessed on the website.

When visualising individual entries online, alongside the data, two additional sections were provided entitled: “feedback on your measurement” and “statistics on your measurement” (see, for example, FreshWater Watch, 2020a).

The “feedback on your measurement section” displayed an assessment of the entry. The statements were automatically generated and included details, such as

- an assessment of the ecological status quality of the water body,

- an assessment of the nutrient concentrations and turbidity,
- a suggestion of potential sources for elevated levels (if applicable), among others,

depending on the entry details.

The “statistics on your measurement” section allowed to compare the data of the selected entry with average values for phosphate, nitrate, and turbidity of a predefined sample area. Links were provided for further comparisons either with the global dataset or with an area defined by the user (see FreshWater Watch, 2020b).

This section was fairly technical. The parameters and their effects were not explained, nor were figures and tables provided.

When visualising the map of the project dataset, a feature allowed to select areas on the map (see embedded map at FreshWater Watch, 2021). The data points that were located in the selected area of the map could be exported as a CSV-file or the analysis feature used. The analysis section allowed to visualise temporal dynamics of the nitrate and phosphate concentrations as well as of turbidity in the form of medians of the selected data points. It also allowed to visualise a median value for each parameter of all the data points in the selected area compared to the global median. The analysis section included a series of filters (i.e. surface water body type, land use in the immediate surroundings, pollution source, and water flow) based on the observations that were part of a data point. This section was also fairly technical. The figures and tables provided and the parameters and their effects were not explained.

Data Publication via a Yearly Report. Alongside publication on the website, data was also published via a yearly report. The results of the project from the first year were subject of a report by the Sustainability Science Research Group (Pickar & König, 2020). It was sent to all citizen scientists and project partners. The report was written with the aim to inform on the findings of the project and to provide background information on the parameters and on the analysis process to make it transparent and equip the reader with essential skills for meaning-making. For this purpose, the report included descriptive sections on the parameters of nitrate, phosphate, and turbidity (including information, such as meaning of different measurement values for nature and humans, and relevant thresholds) as well as on the basic statistical analysis conducted (including information, for example, on the methods used and rationales).

Meaning-Making. While the access by the public to the produced datasets was guaranteed by the Freshwater Watch website, the website did not facilitate public meaning-making. As described above, little to no additional information was provided on the website that was targeted at non-specialists. The yearly report, in contrast, also aimed at providing background information on the parameters and the analysis for transparency.

5.2 The Suitability of Project Streams & Corporate Partnership for Supporting the Adaptive Governance of Social-Ecological Systems

Following the presentation of the results based on the implementation of the Project Streams & Corporate Partnership, project documentation, and other documentary review, a discussion is offered. The discussion attempts to develop an answer to Research Question B, "What is the potential of contributory citizen science for fostering the adaptive governance of social-ecological systems? How can it address the opportunities identified in the answer to question A?", by making connections with the criteria identified in the conceptual framework (section 2.5.1) and with the gaps and opportunities identified in the previous chapter (section 4.4.4). The structure of the discussion is displayed is the same as in Chapter 4 and is displayed in Table 9.

5.2.1 The Suitability of Project Streams & Corporate Partnership for the Objectives of Ideal Data Collection and Meaning-Making in Adaptive Governance

A summary of the discussion is provided in Table 15.

Table 15

Summary of the Discussion of the Criteria Related to Objectives of Data Collection and Meaning-Making in Adaptive Governance

Criterion	Guiding Question and Key Factor	Project Streams & Corporate Partnership
Furthering the scientific understanding of system processes	Is the data collection programme aimed at studying cause-effect relationships?	+/-
Detecting and tracking changes in the system	a) Is the data collection programme well-suited for detecting and tracking trends, i.e. is it open-ended? b) Is the data collection programme well-suited for detecting and tracking of fluctuations? The suitability is considered in a positive relationship with the data collection frequency with a guiding threshold of multiple data points per site per year.	a) Time-limited b) Rather well-suited
Detecting and tracking of effects of interventions	Is the data collection programme aimed at studying the effects of interventions?	-
Detecting and tracking of drivers of change	Does the data collection programme consider social, ecological, and technological factors in combination?	+
Swift detection of place-based changes and place-specific context factors	a) Is the data collection programme aimed at studying place-based changes in the system and/or place-based factors? b) Is the data collection site density of the programme well-suited for studying place-based changes and factors? The suitability is considered in a positive relationship with the data collection site density. c) Is the data collection frequency suitable for the swift detection of place-based changes? This was already discussed as part of question b) under 2.	a) + b) Rather well-suited c) Rather well-suited

Furthering the scientific understanding of system processes, detecting and tracking changes in the system, and detecting and tracking the effects of interventions. In the following, Project Streams & Corporate Partnership is discussed in relation to its suitability to further the scientific understanding of system processes, detecting and tracking changes in the system, and detecting and tracking the effects of interventions.

The contributory citizen science Project Streams & Corporate Partnership was designed with the aim to study the status of the Aalbaach, Bouneschbaach, and Staflick as well as the effects of social-technological and environmental circumstances on stream water quality. The project was also designed as a pilot for insights into the potential of contributory citizen science and citizen science, in general, to contribute to the governance and management of surface water bodies in Luxembourg with a particular focus on the produced dataset and the findings.

The dataset held only limited potential for studying cause-effect relationships, such as for tracing the effects of social-technological and environmental circumstances on stream water quality. To identify cause-and-effect relationships of this kind, more data is needed. The dataset, however, allowed to flag potential pollution hot spots (on-going or events), which could be linked with land use data and other circumstances at the site. This allowed to hypothesise on potential causes for pollution, and the insights can represent a starting point for further research. Project Streams & Corporate Partnership was also not designed with the aim to detect and track the effects of specific interventions.

Since the project only ran over two years, the produced dataset cannot contribute to longer-term trend detection. The data collection frequency in the first year, however, does not give any reason to believe that longer-term datasets cannot be produced. The potential of citizen science to support long-term data collection has been justified by multiple cases (Aceves-Bueno et al., 2015).

For a discussion of the potential of the project to support the detection of fluctuations and a swift detection of system changes, a closer look has to be taken on the data collection frequency. As section 5.1.2 described in more detail, the data collection frequency over the first project year turned out somewhat uneven. For example, for site B3 1.2 samples were taken per month, for site B4 0.5 samples (that is, 1 sample every other month), while for A1 and A2 only about 0.2 and 0.3 samples were taken per month, equalling to 1 sample every 5 months and about one sample every 3 months respectively.

If we consider the data collection frequency per stream, the situation presents itself slightly differently. For example, the Aalbaach was sampled in 7 out of 11 months in total and the Bouneschbaach was sampled in 11 out of 11 months in total. The Staflick was sampled in 6 out of 11 months in total. As a result, although the data collection frequency turned out uneven, the data collection frequency per stream supports, at least, one sample every other month. Therefore, it can be said that the project supported fairly frequent data collection and produced a dataset that has the potential to support detecting shorter-term fluctuations and the swift detection of system changes. For determining human impacts on water bodies regarding, for example, nitrate concentrations, first, natural levels or ranges have to be identified. Due to the natural variability of many parameters, it may also be difficult to compare results among sites as well as results for the same site obtained from different periods in time. Some limitations apply. For example, the uneven distribution of data points across the different sites may lead to only partial views at a given moment on the status of the Aalbaach and Bouneschbaach, as the results for an individual site can only give insights into circumstances of upstream segments, which also limits the comparability of results between sites.

In terms of the research aim of the project, the dataset supports insights into the water quality of the Aalbaach, Bouneschbaach, and Staflick. In fact, as the first report of the project, *Citizen Science at the Syr,* details, the overall nutrient and turbidity levels suggested relatively good water quality (Pickar & König, 2020). In addition, the dataset allowed to capture longer-term elevations and shorter-term fluctuations, connected with on-going pollution and pollution events respectively.

Detecting and Tracking Drivers of Change. Another objective of ideal data collection and meaning-making in adaptive governance, aside furthering the scientific understanding of system processes, detecting and tracking changes in the system, and detecting and tracking the effects of interventions, is the detection and tracking of drivers of change internal and external to the system. This is important for isolating the effects of specific interventions in the best way possible and for detecting undesirable change. A set requirement for the detection and tracking of drivers of change in social-ecological systems is the consideration of social and technological factors alongside ecological factors. The phenomena of the Project Streams & Corporate Partnership are classified and represented in The parameter-set is geared to giving insights into pollution levels in the sampled water bodies (e.g. floating foam or oil and turbidity) with a focus on nutrients and to identify possible causes (e.g. land use in the immediate surrounding and presence of pollution sources).

Nutrients play a significant role in the quality of surface water around the globe. Increased nutrient contents in surface waters may lead to accelerated eutrophication, which is characterised by excessive plant and algal growth in the water (Chislock et al., 2013). Accelerated eutrophication comes with a number of implications for humans and nature. It leads to unfavourable habitat conditions for aquatic life forms (e.g. fish) and it can come in the form of toxic algal blooms (European Environment Agency, 2016). If ingested in high doses by humans, nitrate can also cause health implications. Different thresholds for the evaluation of water bodies in relation to their nutrient status are available [e.g. for Luxembourg, see Administration de la Gestion de l'Eau (2009)].

Table 13. The parameter-set is geared to giving insights into pollution levels in the sampled water bodies (e.g. floating foam or oil and turbidity) with a focus on nutrients and to identify possible causes (e.g. land use in the immediate surrounding and presence of pollution sources).

Nutrients play a significant role in the quality of surface water around the globe. Increased nutrient contents in surface waters may lead to accelerated eutrophication, which is characterised by excessive plant and algal growth in the water (Chislock et al., 2013). Accelerated eutrophication comes with a number of implications for humans and nature. It leads to unfavourable habitat conditions for aquatic life forms (e.g. fish) and it can come in the form of toxic algal blooms (European Environment Agency, 2016). If ingested in high doses by humans, nitrate can also cause health implications. Different thresholds for the evaluation of water bodies in relation to their nutrient status are available [e.g. for Luxembourg, see Administration de la Gestion de l’Eau (2009)].

As the classification shows, the data collection activities included a series of ecological parameters. A distinction is made between the parameters that were collected using measurement devices - that is, nitrate, phosphate, and turbidity - and those that were collected using observation, such as riverside vegetation, and water flow and level. In general, the data collection programme and meaning-making approach focused on the detection of nutrient concentrations and turbidity levels, and on identifying potential sources for elevated levels, such as pollution sources.

Alongside the different ecological parameters, the project involved the collection of data on human and technological factors with the potential to influence water quality. For example, the parameter Presence of Pollution Sources may help detect point-source pollution by identifying visual potential pollution sources, such as discharge pipes from industry, residences or roads, or agricultural discharge. The parameter Human Uses of the Water Body may be linked with the quality of stream water and give insights into the effect of different uses, such as fishing and swimming, on water quality. For research in social-ecological systems, it is considered essential to collect data not only on ecological factors, but also on social and technological factors. It is the only way to begin to compose a picture of the system and system dynamics that is as comprehensive as possible. Linking ecological with social and technological data in place, time, and in data collector is considered advantageous over considering separate datasets of ecological and social data, as it may allow to draw stronger connections between the different sorts of data (Crain et al., 2014).

The Swift Detection of Place-Based Changes and Place-Specific Context Factors.

The scale of the data collection activities is also considered a key factor in adaptive governance. In the following, the scale of data collection programme and meaning-making approach of Project Streams & Corporate Partnership is discussed in terms of its suitability to capture place-based social, ecological, and technological factors. This is crucial for the adequate design of management interventions and for the swift detection of changes to be able to, for instance, react to undesirable consequences in a timely manner and to increase accountability of polluters.

The potential of the Project Streams & Corporate Partnership to contribute to place-based datasets helping to adequately design management interventions is relatively high. The project involved data collection at 8 sampling sites distributed across three smaller streams in the commune of Niederanven. To give a more detailed account of the scale, both the Aalbaach and Bouneschbaach are about 3.5 km long, while the Staflick is about half their size (roughly 1.75 km). Considering the number of 8 sampling sites on the total stream length of about 9 km, means that, in average, there is approximately one site per km of stream. It is fair to say that the number of sites per km of water body makes the project particularly relevant, as it is rarely matched by other current data collection programmes and meaning-making approaches (if at all).

In addition, the project involved data collection on ecological as well as social and technological data. Considering also social and technological circumstances is essential in the context of sustainability challenges, in which every application setting is unique, issue definitions, and social values and norms are under dispute.

Even though the sampling frequency turned out to be somewhat uneven across the different sampling sites, a fairly high total frequency per water body was guaranteed (i.e. at least one sample every other month). This kind of sampling frequency supports a datasets that is fairly sensitive to the variations of the parameters. Due to the natural variability of many parameters, such as nitrate, the challenge is not only to detect variations, but also to better understand the role of anthropogenic pressures in these variations. It is obvious that a higher and more even sampling frequency across sites holds even higher potential.

5.2.2 The Suitability of Project Streams & Corporate Partnership for the Input and Process Criteria of Ideal Data Collection and Meaning-Making in Adaptive Governance

A summary of the discussion of the suitability of Project Streams & Corporate Partnership for the Input and Process Criteria for ideal data collection and meaning-making in adaptive governance can be found in Table 16. In the following, Project Streams & Corporate Partnership is discussed in function of the degree of transparency that it facilitates. The degree of transparency is evaluated using two key factors: public access of the data and the facilitation of public meaning-making.

Table 16

Summary of the Discussion of the Criteria Related to Objectives of Data Collection and Meaning-Making in Adaptive Governance

Criterion	Guiding Question and Key Factor	Project Streams & Corporate Partnership
Transparency	a) Is the data physically accessible to the public? b) Is the data presented with meaning (i.e. interpretations)? c) Are tools for individual meaning-making accessible in combination with the data?	a) + website, report b) + website, report c) + report
Stakeholder engagement in design and implementation	a) In how far are stakeholders engaged in the design and implementation? b) In how far does the project contribute to a more polycentric data landscape?	a) + co-design, citizen scientists b) + non-specialists, new funding sources

Transparency. ***Access to Data.*** As regards access to data, section 5.1.3 describes that the entire dataset produced in the framework of the Project Streams & Corporate Partnership was available to be viewed online and to be downloaded. As such, access to data was guaranteed.

Public Meaning-Making. The representation of a dataset in its "purest" form is probably in a table with an entry for each data point, even though decisions in the design of data collection programmes have many implications for meaning-making. This includes, for example, the selection of parameters and data collection methods. Data may be quantitative or qualitative, and both come with varying collection methods, such as measurements and observations, which again have a number of different implications for meaning-making.

Designing data collection programmes is a complicated process. Here, however, the representation of a dataset as a table with an entry for each data point is considered the baseline. Any other representation of data, for example, in the form of figures, is likely to hide certain aspects and highlight others. The aggregation of data for representation in figures or tables, or in other formats shares that characteristic. Going one step further, the attribution of meaning to a dataset or the representation of data also comes with a number of important choices. Naturally, there is not only one way of doing so. The distinction of access to data meaningful to non-specialists and access to information for meaning-making, therefore, is essential. Access to data meaningful to non-specialists is to have access to a representation of data with information for meaning-making. The choices are made by the author. In this case, it is essential to make the choices along the way transparent as well as to make available the original dataset. Facilitating public meaning-making involves providing the audience with tools to perform meaning-making of their own, for example, based on the original dataset. This includes providing varied information, for instance, on the parameters and, if applicable, the meaning of different values for nature and humans (e.g. in the case of nutrient concentrations), relevant thresholds *with* the relevant uncertainties, on any relationships between the parameters as well as important statistical tools and their implications.

In the Project Streams & Corporate Partnership, the aim was to be as transparent as possible. As section 5.1.3 describes, this involved the publication of unedited datasets (excluding the editing needed to anonymise data, if necessary), the presentation of information for individual meaning-making, and the provision of meaning with reflections about uncertainty and transparency about the choices along the way.

Stakeholder Engagement in Project Design. Project Streams & Corporate Partnership was co-designed with two interested stakeholders: the River Partnership Syr and the Commission of Sustainable Development of the Commune of Niederanven. Both organisations were able to bring in their perspectives and the final design was agreed with them beforehand. As regards the diversity of stakeholders involved in project design, the two organisations involved represent a large group of people. As section 5.1.1 details, any individual or group of people is, in theory, allowed to be part; that is, citizens as well as any organisations with an interest in the topic. The River Partnership is an initiative based on the collaboration of communes, intercommunal syndicates, and associations from the water domain. Considering the actual number of stakeholders in the project design, of course, does not suggest diversity. The design process was also rather closed to other organisations. This is partly due to the particular circumstances (see section 5.1). The design process was rather fast-paced due to a start of the process close to the deadline for the submission of the project proposal.

Discussion of the Potential of the Actors of Project Streams & Corporate Partnership to Contribute to Polycentricity. Considering the Project Streams & Corporate Partnership in combination with the current data collection programmes and meaning-making approaches introduced in Chapter 4, as series of statements can be made. In fact, the project constitutes a centre of data collection and meaning-making of its own, and it has been able to produce a dataset that is tailored to place-specific management questions involving non-specialists, in particular interested employees of the Royal Bank of Canada, in data collection and meaning-making. Further, the dataset has the potential to help increase the accountability of existing data collectors by providing data that are alternatively sourced and of polluters by helping to detect longer- and shorter-term pollution and providing data about human activities with potential effects on water quality. It can, therefore, be said that projects of this kind have the potential to contribute to a more dynamic, decentralised and diverse network of data collectors.

As regards stakeholders involved in data collection, the project demonstrated an interest from private businesses, in particular banks, in funding data collection programmes and meaning-making approaches. This represents a new source of funding and has the potential to help to decentralise away from government and from governmental funding criteria. This may also increase the availability of funds for project with differing agendas, making the data available as well as the actors involved more diverse.

5.3 Case Study 2 - Project Waterblitz

The second case study of contributory citizen science is Project Waterblitz. To begin the presentation of the results, the following gives an overview of Project Waterblitz, before delving in deeper into the presentation of the specificities of the project starting with the presentation of important actors, and roles and motivations.

5.3.1 Project Waterblitz

Project Waterblitz was an event on national level, running over a four-day-weekend in September 2019, in the boundaries of which anyone interested could register to receive a free water testing kit to collect data on the quality of the surface water body of their choice. A major aim of Project Waterblitz was to incite the participation of as many people as possible and to collect as many data points as possible, preferably distributed well across space (but as data collection site selection was performed by data collectors, this was a matter of luck) for an overview of the state of Luxembourg's surface water bodies. The focus of the data collection was on nitrate and phosphate concentrations alongside social-technological and environmental circumstances with potential effects on water quality. A secondary aim of the Project Waterblitz was to gain insights into the potential of Project Waterblitz format of contributory citizen science and, by extension, contributory citizen science, in general, to contribute to the governance and management of surface water bodies in Luxembourg with a particular focus on the produced dataset and the findings. The particularity with the approach was that data collection took place in a very short period of time allowing for a snapshot of the status of the Luxembourgish surface water bodies.

Similar to the Project Streams & Corporate Partnership, Project Waterblitz relied on the Freshwater Watch citizen science tool for data collection and visualisation. The only difference between the tool used in the two projects was that the kit for Project Waterblitz came in a reduced format without the Secchi-tube for turbidity tests, thus, encompassing tests for nitrate and phosphate only, as well as with a reduced set of observable parameters. The kit was sent out to citizen scientists for free upon registration. Each registrant was able to ask for multiple tests allowing them to upload up to five data points.

Project Waterblitz took place in the boundaries of the collaboration between the Sustainability Science Research Group at the University of Luxembourg, Earthwatch, and the Royal Bank of Canada. For this reason, the event was coordinated across three cities, London, Paris, and Dublin, and the country of Luxembourg, and it took place at the same time in all locations. In Luxembourg, the event was organised by the

Sustainability Science Research Group and promoted by a series of national organisations, such as Natur&Emwelt and the nature parks. In addition, it was announced over national radio and in a couple of newspapers. The Waterblitz format was designed by Earthwatch. It has organised multiple editions in the past years in the Thames Valley, UK.

5.3.2 Important Actors, and Roles and Motivations

To start the presentation of results, first, the following focuses on the presentation of important actors more generally as well as on the presentation of the roles and motivations of each actor to participate in the Project Waterblitz more specifically. Documentary review was used to deepen the descriptions of important actors, where appropriate and possible. For ease of reading, first, an overview of the network of actors is presented.

Table 17 provides and overview of the most important actors involved in the Project Waterblitz and of the roles and motivations of each actor.

Table 17

Important Actors, and Roles and Motivations in Project Waterblitz

Actor	Role	Motivation
Royal Bank of Canada	• Project funder • Intermediary for citizen scientist recruitment	Supporting charities with funds and employee volunteers for the benefit of the community
Earthwatch Europe	• Establish Royal Bank of Canada and University of Luxembourg partnerships • Co-Coordinator • Co-Administrator • Provider of Freshwater Watch methods • Funding recipient • Reporter	More sustainable governance of aquatic ecosystems (also project Freshwater Watch)
Citizen scientists community	Data collection	• More sustainable governance of freshwater bodies in Luxembourg • Research
Sustainability Science Research Group	• Co-Coordinator • Co-Administrator • Reporter • Funding recipient	More sustainable governance of freshwater bodies in Luxembourg via transdisciplinary research (and citizen science)

As the projects Waterblitz and Streams & Corporate Partnership were fairly similar as regards important actors, only the differences are discussed in the following.

One of the most important differences between the two projects was that, in the case of Project Waterblitz, there was no additional project design involved. The Waterblitz format was taken as designed by Earthwatch and applied in Luxembourg without alterations. Project Waterblitz, therefore, did not engaged any actors in project design. The citizen scientist community was also considerably different in Project Waterblitz. In the case of Project Waterblitz, it was made up of around 80 individuals from Luxembourg, who were mostly unrelated to the Royal Bank of Canada. As such, Project Waterblitz engaged a more diverse and a larger citizen scientist community than Project Streams & Corporate Partnership.

5.3.3 Phenomena and Distribution of Data Points

In the following, the focus shifts to the phenomena subject to data collection, standard protocols, data quality mechanisms, and data collection frequencies and sites of Project Waterblitz.

Presentation of Phenomena. Table 18 provides an overview of the parameters of the data collection activities of Project Waterblitz.

Table 18

Parameters of Project Waterblitz.

Indicator	Physical chemical	Biological	Hydromorphological	Naturally occurring substances associated with pollution	Other pollutants	Social technological contexts
Nitrate				M		
Phosphate				M		
Riverside vegetation		O				O
The appearance of the water body by the presence of foam, floating algae, litter, and oil					O	
Type of water body			O			
Water colour	O	O		O		
Land use in the immediate surroundings						O

Note. The parameters are listed in the order of appearance on the data collection form. The letter “M” stands for measurement and the letter “O” for observation.

As during Project Waterblitz, a reduced version of the Freshwater Watch tool was used, data was also collected for less parameters. In fact, Project Streams & Corporate Partnership included the parameters Presence of Algae, Water Flow, Water Level, Presence of Aquatic Life Forms and Turbidity, which were not part of Project Waterblitz. The rationale is multi-dimensional. The omission of the parameter Turbidity was mainly for practical reasons, since sending the turbidity tube to every registrant would come with a significant increase in postage costs due to its size. In addition, it allowed to reduce the costs of a single kit. Since the parameters Water Flow and Water Level are best in citizen science projects, in which citizen scientists collect data recurrently at the same site, allowing them to develop reference points, they were also omitted. The omission of Presence of Algae can be justified based on the argument that other parameters could give similar insights into the water quality, such as The Appearance of the Water Body by the Presence of Foam, Floating Algae, Litter, and Oil, which included the answer option “floating algae”. In addition, the presence of algae can also be judged based on the uploaded photograph. Similarly, the omission of the parameter Presence of Aquatic Life Forms can be based on the fact that the uploaded photo may give similar insights.

In general, a rationale for reducing the size of a data point can also be linked to the shorter time needed for data collection and upload to decrease the difficulty of data collection as well as to reduce the hurdle for collecting data thanks to the reduced time investment.

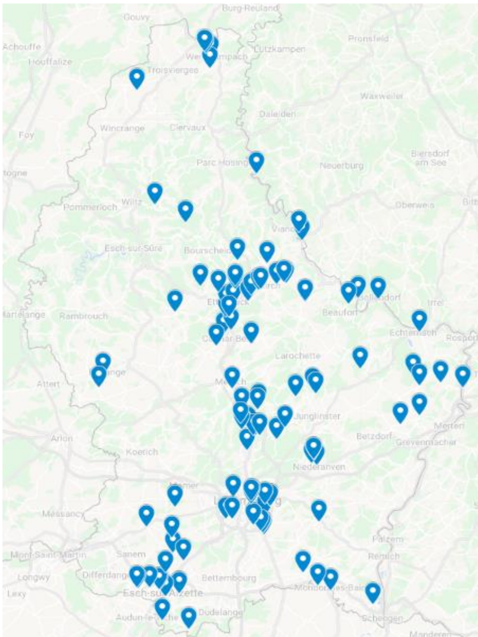
Presentation of Data Quality Mechanisms. The data quality mechanisms between the two projects were largely the same. Due to the different format of Project Waterblitz, holding a training sessions was not possible. This may have led to an increased error count, although the standard protocols were described in detail and sent as part of the kit to all citizen scientists. Common sources of error and how to avoid them were described in the mobile application.

The reduced number of parameters also led to a smaller size of the triangulation clusters. The main approach to quality assurance was the so-called social approach, in which other data points are used to confirm or relativise other measurements or observations. Multiple similar results can bear heavier weight in analysis. In addition, it is unlikely that two or more different citizen scientists make the same error in data collection.

Distribution of Data Points In Luxembourg. Figure 19 shows the distribution of data points in Luxembourg for Project Waterblitz.

Figure 19

Distribution of Data Points in Luxembourg for Project Waterblitz



Note. Map from Google Maps.

Of the 102 surface water bodies of Luxembourg (Administration de la Gestion de l'Eau, 2016b), 56 were sampled as part of Project Waterblitz, which is more than half (ca. 55 %). Most data have been uploaded, by far, for the Alzette and Sure with 19 (ca. 17 %) and 15 (13 %) data points respectively. 31 % of all samples (35 in absolute terms) are only samples for the respective surface water bodies. Accordingly, 69 % (or 78 samples) are taken from a surface water body that was sampled at least twice.

As Figure 19 shows, the sampling is oriented towards the most densely populated areas. The North West, the very North in general (area north of Diekirch) and perhaps the South East are not so well represented by the dataset. This distribution of samples can also explain the high number of records for the Alzette and Sure, since along their course, there are the most densely populated areas in the country.

Another observation can be made. There are no data points for the Moselle, the largest river of the country. A clear reason cannot be pinpointed. However, it can be hypothesised that the low number of records can be linked to its large size. It is considerably bigger than any other river in Luxembourg (discharge average 290 cubic meters per second, compared to 54 for the Sure, the second largest river in Luxembourg - Wikipedia). Due to its higher discharge, it may be considered more dangerous to access the river to take a sample. In and around agglomerations, the Moselle banks may also be secured to protect people from falling in the water and to protect settlements from regular floods. Access seems to play a major role, in terms of proximity to densely populated areas as well as access to the actual water of the water body.

5.3.4 Data Publication Practices and Public Meaning-Making

There were no significant differences between the data publication practices and of public meaning-making of the projects Streams & Corporate Partnership and Waterblitz. Therefore, refer to section 5.1.3 for a detailed presentation of the data publication practices and of public meaning-making.

5.4 The Suitability of Project Waterblitz for Supporting the Adaptive Governance of Social-Ecological Systems

Following the presentation of the results based on the implementation of the Project Waterblitz, project documentation, and other documentary review, a discussion is offered. The discussion attempts to develop an answer to Research Question B, "What is the potential of contributory citizen science for fostering adaptive governance of social-ecological systems? How can it address the opportunities identified in the answer to question (a)?", by making connections with the criteria identified in the conceptual framework (section 2.5.1) and with the gaps and opportunities identified in the previous chapter (section 4.4.4). The structure of the discussion is the same as in Chapter 4 and is displayed in Table 9.

5.4.1 The Suitability of Project Waterblitz for the Objectives of Ideal Data Collection and Meaning-Making in Adaptive Governance

A summary of the discussion is provided in Table 19.

Table 19

Summary of the Discussion of the Criteria Related to Objectives of Data Collection and Meaning-Making in Adaptive Governance

Criterion	Guiding Question and Key Factor	Project Waterblitz
Furthering the scientific understanding of system processes	Is the data collection programme aimed at studying cause-effect relationships?	-
Detecting and tracking changes in the system	a) Is the data collection programme well-suited for detecting and tracking trends, i.e. is it open-ended? b) Is the data collection programme well-suited for detecting and tracking of fluctuations? The suitability is considered in a positive relationship with the data collection frequency with a guiding threshold of multiple data points per site per year.	a) - Time-limited b) - not well-suited
Detecting and tracking of effects of interventions	Is the data collection programme aimed at studying the effects of interventions?	-
Detecting and tracking of drivers of change	Does the data collection programme consider social, ecological, and technological factors in combination?	+
Swift detection of place-based changes and place-specific context factors	a) Is the data collection programme aimed at studying place-based changes in the system and/or place-based factors? b) Is the data collection site density of the programme well-suited for studying place-based changes and factors? The suitability is considered in a positive relationship with the data collection site density. c) Is the data collection frequency suitable for the swift detection of place-based changes? This was already discussed as part of question b) under 2.	a) + place-based factors b) + Rather well-suited, but oriented towards areas with higher population density c) - not well-suited

Furthering the scientific understanding of system processes, detecting and tracking changes in the system, and detecting and tracking the effects of interventions. In the following, Project Waterblitz is discussed in relation to its suitability to further the scientific understanding of system processes, detecting and tracking changes in the system, and detecting and tracking the effects of interventions.

The contributory citizen science Project Waterblitz was designed with the aim to collect as many data points as possible in the course of four days for a high-resolution overview of the state of Luxembourg's surface water bodies. In addition, it was organised to gain insights into the potential of Project Waterblitz format of contributory citizen science and, by extension, citizen science to contribute to the governance and management of surface water bodies in Luxembourg with a particular focus on the produced dataset and the findings.

The dataset of Project Waterblitz only holds limited potential for studying cause-effect relationships, such as tracing the effects of social-technological and environmental circumstances on stream water quality. The data of social-technological circumstances (in this case, data on the land use in the immediate surrounding), however, when connected with, for example, high nutrient concentrations, can provide first insights into possible emission sources.

The dataset produced by Project Waterblitz has also shown that it can be helpful to flag potential water quality issues across the country. For example, the dataset showed quality issues in the Alzette River regarding phosphate concentrations (based on 19 records for the Alzette), and the Gander in Mondorf-les-Bains regarding nitrate and phosphate concentrations (based on two records showing similar results), and a potential pollution source in Hunsdorf based on the detected nitrate concentrations (based on one record for the Millebaach and one for the Alzette uploaded in Hunsdorf showing similar results). Interpretation of single data points - that is, data points, which cannot be confirmed by other data points on the same water body or from the same location - has to be performed with great caution. For determining the impacts of human activity on water bodies, first, natural levels or ranges have to be determined. In general, the "social approach" to quality assurance was used where possible (see section 5.1.2 and 5.3.3). In the case, where multiple data points were uploaded along the course of a water body, such as it was the case with the Alzette and Sure, the dataset is able to show variations in the nutrient concentrations along the watercourses, for example, higher readings of nitrate concentrations for the Sure between Ingeldorf and Bettendorf.

As Project Waterblitz was designed to provide an instant picture of the quality of surface water bodies, the dataset alone cannot provide insights into longer-term trends and shorter-term fluctuations. If the exercise was repeated, however, for example, yearly, than the resulting dataset may support the detection of longer-term trends. Project Waterblitz was also not designed to detect and track the effects of specific interventions.

A limitation regarding the suitability of the Waterblitz format to contribute to the detection and tracking of trends is the fact that each citizen scientists is free to select the data collection sites according to their particular interests. In other words, in the boundaries set by, for example, the selected parameters and the limit of kits per registrant, the citizen scientists are free to define the purpose of their particular data collection programme and meaning-making approach as they see fit. One citizen scientist may want to participate to contribute to the national overview by taking samples at different strategically selected spots to capture as much of a watershed area as possible (e.g. at the spot, where two watercourses meet). Another may want to use the kit to get insights into the scientific methodologies, and another may want to find out more about the status of a particular water body, for example, to pursue a specific agenda by taking multiple samples in that water body. This plurality of purposes facilitated and encouraged by the Waterblitz format can lead to different outcomes of different editions, for example, as regards the distribution of samples nationally.

This freedom of choice regarding data collection site also limits the representativeness of a single sample of the water quality of the entire water body. If a site is the only site on a stream and located, for example, near its source or near the middle point, no information is available about any variations in conditions or water quality downstream.

Detecting and Tracking of Drivers of Change. Another objective of ideal data collection and meaning-making in adaptive governance, aside furthering the scientific understanding of system processes, detecting and tracking changes in the system, and detecting and tracking the effects of interventions, is the detection and tracking of drivers of change internal and external to the system. This is important for isolating the effects of specific interventions in the best way possible and for detecting undesirable change. A set requirement for the detection and tracking of drivers of change in social-ecological systems is the consideration of social and technological factors alongside ecological factors. The phenomena of the Project Waterblitz are classified and represented in Table 18.

In comparison with the dataset of Project Streams & Corporate Partnership (see section 5.2.1), the dataset of Project Waterblitz contains significantly less data on social-technological factors per data point. The parameter “land use in the immediate surrounding” was the most important of this kind. This fact limits the potential of the dataset to link social-technological factors with potential water quality issues.

The Swift Detection of Place-Based Changes and Place-Specific Context Factors. The scale of the data collection activities is also considered a key factor in adaptive governance. In the following, the scale of data collection programme and meaning-making approach of Project Waterblitz is discussed in terms of its suitability to capture place-based social, ecological, and technological factors. This is crucial for the adequate design of management interventions and for the swift detection of changes to be able to, for instance, react to undesirable consequences in a timely manner and to increase accountability of polluters.

As Project Waterblitz only facilitated data collection during four days, alone, it cannot facilitate the swift detection of place-based changes. Even if the Waterblitz format was used recurrently (perhaps in yearly intervals), the potential for rapidly detecting changes in limited. In contrast, Project Waterblitz is better-suited for capturing place-specific context factors, in the form of elevated nutrient levels and possible causes in function of land use. Therefore, Project Waterblitz dataset can help warrant further research in the water quality issues identified.

The Waterblitz format, in general, offers interested individuals or groups of individuals the opportunity to undertake more detailed place-based data collection and meaning-making. The most considerable limit for the relevance to place-based management questions is the rather small number of parameters included, which, for example, does not allow for the same amount of detail in data collection as the parameter-set used by Project Streams & Corporate Partnership. Due to the specific set of parameters, which includes only very little social and technological factors, the dataset of Project Waterblitz can hardly help detect pollution sources and their effects on water quality. It can, however, help to research nutrient concentrations in a water body in detail (e.g. the cases of Alzette and Sure). It is also the cases of the Alzette and Sure, which suggest that Project Waterblitz format can contribute to building longitudinal profiles of single water bodies essential for insights into the water quality of the entire water body, for example, for identifying pressures and locating pollution hotspots.

5.4.2 The Suitability of Project Waterblitz for the Input and Process Criteria of Ideal Data Collection and Meaning-Making in Adaptive Governance

A summary of the discussion of the suitability of Project Waterblitz for the Input and Process Criteria for ideal data collection and meaning-making in adaptive governance can be found in Table 20.

Table 20

Summary of the Discussion of the Criteria Related to Objectives of Data Collection and Meaning-Making in Adaptive Governance

Criterion	Guiding Question and Key Factor	Project Streams & Corporate Partnership
Transparency	a) Is the data physically accessible to the public? b) Is the data presented with meaning (i.e. interpretations)? c) Are tools for individual meaning-making accessible in combination with the data?	a) + website, report b) + website, report c) + report
Stakeholder engagement in design and implementation	a) In how far are stakeholders engaged in the design and implementation? b) In how far does the project contribute to a more polycentric data landscape?	a) + citizen scientists b) + non-specialists, new funding sources

Transparency. As the data publication practices do not differ from those of the Project Streams & Corporate Partnership, for a discussion of “transparency”, please refer to section 5.2.2.

Stakeholder Engagement in Project Design. As section 5.3.1 outlined, stakeholder engagement was not foreseen in the design of Project Waterblitz.

Discussion of the Potential of the Actors of Project Streams & Corporate Partnership to Contribute to Polycentricity. Project Waterblitz supported data collection and meaning-making for multiple purposes and agendas. Within the boundaries of the parameter-set and the maximum number of kits per registrant, each data collector or group of data collectors was free to design their data collection programme and meaning-making approach according to their need and interest. Project Waterblitz can, therefore, be considered not only as one additional centre of data collection and meaning-making, but multiple centres.

It, further, contributed to the engagement of specialists and non-specialists in data collection and meaning-making. As section 5.3.3 describes in more detail, more than 80 people participated in Project Waterblitz. Similarly to Project Streams & Corporate Partnership, Project Waterblitz was funded by the Royal Bank of Canada (see section 5.2.2). New funding sources may help to decentralise the data collection and meaning-making network in relation to surface water quality and to move away from governmental funding criteria. This move can help to diversify the purposes of projects as well as the people involved.

5.5 The Potential Contributions of Contributory Surface Water Citizen Science to Current Data Collection and Meaning-Making Towards more Adaptive Surface Water Governance

Now that the findings have been presented in relation to the suitability of Project Streams & Corporate Partnership and Waterblitz to support adaptive governance, the findings are put in relation to the opportunities for change identified in Chapter 4, in particular in section 4.4.4.

Table 21 provides an overview of the potential contributions per case study in relation to the respective opportunity for change identified.

Table 21

Potential Contributions of Contributory Surface Water Citizen Science to Current Data Collection and Meaning-Making Towards More Adaptive Surface Water Governance

Opportunity for change		Potential Contribution of Project Streams & Corporate Partnership		Potential Contribution of Project Waterblitz
Limited engagement of multiple and diverse stakeholders in research design, data collection and meaning-making	+	Citizen scientist engagement in data collection and meaning-making	+	Citizen scientist engagement in data collection and meaning-making
Relatively low diversity of approaches to and purposes of research	+	New funding sources and new funding criteria	+ +	New funding sources and new funding criteria Individual definition of sampling sites
Limited physical access to project-based datasets	+	Produced datasets are publicly available	+	Produced datasets are publicly available
Limited access to meaning and meaning-making of published datasets for non-specialists	+	Published reports were designed to provide insights into meaning and meaning-making of produced datasets for non-specialists	+	Published reports were designed to provide insights into meaning and meaning-making of produced datasets for non-specialists
Limited access to disaggregated data, when aggregated data is published	+	Place-based datasets add detail to datasets produced for larger geographical scales	+	Place-based datasets add detail to datasets produced for larger geographical scales
Relatively low guaranteed data collection frequency at smaller geographical scales	+	Place-based data collection programme adds to the data collection frequency at lower geographical scales	+	Place-based data collection programme adds to the data collection frequency at lower geographical scales
Limited consideration of social and technological factors in data collection and meaning-making	+	Data collection programme includes social and technological factors as potential drivers of change	+	Data collection programme includes social and technological factors as potential drivers of change

Note. Insert note here.

The following discussion is ordered in function of the opportunities for change as displayed in Table 21.

Input/ Process. Projects Streams & Corporate Partnership and Waterblitz have demonstrated that contributory citizen science can engage multiple stakeholders in different research phases. This insight has been developed based on the examination of the two case studies, in particular the actors engaged in the two projects. As sections 5.1.1 and 5.2.2 describe in more detail, Project Streams & Corporate Partnership was designed in collaboration with the River Partnership Syr and the Committee for Sustainable Development of the Commune of Niederanven. In addition, both projects engaged volunteers in data collection and meaning-making (see also sections 5.4.2 and 5.3.2 for more detail on Project Waterblitz).

As section 2.2.2 highlights, citizen science, by definition, is based on the engagement of citizen scientists in research processes. The types of people engaged and the roles that they fulfil are highly variable across projects (see 2.2.1, in particular the description of the different typologies). The engagement of citizen scientists in research processes promises to open channels for taking account of multiple and diverse perspectives as well as types of knowledge in research processes and to increase the quality and legitimacy of knowledge, decisions, and actions.

Stakeholder engagement in the contributory citizen science case studies was subject to a number of limitations. Due to the short timeframe of the research design process of Project Streams & Corporate Partnership, the engagement of the two actors rather took the form of two separate consultations on a draft of the research proposal and on key questions, for which their knowledge of the region seemed particularly important, such as for the selection of data collection sites. Although the co-design process engaged two stakeholders, which can be seen as representing a variety of other stakeholders as described in section 5.2.2, it can be argued that a longer process, which would have aimed to engage more stakeholders and, therefore, perspectives and knowledge types could have been beneficial for the design of the research according to adaptive governance criteria. In similar situations, it may be worthwhile to arrange more stakeholder engagement in the later stages of the research process, perhaps in the form of iterative cycles taking place in regular intervals, such as every year, to adapt the approach to the findings and new perspectives.

As regards stakeholder engagement in data collection and meaning-making, the two projects, especially project Waterblitz, have demonstrated that the engagement of specialists and non-specialists is possible in contributory citizen science. The opportunities for the citizen scientists in the two projects to bring in their perspectives and knowledge, however, were fairly limited. In Project Streams & Corporate Partnership the most important channel can be identified as the Comment Field in the data collection form, which allowed the citizen scientists to give additional information. Often, the field was left blank. In some instances additional information was provided, which also turned out helpful in the interpretation of the dataset (e.g. the observation of grass clippings in the water could be linked with increased nutrient values). Project Waterblitz included one more important channel, as citizen scientists were allowed to select sampling sites freely. This left the citizen scientists with more freedom to use their perspectives and knowledge to influence the research design and process (see section 5.4.2). Increasing the freedom in similar ways may increase the difficulty of data analysis and interpretation, but it is essential for engaging diverse perspectives and knowledge types at the stage of data collection.

The role of the Royal Bank of Canada in the Projects Streams & Corporate Partnership and Waterblitz has to be highlighted. As part of the Bank's partnership with Earthwatch and its efforts for a positive social impact, it provided the funding required for the projects. Funding for data collection and meaning-making by organisations traditionally not engaged in research for management and governance has the potential to broaden the range of approaches to and purposes of data collection and meaning-making that are actualised also due to new funding criteria and interests.

Process. As regards the transparency, the two case studies have shown that contributory citizen science may be able to help increase the amount of data on surface water quality that is publicly available. As discussed in more detail in sections 5.2.2 and 5.4.2, this has the potential to increase the transparency of surface water quality in Luxembourg. This insight is based on the examination of the two projects and, in particular, their data publication practices (see section 5.1.3 and 5.3.4). As section 2.2 described in more detail, citizen science has been credited with contributing to increased transparency of the state of surface water bodies. Even if citizen science data is not used in decision-making processes, publicly available datasets provide the opportunity for increased accountability of decision-makers and polluters (Buytaert et al., 2016). The publication of datasets is linked with public meaning-making (see section 4.4.4). Both projects demonstrated ways of facilitating public meaning-making (see sections 5.1.3 and 5.3.4). Especially in the published reports, pure datasets were available alongside careful interpretations and information important for individual meaning-making. For the communication of datasets, in particular, to non-specialists, it is essential to represent the data in ways, which is accessible to them, thus requiring little to no specialist knowledge (Buytaert et al., 2014).

This approach, however, was subject to a number of limitations. The format of a mere one-sided provision of data and information by a research team with no specific skills in the communication of scientific data and information to non-specialists can be seen critically. A more interactive approach could have been beneficial for further increasing the accessibility of data, interpretations, and information for meaning-making for example, in the form of organising opportunities for the discussion of the results with interested members of the public (e.g. stakeholders, citizens). This could have also been a good opportunity for more feedback on research process and results by the citizen scientists. In addition, as science communication is a difficult undertaking, the engagement of a person trained in the practice could have been advantageous. The amount of resources available to the research team, however, posed limits. Alongside the publication of data and information in reports, their publication on a website was also an important factor among the publication practices in the two case studies. Data publication on the Freshwater Watch website was rather technical and, thus, not so accessible to non-specialists. In addition, the navigation did not prove straightforward (see section 5.1.3). A more accessible way to present datasets for meaning-making needs to be developed. The context, in which data is presented, is important for meaning-making: This may include the natural levels of a parameter (natural variations may occur), possible natural and anthropogenic sources, and thresholds for eutrophication and health impacts. This is a marginal work package to this thesis, and a website is being developed for the publication of data and information that is easily accessible and provides not only information for meaning-making, but also on the relevant uncertainties.

In addition, Project Streams & Corporate Partnership has demonstrated intensive data collection in space and time is possible with contributory citizen science. This insight has been developed based on the distribution of data collection sites and the data collection frequency (see section 5.1.2). Intensive data collection in space and time is a key factor in the ability to swiftly detect changes in the system to adapt in the case of undesirable changes (Hasselman, 2017). Since both case studies do not represent time-unlimited programmes, they can only complement the guaranteed data collection frequency for now.

The design of such projects needs to pay attention to the fact that it may be challenging to support a pre-defined and required minimum data collection frequency. As regards Project Waterblitz, in turn, it is more differentiated. This is due to the fact that sampling sites could be selected freely by the citizen scientists and that site selection is strongly related to the resulting number of data points per unit of water course length. For example, one citizen scientist may choose to take multiple samples in a single stream, whereas another may choose to take only one sample or multiple samples but in different streams and in different regions. Water bodies located in and around larger agglomerations may be sampled multiple times in any case, as it appears that population density plays a role in site distribution (as, for example, the case with the Alzette and the Sure). In addition, as site selection and number of citizen scientists is not pre-determined, the distributions and number of data points is going to vary between editions of Project Waterblitz, if repeated. As regards the data collection frequency, citizen science projects such as Project Waterblitz are usually organised on a yearly basis and, therefore, can only provide data in these intervals, which, taken separately, reduces their potential for the swift detection of place-based changes (similar to the Water Management Agency's Operational Control). Taken in combination with other place-based data collection programmes and meaning-making approaches, however, they have the potential to contribute to the overall data collection frequency.

Projects Streams & Corporate Partnership and Waterblitz have also demonstrated that it is possible to collection data on social and technological factors alongside ecological factors in contributory citizen science projects. This insight is based on an examination of the parameter sets of the two projects (see sections 5.1.2 and 5.3.3). In the citizen science literature, citizen science has been credited with the feature of being able to link social, technological, and ecological data by time, date, location, and data collector, which can give better insights into human-nature relationships and into social-ecological system processes (Crain et al., 2014).

The rather modest size of the parameter sets and the datasets of the two projects, however, makes such insights rather difficult to attain. Both projects included only a small number of parameters that could be seen as related to social or technological factors (e.g. land use in the immediate surrounding, presence of inlets - see section sections 5.1.2 and 5.3.3). Yet, the analysis has shown that even though cause-effect relationships between social, technological, and ecological factors are hard to determine, collecting data on social and technological factors allows to build some understanding of drivers of change internal and external to the system, which can then be linked with ecological factors (e.g. land use and nutrient levels). Like this, one may be able to gain first insights into system processes, which can be subjected to further research, if deemed important.

Chapter 6. Case Studies 3 and 4: Co-Created Surface Water Citizen Science in Luxembourg and its Contributions to Adaptive Governance

The goal of this third empirical chapter is to develop an answer to Research Question (b): *"What is the potential of co-created citizen science for fostering adaptive governance of social-ecological systems? How can it address the opportunities identified in the answer to question (a)?".* To arrive at an answer to this question, first, two co-created citizen science projects are presented that were co-designed as part of this thesis. The presented information is based on multiple co-design workshops including various maps (as products of the workshops), and audio recordings (see section 3.4).

Second, a discussion is offered based on the presented results assessing the suitability of the two co-created citizen science projects, and of co-created citizen science in general for fostering adaptive governance of social-ecological systems by making connections with the criteria identified in the conceptual framework (see section 2.5).

6.1 Introduction of the two case studies: Project Sources-Mullerthal and Streams-Syr

From the co-design process two co-created citizen science projects developed, Project Sources-Mullerthal and Streams-Syr. The former was designed to fit an existing project with a focus on the protection and renaturation of sources in the Mullerthal region. The aim was to design to citizen science project in such a way that it would contribute to the goals of the Source Renaturation Project of monitoring the state of sources and public outreach. Projects Streams-Syr was aimed at further developing Project Streams & Corporate Partnership (see section 5.1) and at further adapting it to perspectives and knowledge of interested people from the Syr-region.

6.2 Important Actors, and Roles and Motivations

The following focuses on the presentation of the important actors, including the roles and motivations of each actor of the Projects Sources-Mullerthal and Streams-Syr. The results are mainly based on the co-design workshops and, in particular, the stakeholder mapping exercise (see section 3.4).

(1) Project Sources-Mullerthal

In Project Sources-Mullerthal, the stakeholder mapping exercises resulted in the identification of diverse actors.

The actors present at the co-design workshop identified themselves as the most important actors in Project Sources-Mullerthal. The Natur- & Geopark Mëllerdall, Natur&Emwelt, the Water Management Agency and the Nature and Forest Agency were present at the workshops and collaborating on the Source Renaturalisation Project. According to the results, they would be in charge of the implementation and administration of Project Sources-Mullerthal. They would be most interested in the scientific findings that could be developed based on the dataset with the potential to further the scientific understanding of challenges in the water domain as well as in the potential for raising awareness related to the topic complex.

As Natur&Emwelt and the Water Management Agency have already been introduce in Chapter 4, only the Natur- & Geopark Mëllerdall and the Nature and Forest Agency are presented here. The Natur- & Geopark Mëllerdall is a special purpose association of communes and the State (Natur- & Geopark Mëllerdall, 2018a). It was established by the Grand-Ducal regulation in 2016 (*Règlement Grand-Ducal Du 17 Mars 2016 Portant Déclaration Du Parc Naturel Du «Mëllerdall»*, 2016) based on the appropriate law (*Loi Du 10 Août 1993 Relative Aux Parcs Naturels*, 1993). The Nature Park is administered by a syndicate. Its commission is administered by a committee, which is composed of representatives of interested ministries and governmental agencies as well as of communes and intercommunal syndicates (if applicable). The implementation of the yearly management plan is at charge of the service of the Nature Park, which encompasses permanent positions (*Loi Du 10 Août 1993 Relative Aux Parcs Naturels*, 1993). The mission of the Nature Park relates to the protection and restauration of the natural environment, the protection of the quality of the air, water and soil, the protection and restauration of the cultural heritage, the promotion and orientation of economic and socio-cultural development including social factors, such opportunities for employment, quality of life and living space, as well as the promotion and orientation of touristic and leisure activities (*Loi Du 10 Août 1993 Relative Aux Parcs Naturels*, 1993).

Alongside the Water Management Agency, the Nature and Forest Agency is one of three agencies supporting the Ministry of Environment, Climate and Sustainable Development in its mission (The Luxembourg Government, 2018). The Agency was established by law in 2009 (*Loi Du 5 Juin 2009 Portant Création de l'Administration de La Nature et Des Forêts*, 2009). It encompasses a board, a division of central services including the Nature and Forest Departments, and a division of regional services. The missions of the Agency are defined as follows: the protection of nature, natural resources, biodiversity and the diversity of landscapes, the protection and sustainable management of forests, the promotion of sustainable forest management, the protection and sustainable management of wildlife, raising awareness in the domain of nature and forests, and the monitoring and policing in the field of nature protection, forestry, hunting and fisheries (*Loi Du 5 Juin 2009 Portant Création de l'Administration de La Nature et Des Forêts*, 2009).

The actors that should be engaged and informed in-depth about project developments due to their estimated high interest and rather low influence level were identified as primary and secondary schools, members of nongovernmental organisations, "active citizens" (i.e. the citizens, who have shown an interest in similar project and often engage) and citizens in general, the Regional Tourist Office, and the biologists and geographers of the National Museum of Natural History. Their roles would be varied. The schools, the members of nongovernmental organisations, and citizens may be interested in the use of the tool as well as in the use of the data. The use of the tool and the data was attributed a high educational value making it relevant to pupils or families. It allows to get into contact with scientific research methodologies through the application in a practical and concrete case, while combining different subjects, such as biology, chemistry, and mathematics including statistics. The potential of the project to make pupils and citizens, in general, more familiar with the topic of surface water quality with a focus on source protection and renaturalisation was also considered high. The Regional Tourist Office may be most interested in offering the use of the tool to tourists, for example, during guided hikes or in offering it to anyone interested as part of regional marketing. Nongovernmental organisations could bring in their “networks” (e.g. member bases and organisational partners) and provide continuity in the project.

Farmers, the Ministry of the Environment, Climate and Sustainable Development, and communes including their technical services were attributed high influence over with less interest in the project. They should, thus, be positively positioned towards the project and loosely informed about developments. Farmers and the Ministry may be interested in the use of the dataset for their purposes, whereas the communes including their technical services may be most interested in data use and data collection for their purposes. The interest of communes was considered to be centred around identifying pressures on water quality to better approach challenges in the water domain, in particular, related to drinking water provision. Communes and the Ministry may be also interested in the potential of the project to raise awareness on related issues.

(2) Project Streams-Syr

In contrast to the workshop for Project Sources-Mullerthal, in the workshop for Project Streams-Syr, important stakeholders were only marginally discussed. The main reasons for this were the significantly shorter duration of the workshop, as noted in section 3.4, and the aim of the workshop to further develop the approach of Project Streams & Corporate Partnership to reflect perspectives and knowledge of people from the region. In terms of important actors, the Commission of Sustainable Development of the Commune of Niederanven and the River Partnership Syr have to be named. Not only were they actively engaged in the design and implementation of Project Streams & Corporate Partnership, but they also attended the co-design workshop with an interest in the further design of the approach. The rather wide call for participation in the workshop was met by a handful of people from the area, most of which could be considered specialists in the water domain due to their professions.

As a result of the above circumstances, two actors emerged from the workshop, which may be of relevance: the Water Management Agency and the Commune of Niederanven. The former may help with making the datasets more usable in current governance by, for example, adapting data collection methods (e.g. instead of evaluating the water level based on experience and other visual indicators, such as marks on river beds, evaluating the water level using a measuring stick fixed at, for example, bridges), whereas the latter may help in the practical implementation of the changes in methods, such as with constructional aspects (e.g. attaching measuring sticks for water level measurements).

In general, Project Streams-Syr was not targeted at a specific user group. In earlier meetings with the Commission some groups were identified as potentially relevant for Project Streams-Syr, such as forest rangers, hunters, and the Photography Club of the Commune.

6.3 Phenomena and Possible Data Collection Frequencies

After the presentation of the important actors in the projects Mullerthal and Syr with their roles and motivations, in the following, the focus shifts to the phenomena relevant for data collection and envisaged data collection frequencies.

6.3.1 Phenomena

(1) Project Sources-Mullerthal

Table 22 provides an overview of the parameters of relevance for data collection in Project Sources-Mullerthal. Table 23 gives more detail on each parameter.

Table 22

Parameters of Project Sources-Mullerthal

Parameter	Physical chemical	Biological	Hydromorphological	Naturally occurring substances associated with pollution	Other pollutants	Social technological contexts
Habitat closeness to natural state						O
Presence of fire salamander, dragon fly, golden saxifrage, great horsetail, and nettles as indicator species		O				
Water hardness	M					
Water temperature	M					
Well-being						O
pH-level	M					
Water flow rate			O			
Presence of litter					O	O

Note. The parameters are listed in the order of decreasing relevance, as identified in the workshops. The letter “M” stands for measurement and the letter “O” for observation.

Table 23

Descriptions of the Parameters of Project Sources-Mullerthal

Parameter	Answer options (if specified)	Challenges	Aim (if specified)
Habitat Closeness to Natural State	Occurrence of tree clearances, piping of watercourses, illegal water extraction		
Presence of Specific Indicator Species	Presence of fire salamander, dragon fly, golden saxifrage, great horsetail	Potential disturbances of the species or habitat due to the data collection and the degree of difficulty of a sighting	Indicators of good water quality
	Occurrence of nettles on the banks		Indicator for nitrate levels
Water hardness			Insights into dynamics of calcareous tufa springs
Wellbeing	Personal assessments of aesthetics, access, biodiversity, infrastructure related to the data collection site		Incite reflection about social norms and values.
pH			Distinction between natural acidic and acidified sources
Water flow rate, water temperature			Insights into origins of the water and retention times in the ground
Presence of litter			

(2) Project Streams-Syr

Table 24 provides an overview of the parameters considered relevant for Project Streams-Syr. The parameters discussed and highlighted in the co-design workshop are displayed in green.

Table 24

Parameters of Projects Streams-Syr and Streams & Corporate Partnership

Indicator	Physical chemical	Biological	Hydromorphological	Naturally occurring substances associated with pollution	Other pollutants	Social technological contexts
Nitrate				M		
Phosphate				M		
Riverside vegetation		O				O
The appearance of the water body by the presence of foam, floating algae, litter, and oil					O	
The presence and composition of algae in and on the water		O		O		
The presence of aquatic life forms, such as fish, plants, etc.		O				
The presence of pollution sources, such as from industry, residences, etc.					O	O
Turbidity	M					
Type of water body			O			
Uses of the water body, such as fishing, swimming, etc.						O
Water colour	O	O		O		
Water flow			O			
Water level			O			
Oxygen content	M					
Temperature	M					
Plant diversity		O				

Note. The table contains the parameters of Project Streams & Corporate Partnership and the additional parameters identified in the co-design workshop for Project Streams-Syr. The rows with text in green colour indicate parameters highlighted in the co-design workshop for Project Streams-Syr. The letter “M” stands for measurement and the letter “O” for observation.

For Project Streams-Syr, the co-design partners suggested some adaptations to the parameter set of Project Streams & Corporate Partnership. One suggestion concerned the parameter Plant Diversity. Much like in Project Sources-Mullerthal, this parameter could be used to capture particular indicator species with the potential of giving insights into the state of a water body. In particular, “nettles” were discussed as one such indicator species. Plant Diversity could be added as a supplementary parameter with or without the focus on specific indicator species. The co-design partners also suggested to change the mode of data collection of parameter Water Level. Instead of visual assessment, which may be rather difficult, a measuring stick could be attached at the data collection sites (if possible). In addition, it could be coupled with a fixed thermometer for temperature readings. In addition, Oxygen Content was considered a worthwhile addition, for insights into the state of a water body.

6.3.2 Possible Data Collection Frequencies

As regards the envisaged data collection frequencies in the projects, first, it has to made clear that the data collection frequencies described here are of purely theoretical character. The frequencies are based on the estimations of the co-design partners. This section aims at giving some insights into the envisaged frequencies as a basis for discussion. Second, this section only refers to Project Sources-Mullerthal as data collection frequencies were not subject to discussion in the co-design workshop for Project Streams-Syr. To describe possible sampling frequency, different modes of engagement will be referred to, which facilitate different sampling frequencies.

Regular uses of the citizen science tool are designed to engage citizen scientists in on-going and repetitive data collection, whereas irregular uses do not require such a commitment. Spontaneous uses - that is uses, which happen spontaneously and without preparation, when an individual or group finds themselves at the data collection site and is made aware about the project by, for instance, an informative panel - is most compatible with irregular uses. Spontaneous uses do not support the use of special equipment other than what can be provided at the site or what people carry with them. Prepared uses - that is, uses, which require some preparation beforehand, such as the collection of a kit including special measuring equipment and for which individuals or groups intentionally move to the data collection site - can happen in the context of both regular and irregular uses.

In Project Sources-Mullerthal, it was envisaged to offer both modes, spontaneous and prepared uses. Schools would rather qualify for prepared uses regularly and/or irregularly. They may be engaged, for instance, in the form of “source sponsorships” (i.e. “adopt-a-source programmes”) or as part of excursions. Interested citizens could be engaged in both prepared regular and irregular as well as in spontaneous irregular uses. Prepared participation might take place during organised “theme trails”, renaturalisation activities or as part of special events (like Project Waterblitz). Any interested individual or group could participate spontaneously, for example, when reaching a data collection site during a hike a bicycle ride. The Regional Tourist Office may link the data collection and meaning-making activities with organised hikes in the form of prepared regular uses. Prepared irregular uses may also be possible, for example, when a tourist finds out about the project in the Office or online before a visit and collects a kit from the Office. Spontaneous uses are also possible during hikes or bicycle rides.

6.3.3 Envisaged Data Publication Practices

After the presentation of the phenomena and possible data collection frequencies for projects Mullerthal and Syr, the focus shifts in the following towards the envisaged data publication practices. One major aim linked to the co-design of citizen science projects was the co-design of a citizen science tool. This citizen science tool would include a website for data visualisation and the provision of related information. In the context of the second workshop for Project Sources-Mullerthal, a shorter discussion was led on the design and content of the website. It was agreed that the website should be ordered in function of detail in such a way that the landing page would show only the most important information, whereas the further pages would give more detailed information, for example, about the parameters and the datasets. In other words, “layer 1” would show content visually and in an easily accessible way, while “layer 2” would encompass shorter explanations and “layer 3” important details and background information, if relevant. Data representation would be aimed at a non-specialist audience and oriented towards facilitating meaning-making. It was noted that raw datasets are rather difficult to access by non-specialists and that the focus should be on presenting data as part of “stories”. As regards Project Streams-Syr, no results can be presented on the topic of data publication.

6.4 The Suitability of Co-Created Citizen Science for Supporting the Adaptive Governance of Social-Ecological Systems

Following the presentation of the results based on the co-design of the Projects Sources-Mullerthal and Streams-Syr, in particular the organised co-design workshops and other meetings, a discussion is offered. The discussion attempts to develop an answer to research question (c): “What is the potential of co-created citizen science for fostering adaptive governance of social-ecological systems? How can it address the opportunities identified in the answer to question (a)?” by making connections with the criteria identified in the conceptual framework (section 2.5.1) and with the gaps and opportunities identified in section 4.4.4. The structure of the discussion is the same as in Chapter 4 and is displayed in Table 9.

6.4.1 The Suitability of Projects Sources-Mullerthal and Streams-Syr for the Objectives of Ideal Data Collection and Meaning-Making in Adaptive Governance

A summary of the discussion is provided in Table 25.

Table 25

Summary of the Discussion of the Criteria Related to Objectives of Data Collection and Meaning-Making in Adaptive Governance

Criterion	Guiding Question and Key Factor	Project Sources-Mullerthal	Project Streams-Syr
Furthering the scientific understanding of system processes	Is the data collection programme aimed at studying cause-effect relationships?	-	-
Detecting and tracking changes in the system	a) Is the data collection programme well-suited for detecting and tracking trends, i.e. is it open-ended? b) Is the data collection programme well-suited for detecting and tracking of fluctuations? The suitability is considered in a positive relationship with the data collection frequency with a guiding threshold of multiple data points per site per year.	a) +/- Not determined b) + Based on envisaged data collection frequency	a) +/- Not determined b) + Based on envisaged data collection frequency
Detecting and tracking of effects of interventions	Is the data collection programme aimed at studying the effects of interventions?	+	-
Detecting and tracking of drivers of change	Does the data collection programme consider social, ecological, and technological factors in combination?	+	+
Swift detection of place-based changes and place-specific context factors	a) Is the data collection programme aimed at studying place-based changes in the system and/or place-based factors? b) Is the data collection site density of the programme well-suited for studying place-based changes and factors? The suitability is considered in a positive relationship with the data collection site density. c) Is the data collection frequency suitable for the swift detection of place-based changes? This was already discussed as part of question b) under 2.	a) + Place-Based changes, factors b) + Rather well-suited (multiple sites across Mullerthal-region) c) + Based on envisaged data collection frequency	a) + Place-Based changes, factors b) + Rather well-suited (multiple sites across Syr watershed area) c) + Based on envisaged data collection frequency

Furthering the scientific understanding of system processes, detecting and tracking changes in the system, and detecting and tracking the effects of interventions. In the following, Projects Sources-Mullerthal and Streams-Syr are discussed in relation to their suitability to further the scientific understanding of system processes, detecting and tracking changes in the system, and detecting and tracking the effects of interventions.

The co-created citizen science Project Sources-Mullerthal was designed with the aim to collect data related to the state of sources in the Mullerthal-region for a better overview, for tracking the effects of renaturalisation measures, and for raising awareness among the public. The potential of the expected dataset of Project Source-Mullerthal to identify cause-effect relationships is limited. The data collected on social-technological factors (e.g. closeness of the source to natural state, occurrence of litter), however, could be linked with ecological factors for first insights into system processes.

The potential of Project Sources-Mullerthal to contribute to trend detection is dependent on the timeframe, during which it takes place. The project was not designed with an end date and, therefore, one could assume that, if successful, it could shape to be a longer-term endeavour. The Project's potential for detecting and tracking fluctuations is dependent on the achieved data collection frequency. It is highly uncertain at this stage of the Project, as it covers a high range, depending on the kind of group that can be engaged in data collection and the mode, in which it happens (see section 6.3.2). As Project Streams & Corporate Partnership has demonstrated, one may need to expect deviations from the expected data collection frequency, which should be considered in the design of the programmes. Nevertheless, it can be expected that Project Sources-Mullerthal may be rather well-suited for the detection and tracking of fluctuations based on the expected data collection frequency.

The co-created citizen science Project Streams-Syr was designed with the aim to further adapt the approach of Project Streams & Corporate Partnership to perspectives and knowledge of people from the Syr-region. As a result, Project Streams-Syr is rather similar to Project Streams & Corporate Partnership. The key differences are the additional parameters of interest and the adapted data collection methods in Project Streams-Syr. As these differences are less significant for the key factors discussed in this section, please see section 5.2.1 for a detailed discussion related to Project Streams & Corporate Partnership.

Detecting and Tracking of Drivers of Change. The phenomena of Project Sources-Mullerthal and Streams-Syr are presented in Table 22 and Table 24. A set requirement for the detection and tracking of drivers of change in social-ecological systems is the consideration of social and technological factors alongside ecological factors (see Table 9). Project Sources-Mullerthal includes multiple parameters related to ecological factors, namely the Occurrence of Certain Indicator Species, Water Hardness, Water Temperature, pH-level, and Water Flow Rate, and social-technological system factors, namely Habitat Closeness to Natural State, Well-Being, and Presence of Litter (see Table 22). In comparison with Projects Streams & Corporate Partnership and Streams-Syr, where certain parameters were selected to inform on pollution and on possible origins, in Project Sources-Mullerthal the focus rather lies on physical-chemical and hydromorphological characteristics of sources and social-technological factors, which are not clearly connected. As Table 23 shows, only the parameter Occurrence of Specific Indicator Species is primarily aimed at informing about water quality. A key reason may be that a major aim of Project Sources-Mullerthal was to contribute to awareness raising among the public on the matter of sources and associated challenges. Nevertheless, Habitat Closeness to Natural State and Presence of Litter can give insights into social-technological circumstances with effects for water quality. Well-Being can be seen as a rather distinct parameter in this context. Its main aim was to incite reflection about social norms and values (see Table 23), which underlie human-nature interactions. Well-Being may, therefore, also inform about underlying causes of environmental degradation. Data and reflection among citizen scientists may have the potential to lead behavioural change.

In the workshop of Project Streams-Syr, the importance of a number of parameters was highlighted with the purpose to further adapt the Freshwater Watch approach to the place-specific context. The co-design partners highlighted the importance of the parameters Nitrate, Presence of Foam, Presence of Litter, and Presence of Inlets. These had already been part of the parameter set of Project Streams & Corporate Partnership. Water Temperature, Oxygen Content, and Plant Diversity were considered useful additions to the parameter set of Project Streams & Corporate Partnership. These additions mainly represent ecological parameters. They can help in assessing the water quality in more detail and, as such, their inclusion has important benefits. In combination with the parameters related to important social-technological factors, highlighted by the partners as well as already part of the Project Streams & Corporate Partnership, the extended parameter set promises to provide more detailed insights water quality issues and possible causes.

The Swift Detection of Place-Based Changes and Place-Specific Context Factors. The swift detection of place-based changes and place-specific context factors is dependent on the intensity of a data collection programme in time and in space. This means that a higher data collection frequency and more sampling sites per unit of surface area are beneficial. Since the co-created projects presented in this chapter have not yet been implemented, only the envisaged data collection frequencies and sampling site densities can be used as a basis for discussion. Project Sources-Mullerthal was designed to encompass multiple sampling sites in the Mullerthal-region [in the co-design workshops, about 10 sampling sites were discussed (Pickar & König, 2019)]. The region extends over approximately 180 km^2 [Wikipedia - Little Switzerland (Luxembourg)]. Although the data collection site density of 10 per 180 km^2 is considerably lower than of, for example, Project Streams & Corporate Partnership, it is higher than the site density of, for example, Monitoring Control of the Water Management Agency, which is aimed at developing overviews of the water quality of the major surface water bodies in Luxembourg (see section 4.3.1). The data collection frequency is very difficult to predict, as depending on the kind of group that can be engaged and the mode, in which it happens, it may range from 2-4 times per year to monthly or more (see section 6.3.2). Even on the lower end of the spectrum, the frequency may be rather well-suited for the swift detection of place-based changes, if it can be maintained in fairly regular intervals. Irregular uses of the citizen science tool may pose a challenge. Since Project Streams-Syr was fairly similar to Project Streams & Corporate Partnership and data collection frequency and site distribution were not discussed during the co-design workshop, please see section 5.2.1 for a discussion related to Project Streams & Corporate Partnership.

6.4.2 The Suitability of Projects Sources-Mullerthal and Streams-Syr for the Input and Process Criteria of Ideal Data Collection and Meaning-Making in Adaptive Governance

A summary of the discussion of the suitability of Projects Sources-Mullerthal and Streams-Syr for the Input and Process Criteria for ideal data collection and meaning-making in adaptive governance can be found in Table 26 .

Table 26

Summary of the Discussion of the Criteria Related to Objectives of Data Collection and Meaning-Making in Adaptive Governance

Criterion	Guiding Question and Key Factor	Project Sources-Mullerthal	Project Streams-Syr
Transparency	a) Is the data physically accessible to the public? b) Is the data presented with meaning (i.e. interpretations)? c) Are tools for individual meaning-making accessible in combination with the data?	a) + Website b) + Website c) + Website	
Stakeholder engagement in design and implementation	a) In how far are stakeholders engaged in the design and implementation? b) In how far does the project contribute to a more polycentric data landscape?	a) + Co-Design, citizen scientists b) + Non-specialists, specialists	a) + Co-Design, citizen scientists b) + Non-specialists, specialists

Note. For Project Streams-Syr only the fields are filled, for which content from the co-design workshop was available.

Transparency. As regards the transparency of Project Sources-Mullerthal and Streams-Syr, only the plans for data publication can be commented. As no results were available regarding data publication practices of Project Streams-Syr, the following focuses on the discussion related to Project Sources-Mullerthal. The envisaged data publication practices are described in section 6.3.3. The key channel discussed during the workshops was a website. Its structure was designed in different layers. The first layer would provide the most important information including a representation of each data point on a map. Every subsequent layer would introduce more detailed information with a total of three layers. Data publication would be aimed at non-specialists and facilitating individual meaning-making. “Stories” was considered a presentation method that is more accessible to a non-specialist audience than, for instance, raw data. Further, the meaning of the data points would be described, at least, from the perspectives of geology, biodiversity, and natural protection.

This short recapitulation of section 6.3.3 shows that the co-design partners opted for an approach to data publication that aims to facilitate public meaning-making from diverse perspectives and that is targeted at a non-specialist audience. In particular, embedding data in stories and representing data on a map aiming to facilitate meaning-making provides interesting avenues of exploration potentially relevant for other actors engaged in data publication.

Regarding the engagement of stakeholders in decision-making processes, the co-design processes of the Projects Sources-Mullerthal and Streams-Syr have to be highlighted. First, the co-design processes provided interested groups in Luxembourg with the opportunity to co-design a citizen science project and tool with the Sustainability Science Research Group at the University of Luxembourg for their purposes. Second, the organised co-design workshop invited the engagement of multiple actors. For Project Sources-Mullerthal, the participating actors were defined by the Source Renaturalisation Project (see section 6.1). For Project Streams-Syr participation by anyone interested in the Syr-area was invited. In addition, the workshops were designed to represent a level playing field for those present and to promote the development of a common output.

A number of limitations can be identified. In fact, the advertisement of the Syr workshop was limited in its capacity to lead to participation by diverse actors including non-specialists. An improved approach of advertisement is needed to also incite participation beyond the “usual suspects”. The workshops, further, did not engage any of the identified user groups. After a period of use of the tool, a feedback loop could be designed allowing user groups to adapt the project according to their experiences.

Discussion of the Potential of the Actors of Project Streams & Corporate Partnership to Contribute to Polycentricity. As regards the potential of Project Sources-Mullerthal and Streams-Syr to contribute to polycentricity in the actor network engaged in data collection and meaning-making on water quality, at this stage, an assessment is difficult. However, Project Sources-Mullerthal, if implemented and successful in engaging, at least, one of the user groups (see section 6.2), may represent at least one additional centre of data collection and meaning-making. In that case, it would engage specialists as well as non-specialists in the place-based data collection programme and meaning-making approach and focus on the state of natural water sources in the Mullerthal-region. Since it was co-designed with place-based partners, the future dataset has the potential to contribute to place-specific management questions and help in the design of interventions.

As regards Project Streams-Syr, the assessment presented in section 5.2.2 can be viewed for a more general account related to the approach. If Project Streams-Syr manages to extend the use of the tool beyond the user group of employees of the Royal Bank of Canada, it may be able to extend the use geographically as well to include other streams and places into the data collection activities. This would allow involving more interested groups and individuals in data collection, also including non-specialists.

A feedback loop for adaptations of the approaches, for example, by the citizen scientists may allow additional avenues for including additional and related purposes in the programmes.

6.5 The Potential Contributions of Co-Created Surface Water Citizen Science to Current Data Collection and Meaning-Making Towards more Adaptive Surface Water Governance

Now that the findings have been presented in relation to the adequacy of Project Sources-Mullerthal and Streams-Syr for adaptive governance, the findings are put in relation to the opportunities for change identified in section 4.4.4 of the current data collection programmes and meaning-making approaches.

Table 27 provides an overview of the potential contributions per case study in relation to the respective opportunity for change identified.

Table 27

Potential Contributions of Co-Created Surface Water Citizen Science to Current Data Collection and Meaning-Making Towards more Adaptive Surface Water Governance

Opportunity for change	Potential Contribution of Project Sources-Mullerthal	Potential Contribution of Project Streams-Syre
Limited engagement of multiple and diverse stakeholders in research design, data collection and meaning-making	+ Stakeholder engagement in co-design of research programme + Citizen scientist engagement in data collection and meaning-making	+ Stakeholder engagement in co-design of research programme + Citizen scientist engagement in data collection and meaning-making
Relatively low diversity of approaches to and purposes of research	+ Co-Design process offered the opportunity to diverse groups in Luxembourg to design a citizen science project for their purposes	+ Co-Design process offered the opportunity to diverse groups in Luxembourg to design a citizen science project for their purposes
Limited physical access to project-based datasets	+ Produced datasets are envisaged to be publicly available	+ Produced datasets are envisaged to be publicly available
Limited access to meaning and meaning-making of published datasets for non-specialists	+ Website designed to provide access to meaning and meaning-making of published datasets for non-specialists	
Limited access to disaggregated data, when aggregated data is published	+ Place-based datasets add detail to datasets produced for larger geographical scale	+ Place-based datasets add detail to datasets produced for larger geographical scales
Relatively low guaranteed data collection frequency at smaller geographical scales	+ Place-based data collection programme adds to the data collection frequency at lower geographical scales	+ Place-based data collection programme adds to the data collection frequency at lower geographical scales
Limited consideration of social and technological factors in data collection and meaning-making	+ Data collection programme includes social and technological factors	+ Data collection programme includes social and technological factors

The following discussion is ordered in function of the opportunities for change as displayed in Table 21.

Input/ Process. Projects Sources-Mullerthal and Streams-Syr have demonstrated that co-created citizen science is well-suited for engaging multiple stakeholders in the design of citizen science projects. This insight has been developed based on the examination of the two case studies, in particular the actors that engaged in the co-design processes. As sections 6.1 and 6.2 discussed in more detail, Project Sources-Mullerthal was co-designed with the Natur- & Geopark Mëllerdall, Natur&Emwelt, the Water Management Agency, and the Nature and Forest Agency. Project Streams-Syr was co-designed with the Commission of Sustainable Development of the Commune of Niederanven (2 people), the River Partnership Syr (1 person), and two people, who followed the open invitation. The two people were known to the Sustainability Science Research Group due to participation at other occasions (e.g. interviews and other workshops) based on their professional affiliation and characterisation as specialists in the water domain. Both projects also envisaged two engage stakeholders in data collection and meaning-making, as section 6.2 outlines. In Projects Sources-Mullerthal, schools, the Regional Tourist Office, and the general public were identified as the most important data collectors. In the co-design workshop of Project Streams-Syr, the public was considered the most important data collector without mentions of specific groups.

Stakeholder engagement in the co-created citizen science case studies was subject to a number of limitations. The co-design workshops engaged a very limited number of actors for the two projects (see previous paragraph). For Project Sources-Mullerthal, this was due to design, as only the stakeholders of the Source Renaturalisation Project were invited. The co-design workshop for Project Streams-Syr was, in contrast, aimed at engaging multiple members of the broader public, but failed to do so. A key reason can be identified as the approach taken for inviting the public to the workshop. The invitation was circulated by a few place-based organisations as well as displayed on the communal website. A more active and differentiated approach for reaching the public could have been beneficial, for example, by actively seeking to establish exchanges with people during gatherings or by other means. The approach taken was limited by the resources available in the research project, such as person-hours. As a result, important perspectives may have been missing in the co-design workshops, such as those of non-specialists. The workshops for both projects did not engage non-specialists in the design. An approach to remedy could be to organise occasions for feedback by non-specialists and other specialists in the later stages of the projects, for example, after the first year of implementation and to adapt the projects accordingly. In the same way, the co-design workshops did not engage any potential future users of the citizen science tools (i.e. data collectors and citizen scientists). In design processes, the perspective of users is considered important for the usefulness and usability of the object or service to be designed (Haklay & Tobón, 2003; Sturm & Tscholl, 2019). It may, therefore, be appropriate to foresee a channel for feedback by users, such as in the design of the citizen science tool, for example, in the form of an additional field in the data collection form. Since the engagement of potential future data collectors was lacking in the co-design processes, the projects may have been designed in ways that prove difficult for engaging the targeted groups (e.g. due to a lack of interest, relevance). If this turns out to be the case, it may be worthwhile to organise occasions for discussion to move the design closer to the interests of the targeted data collector groups.

In addition, the rather short duration of the workshops, especially of the workshop for Project Streams-Syr, made it difficult to discuss all the topics relevant to project design. The duration of the workshops was set in discussion with the initial co-design partners (for Project Sources-Mullerthal, this was the Natur- & Geopark Mëllerdall and Natur&Emwelt; for Project Streams-Syr, this was the Commission of Sustainable Development of the Commune of Niederanven and the River Partnership Syr). A rather large difference between the durations of the workshops for the two projects can be noticed (2 hours versus 4 hours; see section 3.4). A key reason for the shorter duration of the workshop for Project Streams-Syr was the fact that it was aimed at engaging the broader public. In contrast to the specialists engaged in Project Sources-Mullerthal, it could not be assumed that the interested members of the public could engage as part of their job. As a result, they would have needed to attend in their leisure time after work. This time limit contrasted with the intricacy of the design processes and significantly limited the amount and detail of topics that could be discussed.

Process. As regards transparency, both projects were linked with plans to make the potential future datasets publicly available. As a result, if the projects are implemented successfully and manage to generate data, they can help increase the amount of data on surface water quality that is publicly available. This insight is based on the examination of the envisaged data collection programmes and data publication practices presented in section 6.3. In terms of the adequacy of the projects to facilitate public meaning-making, only the plans for the website can be drawn on as presented in section 6.3. The plans for the website indicate that, if implemented comparably, it may be able to facilitate individual meaning-making.

It has to be noted that representing data with meaning accessible to non-specialists is not an easy undertaking. The required simplicity of the representation contrasts starkly with the complexity of the message. Data, for example, comes with multiple dimensions of uncertainty, which must be represented carefully. Uncertainty may be introduced by technical aspects of the research, such as the accuracy and precision of the data collection methods (e.g. nitrate and phosphate tests as well as observations - see Chapter 5) or errors in data collection and processing, such as deviations from standard protocols and faults in hardware and software. It may also be linked with the selected parameters and their ability to adequately capture, in this case, the state of surface water bodies. Uncertainty can also be linked with the social values and norms that underlie the processes of research design and data interpretation. In general, uncertainty in adaptive governance can be divided into reducible and irreducible. Reducible uncertainty is linked to imperfect knowledge and can be further reduced by scientific research. It is also linked to incomplete knowledge, which requires the engagement of diverse stakeholders to further our understanding of system processes. Irreducible uncertainty is related to the inherent unpredictability of social and natural systems (Ascough et al., 2008; Hasselman, 2017; W. E. Walker et al., 2003).

In addition, the design of the two co-created citizen science case studies indicates their suitability for intensive data collection in space and in time. Both projects were focused on a relatively small geographical area and in both projects, it was planned to collect data at multiple sites in these regions. This insight is based on the examination of the envisaged data collection frequencies and sites, in particular, related to Project Sources-Mullerthal (see section 6.3). It has to be noted, however, that one has to wait for the implementation of the projects to get an idea of the actual data collection sites and frequencies for a more reliable evaluation.

The designs of Projects Sources-Mullerthal and Streams-Syr have also indicate their suitability for collecting data on social and technological factors alongside ecological factors. This insight is based on the examination of the parameter-sets of the two projects, as presented in section 6.3.1. Project Sources-Mullerthal is particular in the way that the parameter-set was not primarily designed to determine pollution and to identify possible causes (see section 6.4.1). While nutrient concentrations in the water bodies in the Mullerthal-region are a major source of concern, a key reason was to avoid assigning blame to and alienating farmers, as some of the co-design partners were aspiring to collaborate with farmers to implement measures to improve water quality. The occurrence of nettles on the banks of the water bodies was chosen as an alternative indicator of nitrate concentrations in the water. The omission of important parameters, such as nutrients concentrations and land uses, significantly limits the capacity of Project Sources-Mullerthal to adequately capture the state of the sources and its ability make links with social-technological circumstances. Another particularity of Project Sources-Mullerthal is the design of the Well-Being Parameter. As section 6.4.1 describes in more detail, its main aim was to incite reflection about social norms and values, which underlie human-nature interactions. Alongside individual reflection, data on the multiple ways, in which humans relate to nature, has the potential to lead to a better understanding of human-environment relationships and to help in addressing sustainability challenges (Raymond et al., 2013).

Chapter 7. Contributory and Co-Created Surface Water Citizen Science: A Comparison of Findings and Experiences

This chapter aims to compare the findings related to the contributory and co-created citizen science case studies, to discuss differences, and particularities. This comparison builds on all results presented in the previous chapters and refers to key pieces of literature (see Chapter 2) and highlights important differences, prevailing views on, and approaches to citizen science.

Chapter 4 was aimed at exploring the compatibility of current data collection programmes and meaning-making approaches with key criteria for data collection and meaning-making in adaptive governance and at identifying opportunities for change. Chapter 5 and Chapter 6 were aimed at exploring the compatibility of the contributory citizen science case studies Projects Streams & Corporate Partnership and Waterblitz and the co-created citizen science case studies Projects Sources-Mullerthal and Streams-Syr with key criteria for data collection and meaning-making in adaptive governance and the ways, in which the citizen science case studies may be able to contribute to the opportunities of change identified in Chapter 4. Building on these previous chapters, in particular sections 4.4.4, 5.5, and 6.5, a summary of the comparison of the findings related to the contributory and co-created citizen science case studies can be found in Table 28.

Table 28

Comparison of Strengths and Challenges Highlighted by the Case Studies for Addressing the Opportunities for Change in Current Data Collection and Meaning-Making and to Contribute to Adaptive Governance

	Current data collection programmes and meaning-making approaches		Contributory citizen science case studies		Co-created citizen science case studies	
Criteria	Key insights	Challenges	Strengths	Challenges	Strengths	Challenges
Input/ Process: stakeholder engagement	Stakeholder engagement rather low	• Differences in vocabularies between specialists and non-specialists • Resource-intensive for both sides • Perspectives on value of non-scientifically produced knowledge	• Engagement of specialists in design phases and non-specialists in data collection and meaning-making • Freedom (e.g. in site selection) for citizen scientists allows for expressing perspectives • New funding sources with alternative funding criteria for more diversity in approaches	• Limited stakeholder engagement in design phase resulting in lack of important perspectives • Limited opportunities for citizen scientists to bring in their perspectives and knowledge	• Engagement of specialists in project design and meaning-making • Engagement of non-specialists in data collection and meaning-making	• Small number of people engaged in design: e.g. lack of non-specialists and "users" • Limited duration of the workshops
Process: transparency	Project-based datasets not easily accessible	• Resource-intensive • Formatting problems • Benefits for uploader rather uncertain	Increased access to data on the state of surface water bodies		Increased access to data on the state of surface water bodies	
	Publication of aggregated datasets	• Perspectives on the publication of raw data				

	Current data collection programmes and meaning-making approaches		Contributory citizen science case studies		Co-created citizen science case studies	
Criteria	Key insights	Challenges	Strengths	Challenges	Strengths	Challenges
		• Difficulties in interpretation for non-specialists				
	Access to meaning and information facilitating meaning-making lacking	• Interpretation of data often difficult for specialists • No legal framework for publication • Resource-intensive	Increased access to meaning and information for meaning-making	• Limited resources for communication • Rather technical representation of data of Freshwater Watch website	Increased access to meaning and information for meaning-making	Adequate representation of uncertainties
Objectives: Swift detection of place-based changes and place-specific context factors	Low guaranteed data collection frequency at lower geographical scales	• Resource-intensive • Uncertain benefits	Intensive data collection in space and time	• Deviations from set data collection frequencies • Frequency of Waterblitz-like events	Suitability for intensive data collection in space and time	
Objectives: Detecting and tracking of drivers of change	Negligence of social and technological factors		Links between ecological and social-technological factors	Limited size of parameter-sets	• Suitability for collecting data on social-technological and ecological parameters • Well-Being Parameter	Limits to representativeness of the parameter-set for the state of sources

7.1 A Comparison of Findings for the Contributory and Co-Created Citizen Science Case Studies in Relation to Stakeholder Engagement in Research Design and Implementation

The structure of the chapter largely follows the structure of the conceptual framework: input and process, and objectives (see section 2.5). A key insight from the examination of the current data collection programmes and meaning-making approaches was that stakeholder engagement in the design and implementation of programmes was rather low. The challenges to stakeholder engagement that could be identified were differences in the vocabularies between specialists and non-specialists, its resource-intensive nature for those who engage and those who organise engagement, and perspectives, which put into question the value of non-scientifically produced knowledge in governance.

In the literature, contributory and co-created forms of citizen science are distinguished based on the level of engagement of members of the public in the different research phases. Contributory citizen science is “generally designed by scientists and (…) members of the public primarily contribute data” and co-created citizen science is “designed by scientists and members of the public working together and (…) at least some of the public participants are actively involved in most or all aspects of the research process” (Shirk et al., 2012, p. 4). The descriptions of the case studies have shown that some of the projects have deviated from the conceptualisations in different ways. While the contributory case study Project Waterblitz represented a typical example, contributory case study Project Streams & Corporate Partnership engaged two stakeholders in the design of the research (i.e. in selection of parameters and data collection sites). In the co-created case studies Projects Sources-Mullerthal and Streams-Syr, different groups were considered to hold different roles in the project. While the projects were designed with specialists in the water quality domain, data collection was to be carried out largely by non-specialists (e.g. pupils, tourists, and members of the broader public). Due to these deviations from the conceptualisations, the contributory and co-created case studies could not be as clearly distinguished from one another as the conceptualisations suggest.

The first point of discussion is stakeholder engagement in design. It is particular in the way that, by definition, it is not foreseen in contributory citizen science (Shirk et al., 2012). The contributory citizen science case study Project Streams & Corporate Partnership, nevertheless, demonstrated stakeholder engagement in research design. It could be characterised as a rather informal and brief process of stakeholder consultation on the selection of parameters and data collection sites due to their familiarity with the Syr-region and with the associated sustainability challenges. The co-created citizen science case studies Project Sources-Mullerthal and Streams-Syr, in comparison, demonstrated a more systematic process of stakeholder engagement using a co-design methodology, in which only the overarching focus of the research, namely surface water quality, was pre-determined. It is evident that the co-created case studies provided more room for the engagement of diverse perspectives and types of knowledge in design. Yet, both processes of stakeholder engagement were marked by the absence of non-specialists. In Projects Streams & Corporate Partnership and Waterblitz, this circumstance was due to design. In the co-created citizen science case studies, the absence of non-specialists may be due to the approach taken for engagement. As section 3.4 describes in more detail, initial contact was established by email and phone call. If the contacted groups were interested, one or multiple meetings were held for further discussion. A more pro-active offer for reaching more groups and individuals, for example, in the form of presentations in group meetings, in schools or other social gatherings may have had more success in engaging non-specialists. As a result, both forms of citizen science were missing important perspectives in the design phases. Engaging non-specialist perspectives alongside specialist perspectives is considered essential in an adaptive governance context to gather all available information in situations that are complex and highly uncertain (Brunner et al., 2005; Folke et al., 2005).

Citizen science, in general, is characterised by the engagement of citizen scientists in research projects (Silvertown, 2009). As section 2.2.1 describes in more detail, different types of citizen science projects engage various types of people in different project phases. Environmental citizen science has proven able to engage diverse people, such as professionals and non-professionals as well as specialists and non-specialists (e.g. Bonney et al., 2015; Cooper et al., 2007; Danielsen et al., 2009). As section 2.1.4 discusses in more detail, the engagement of diverse stakeholders allows to take account of multiple and diverse perspectives as well as types of knowledge, which is important in adaptive governance (e.g. Cooney & Lang, 2007). In the four citizen science case studies presented in this thesis, only limited non-specialist knowledge and perspectives could be considered in the design of the projects. While this was expected in the design and data collection phases of the contributory citizen science projects, the co-design process was initially also targeted at non-specialists groups (e.g. place-based or interest-based communities). Even though many groups showed initial interest in the topic, none of them expressed interest to engage further. A regional amateur environmental organisation, for example, showed relatively high interest into the topic, as two meetings were held to sound out potential collaboration. In the end, it seemed that they felt they did not have enough specialist knowledge to design a data collection programme and meaning-making approach, in particular a set of specific parameters, which could be useful for them. A similar situation was encountered with a club active in sportive activities related to surface water. Two representatives even participated in an additional co-design workshop not previously featured in this thesis, but they decided to not take the project any further due to a lack of relevance. The co-design workshop also turned out considerably different from the other ones previously mentioned. It proved very difficult for them as non-specialists to discuss relevant aspects to measure or observe and to make connections to their interests. As a result, it can be noted that the approach to co-design taken as part of this thesis showed significant limitations in motivating non-specialists to engage. One reason may be that the non-specialist groups were not provided appropriate preparatory information by the researcher to contribute to designing a data collection programme in such a co-design process. In addition, the connections of people to places may not be that strong in the developed world. Further, the way that the co-design process was designed was very open to give groups the opportunity to design a project and tool that are relevant for them without leading them too much into different directions. This openness could have been counter-productive for non-specialist groups, as they may need more guidance to actualise their ideas due to a lack of specialist knowledge. This latter point may also explain, why it proved itself easier to engage non-specialists into the contributory citizen science projects mainly as data collectors, as the barrier to participation was lower. The engagement in these projects required also a much smaller time investment by the individuals. In the literature, co-created citizen science projects often come in the form of community-based environmental monitoring and management (Danielsen et al., 2005; Fernandez-Gimenez et al., 2008). This type of citizen science generally focuses on a specific natural resource, on which the communities that are engaged in the citizen science projects rely, for example, for their livelihood (Fernandez-Gimenez et al., 2008). This may already represent a key difference with the co-created citizen science case studies explored in this thesis. The relationship of the groups contacted as part of the co-design process with the natural resource in question (in this case a surface water body) was different. The role of the surface water body in the lives of the group members was most likely less central (for example, for their survival).

Stakeholder engagement in the implementation of research projects is a key criterion of citizen science, in general (Silvertown, 2009). Both forms of citizen science demonstrated the engagement of or indicated the suitability for engaging stakeholders in data collection and meaning-making. An aspect that was not examined in detail in the literature relates to the engagement of diverse perspectives and knowledge types beyond research design. In general, the reviewed literature on citizen science focused more on who is engaged in design, data collection, and processing, rather than at which stages in the process the engagement of diverse perspectives and knowledge types is facilitated (e.g. Bonney et al., 2015; Danielsen et al., 2009). The contributory citizen science case studies provided opportunities for the engagement of diverse perspectives and knowledge types in data collection. The engagement depended on the opportunities for citizen scientists to influence research design (e.g. data collection site selection) or the kind of data that is collected (e.g. via a comment-field). Such opportunities seem particularly important in regard to the potential for adaptive governance in forms of citizen science, where data collectors are not engaged in research design (e.g. contributory citizen science in general, and the co-created citizen science case studies).

Another aspect that proved important in the case studies, but had not been subject to much attention in the literature, is the potential of citizen science to access alternative funding sources. The contributory citizen science case studies have demonstrated the potential for accessing funding sources, which are currently not being accessible to data collection and meaning-making for governance and management (in this case, funding by the Royal Bank of Canada). This allows not only to diversify funding criteria of such programmes, but also to increase the total funds available to undertake them. Alternative funding sources can have implications for the diversity of approaches to data collection and meaning-making, data availability, and accountability of polluters and decision-makers, among others, which are considered of high importance in adaptive governance (e.g. Buytaert et al., 2016).

7.2 A Comparison of Findings for the Contributory and Co-Created Citizen Science Case Studies in Relation to Transparency

Another key insight from the examination of the current data collection programmes and meaning-making approaches was that project-based datasets were largely linked with difficult access (see section 4.2.3) and that the publication of data in aggregated format needs to be seen critically in regard to transparency (as the case of syndicates for the decontamination of wastewater - see section 4.4.2). As these challenges are rather case-specific, the citizen science case studies were not well-suited to help overcome them. In terms of transparency, however, the citizen science case studies were either able to contribute or indicated the suitability to contribute to increased access to data on the state of surface water bodies. In this aspect, the contributory and co-created citizen science case studies did not differ significantly, as the projects were all marked by publicly available datasets.

Chapter 4 also identified the challenge in current data collection programmes and meaning-making approaches of rather poor access to representations of data meaningful to non-specialists and to information facilitating meaning-making. These two features form part of the argument for transparency and legitimacy in adaptive governance (Chaffin et al., 2014; Van Assche et al., 2017). Key challenges to this access were the fact that interpretation of datasets is often also difficult for the issuer organisations (i.e. specialists), there is no legal framework that requires this access and that providing such access is resource-intensive. The contributory and co-created citizen science case studies all demonstrated or indicated the suitability for contributing to increased access to representations of data meaningful to non-specialists and information facilitating meaning-making. In the contributory citizen science case studies, the project websites (i.e. Freshwater Watch website) were marked by rather technical representations of data. In the co-created citizen science case studies, in particular in Project Sources-Mullerthal, in contrast, the website (that was designed during the co-design workshops) was especially designed for representations of data meaningful to non-specialists and for providing information for meaning-making. A key challenge was identified as the adequate representation of uncertainties related to the datasets meaningful to non-specialists.

7.3 A Comparison of Findings for the Contributory and Co-Created Citizen Science Case Studies in Relation to the Swift Detection of Place-Based Changes and the Tracking of Drivers of Change

The examination of current data collection programmes and meaning-making approaches also showed that the swift detection of place-based changes and place-specific context factors can only be guaranteed in a limited way due to the low guaranteed data collection frequency of programmes with higher sampling site densities. Rapid responses to undesirable changes are important to minimise their extend and implications and to increase accountability of polluters (Hasselman, 2017). The challenges to increase the frequency were linked to the rather resource-intensive nature of such programmes and the rather uncertain benefits. Both forms of citizen science have demonstrated or indicated the suitability for intensive data collection in space and in time with the potential to contribute to the guaranteed data collection frequency of programmes with higher data collection site densities. Projects Streams & Corporate Partnership, Sources-Mullerthal, and Streams-Syr were all designed to support in varying degrees multiple sites around particular places. One potential explanation for this is the fact that smaller-scale projects were considered more feasible in terms of design and implementation within the time-frame and scope of this thesis. Project Waterblitz, in contrast, demonstrated that a dataset of a single project can be useful at varying spatial levels, which is an important feature in adaptive governance (Ostrom, 2010). This type of crowdsourcing data points can lead to a relatively high-resolution overview of particular places, regions, and countries. The contributory case studies have shown that deviations from set data collection frequencies may occur, which needs to be considered in the design of such projects.

Another key insight from Chapter 4 was that social and technological factors are not well-presented in the parameter-sets in current data collection programmes and meaning-making approaches, which is however essential for a more complete picture of social-ecological systems (Chapman, 2014). Both forms of citizen science have demonstrated or indicated the suitability for collecting data on social, technological, and ecological factors in combination. The suitability of the contributory citizen science case studies was challenged by the rather limited size of parameter-sets. The suitability of the co-created citizen science case study Project Sources-Mullerthal for detecting and tracking drivers of change was limited by the representativeness of the parameter-set for the state of sources.

7.4 Summary

Based on the above discussion, one can identify a couple of key differences between the contributory and co-created citizen science case studies in contributing to the opportunities for change of current data collection and meaning-making towards more adaptive governance. First, the two forms demonstrated major differences in engaging stakeholders in research design. This difference was due to the design of the approaches and could be expected. The case studies, however, also demonstrated that contributory and co-created citizen science may not be as clearly distinguishable as suggested by the literature (e.g. Shirk et al., 2012). In particular, co-created approaches may take a hybrid form, where data collectors are not necessarily engaged in research design. Second, the comparison of the insights for the different citizen science case studies surfaced that the engagement of non-specialists (at least initially) may be easier in a contributory citizen science format at the data collection stage rather than in co-created citizen science at the stage of research design. Third, in comparison with the contributory citizen science case studies, the co-created citizen science case studies demonstrated that the engagement of stakeholders in co-design processes may lead to limits in the representativeness of the selected parameter-sets for the state of surface water bodies. Parameter-sets may focus on exploring general properties of the water rather than the concentration of substances associated with pollution.

Next to these key differences of the contributory and co-created citizen science case studies, the explorations also surfaced a series contributions of citizen science, which did not receive as much attention in the literature as other contributions. First, in particular the contributory citizen science case studies have shown that the engagement of perspectives and knowledge in the data collection phase is largely dependent on the opportunity for data collectors to influence research design (e.g. data collection site selection) or the kind of data that is collected (e.g. via a comment-field). For the potential for adaptive governance, such liberties seem crucial, as they increase the number of perspectives that can be engaged in the process (Brunner et al., 2005; Folke et al., 2005). Second, the contributory citizen science case studies have also demonstrated that citizen science can access funding sources, which are not yet accessed for data collection and meaning-making for governance purposes. Such funding opportunities seem important for more diverse funding criteria and, thus, more diverse approaches to data collection and meaning-making, which is considered of high importance in adaptive governance (see Buytaert et al., 2016). Third, access to data that is meaningful to non-specialists as well as information for meaning-making is similarly important for transparency as the mere publication of datasets. The citizen science case studies have demonstrated not only to be able to contribute to increased access to data, but also to data meaningful to non-specialists and information for meaning-making. Such access also seems important for the increased accountability of polluters and decision-makers, which is also essential for quality control in adaptive governance (Herrfahrdt-Pähle, 2013; Ravetz, 1999). Forth, the co-created citizen science case study Project Sources-Mullerthal has pointed out the unique position of citizen science to collect data on social norms and values (see Well-Being Parameter), which underlie human-nature interactions (Crain et al., 2014). Reflexion on these values may contribute to increased awareness and changes in behaviour towards more sustainable patterns.

Chapter 8 represents the concluding chapter of this thesis. It has multiple purposes. In the first section, it aims to provide brief summaries of the chapters of this thesis including a summary of the key take-away messages. In the second section, it revisits the research questions of the thesis and attempts to draw final conclusions based on the analysis and interpretation of the empirical results. The current chapter also provides an outlook on the citizen science case studies discussed in this thesis and suggests future research avenues.

8.1 Summaries of the Chapters

Chapter 1 showed that surface water quality and its governance is a topic of increasing importance due to multiple and diverse drivers of change (e.g. climate change, population growth, technological advancement) in Luxembourg and globally (e.g. Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services, 2019b; United Nations Environment Programme, 2021). It further demonstrated that citizen science is increasingly being promoted as a kind of research with the potential to increase public engagement in research and governance, and to increase accountability (United Nations, 2021; United Nations Environment Programme, 2021). If citizen science is to be employed as a form of research in the governance of surface water bodies, how citizen science can contribute to more sustainable water governance needs to be explored in more detail. In line with the argument, Chapter 1 detailed the overarching research question of the thesis: *"What role can citizen science play in data collection and meaning-making for the adaptive governance of social-ecological systems?"*.

Chapter 2, in a first phase, laid out different strands in the adaptive governance literature and directly and indirectly discussed the form and process of data collection and meaning-making, which allow it to support the adaptive governance of social-ecological systems. This review of relevant literature served as a basis for the development of a framework for the evaluation of the compatibility of data collection and meaning-making for adaptive governance (section 2.5.1) that was put to use in the empirical chapters. In a second phase, the chapter laid out different strands in the citizen science literature and discussed features of citizen science, which have the potential to contribute to data collection and meaning-making in adaptive governance. Again, this review of relevant literature led to the development of a framework for the evaluation of the contributions of citizen science to adaptive governance identified in the examinations of the citizen science case studies. Chapter 2 also determined the research areas in the literature, to which the thesis set out to contribute, and the research questions that were designed to do so:

A. In how far are current data collection programmes and meaning-making approaches compatible with key principles of the adaptive governance of social-ecological systems? What are opportunities for change?
B. How can contributory citizen science contribute to the adaptive governance of social-ecological systems? How can it address the opportunities for change identified in Question A?
C. How can co-created citizen science contribute to the adaptive governance of social-ecological systems? How can it address the opportunities for change identified in Question A?

In addition, it described the research scope.

Chapter 3 outlined the research approach of this thesis, which was identified as transdisciplinary sustainability science that is based on the engagement of multiple types of knowledge (e.g. scientific and non-scientific, and abstract and place-based) and on the engagement of multiple and diverse perspectives by collaboration and negotiation, as science especially in the context of sustainability challenges involves value-choices (Cooney & Lang, 2007). The chapter also outlined the research paradigm that the thesis followed, which is based on many elements of the participatory inquiry paradigm of Heron and Reason (1997). It acknowledges the existence of a reality beyond human cognition, and puts forward that this reality is inter-subjectively experienced by humans - that is, by the person who experiences and mediated by, for example, shared cultural beliefs, values, and norms. The chapter, then, described the main data collection methods: semi-structured interviews with specialists in the water domain, co-design processes including workshops, and documentary review, and the associated methods of data analysis. In a last instance, it discussed the key limitations of the study.

Chapter 4 was concerned with the exploration of the compatibility of current data collection programmes and meaning-making approaches related to surface water governance in Luxembourg with key principles of data collection and meaning-making in adaptive governance. It also put forward a series of opportunities for change. In terms of the compatibility, some limitations were identified:

- stakeholder engagement was rather low in the design of data collection programmes and in their implementation, which limits the diversity of perspectives and knowledge types that are considered,
- project-based datasets were rather difficult to access negatively affecting transparency,
- the publication of representations of aggregated data needs to be accompanied by the publication of original datasets for transparency,
- access to data meaningful to non-specialists and to information for meaning-making was rather low, rendering datasets rather inaccessible to non-specialists,

- the guaranteed data collection frequency of programmes with higher sampling site densities was relatively low limiting the capacity to swiftly detect changes at lower geographical levels, and
- social and technological factors are largely neglected in the programmes making the detecting and tracking of drivers of change difficult.

Chapter 5 explored the citizen science case studies Projects Streams & Corporate Partnership and Waterblitz, their compatibility with key principles of data collection and meaning-making in adaptive governance, and the ways, in which they can contribute to the opportunities of change identified in the previous chapter. The contributory citizen science case studies have demonstrated

- to be able to engage specialists in the design phases and non-specialists in data collection and meaning-making,
- ways of engaging diverse perspectives and knowledge types in the data collection phase by providing data collectors with liberties to influence research design (e.g. data collection site selection) and the data collected (e.g. by a comment-field),
- to be able to access funding sources with alternative funding criteria for more diversity,
- to be able to contribute to increased access to data on the state of surface water bodies,
- To be able to contribute to increased access to data meaningful to non-specialists and information for meaning-making for more transparency,
- To be able to produce datasets for multiple levels and to contribute to the guaranteed data collection frequency at lower geographical levels, and
- To produce datasets on ecological, social, and technological factors in combination.

Chapter 6 examined the compatibility of the co-created citizen science case studies Projects Sources-Mullerthal and Streams-Syr with key principles of data collection and meaning-making in adaptive governance, and the ways, in which they can contribute to the opportunities of change identified in the previous chapter. The co-created citizen science case studies, in particular their designs,

- demonstrated the ability to engage specialists in project design and indicated the suitability to engage non-specialists in data collection and meaning-making,
- indicated the suitability to contribute to increased access to data on the state of surface water bodies,
- indicated the suitability for increased access to data meaningful to non-specialists and information for meaning-making,
- indicated the suitability for intensive data collection in space and time to complement the guaranteed data collection frequency at lower geographical levels, and
- for collecting data on social, ecological, and technological factors in combination with a particular mention of the Well-Being Parameter, which holds the potential to contribute to the development of a better understanding of social norms and values underlying human-nature interactions and to reflexion and behavioural change.

Chapter 7 was concerned with comparing the findings related to the contributory and co-created citizen science case studies, in particular, with discussing differences and particularities. The comparison surfaced that:

- stakeholder engagement in the design of the projects was more systematic and comprehensive in the co-created citizen science case studies (which was expected due to differences in the design),

- the two forms of citizen science may not be as easily distinguishable as the literature suggests, as the co-created citizen science case studies did not engage data collectors in design,
- the initial engagement of non-specialists was easier in the contributory citizen science format as data collectors rather than in the co-design phase, and
- engaging stakeholders in co-design processes influenced the representativeness of the selected parameter-sets for the state of surface water bodies.

8.2 Research Questions Revisited

The aim of this section is to draw the final conclusions in regard to the research questions based on the results, analysis, and interpretation presented. It, therefore, does not attempt to reiterate all findings presented in Chapter 4 to Chapter 7, but aims to develop conclusions based on them. The final conclusions are presented by research question.

A. *Are current data collection programmes and meaning-making approaches compatible with key principles of the adaptive governance of social-ecological systems? What are opportunities for change?*

Research Questions A was subject of the first empirical chapter. The results, discussion, and findings have been presented in Chapter 4 as well as the identified opportunities for change (section 4.4.4). A summary of the limitations to the compatibility has also been given in the previous section (section 8.1). Based on the findings presented in Chapter 4, one can conclude that, while the current data collection programmes and meaning-making approaches proved suitable for furthering the scientific understanding of system processes, detecting and tracking changes in the system, detecting and tracking the effects of specific interventions, stakeholder engagement in design and implementation of the programmes was rather low. Stakeholder engagement in data collection and meaning-making is considered important in adaptive governance for engaging diverse perspectives in the value choices that come with research in the context of sustainability challenges (Cooney & Lang, 2007). Some measures for overcoming limited stakeholder engagement may be to find ways to increase the resources available for stakeholder engagement, explore new approaches to stakeholder engagement specifically designed for non-specialists, conduct flagship projects to further explore the value of non-scientifically produced knowledge in governance, and to increase the opportunities available for stakeholder engagement in the design of data collection programmes. The degree of transparency in current data collection and meaning-making was limited by the difficult access to project-based datasets and the publication of representations of aggregated data without original datasets. In adaptive governance, transparency is a key requirement. In general, it is considered a feature of good governance (Lockwood et al., 2010), increases legitimacy of decisions and actions (Curtin & Meijer, 2006) as well as the accountability of decision-makers (Herrfahrdt-Pähle, 2013), and facilitates quality control of decisions (Bäckstrand, 2003). For more transparency, ways to increase the resources for sharing project-based datasets may be sought, one may explore new ways of sharing datasets without the need for reformatting to reduce effort and errors and specifically targeted at non-specialists with a focus on sharing meaningful data and information for meaning-making. The capacity of current data collection programmes and meaning-making approaches for swiftly detecting place-based changes was limited by the rather low guaranteed data collection frequency of programmes with a higher data collection site density. To overcome this challenge, measures may be implemented, such as finding ways to increase the resources for complementing the guaranteed data collection frequency of programmes with a higher data collection site density, while considering the appropriate frequency for each parameter, for example, based on the implications for nature and humans. The appropriate data collection frequency of a specific parameter is dependent on the implications of different concentrations and variations for nature and humans. For some parameters, surpassing a certain threshold may have vast consequences for nature, even if it is for a short amount of time (e.g. nitrite concentrations). For other parameters, small fluctuations in the concentrations do not lead to dramatic implications for nature, and averages for certain time periods are more important (e.g. nitrate concentrations). For a better understanding of drivers of change and of social-ecological system processes, it is also important to consider more social and technological factors in combination with the measured ecological factors (Chapman, 2014; Crain et al., 2014). For example, changing agricultural practices may have implications for ecosystems (e.g. changing approaches to fertiliser application) as well as changing river bank vegetation (e.g. due to clearances).

As Section 2.3 Identified Research Areas and Questions outlines, answering Research Question A involved the development of an evaluation framework as presented in Section 2.5.1. The evaluation framework was identified as a key conceptual contribution to the field of adaptive governance. Section 4.4.3 put forward a number of limitations that were experienced during the application of the evaluation framework, and a number of opportunities for improvement. The analysis presented in Chapter 4 surfaced that the lack of general thresholds introduced a number of challenges, for example, in the evaluation of the data collection frequencies and of the sampling site densities for detecting changes in the system in a timely manner. Here a more differentiated approach considering parameters individually would be more appropriate, as the differences in the consequences for nature and humans of different magnitudes of changes are considerable. In addition, instead of considering the different data collection programmes and meaning-making approaches individually, it would be more appropriate to consider all sources of data at the same time that can be used for a specific purpose. This rests on the fact that each individual programme can hardly fulfil all the objectives of data collection and meaning-making in adaptive governance, as objectives may be not be compatible for one programme (such as the purposes of the detection and tracking of impacts of management interventions and national trend detection). In the same manner, it would be important to consider all sources of data used for a specific purpose, including those with different original purposes than the governance and management of surface water bodies, especially in regard to social and technological factors.

B. *How can contributory citizen science contribute to the adaptive governance of social-ecological systems? How can it address the opportunities for change identified in Question A?*

Research Question B was subject of the second empirical chapter. The results, discussion, and findings have been presented in Chapter 5 as well as the ways, in which the contributory citizen science case studies have demonstrated to be able to contribute to the opportunities for change identified in Chapter 4 (section 5.5). A summary has also been provided in the previous section (section 8.1). In the following, the final conclusions in regard to Research Question B are presented, which can also be considered a list of aspects of contributory citizen science projects, which proved key for their potential in an adaptive governance context. In Section 2.3, a key conceptual contribution of the thesis was identified as furthering the conceptualisation of environmental citizen science in an adaptive governance context.

The examination of the contributory citizen science case studies has shown that contributory citizen science can engage stakeholders in design (specialists) and implementation (non-specialists) of research projects. Stakeholder engagement is considered of high importance in adaptive governance for considering diverse perspectives and knowledge types in research and governance, and for legitimacy of decisions and action (Cooney & Lang, 2007). Due to the lack of a systematic and comprehensive engagement of stakeholders (specialists and non-specialists, alike) in the design of the projects, opportunities for engagement may be foreseen in later stages. Provisions for liberties for data collectors to influence research design and the type of data collected seem crucial for contributory citizen science projects, for opportunities for the engagement of diverse perspectives and types of knowledge in the data collection phase. Based on the reviewed literature, this finding is original to this thesis and holds the potential to increase the engagement of diverse perspectives and types of knowledge in environmental citizen science essential for supporting adaptive governance.

In addition, new funding sources for research for governance could be explored further (such as the Royal Bank of Canada). The contributory citizen science case studies have also demonstrated their ability to contribute to increased access to data on the state of surface water bodies, which is in line with other studies (e.g. Buytaert et al., 2016) and, in particular, data that is meaningful to non-specialists and information for meaning-making. Focusing not only on access to data but also on data meaningful to non-specialists and information for meaning-making in environmental citizen science by the example set in this thesis is a novel perspective with the potential to increase transparency and accountability beyond specialist groups. Accordingly, transparency was identified as a key feature of environmental citizen science for adaptive governance (see also Buytaert et al., 2014). In this regard, projects may benefit from increased resources for communication with the citizen scientists. A more interactive approach to communication on data and meaning between researchers and citizen scientists, for example, in the form of workshops, may increase collective meaning-making. Further exploration of ways for representing meaningful datasets and information is needed, for which citizen science, in general, is well-positioned. In addition, the case studies have demonstrated the ability to produce datasets on multiple geographical and temporal levels, similarly to other studies (e.g. Aceves-Bueno et al., 2015), and their suitability for intensive data collection in space and in time. Especially focusing on projects with higher sampling densities can be beneficial to complement governmental datasets, which may reveal gaps in that regard, as the example of Luxembourg has demonstrated. Based on the reviewed literature, this is an innovative finding that can help in the design of environmental citizen science for adaptive governance.

Projects need to account for deviations from set data collection frequencies in the design of the projects. The projects also showed the ability to collect data on ecological and social-technological factors in combination. This is a special attribute of citizen science, in general, and deserves more attention, especially in the context of the adaptive governance of social-ecological systems (see also Crain et al., 2014). Due to the potentially limited size of the parameter-sets in contributory citizen science, parameters need to be chosen carefully to reflect the purpose of the research well.

C. *How can co-created citizen science contribute to the adaptive governance of social-ecological systems? How can it address the opportunities for change identified in Question A?*

Research Questions C was subject of the third empirical chapter. The results, discussion, and findings have been presented in Chapter 6 as well as the ways, in which the co-created citizen science case studies have demonstrated to be able to contribute to the opportunities for change identified in Chapter 4 (section 6.5). A summary has also been provided in the previous section (section 8.1). In the following, the final conclusions in regard to Research Question C are presented, which can also be considered a list of aspects of co-created citizen science projects, which proved key for their potential in an adaptive governance context. In Section 2.3, a key conceptual contribution of the thesis was identified as furthering the conceptualisation of environmental citizen science in an adaptive governance context.

The examination of the co-created citizen science case studies has shown that the engagement of stakeholders in the design of the research projects is possible (specialists) and indicated that the engagement of stakeholders in the implementation of the research (i.e. data collection; non-specialists) is possible. This finding provides new evidence into stakeholder engagement in citizen science, adding detail to existing conceptualisations of (environmental) citizen science (e.g. Shirk et al., 2012). Due to the rather small number of stakeholders engaged in design, further opportunities for the engagement of, for example, data collectors (i.e. "users") may be foreseen in the later stages of the projects to work towards engaging more diverse perspectives in design crucial in adaptive governance (Cooney & Lang, 2007). New approaches to the co-design processes and workshops may be explored to facilitate the engagement of non-specialists and "users", for example, by pre-defining certain aspects of the projects in advance to make to process less open and, perhaps, less overwhelming. This is a novel perspective gained by means of this thesis with the potential to further develop co-design as a methodology for designing environmental citizen science for adaptive governance, among others.

The co-created citizen science case studies have also indicated their suitability for contributing to the increased access to data on the state of surface water bodies, which is in line with what other studies suggest (e.g. Buytaert et al., 2016), and to data meaningful to non-specialists and information for meaning-making. A key challenge, which needs further exploration, is the adequate and meaningful representation of uncertainties. In addition, the projects have indicated the suitability for intensive data collection in space and in time, and the suitability for collecting data on ecological and social-technological factors in combination. For this, citizen science holds a unique position (see Crain et al., 2014). To ensure the adequacy of the parameters for the intended purposes, guidance by specialists may be needed. The design of the Well-Being Parameter, in particular, has pointed towards the suitability of the projects for informing on social norms and values underlying human-nature interactions, reflection, and behavioural change.

What role can citizen science play in data collection and meaning-making for the adaptive governance of social-ecological systems?

Based on the findings for the contributory and co-created citizen science case studies, citizen science has the potential to

- increase stakeholder engagement in design and implementation of research projects,
- access new funding sources for scientific inquiry for governance,
- increase access to data on the state of surface water bodies, and to meaningful data and information for meaning-making,
- complement the data collection frequency at multiple geographical levels, and
- inform on social-technological factors in combination with ecological factors for better understanding of social-ecological system processes and of human-nature relationships.

The comparison of the two common forms of environmental citizen science has also produced findings of novel character. Contributory and co-created citizen science may not be as easily distinguishable, as is suggested by the literature (e.g. Shirk et al., 2012) , in particular, as they can come in hybrid formats. As the case studies have demonstrated, stakeholders may be engaged in the design of contributory citizen science and non-specialists and “data collectors” may not be engaged in design processes in co-created citizen science. In addition, the case studies have shown that the engagement of non-specialists may be easier at the data collection stage rather than in research design (at least initially), as, for example, the required commitment (e.g. time) is smaller.

8.3 Outlook on the Case Studies

This section aims to provide an outlook on the case studies. The duration of the contributory citizen science case study Project Streams & Corporate Partnership was set for two years (as noted in the collaboration agreement between Earthwatch and the Sustainability Science Research Group at the University of Luxembourg). It started in June 2019 and finished in June 2021. The Project, therefore, has been completed. Contributory citizen science case study Project Waterblitz was an event in September 2019. Two Waterblitz-events were planned for the duration of Project Streams & Corporate Partnership (collaboration agreement between Earthwatch and the Sustainability Science Research Group). The second event took place in May 2021. The Research Group has expressed its interest in taking part in further events in the future. The co-created case studies Projects Sources-Mullerthal and Streams-Syr are still in development. The finding of an adequate team of developers for the mobile application and website took longer than expected. A collaboration agreement was set with Spotteron in 2021, a company offering citizen science software packages based in Austria with many years of experience. The development of the mobile application and website is underway and first tests are scheduled for end of 2021. Once the citizen science tool is established, the projects can be implemented.

8.4 Future Research Avenues

The research project that is subject of this thesis explored the potential of environmental citizen science to contribute to more adaptive surface water governance in Luxembourg and beyond. It examined two contributory and co-created surface water citizen science case studies and the evaluation was based on key criteria of data collection and meaning-making for the adaptive governance of social-ecological systems and opportunities for change identified based on current data collection programmes and meaning-making approaches. The research project that is the subject of this thesis led to two citizen science datasets of contributory citizen science Projects Waterblitz and Streams & Corporate Partnership. To further investigate their usefulness in governance, further potential research may focus on exploring different perspectives, such as of decision-makers, specialists, and non-specialists. Such research would allow to gain more insights into how the datasets can be put to use in governance, and it may lead to a better understanding of the requirements and, by extension, design requisites for citizen science datasets.

Another research avenue that presents itself is related to the co-created citizen science case studies. Since both projects were assessed before implementation, further research may focus on following the two projects beyond implementation to further explore their potential to contribute to and to explore their actual contributions to more adaptive governance and sustainability. Such research would also allow to compare findings between the potential and actual contributions.

The research project pointed out a number of challenges in engaging non-specialists in the design of citizen science projects. A further research avenue may be to further explore co-design as a method, and to identify requirements for non-specialist engagement. Such research is detrimental for engaging non-specialists perspectives into the design of research projects, also allowing to move beyond a technical view of meaning-making.

Reference List

Abel, N., Ross, H., & Walker, P. (1998). Mental Models in Rangeland Research, Communication and Management. *The Rangeland Journal*, *20*(1), 77. https://doi.org/10.1071/RJ9980077

Abson, D. J., Fischer, J., Leventon, J., Newig, J., Schomerus, T., Vilsmaier, U., von Wehrden, H., Abernethy, P., Ives, C. D., Jager, N. W., & Lang, D. J. (2017). Leverage points for sustainability transformation. *Ambio*, *46*(1), 30–39. https://doi.org/10/f9nm94

Aceves-Bueno, E., Adeleye, A., Bradley, D., Brandt, W., Callery, P., Feraud, M., Garner, K., Gentry, R., Huang, Y., McCullough, I., Pearlman, I., Sutherland, S., Wilkinson, W., Yang, Y., Zink, T., Anderson, S., & Tague, C. (2015). Citizen Science as an Approach for Overcoming Insufficient Monitoring and Inadequate Stakeholder Buy-in in Adaptive Management: Criteria and Evidence. *Ecosystems*, *18*(3), 493–506. https://doi.org/10.1007/s10021-015-9842-4

Administration de la Gestion de l'Eau. (2009). *Bewirtschaftungsplan für das Großherzogtum Luxemburg*. https://eau.public.lu/actualites/2009/12/plan_de_gestion/plan_de_gestion.pdf

Administration de la Gestion de l'Eau. (2014). *Missions*. https://eau.public.lu/administration/missions/index.html

Administration de la Gestion de l'Eau. (2015a). *Plan de gestion pour les parties des districts hydrographiques internationaux Rhin et Meuse situées sur territoire luxembourgeois (2015-2021)*. https://eau.gouvernement.lu/fr/administration/directives/Directive-cadre-sur-leau/2e-cycle-(2015-2021)/Plan-de-gestion-des-districts-hydrographiques.html

Administration de la Gestion de l'Eau. (2015b). *Umsetzung der europäischen Wasserrahmenrichtlinie (200/60/EG)—Bewirtschaftungsplan für die luxemburgischen Anteile an den internationalen Flussgebietseinheiten Rhein und Maas (2015-2021)*. http://geoportail.eau.etat.lu/pdf/plan%20de%20gestion/2.%20Bewirtschaftungsplan%20f%C3%BCr%20Luxemburg%20(2015-2021)_22.12.2015.pdf

Administration de la Gestion de l'Eau. (2016a). *Explication d'un bulletin d'analyse de l'eau potable*. https://www.ell.lu/attachments/article/150/explication%20analyse%20d'eau%20pour%20le%20public_final.pdf

Administration de la Gestion de l'Eau. (2016b). *Surface Water Body*. https://data.public.lu/en/datasets/surface-water-body/

Administration de la Gestion de l'Eau. (2018). *Qualité des Eaux Distributées au Luxembourg: Présentation des Résultats des Analyse des Années 2015*. https://eau.public.lu/publications/rapport-qualite-eau-potable/DIV_FinalRappIntern2015_CKR_180223_0_1.pdf

Anderson, L., Gold, J., Stewart, J., & Thorpe, R. (2015). *A Guide to Professional Doctorates in Business and Management*. SAGE.

Arrêté grand-ducal du 5 décembre 2018 portant énumération des Ministéres, (2018). http://data.legilux.public.lu/eli/etat/leg/agd/2018/12/05/a1099/jo

Arrêté grand-ducal du 8 juillet 1963 portent institution du Syndicat des Eaux du Barrage d'Esch-sur-Sûre, (1963). https://sebes.lu/wp-content/uploads/2016/11/Loi-du-31-juillet-1962.pdf

Ascough, J. C., Maier, H. R., Ravalico, J. K., & Strudley, M. W. (2008). Future research challenges for incorporation of uncertainty in environmental and ecological decision-making. *Ecological Modelling*, *219*(3–4), 383–399. https://doi.org/10.1016/j.ecolmodel.2008.07.015

Audubon. (2021). *History of the Christmas Bird Count*. http://www.audubon.org/history-christmas-bird-count

August, T. A., West, S. E., Robson, H., Lyon, J., Huddart, J., Velasquez, L. F., & Thornhill, I. (2019). Citizen meets social science: Predicting volunteer involvement in a global freshwater monitoring experiment. *Freshwater Science*, *38*(2), 321–331. https://doi.org/10.1086/703416

Bäckstrand, K. (2003). Civic Science for Sustainability: Reframing the Role of Experts, Policy-Makers and Citizens in Environmental Governance. *Global Environmental Politics*, *3*(4), 24–41. https://doi.org/10.1162/152638003322757916

Balázs, B., Mooney, P., Nováková, E., Bastin, L., & Arsanjani, J. J. (2021). Data quality in citizen science. In *The Science of Citizen Science* (1st ed.). Springer. https://doi.org/10.1007/978-3-030-58278-4

Barratt, B. I. P., Derraik, J. G. B., Rufaut, C. G., Goodman, a. J., & Dickinson, K. J. M. (2003). Morphospecies as a substitute for Coleoptera species identification, and the value of experience in improving accuracy. *Journal of the Royal Society of New Zealand*, *33*(2), 583–590. https://doi.org/10.1080/03014223.2003.9517746

Berkes, F. (1989). Co-Management and the James Bay Agreement. In *Co-operative management of local fisheries* (pp. 189–208). University of British Columbia Press.

Berkes, F. (2009). Evolution of co-management: Role of knowledge generation, bridging organizations and social learning. *Journal of Environmental Management*, *90*(5), 1692–1702. https://doi.org/10.1016/j.jenvman.2008.12.001

Bingenheimer, V. (2019). Kühle Nass aus sauberen Quellen. *Luxemburger Wort*. https://www.pressreader.com/luxembourg/luxemburger-wort/20191122/282973926876534

Bloniarz, D. V., & Ryan, H. D. P. (1996). The use of volunteer initiatives in conducting urban forest resource inventories. *Journal of Arboriculture*, *22*(2), 75–82.

Bonney, R. (1996). Citizen science: A lab tradition. *Living Bird*, *15*(4), 7–15.

Bonney, R., Cooper, C. B., Dickinson, J., Kelling, S., Phillips, T., Rosenberg, K. V., & Shirk, J. (2009). Citizen Science: A Developing Tool for Expanding Science Knowledge and Scientific Literacy. *BioScience*, *59*(11), 977–984. https://doi.org/10.1525/bio.2009.59.11.9

Bonney, R., Phillips, T., Ballard, H., & Enck, J. (2015). Can citizen science enhance public understanding of science? *Public Understanding of Science*, *25*(1), 2–16. https://doi.org/10.1177/0963662515607406

Bowser, A., Hansen, D., Preece, J., He, Y., Boston, C., & Hammock, J. (2014). Gamifying citizen science: A study of two user groups. *Proceedings of the Companion Publication of the 17th ACM Conference on Computer Supported Cooperative Work & Social Computing*, 137–140. http://dx.doi.org/10.1145/2556420.2556502

Brandt, P., Ernst, A., Gralla, F., Luederitz, C., Lang, D. J., Newig, J., Reinert, F., Abson, D. J., & von Wehrden, H. (2013). A review of transdisciplinary research in sustainability science. *Ecological Economics*, *92*, 1–15. https://doi.org/10.1016/j.ecolecon.2013.04.008

Bremer, S., Haque, M. M., Aziz, S. B., & Kvamme, S. (2019). 'My new routine': Assessing the impact of citizen science on climate adaptation in Bangladesh. *Environmental Science & Policy*, *94*, 245–257. https://doi.org/10.1016/j.envsci.2018.12.029

Brunner, R., Steelman, T., Coe-Juell, L., Cromley, C., Edwards, C., & Tucker, D. (2005). *Adaptive Governance: Integrating Science, Policy, and Decision Making*. Columbia University Press.

Buytaert, W., Dewulf, A., De Bièvre, B., Clark, J., & Hannah, D. M. (2016). Citizen Science for Water Resources Management: Toward Polycentric Monitoring and Governance? *Journal of Water Resources Planning and Management*, *142*(4), 1–4. https://doi.org/10.1061/(ASCE)WR.1943-5452.0000641

Buytaert, W., Zulkafli, Z., Grainger, S., Acosta, L., Alemie, T. C., Bastiaensen, J., De Bièvre, B., Bhusal, J., Clark, J., Dewulf, A., Foggin, M., Hannah, D. M., Hergarten, C., Isaeva, A., Karpouzoglou, T., Pandeya, B., Paudel, D., Sharma, K., Steenhuis, T., … Zhumanova, M. (2014). Citizen science in hydrology and water resources: Opportunities for knowledge generation, ecosystem service management, and sustainable development. *Frontiers in Earth Science*, *2*(October), 1–21. https://doi.org/10.3389/feart.2014.00026

Capdevila, A., Kokimova, A., Sinha Ray, S., Avellán, T., Kim, J., & Kirschke, S. (2020). Success factors for citizen science projects in water quality monitoring. *Science of The Total Environment*, *728*, 1–17. https://doi.org/10.1016/j.scitotenv.2020.137843

Chaffin, B., Gosnell, H., & Cosens, B. (2014). A decade of adaptive governance scholarship: Synthesis and future directions. *Ecology and Society*, *19*(3), 1–14. https://doi.org/10.5751/ES-06824-190356

Chapman, S. (2014). A framework for monitoring social process and outcomes in environmental programs. *Evaluation and Program Planning*, *47*, 45–53. https://doi.org/10.1016/j.evalprogplan.2014.07.004

Charles, A., Loucks, L., Berkes, F., & Armitage, D. (2020). Community science: A typology and its implications for governance of social-ecological systems. *Environmental Science & Policy*, *106*, 77–86. https://doi.org/10.1016/j.envsci.2020.01.019

Chislock, M. F., Doster, E., Zitomer, R., & Wilson, A. (2013). Eutrophication: Causes, Consequences, and Controls in Aquatic Ecosystems. *Nature Education Knowledge*, *4*(4), 1–8. https://www.researchgate.net/profile/Rachel-Zitomer/publication/313612977_Eutrophication_Causes_consequences_and_controls_in_aquatic_ecosystems_Nature_Edu/links/5f04a7cb92851c52d61e2f0b/Eutrophication-Causes-consequences-and-controls-in-aquatic-ecosystems-Nature-Edu.pdf

Clark, W. C., & Dickson, N. M. (2003). Sustainability science: The emerging research program. *Proceedings of the National Academy of Sciences*, *100*(14), 8059–8061. https://doi.org/10.1073/pnas.1231333100

Cohn, J. P. (2008). Citizen Science: Can Volunteers Do Real Research? *BioScience*, *58*(3), 192–197. https://doi.org/10.1641/B580303

Collins, K., Steyaert, P., Marco, T., Brives, H., Roche, B., Paul Billau, J., & Powell, N. (2004). Stakeholders and Stakeholding in Integrated Catchment Management and Sustainable Use of Water (SLIM). *Slim Policy Briefing No. 2*, 1–4. https://www.researchgate.net/publication/238695062_Stakeholders_and_Stakeholding_in_Integrated_Catchment_Management_and_Sustainable_Use_of_Water

Convention on Access to Information, Public Participation in Decision-Making and Access to Justice in Environmental Matters, United Nations Economic Commission for Europe (1998). https://unece.org/DAM/env/pp/documents/cep43e.pdf

Cooney, R., & Lang, A. T. F. (2007). Taking Uncertainty Seriously: Adaptive Governance and International Trade. *European Journal of International Law*, *18*(3), 523–551. https://doi.org/10.1093/ejil/chm030

Cooper, C. B., Dickinson, J., Phillips, T., & Bonney, R. (2007). Citizen Science as a Tool for Conservation in Residential Ecosystems. *Ecology and Society*, *12*(2), 1–11. https://www.jstor.org/stable/26267884

Council Decision 2005/370/EC of 17 February 2005 on the conclusion, on behalf of the European Community, of the Convention on access to information, public participation in decision-making and access to justice in environmental matters, (2005). http://data.europa.eu/eli/dec/2005/370/oj/eng

Council Directive 91/271/EEC of 21 May 1991 concerning urban waste-water treatment, (1991). http://data.europa.eu/eli/dir/1991/271/oj/eng

Council Directive of 12 December 1991 concerning the protection of water against pollution caused by nitrates from agricultural sources (91/676/EEC), (1991). https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A01991L0676-20081211

Crain, R., Cooper, C., & Dickinson, J. L. (2014). Citizen Science: A Tool for Integrating Studies of Human and Natural Systems. *Annual Review of Environment and Resources*, *39*(1), 641–665. https://doi.org/10.1146/annurev-environ-030713-154609

Crall, A. W., Newman, G. J., Stohlgren, T. J., Holfelder, K. A., Graham, J., & Waller, D. M. (2011). Assessing citizen science data quality: An invasive species case study. *Conservation Letters*, *4*(6), 433–442. https://doi.org/10.1111/j.1755-263X.2011.00196.x

Cundill, G., & Fabricius, C. (2009). Monitoring in adaptive co-management: Toward a learning based approach. *Journal of Environmental Management*, *90*(11), 3205–3211. https://doi.org/10.1016/j.jenvman.2009.05.012

Curtin, D., & Meijer, A. J. (2006). Does transparency strengthen legitimacy? *Information Polity*, *11*(2), 109–122. https://doi.org/10.3233/IP-2006-0091

Danielsen, F., Burgess, N. D., & Balmford, A. (2005). Monitoring matters: Examining the potential of locally-based approaches. *Biodiversity & Conservation*, *14*(11), 2507–2542. https://doi.org/10.1007/s10531-005-8375-0

Danielsen, F., Burgess, N. D., Balmford, A., Donald, P. F., Funder, M., Jones, J. P. G., Alviola, P., Balete, D. S., Blomley, T., Brashares, J., Child, B., Enghoff, M., Fjeldså, J., Holt, S., Hübertz, H., Jensen, A. E., Jensen, P. M., Massao, J., Mendoza, M. M., … Yonten, D. (2009). Local Participation in Natural Resource Monitoring: A Characterization of Approaches. *Conservation Biology*, *23*(1), 31–42. https://doi.org/10.1111/j.1523-1739.2008.01063.x

Danielsen, F., Jensen, P. M., Burgess, N. D., Altamirano, R., Alviola, P. A., Andrianandrasana, H., Brashares, J. S., Burton, A. C., Coronado, I., Corpuz, N., Enghoff, M., Fjeldså, J., Funder, M., Holt, S., Hübertz, H., Jensen, A. E., Lewis, R., Massao, J., Mendoza, M. M., … Young, R. (2014). A Multicountry Assessment of Tropical Resource Monitoring by Local Communities. *BioScience*, *64*(3), 236–251. https://doi.org/10.1093/biosci/biu001

Darwall, W., & Dulvy, N. K. (1996). An evaluation of the suitability of non-specialist volunteer researchers for coral reef fish surveys. Mafia Island, Tanzania—A case study. *Biological Conservation*, *78*(3), 223–231. https://doi.org/10.1016/0006-3207(95)00147-6

Data.public.lu. (2021a). *Découvrir l'OpenData*. https://data.public.lu/en/faq/

Data.public.lu. (2021b). *Search 'surface water'*. https://data.public.lu/en/search/?q=surface+water

Dedeurwaerdere, T. (2014). *Sustainability science for strong sustainability*. Edward Elgar. https://doi.org/10.4337/9781783474561

Denzin, N. K., & Lincoln, Y. S. (2011). Introduction: The Discipline and Practice of Qualitative Research. In *The SAGE Handbook of Qualitative Research* (3rd ed., pp. 1–33). SAGE.

Dickinson, J. L., Zuckerberg, B., & Bonter, D. N. (2010). Citizen Science as an Ecological Research Tool: Challenges and Benefits. *Annual Review of Ecology, Evolution, and Systematics*, *41*, 149–172. https://doi.org/10.2307/27896218

Dietz, T., Ostrom, E., & Stern, P. C. (2003). The Struggle to Govern the Commons. *Science*, *302*(5652), 1907–1912. https://doi.org/10.1126/science.1091015

Digital Luxembourg. (2021). *About us*. https://digital-luxembourg.public.lu/homepage

Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy, (2000). http://data.europa.eu/eli/dir/2000/60/oj/eng

Directive 2003/4/EC of the European Parliament and of the Council of 28 January 2003 on public access to environmental information and repealing Council Directive 90/313/EEC, (2003). http://data.europa.eu/eli/dir/2003/4/oj/eng

Directive 2003/35/EC of the European Parliament and of the Council of 26 May 2003 providing for public participation in respect of the drawing up of certain plans and programmes relating to the environment and amending with regard to public participation and access to justice, (2003). http://data.europa.eu/eli/dir/2003/35/oj/eng

Djalante, R., Holley, C., & Thomalla, F. (2011). Adaptive governance and managing resilience to natural hazards. *International Journal of Disaster Risk Science*, *2*(4), 1–14. https://doi.org/10.1007/s13753-011-0015-6

Drénkwaasser. (2021). *L'eau dans votre commune*. https://drenkwaasser.lu/fr/communes

Earthwatch. (2018a). *FreshWater Watch*. https://earthwatch.org.uk/get-involved/freshwater-watch

Earthwatch. (2018b). *Our mission and strategy*. https://earthwatch.org.uk/who-we-are/our-mission-and-strategy

Earthwatch. (2018c). *Royal Bank of Canada partnership*. https://earthwatch.org.uk/component/k2/royal-bank-of-canada-partnership

eBird. (2021). *About eBird*. https://ebird.org/ebird/about

EmiSure. (2021). *Allgemeine Projektbeschreibung*. https://www.emisure.lu/Description_g%C3%A9n%C3%A9rale_synth%C3%A9tique_du_projet_et_pr%C3%A9sentation_de_la_plus_value_transfrontali%C3%A8re_du_projet-7403

Engel, S. R., & Voshell, J. R. (2002). Volunteer biological monitoring: Can it accurately assess the ecological condition of streams? *American Entomologist*, *48*(3), 164–177. https://doi.org/citeulike-article-id:9349617

European Commission. (2021). *Aarhus Convention*. https://ec.europa.eu/environment/aarhus/legislation.htm

European Environment Agency. (2016). *Eutrophication*. https://www.eea.europa.eu/publications/92-9167-205-X/page014.html

European Environment Agency. (2018). *European waters: Assessment of status and pressures*. https://www.eea.europa.eu/publications/state-of-water

Eurostat. (2012). *Agri-environmental indicator—Nitrate pollution in rivers*. https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Archive:Agri-environmental_indicator_-_nitrate_pollution_of_water&oldid=104304

FeederWatch. (2021). *Project Overview*. https://feederwatch.org/about/project-overview/

Fernandez-Gimenez, M. E., Ballard, H. L., & Sturtevant, V. E. (2008). Adaptive Management and Social Learning in Collaborative and Community-Based Monitoring: A Study of Five Community-Based Forestry Organizations in the western USA. *Ecology and Society*, *13*(2), 1–23. https://www.jstor.org/stable/26267955

Flusspartnerschaft Syr. (2011). *Règlement d'Ordre intérieur du comité de rivière Syre*. http://www.partenariatsyr.lu/de/index.php?/ongoing/comite-de-riviere/

Flusspartnerschaften. (2019). *Luxemburgs Flusspartnerschaften*. https://www.flusspartnerschaften.lu

Folke, C., Hahn, T., Olsson, P., & Norberg, J. (2005). Adaptive Governance of Social-Ecological Systems. *Annual Review of Environment and Resources*, *30*(1), 441–473. https://doi.org/10.1146/annurev.energy.30.050504.144511

FreshWater Watch. (2020a, March 15). *A2-15-03-2020-0*. https://freshwaterwatch.thewaterhub.org/fr/sample/a2-15-03-2020-0

FreshWater Watch. (2020b, July 22). *Explore our data*. https://freshwaterwatch.thewaterhub.org/our-data/explore-our-data

FreshWater Watch. (2021). *Nexus citizen science*. https://freshwaterwatch.thewaterhub.org/fr/group/nexus-citizen-science

Funtowicz, S. O., & Ravetz, J. R. (1993). Science for the post-normal age. *Futures*, *25*(7), 739–755. https://doi.org/10.1016/0016-3287(93)90022-L

Gardiner, M. M., Allee, L. L., Brown, P. M. J., Losey, J. E., Roy, H. E., & Smyth, R. R. (2012). Lessons from lady beetles: Accuracy of monitoring data from US and UK citizen-science programs. *Frontiers in Ecology and the Environment*, *10*(9), 471–476. https://doi.org/10.1890/110185

Geoportal. (2021a). *About us*. http://www.geoportail.lu/en/about-us/

Geoportal. (2021b). *Water: Drinking Water Syndicates*. https://map.geoportail.lu/theme/eau?version=3&zoom=10&X=661930&Y=6411339&lang=en&rotation=0&layers=538&opacities=1&bgLayer=basemap_2015_global&crosshair=false

Geoportal. (2021c). *Water: Monitoring progamms results*. https://map.geoportail.lu/theme/eau?version=3&zoom=9&X=743062&Y=6421317&lang=en&layers=768&opacities=1&bgLayer=basemap_2015_global&rotation=0

Geoportal. (2021d). *Water: Wastewater treatment plants*. https://map.geoportail.lu/theme/eau?version=3&zoom=10&X=706081&Y=6407657&lang=en&rotation=0&layers=645&opacities=1&bgLayer=basemap_2015_global

GLOBE Switzerland. (2019). *Interpretation der chemischen und physikalischen Untersuchungen in Fließgewässern*. GLOBE Switzerland. https://www.globe-swiss.ch/files/Downloads/865/Download/Interpretation%20Hydrologieparameter.pdf

Google Dictionary. (2021a). *Level*. https://www.google.com/search?q=define+level+&rlz=1C1OKWM_deDE900DE901&sxsrf=AOaemvK1XMeQAygd-QpmSOCdjNFUirLofg%3A1636382604032&ei=jDeJYbbAAZOejLsPg76S-A4&oq=define+level+&gs_lcp=Cgdnd3Mtd2l6EAMyBAgjECcyBQgAEJECMgUIABCABDIFCAAQgAQyBQgAEIAEMgUIABCABDIFCAAQgAQyBQgAEIAEMgUIABCABDIFCAAQgAQ6BwgjELADECc6BwgAEEcQsANKBQg8EgEySgQIQRgAUNcKWNcKYL4MaAJwAngAgAFliAFlkgEDMC4xmAEAoAEByAEJwAEB&sclient=gws-wiz&ved=0ahUKEwi2ttGegIn0AhUTD2MBHQOfBO8Q4dUDCA4&uact=5

Google Dictionary. (2021b). *Scale*. https://www.google.com/search?q=define+scale&rlz=1C1OKWM_deDE900DE901&sxsrf=AOaemvKv2hMSuOnxSrwzIFJoA5q9sRSJdA%3A1636382804248&ei=VDiJYf_WDuqjgwfooIeADw&oq=define+scale&gs_lcp=Cgdnd3Mtd2l6EAMyBAgjECcyBQgAEJECMgoIABCABBCHAhAUMgUIABCABDIFCAAQkQIyCggAEIAEEIcCEBQyBQgAEIAEMgUIABCABDIFCAAQgAQyBQgAEIAEOgcIIxCwAxAnOgcIABBHELADOgUIABDLAUoFCDwSATJKBAhBGABQmQRYgwlgwQpoAnACeACAAYIBiAH9A5IBAzMuMpgBAKABAcgBCsABAQ&sclient=gws-wiz&ved=0ahUKEwj_0I3-gIn0AhXq0eAKHWjQAfAQ4dUDCA4&uact=5

Guichet. (2019). *Communes (communal administrations)*. https://guichet.public.lu/en/organismes/organismes_entreprises/administrations-communales.html

Haklay, M. (2013). Citizen Science and Volunteered Geographic Information – overview and typology of participation. In *Crowdsourcing Geographic Knowledge: Volunteered Geographic Information (VGI) in Theory and Practice* (pp. 105–122). Springer. https://doi.org/10.1007/978-94-007-4587-2

Haklay, M. (2015). *Citizen Science and Policy: A European Perspective*. Woodrow Wilson International Center for Scholars. https://www.scribd.com/document/256283024/Citizen-Science-and-Policy-A-European-Perspective

Haklay, M., & Tobón, C. (2003). Usability evaluation and PPGIS: Towards a user-centred design approach. *International Journal of Geographical Information Science*, *17*(6), 577–592. https://doi.org/10.1080/1365881031000114107

Haklay, M., & Weber, P. (2008). OpenStreetMap: User-generated street maps. *IEEE Pervasive Computing*, *7*(4), 12–18. https://doi.org/10.1109/MPRV.2008.80

Hasselman, L. (2017). Adaptive management; adaptive co-management; adaptive governance: What's the difference? *Australasian Journal of Environmental Management*, *24*(1), 31–46. https://doi.org/10.1080/14486563.2016.1251857

Haywood, B. K. (2014). A "Sense of Place" in Public Participation in Scientific Research. *Science Education*, *98*(1), 64–83. https://doi.org/10.1002/sce.21087

Hecker, S., Haklay, M., Bowser, A., Makuch, Z., & Vogel, J. (2018). *Citizen Science: Innovation in Open Science, Society and Policy*. UCL Press. https://doi.org/10.14324/111.9781787352339

Heron, J., & Reason, P. (1997). A Participatory Inquiry Paradigm. *Qualitative Inquiry*, *3*(3), 274–294. https://doi.org/10/fbnwc6

Herrfahrdt-Pähle, E. (2013). Integrated and adaptive governance of water resources: The case of South Africa. *Regional Environmental Change*, *13*(3), 551–561. https://doi.org/10.1007/s10113-012-0322-5

Ho, L., Jerves-Cobo, R., Barthel, M., Six, J., Bode, S., Boeckx, P., & Goethals, P. (2020). Effects of land use and water quality on greenhouse gas emissions from an urban river system. *Biogeosciences Discussions*, 1–22. https://doi.org/10.5194/bg-2020-311

Ho, S. Y.-F., Xu, S. J., & Lee, F. W.-F. (2020). Citizen science: An alternative way for water monitoring in Hong Kong. *Plos One*, *15*(9), 1–17. https://doi.org/10.1371/journal.pone.0238349

Hochachka, G. (2021). Finding shared meaning in the Anthropocene: Engaging diverse perspectives on climate change. *Sustainability Science*, 1–21. https://doi.org/10.1007/s11625-021-00965-4

Holling, C. S. (1978). *Adaptive environmental assessment and management*. John Wiley & Sons. http://pure.iiasa.ac.at/823

Huitema, D., Mostert, E., Egas, W., Moellenkamp, S., Pahl-Wostl, C., & Yalcin, R. (2009). Adaptive Water Governance: Assessing the Institutional Prescriptions of Adaptive (Co-

)Management from a Governance Perspective and Defining a Research Agenda. *Ecology and Society*, *14*(1), 1–19. https://doi.org/10.5751/ES-02827-140126

Inondations. (2017). *Information*. https://www.inondations.lu/information

Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. (2019a). *Global assessment report on biodiversity and ecosystem services* (p. 1148). https://zenodo.org/record/3831674#.YTIaL50zZPY

Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. (2019b). *Global assessment report on biodiversity and ecosystem services: Summary for policy-makers* (p. 60). https://zenodo.org/record/3553579#.YTIVIp0zZPY

Interviewee 1, group interview. (2017). *Interviewed by K. Pickar on the Luxembourgish water data landscape, 24 November* [Personal communication].

Interviewee 2, group interview. (2017). *Interviewed by K. Pickar on the Luxembourgish water data landscape, 24 November* [Personal communication].

Interviewee 4, personal interview. (2017). *Interviewed by K. Pickar on the Luxembourgish water data landscape, 11 December* [Personal communication].

Interviewee 6, personal interview. (2017). *Interviewed by K. Pickar on the Luxembourgish water data landscape, 20 December* [Personal communication].

Interviewee 8, personal interview. (2018). *Interviewed by K. Pickar on the Luxembourgish water data landscape, 9 January* [Personal communication].

Interviewee 9, group interview. (2018). *Interviewed by K. Pickar on the Luxembourgish water data landscape, 24 January* [Personal communication].

Interviewee 11, personal interview. (2018). *Interviewed by K. Pickar on the Luxembourgish water data landscape, 26 January* [Personal communication].

Irwin, A. (1995). *Citizen Science: A Study of People, Expertise and Sustainable Development*. Psychology Press.

Jerneck, A., Olsson, L., Ness, B., Anderberg, S., Baier, M., Clark, E., Hickler, T., Hornborg, A., Kronsell, A., Lövbrand, E., & Persson, J. (2011). Structuring sustainability science. *Sustainability Science*, *6*(1), 69–82. https://doi.org/10/dr48wq

Jollymore, A., Haines, M. J., Satterfield, T., & Johnson, M. S. (2017). Citizen science for water quality monitoring: Data implications of citizen perspectives. *Journal of Environmental Management*, *200*, 456–467. https://doi.org/10.1016/j.jenvman.2017.05.083

Jones, N. A., Ross, H., Lynam, T., Perez, P., & Leitch, A. (2011). Mental Models: An Interdisciplinary Synthesis of Theory and Methods. *Ecology and Society*, *16*(1). https://www.jstor.org/stable/26268859

Jordan, R. C., Ballard, H. L., & Phillips, T. B. (2012). Key issues and new approaches for evaluating citizen-science learning outcomes. *Frontiers in Ecology and the Environment*, *10*(6), 307–309. https://doi.org/10.1890/110280

Kaneshiro, K. Y., Chinn, P., Duin, K. N., Hood, A. P., Maly, K., & Wilcox, B. A. (2005). Hawai'i's Mountain-to-Sea Ecosystems: Social–Ecological Microcosms for Sustainability Science and Practice. *EcoHealth*, *2*(4), 349–360. https://doi.org/10.1007/s10393-005-8779-z

Kates, R. W., Clark, W. C., Corell, R., Hall, J. M., Jaeger, C. C., Lowe, I., McCarthy, J. J., Schellnhuber, H. J., Bolin, B., Dickson, N. M., Faucheux, S., Gallopin, G. C., Grübler, A., Huntley, B., Jäger, J., Jodha, N. S., Kasperson, R. E., Mabogunje, A., Matson, P., … work(s):, U. S. R. (2001).

Sustainability Science. *Science, New Series*, *292*(5517), 641–642. https://doi.org/10.1126/science.1059386

Komiyama, H., & Takeuchi, K. (2006). Sustainability science: Building a new discipline. *Sustainability Science*, *1*(1), 1–6. https://doi.org/10.1007/s11625-006-0007-4

König, A. (2018). Sustainability science as a transformative social learning process. In A. König & J. Ravetz (Eds.), *Sustainability Science* (1st ed., pp. 3–28). Routledge. https://doi.org/10.9774/gleaf.9781315620329_2

Kremen, C., Ullman, K. S., & Thorp, R. W. (2011). Evaluating the quality of citizen-scientist data on pollinator communities. *Conservation Biology*, *25*(3), 607–617. https://doi.org/10.1111/j.1523-1739.2011.01657.x

Lang, D. J., Wiek, A., Bergmann, M., Stauffacher, M., Martens, P., Moll, P., Swilling, M., & Thomas, C. J. (2012). Transdisciplinary research in sustainability science: Practice, principles, and challenges. *Sustainability Science*, *7*(S1), 25–43. https://doi.org/10.1007/s11625-011-0149-x

Lang, D. J., Wiek, A., & von Wehrden, H. (2017). Bridging divides in sustainability science. *Sustainability Science*, *12*(6), 875–879. https://doi.org/10.1007/s11625-017-0497-2

Levin, S. A., & Clark, W. C. (2010). *Toward a Science of Sustainability*. Center for International Development Working Papers 196, John F. Kennedy School of Government, Harvard University. http://nrs.harvard.edu/urn-3:HUL.InstRepos:9774654

Lintott, C. J., Schawinski, K., Slosar, A., Land, K., Bamford, S., Thomas, D., Raddick, M. J., Nichol, R. C., Szalay, A., Andreescu, D., Murray, P., & Vandenberg, J. (2008). Galaxy Zoo: Morphologies derived from visual inspection of galaxies from the Sloan Digital Sky

Survey. *Monthly Notices of the Royal Astronomical Society*, *389*(3), 1179–1189. https://doi.org/10.1111/j.1365-2966.2008.13689.x

Lockwood, M., Davidson, J., Curtis, A., Stratford, E., & Griffith, R. (2010). Governance Principles for Natural Resource Management. *Society & Natural Resources*, *23*(10), 986–1001. https://doi.org/10.1080/08941920802178214

Loi communal, (1988). http://legilux.public.lu/eli/etat/leg/loi/1988/12/13/n1/jo

Loi du 3 décembre 2014 ayant pour objet l'organisation des centres de recherche publics, (2014). http://www.legilux.lu/eli/etat/leg/loi/2014/12/03/n2/jo

Loi du 5 juin 2009 portant création de l'Administration de la nature et des forêts, (2009). http://legilux.public.lu/eli/etat/leg/loi/2009/06/05/n6/jo

Loi du 10 août 1993 relative aux parcs naturels, (1993). http://legilux.public.lu/eli/etat/leg/loi/1993/08/10/n1/jo

Loi du 19 décembre 2008 relative à l'eau, (2008). http://data.legilux.public.lu/eli/etat/leg/loi/2008/12/19/n17/jo

Loi du 25 novembre 2005 concernant l'accès du public à l'information en matière d'environnement, (2005). https://legilux.public.lu/eli/etat/leg/loi/2005/11/25/n4/jo

Loi du 28 mai 2004 portant création d'une Administration de la Gestion de l'Eau, (2004). http://legilux.public.lu/eli/etat/leg/loi/2004/05/28/n1/jo

Luxembourg Institute of Science and Technology. (2019). *L'impact: Le moteur de notre excellence—Rapport annuel.* https://www.list.lu/fileadmin/files/corporate_content/Rapports-annuels/LIST_ANNUAL_REPORT_2019_EN.pdf

Luxembourg Institute of Science and Technology. (2020). *Mission, Vision, Values*. https://www.list.lu/en/institute/who-we-are/mission-vision-values/

Mapping for Change. (2021). *Our Company*. https://mappingforchange.org.uk/our-company/

Mason, J. (2002). *Qualitative researching* (2nd ed.). Sage Publications.

Merriam-Webster. (2021). *Public*. https://www.merriam-webster.com/dictionary/public

Midgley, G. F., Hughes, G. O., Thuiller, W., & Rebelo, A. G. (2006). Migration rate limitations on climate change-induced range shifts in Cape Proteaceae. *Diversity and Distributions*, *12*(5), 555–562. https://doi.org/10.1111/j.1366-9516.2006.00273.x

Mielke, J., Vermaßen, H., Ellenbeck, S., Fernandez Milan, B., & Jaeger, C. (2016). Stakeholder involvement in sustainability science—A critical view. *Energy Research & Social Science*, *17*, 71–81. https://doi.org/10.1016/j.erss.2016.04.001

Miller, T. R. (2013). Constructing sustainability science: Emerging perspectives and research trajectories. *Sustainability Science*, *8*(2), 279–293. https://doi.org/10.1007/s11625-012-0180-6

Ministère de l'Intérieur. (2018). *La législation communale*. Ministère de l'Intérieur. https://mint.gouvernement.lu/dam-assets/personnel-communal/recrutement-examen-d-admissibilite/programmes/Organisation-des-communes-admissibilite-B1-A-A2-A1.pdf

Munson, M. A., Caruana, R., Fink, D., Hochachka, W. M., Iliff, M., Rosenberg, K. V., Sheldon, D., Sullivan, B. L., Wood, C., & Kelling, S. (2010). A method for measuring the relative information content of data from different monitoring protocols. *Methods in Ecology and Evolution*, *1*(3), 263–273. https://doi.org/10.1111/j.2041-210X.2010.00035.x

Natur- & Geopark Mëllerdall. (2018a). *About us*. https://www.naturpark-mellerdall.lu/en/the-nature-parc/about-us/

Natur- & Geopark Mëllerdall. (2018b). *Aktionsprogramm zum Quellenschutz*. https://www.naturpark-mellerdall.lu/projekte/aktionsprogramm-zum-quellenschutz-im-natur-geopark-mellerdall/

natur&ëmwelt. (2020a). *natur&ëmwelt a.s.b.l. - Über uns*. https://www.naturemwelt.lu/de/ueber-uns/naturemwelt-a-s-b-l/ueber-uns/

natur&ëmwelt. (2020b). *Unsere Mission—Natur&ëmwelt Fondation Hëllef fir d'Natur*. https://www.naturemwelt.lu/de/ueber-uns/fondation-hellef-fir-dnatur/ueber-uns/

Nelson, R., Howden, M., & Smith, M. S. (2008). Using adaptive governance to rethink the way science supports Australian drought policy. *Environmental Science & Policy*, *11*(7), 588–601. https://doi.org/10.1016/j.envsci.2008.06.005

Newman, C., Buesching, C. D., & Macdonald, D. W. (2003). Validating mammal monitoring methods and assessing the performance of volunteers in wildlife conservation—"Sed quis custodiet ipsos custodies?". *Biological Conservation*, *113*(2), 189–197. https://doi.org/10.1016/S0006-3207(02)00374-9

Newman, G., Chandler, M., Clyde, M., McGreavy, B., Haklay, M., Ballard, H., Gray, S., Scarpino, R., Hauptfeld, R., Mellor, D., & Gallo, J. (2017). Leveraging the power of place in citizen science for effective conservation decision making. *Biological Conservation*, *208*, 55–64. https://doi.org/10.1016/j.biocon.2016.07.019

Oé, J. (2017). Gefährliche Cyanobakterien im Stausee von Esch/Sauer. *Tageblatt Lëtzebuerg*. https://www.tageblatt.lu/headlines/gefaehrliche-cyanobakterien-im-stausee-von-esch-sauer/

Oliver, D. G., Serovich, J. M., & Mason, T. L. (2005). Constraints and Opportunities with Interview Transcription: Towards Reflection in Qualitative Research. *Social Forces*, *84*(2), 1273–1289. https://doi.org/10.1353/sof.2006.0023

Olsson, P., Gunderson, L., Carpenter, S., Ryan, P., Lebel, L., Folke, C., & Holling, C. s. (2005). Shooting the Rapids: Navigating Transitions to Adaptive Governance of Social-Ecological Systems. *Ecology and Society*, *11*(1), 1–21. https://doi.org/10.5751/ES-01595-110118

Österblom, H., & Folke, C. (2013). Emergence of Global Adaptive Governance for Stewardship of Regional Marine Resources. *Ecology and Society*, *18*(2), 1–13. https://doi.org/10.5751/ES-05373-180204

Ostrom, E. (1990). *Governing the commons: The evolution of institutions for collective action*. Cambridge University Press.

Ostrom, E. (2010). Polycentric systems for coping with collective action and global environmental change. *Global Environmental Change*, *20*(4), 550–557. https://doi.org/10.1016/j.gloenvcha.2010.07.004

Penguin Transcription. (2021). *Verbatim, intelligent verbatim or edited transcription?* https://penguin-transcription.co.uk/transcription-type-verbatim-intelligent-verbatim-or-edited/

Pereira, L. M., & Ruysenaar, S. (2012). Moving from traditional government to new adaptive governance: The changing face of food security responses in South Africa. *Food Security*, *4*(1), 41–58. https://doi.org/10.1007/s12571-012-0164-5

Pickar, K., & König, A. (2019). *Bericht: Co-Design Workshop—Müllerthal*. University of Luxembourg. https://sustainabilityscience.uni.lu/wp-content/uploads/sites/48/2021/04/Bericht_Co-Design-Workshop_Quellenschutz-Mullerthal_NEXUS-CITIZEN-SCIENCE.pdf

Pickar, K., & König, A. (2020). *Citizen Science at the Syr: 1st year report*. University of Luxembourg.

Plummer, R., Armitage, D., & de Loë, R. (2013). Adaptive Comanagement and Its Relationship to Environmental Governance. *Ecology and Society*, *18*(1), 1–15. https://doi.org/10.5751/ES-05383-180121

Potter, R. (2019). *Australian Work Health and Safety Policy for Psychosocial Hazards and Risks: Evaluation of the Context, Content, and Implementation* [Doctoral Thesis, University of South Australia]. https://www.researchgate.net/profile/Rachael-Potter/publication/332669251_Australian_Work_Health_and_Safety_Policy_for_Psychosocial_Hazards_and_Risks_Evaluation_of_the_Context_Content_and_Implementation/links/5cc26cff299bf120977f8bc9/Australian-Work-Health-and-Safety-Policy-for-Psychosocial-Hazards-and-Risks-Evaluation-of-the-Context-Content-and-Implementation.pdf

Protea Atlas Project. (2021). *Overview of project*. https://www.proteaatlas.org.za/index.htm

Quinlivan, L., Chapman, D. V., & Sullivan, T. (2020). Validating citizen science monitoring of ambient water quality for the United Nations sustainable development goals. *Science of The Total Environment*, *699*, 1–9. https://doi.org/10.1016/j.scitotenv.2019.134255

Ravetz, J. R. (1999). What is Post-Normal Science. *Futures*, *31*, 647–653. http://www.andreasaltelli.eu/file/repository/Editorials2.pdf

Raymond, C. M., Singh, G. G., Benessaiah, K., Bernhardt, J. R., Levine, J., Nelson, H., Turner, N. J., Norton, B., Tam, J., & Chan, K. M. A. (2013). Ecosystem Services and Beyond: Using Multiple Metaphors to Understand Human-Environment Relationships. *BioScience*, *63*(7), 536–546. https://doi.org/10.1525/bio.2013.63.7.7

RBC Investor & Treasury Services. (2020a). *Citizenship*. https://www.rbcits.com/en/citizenship.page

RBC Investor & Treasury Services. (2020b). *Who we are—At a glance*. https://www.rbcits.com/en/who-we-are/at-a-glance.page

Reed, M. S. (2008). Stakeholder participation for environmental management: A literature review. *Biological Conservation*, *141*(10), 2417–2431. https://doi.org/10.1016/j.biocon.2008.07.014

Reed, M. S., Graves, A., Dandy, N., Posthumus, H., Hubacek, K., Morris, J., Prell, C., Quinn, C. H., & Stringer, L. C. (2009). Who's in and why? A typology of stakeholder analysis methods for natural resource management. *Journal of Environmental Management*, *90*(5), 1933–1949. https://doi.org/10.1016/j.jenvman.2009.01.001

Règlement grand-ducal du 7 octobre 2002 relatif à la qualité des eaux destinées à la consommation humaine, (2002). https://sebes.lu/wp-content/uploads/2016/12/RGD-du-7-octobre-2002.pdf

Règlement grand-ducal du 13 mai 1994 relatif au traitement des eaux urbaines résiduaires, (1994). http://data.legilux.public.lu/eli/etat/leg/rgd/1994/05/13/n1/jo

Règlement grand-ducal du 17 mars 2016 portant déclaration du Parc naturel du «Mëllerdall», (2016). http://legilux.public.lu/eli/etat/leg/rgd/2016/03/17/n4/jo

Règlement grand-ducal du 24 novembre 2000 concernant l'utilisation de fertilisants azotés dans l'agriculture, (2000). https://legilux.public.lu/eli/etat/leg/rgd/2000/11/24/n5/jo

Rittel, & Webber, M. (1973). Dilemmas in a General Theory of Planning. *Policy Sciences*, *4*(2), 155–169. https://doi.org/10.1007/BF01405730

Rotman, D., Hammock, J., Preece, J., Hansen, D., Boston, C., Bowser, A., & He, Y. (2014). Motivations Affecting Initial and Long-Term Participation in Citizen Science Projects in Three Countries. *IConference 2014 Proceedings*, 110–124. https://doi.org/10.9776/14054

Rotman, D., Preece, J., Hammock, J., Procita, K., Hansen, D., Parr, C., Lewis, D., & Jacobs, D. (2012). Dynamic changes in motivation in collaborative citizen-science projects. *Proceedings of the ACM 2012 Conference on Computer Supported Cooperative Work*, 217–226. https://doi.org/10.1145/2145204.2145238

Royal Bank of Canada. (2020). *Our company*. https://www.rbc.com/our-company/index.html

Sanders, E. B. N., Brandt, E., & Binder, T. (2010). A framework for organizing the tools and techniques of participatory design. *Proceedings of the 11th Biennial Participatory Design Conference*, 195–198. https://doi.org/10.1145/1900441.1900476

Shirk, J. L., Ballard, H. L., Wilderman, C. C., Phillips, T., Wiggins, A., Jordan, R., McCallie, E., Minarchek, M., Lewenstein, B. V., Krasny, M. E., & Bonney, R. (2012). Public Participation in Scientific Research: A Framework for Deliberate Design. *Ecology and Society*, *17*(2), 1–21. https://www.jstor.org/stable/26269051

Siebenhüner, B. (2004). Social learning and sustainability science: Which role can stakeholder participation play. *International Journal of Sustainable Development*, *7*(2), 146–163.

http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.453.6189&rep=rep1&type=pdf#page=82

Silvertown, J. (2009). A new dawn for citizen science. *Trends in Ecology and Evolution*, *24*(9), 467–471. https://doi.org/10.1016/j.tree.2009.03.017

Skaburskis, A. (2008). The Origin of "Wicked Problems". *Planning Theory & Practice*, *9*(2), 277–280. https://doi.org/10.1080/14649350802041654

Skarlatidou, A., & Haklay, M. (2021). *Geographic Citizen Science Design: No one left behind*. UCL Press. https://doi.org/10.14324/111.9781787356122

Spangenberg, J. H. (2011). Sustainability science: A review, an analysis and some empirical lessons. *Environmental Conservation*, *38*(3), 275–287. https://doi.org/10.1017/S0376892911000270

Stock, P., & Burton, R. J. F. (2011). Defining Terms for Integrated (Multi-Inter-Trans-Disciplinary) Sustainability Research. *Sustainability*, *3*(8), 1090–1113. https://doi.org/10.3390/su3081090

Stringer, E. (2014). *Action Research* (4th ed.). SAGE Publications.

Sturm, U., Schade, S., Ceccaroni, L., Gold, M., Kyba, C., Claramunt, B., Haklay, M., Kasperowski, D., Albert, A., Piera, J., Brier, J., Kullenberg, C., & Luna, S. (2018). Defining principles for mobile apps and platforms development in citizen science. *Research Ideas and Outcomes*, *4*, 1–12. https://doi.org/10.3897/rio.4.e23394

Sturm, U., & Tscholl, M. (2019). The role of digital user feedback in a user-centred development process in citizen science. *Journal of Science Communication*, *18*(1), 1–19. https://doi.org/10.22323/2.18010203

Sullivan, B. L., Aycrigg, J. L., Barry, J. H., Bonney, R. E., Bruns, N., Cooper, C. B., Damoulas, T., Dhondt, A. A., Dietterich, T., Farnsworth, A., Fink, D., Fitzpatrick, J. W., Fredericks, T., Gerbracht, J., Gomes, C., Hochachka, W. M., Iliff, M. J., Lagoze, C., La Sorte, F. A., … Kelling, S. (2014). The eBird enterprise: An integrated approach to development and application of citizen science. *Biological Conservation*, *169*, 31–40. https://doi.org/10.1016/j.biocon.2013.11.003

Summa Linguae. (2021, April 28). *Verbatim vs. Intelligent vs. Edited Transcription Explained*. https://summalinguae.com/data/verbatim-vs-intelligent-vs-edited-transcription/

Syndicat des Eaux du Barrage d'Esch-sur-Sûre. (2021a). *Die Trinkwasserqualität*. https://sebes.lu/de/qualite-de-leau/potable-du-sebes/

Syndicat des Eaux du Barrage d'Esch-sur-Sûre. (2021b). *Qualitätskontrolle der Zuflüsse des Stausees*. https://sebes.lu/de/qualite-de-leau/du-lac-et-de-ses-affluents/

Syndicat des Eaux du Sud. (2018). *Le réseau du SES*. http://www.ses-eau.lu/online/www/navMain/12/42/FRE/index.html

Syndicat des Eaux du Sud Koerich. (2021). *La qualité de l'eau*. http://www.ses-eau.lu/online/www/navMain/44/FRE/index.html

Syndicat Intercommunal de Dépollution des Eaux Résiduaires de l'Ouest. (2014). *Rapport de gestion 2011-2014*. https://sidero.lu/sites/default/files/rapport_de_gestion_2011-2014_sidero_bd.pdf

Syndicat Intercommunal de Dépollution des Eaux Résiduaires du Nord. (2019). *Rapport d'activité*. https://www.siden.lu/Documents_grand_public-5801

Syndicat Intercommunal de Dépollution des Eaux Résiduaires du Nord. (2021). *Bilanz der Abwasserreinigung*. https://www.siden.lu/index.php?page=5804&&numlangue=2

Syndicat Intercommunal pour la Distribution d'Eau dans la Région de l'Est. (2021). *Analyses—Réseau 9000*. https://www.sidere.lu/fr/Pages/R%C3%A9seau-9000.aspx?TermStoreId=bd2f1f6a-8700-41c5-9dca-088c0d0c9ac4&TermSetId=9d2d1b2b-16a9-444d-939b-51fd1167ffe4&TermId=eb2263ba-5d92-43bd-9d98-800ee25c319e

Syndicat Intercommunal pour l'Assainissement du Bassin de la Chiers. (2017). *Rapport de gestion 2016-2017*. https://www.siach.lu/fr/Documents/Rapport%20de%20gestion%202016%20-%202017.pdf

Syndicat Intercommunal pour l'Assainissement du Bassin de la Chiers. (2020). *Le S.I.A.CH.* https://www.siach.lu/fr/Pages/Le-S-I-A-CH.aspx?TermStoreId=bd2f1f6a-8700-41c5-9dca-088c0d0c9ac4&TermSetId=e413fe89-d452-4a2f-a7c4-9b5e634bd30b&TermId=bc03d10c-176d-4ed1-8f3c-78d0c449cc54

Syndicats des Villes et Communes Luxembourgeoises. (2020). *SIFRIDAWE*. https://www.syvicol.lu/fr/annuaires-des-communes-et-des-syndicats/annuaire-des-syndicats/secteur/fiche/eau/sifridawe

Tageblatt Lëtzebuerg. (2021). *Planschen fällt ins Wasser / Baden im Stausee wegen Blaualgen ab sofort verboten*. https://www.tageblatt.lu/headlines/baden-im-obersauer-stausee-wegen-blaualgen-ab-sofort-verboten/

Termeer, C. J. A. M., Dewulf, A., & van Lieshout, M. (2010). Disentangling Scale Approaches in Governance Research: Comparing Monocentric, Multilevel, and Adaptive Governance. *Ecology and Society*, *15*(4), 1–15. https://doi.org/10.5751/ES-03798-150429

The Luxembourg Government. (2018). *Ministry of the Environment, Climate and Sustainable Development*. https://environnement.gouvernement.lu/en/service.html

Toomey, A. H., Strehlau-Howay, L., Manzolillo, B., & Thomas, C. (2020). The place-making potential of citizen science: Creating social-ecological connections in an urbanized world. *Landscape and Urban Planning*, *200*, 1–8. https://doi.org/10.1016/j.landurbplan.2020.103824

Trumbull, D., Bonney, R., Bascom, D., & Cabral, A. (2000). Thinking Scientifically during Participation in a Citizen-Science Project. *Science Education*, *84*, 265–275. http://dx.doi.org/10.1002/(SICI)1098-237X(200003)84:2%3C265::AID-SCE7%3E3.0.CO;2-5

Turnhout, E., Van Bommel, S., & Aarts, N. (2010). How Participation Creates Citizens: Participatory Governance as Performative Practice. *Ecology and Society*, *15*(4), 1–15. https://doi.org/10.5751/ES-03701-150426

United Nations. (2021). *The United Nations world water development report 2021: Valuing water*. United Nations Educational, Scientific and Cultural Organization. https://www.unwater.org/publications/un-world-water-development-report-2021/

United Nations Environment Programme. (2020, January 31). *New insights into how global change is impacting freshwater environments*. http://www.unep.org/news-and-stories/story/new-insights-how-global-change-impacting-freshwater-environments

United Nations Environment Programme. (2021). *Progress on ambient water quality: Global indicator 6.3.2 updates and accelerated needs*. https://www.unwater.org/publications/progress-on-ambient-water-quality-632-2021-update/

University College London. (2017). *Transcribe Bentham*. http://transcribe-bentham.ucl.ac.uk/td/Transcribe_Bentham

University College London. (2021a). *Extreme Citizen Science (ExCiteS)*. https://www.geog.ucl.ac.uk/research/research-centres/excites

University College London. (2021b). *Publications*. https://www.geog.ucl.ac.uk/research/research-centres/excites/publications

Van Assche, K., Beunen, R., Duineveld, M., & Gruezmacher, M. (2017). Power/knowledge and natural resource management: Foucaultian foundations in the analysis of adaptive governance. *Journal of Environmental Policy & Planning*, *19*(3), 308–322. https://doi.org/10.1080/1523908X.2017.1338560

Vohland, K., Land-Zandstra, A., Ceccaroni, L., Lemmens, R., Perelló, J., Ponti, M., Samson, R., & Wagenknecht, K. (2021a). Editorial: The science of citizen science evolves. In *The science of citizen science*. Springer. https://doi.org/10.1007/978-3-030-58278-4

Vohland, K., Land-Zandstra, A., Ceccaroni, L., Lemmens, R., Perelló, J., Ponti, M., Samson, R., & Wagenknecht, K. (Eds.). (2021b). *The Science of Citizen Science*. Springer. https://doi.org/10.1007/978-3-030-58278-4

Walker, D., Forsythe, N., Parkin, G., & Gowing, J. (2016). Filling the observational void: Scientific value and quantitative validation of hydrometeorological data from a community-based monitoring programme. *Journal of Hydrology*, *538*, 713–725. https://doi.org/10.1016/j.jhydrol.2016.04.062

Walker, W. E., Harremoës, P., Rotmans, J., van der Sluijs, J. P., van Asselt, M. B. A., Janssen, P., & Krayer von Krauss, M. P. (2003). Defining Uncertainty: A Conceptual Basis for Uncertainty Management in Model-Based Decision Support. *Integrated Assessment*, *4*(1), 5–17. https://doi.org/10.1076/iaij.4.1.5.16466

Wals, A. E. J., Hoeven, N. V. D., & Blanken, H. (2009). *The acoustics of social learning: Designing learning processes that contribute to a more sustainable world*. Wageningen Academic Publishers.

Walters, C., & Hilborn, R. (1978). Ecological Optimization and Adaptive Management. *Annual Review of Ecology and Systematics*, *9*, 157–188. https://doi.org/10.1146/annurev.es.09.110178.001105

Waylen, K. A., Blackstock, K. L., van Hulst, F. J., Damian, C., Horváth, F., Johnson, R. K., Kanka, R., Külvik, M., Macleod, C. J. A., Meissner, K., Oprina-Pavelescu, M. M., Pino, J., Primmer, E., Rîșnoveanu, G., Šatalová, B., Silander, J., Špulerová, J., Suškevičs, M., & Van Uytvanck, J. (2019). Policy-driven monitoring and evaluation: Does it support adaptive management of socio-ecological systems? *Science of The Total Environment*, *662*, 373–384. https://doi.org/10.1016/j.scitotenv.2018.12.462

Whitehead, P., Wilby, R., Battarbee, R., Kernan, M., & Wade, A. (2009). A Review of the Potential Impacts of Climate Change on Surface Water Quality. *Hydrological Sciences Journal/Journal Des Sciences Hydrologiques*, *54*(1), 101–123. https://doi.org/10.1623/hysj.54.1.101

Wiggins, A., & Crowston, K. (2011). From Conservation to Crowdsourcing: A Typology of Citizen Science. *44th Hawaii International Conference on System Sciences*, 1–10. https://doi.org/10.1109/HICSS.2011.207

World Health Organization. (2011). *Nitrate and nitrite in drinking-water: Background document for development of WHO guidelines of drinking-water quality*. https://www.who.int/water_sanitation_health/dwq/chemicals/nitratenitrite2ndadd.pdf

Annex 1. Interview Questions with Sub-Questions

The Role of the Organisation Associated with the Interviewee in the Luxembourgish Data Landscape on Water and Water Quality (if Applicable), Data Collection, Data Publication, and Role of Citizens

1. How would you describe the role of your organisation within the Luxembourgish data landscape on water?
    - What are the main motivations of your organisation to collect data on water?
    - Are there any resources made available to your organisation for the collection of data? If so, which?
    - Are the resources enough to fulfil the role of your organisation?
    - How would you evaluate the role of your organisation in the data landscape? Are there any opportunities?
    - Which kinds of data do you collect? How are they collected and why?
    - Who can access the data and how? Which data is publicly accessible?
    - Where is the data stored and for how long (e.g. internally, centrally)?
2. How would you evaluate the quality and quantity of the data your organisation is collecting?
    - Are there any indicators, for which there is only little (if any) data available, which would nevertheless be worth measuring?
    - Which factors are deterring from data collection?
3. What are the reasons for publishing of data?
    - What are the motivations for publishing data?
    - What are the obstacles?
    - Do you think the public is interested in what is published?
4. Do citizens and the public play a role in data collection? If yes, which role?
5. How would you describe your function and role in the organisation?
6. Are there any norms, values or assumptions held throughout public that hinder sustainable water governance?

The Luxembourgish Data Landscape on Water and Water Quality: Actors, Roles, and Motivations, and Relationships

7. How would you describe the national data landscape on water? (also in relation to the actors, who collect, save, process, and use data)
    - Who are the main actors in relation to data on water?
    - Which are the main data flows in Luxembourg? Between whom do they occur?
    - How would you describe the relationship of the actors? (Collaboration, transparency)
    - Is there any data that is necessary for a transition towards sustainable water governance?
    - Can you identify any opportunities in the data landscape?
8. How would you evaluate the quality and quantity of data on water in Luxembourg?
    - Are there any indicators, for which there is only little (if any) data available, which would nevertheless be worth measuring?
    - Which factors are deterring from the data collection?
9. Do you know of any publications on the topic from the last 10 years? Which publications do you find most important?
10. Do citizens and the public play a role in the Luxembourgish data landscape on water? If yes, which role?
11. Is there anything you would like to add?

Citizen Science and Ideas for Citizen Science Project Design

12. What is your view of citizen science?
    - In which areas is citizen science applicable?
    - In which areas is citizen science less applicable?
13. What is your opinion on the citizen science tool we want to develop?
    - Do you think the citizen science tool could be of value in the Luxembourgish data landscape on water?
    - Do you think the citizen science tool could be of interest to your organisation? If yes, how?
14. Which indicators, do you think, are most interesting for the citizen science tool? Why?
15. Do you have any comments concerning the citizen science tool?

Annex 2. Example Consent Form

1

Karl Arthur Pickar
PhD candidate
Faculty of Language and Literature, Humanities, Arts and Education
University of Luxembourg
2, avenue de l'Université
4365 Esch-sur-Alzette
+352 46 66 44 9541
karl.pickar@uni.lu

UNIVERSITÉ DU LUXEMBOURG

Letter of informed consent

In accordance with European and Luxembourg Data Protection Acts, and ethical procedures for academic research undertaken at the University of Luxembourg this project was reviewed and received ethics clearance by the Ethics Review Panel. As a condition, all interviewees have to agree to participate and determine the conditions of documentation, storage, use, and publication of their interview content. The consent is given by reading, completing, and signing this consent form.

Information on NEXUS FUTURES and the interview

Title	NEXUS FUTURES - Anticipating future challenges at the nexus of Luxembourg's water and food systems: Combining a scenario- and systems-approach to co-create a citizen science tool set for monitoring and social learning
Duration	November 2016 – March 2023
Principal investigator	Dr. Ariane König
Researchers	Kristina Hondrila, Frida Ramirez Perrusquia, and Karl Arthur Pickar (in addition, a Post-Doc will be recruited)
Interviewer	Karl Arthur Pickar
Topic and goal	With the interviews, I hope to form an overview of the data landscape on water quality and to explore different views on the citizen science tool. These will help to situate the tool in the Luxembourgish context and to identify indicators for measurement. Other questions are linked to the development of the scenario set (e.g. how does the way we interact with water and land affect water quality and availability in Luxembourg? How can we foster sustainability?)
Duration	Approximately 2 hours

You have the right to stop the interview or withdraw from the research at any time. You have the right to access your interview documentation at any time (i.e. audio recording, transcript and/or summary). If you have any comments or concerns resulting from your participation in this study, please feel free to contact the principal investigator at any time.

Handling of interview content

I, the undersigned and interviewee, understand and agree that (please tick boxes)

2

- ☐ the interview will be recorded (audio) and a transcript and/or summary will be produced by members of the research team,
- ☐ the access to the interview documentation will be limited to the research team, pseudonymised transcripts and/or summaries might be shared with researchers, with whom the team collaborates as part of the research project,
- ☐ any interview content, including direct quotations, made available through academic publication or other channels (reports, events, digital media, etc.) will be anonymized so that any information from the interview that could identify myself is not revealed (unless I agree to the publication of non-anonymized content below),
- ☐ the interview documentation will be kept on a password protected server of the University of Luxembourg, which can only be accessed by the research team members. The electronic documentation will be deleted ten years after the project is completed (i.e. Oct 31, 2033),
- ☐ whenever I wish something to be treated strictly confidential, I can ask for it to be "off the record". The researcher will then pause the audio recording, will not take any notes and will not disclose the information to others in any way.

Handling of the interview documentation

- ☐ I wish to review the transcript and/or summary of my interview.
- ☐ I agree that my identity (name, function, organizational affiliation) is revealed when interview content is made available through academic publication or other channels (reports, events, digital media, etc.).

Use of documentation for other research activities (outside NEXUS FUTURES) (please tick one box only)

- ☐ I do not agree.
- ☐ I agree, but wish to be informed about the research.
- ☐ No interview content shall be used for other research without my consent.

By signing this form, I confirm that I have read and understood its content and ticked the boxes next to all statements I agree with. I also confirm that I do not expect to receive any benefit, compensation or payment for my participation.

Printed name ....

Contact information ....

....	....	....
Date	*Signature participant*	*Signature interviewer*