Utrecht University

Citizen science for climate adaptation governance in cities

Exploring the value of citizen science for enhancement of

urban governance capacity for climate adaptation

Master's thesis, June 2020

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Programme: Sustainable Development

Track: Earth System Governance

GEO4-2321/GEO4-2322: 45 ECTS

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Frontpage Photograph

Waag technology and society: Ten steps to citizen sensing

https://waag.org/en/article/ten-steps-citizen-sensing

Waag technology and society: Citizen Sensing - A Toolkit (p. 173)

https://waag.org/sites/waag/files/2018-03/Citizen-Sensing-A-Toolkit.pdf

Abstract

Climate change poses serious challenges to urban systems and their ability to govern adaptation. The dependence of adaptive capacity of cities on the collective efforts of the public, private and civil society actors highlights the need for exploration of alternative approaches at this interface. This thesis aims to investigate the potential value of one such approach - citizen science - to enhance urban governance capacity for adaptation in the European context. The leading research question was formulated as: *How can citizen science contribute to climate adaptation governance in European cities and urban areas?* In answering this question, the thesis assessed the impact of nine adaptation related citizen science projects around Europe on the scientific, policy and societal sphere of adaptive governance capacities. To achieve this, two case study analysis and assessment frameworks were developed drawing on an extensive literature review, and used to guide 26 semi-structured interviews and desktop analysis of the grey literature related to the projects. Based on this assessment citizen science for climate adaptation was re-conceptualised and general recommendations for citizen science practice were formulated. The results show that citizen science can significantly contribute to scientific aspects of adaptive governance capacity, while being moderately beneficial to societal aspects and having only low impacts on policy. In the context of urban governance, citizen science was shown to be strong for example in production of credible, salient, useful and usable knowledge, enhancement of science-society interaction or individual empowerment. On the other side, it performed weak in mobilization of private actors, steering of behavioral changes or policy impacts. However, citizen science presents important opportunities for enhancing social capital, preparedness to climate risks, access of institutions to up-to-date knowledge or connecting a diversity of stakeholders. This research concludes that distilling the strengths, addressing the weaknesses and paying attention to unexplored opportunities could make citizen science better fitted to the urban governance contexts thereby increasing the potential to contribute to governance capacity for climate adaptation. More empirical research of citizen science and its proper utilization in climate adaptation would be desired. This research may serve scientists and policy-makers as an inspiration for enriching science-policy interfaces and invites European cities and urban areas to consider such a method of public participation in their future governance mechanisms.

Key concepts: citizen science, climate change adaptation, urban governance, adaptive capacity

Acknowledgments

This research was a challenging but interesting journey motivated by the wish to explore ways how citizens can connect more to pressing environmental issues. I am grateful for having two real scientific experts guide me through this process and provide deep insights which made the overall thesis much more complete.

I would like to thank my supervisor Dr Arjan Wardekker who greatly managed to keep me at all times on the right track, for his critical thinking and many inspirational perspectives.

Equally I would like to express gratitude to my co-supervisor Scott Bremer for his very appreciated help, a precise eye, targeted comments and encouragement that kept me motivated.

Last but not least, I appreciate the time and input from every single person who was willing to participate in the interview. Without their enthusiasm and very open approach this thesis could not be completed.

I hope that anybody who reads through this thesis will enjoy it.

Petra Semjanová
Bratislava, June 2020

Table of contents

List of tables

List of figures

1. Introduction

1.1 Introduction to the topic and problem definition

The European cities have been facing numerous challenges resulting from climate change impacts. Functioning of such complex advanced urban systems relies on long-lived infrastructures, transportation networks, sanitation, intensive use of water, energy and emissions-producing waste management whereas they play an important part for larger political, social and economic development (Birkmann et al., 2010). Urban growth bringing about higher population densities only further increases vulnerability (likeliness to suffer from adverse effects) of people and assets. The level of urbanization in Europe is predicted to reach 83,8% by 2050, however there are considerable differences across the European regions, with the most inhabitants living in the northern part of the continent (Schauser et al., 2010; UN, 2007). Accordingly to their contribution to climate change and related consequences, the cities can take on a leading role in dealing with such phenomena (Corfee-Morlot et al., 2010; Schauser et al., 2010). Given the compound stress from climate-induced risks and the expansion of population agglomeration, especially climate change adaptation and urban resilience become of great importance (Birkmann et al., 2010).

Impacts of climate change are expected to exacerbate already existing urban problems such as poor air quality and limited water supplies. In addition, new challenges will be potentially mounted upon the natural and human systems. Especially more frequent heat waves, floods, storms and extreme precipitation events are projected throughout Europe. These can be further distributed according to a strong regional pattern influenced by the geographical location of the European cities, their physical structure, urban design and management. The southern Mediterranean region can expect more heat stress, droughts and water scarcity, northern Europe may suffer from permafrost thaw, heavy precipitation and storms during winter, whereas the central and eastern region would experience excessive heat, low rainfalls and river floods. Not less important is the affected crop yield due to changing growing seasons as well as human health influenced by the unusual physiological nature of heat and cold or by the increased occurrence of water-, food- or vector-borne diseases (EEA, 2010; Behrens, Georgiev & Carraro, 2010; EEA, 2008; Hunt & Watkiss, 2007).

Climatic change is arguably challenging the governance capacities of urban authorities and related administrations. Traditional regulatory frameworks fail to reflect the on-going complementary activities and responsibilities of civil society, private and public sector for adaptation, or unlock the diverse adaptive capacities available to urban populations (Wamsler & Brink, 2014). This has seen moves away from centralised urban management, to endorse networked models of urban climate governance, defined here as "the ways in which public, private, and civil society actors and institutions articulate climate goals, exercise influence and authority, and manage urban climate planning and implementation processes" (Anguelovski & Carmin, 2011, p. 169). Cities find that their urban governance effectiveness - and urban resilience - is directly dependent on public support of adaptation practices, as well as on individuals' own adaptation choices. This is challenging the long-held distribution of responsibilities among urban authorities and citizens in climate adaptation, and opening up alternative approaches at the urban-citizen level (Wamsler et al., 2019).

One alternative approach that attempts to increase co-production and use of climate knowledge is the rising field of citizen science. According to the Oxford English Dictionary, citizen science can be understood as "the collection and analysis of data relating to the natural world by members of the general public, typically as part of a collaborative project with professional scientists" ("Citizen

science", 2020). Informally the concept can be understood as public participation in scientific research with a provided spectrum of learning experiences when citizens are engaged in data collection, long-term monitoring, analysis etc. Citizen science offers support to innovation, knowledge generation and scientific evidence provision, thus in turn fostering various societal goals (Bonn et al., 2018). Yet, despite the academic discourse that citizen science delivers various positive outcomes especially for involved individuals and scientific research (Bonn et al., 2018), there is a lack of theoretical knowledge and empirical evidence to increase understanding of its potential contribution to climate adaptation and governance (Bremer et al., 2019; Wildschut, 2017; Conrad & Hilchey, 2011). The assumed connection between citizen science and governance builds on the claim that a citizen possesses the capacity to enrich the science-policy interactions thus being an active contributor rather than a recipient of decisions (Bäckstrand, 2003). The triple nexus of science, policy and society allows for beneficiation and exchange between the three, ultimately helping to better understand climate effects in different contexts and allowing for a more robust base for adaptation decision-making and designation of climate services (Olazabal et al., 2018; van Kerkhoff & Lebel, 2015). As a result, citizen science is gaining stronger influence on societal decision-making processes and structures, including public policy agendas (Bonn et al., 2018). With respect to climate adaptation, especially urban residents and communities may be justified to take greater part in adaptation governance issues as they experience on-the-ground climate effects as well as implementation of adaptive action (Wamsler et al., 2019). The empirical experience with climate change can even create cognitive shifts in residents in how they understand and interpret the local climate at the places where they live, either to the benefit or disadvantage of adaptation practice. For example, Bergen has shifted in perception of Bergeners from a 'weather city' (the rainiest city in Europe with inherent climate risks) to a 'climate city' (the weather of Bergen is part of global climate, emphasizing the role of cities in global climate risk governance) under (pervasive) social and natural influences of media, science, policy, activism and unusual natural events (Bremer et al., 2020a). Drawing on the discussed reasons, citizen science has the theorized potential to be embedded in, and contribute to urban climate governance.

Against this background, this thesis project assesses the value of citizen science for urban governance capacities to adapt to climate change. More specifically, it studies initiatives in various cities around Europe, chosen for their socio-economic, political and cultural differences and their distinct approaches towards executing citizen science initiatives. The results reveal whether and how citizen science can be used as a form of cooperation between society, scientific experts and policy-makers to enrich climate adaptation in cities and urban areas. This may invite other cities to consider such form of participation in their future governance mechanisms. The thesis is positioned within the Co-Cli-Serv research project which explores ways for co-development of place-based climate services together with local communities, scientists and other stakeholders (Co-Cli-Serv, n.d.).

1.2 Topic in the academic research, knowledge gap and contribution to literature

Most of the contemporary literature on citizen science focuses on its use in ecological research and environmental governance such as conservation efforts, bird watching, monitoring and managing of natural resources, biology (diversity and distribution of animal and plant species), analysing quality of waters, weather- and atmosphere related measurements or observation of ecosystem shifts (e.g. Dickinson et al., 2012; Couvet et al., 2008; Cooper et al., 2007). A few recent publications employed citizen science to study climate change (e.g. Silvertown, 2009). Based on the deep analysis of 888 peer-reviewed articles about citizen science conducted by Follett and Strezov (2015), other disciplines in which citizen science finds its academic concern and practical utilization are astronomy, archeology and community monitoring. Its potential to support climate adaptation or mitigation seems to be

under-researched. However, the literature is present on citizen science in connection to urban environment: urban tree inventories (Roman et al., 2017), urban bird studies (Mc Caffrey, 2005), citizen science for smart cities (Craglia & Granell, 2014), analysis of crop yields in community gardens (Gittleman, Jordan & Brelsford, 2012), cycling safety (Ferster et al., 2017), noise pollution (Maisonneuve et al., 2009) and others. Additionally, the notions of participatory urban adaptation planning and collaborative governance receive wide attention (e.g. Broto, Boyd & Ensor, 2015; Barton, Krellenberg & Harris, 2015; Chu, Anguelovski & Carmin, 2015; Archer et al., 2014). The largest portion of the research on citizen science originates in North America and Europe. Interestingly, a parallel discourse in Africa, Latin America, Asia and the Caribbean puts forward rather ´indigenous knowledge´ and ´ethnoscience´. Both discourses have their own roots and concerns explained for example by Leach and Fairhead (2002).

Methodologically, assessments of citizen science projects usually look at the quality of scientific outcomes and impacts on individuals (citizen scientists) in terms of learning experience or behavioral changes (e.g. Pandya, 2012; Dickinson et al., 2012; Brossard, Lewenstein & Bonney, 2005). However, there is more that citizen science can provide when extending the focus beyond individuals to the governing systems in which they are embedded. The current literature lacks such assessment frameworks to cover the whole range of citizen science impacts beyond citizen scientists themselves. In this regard, a few studies have created a theoretical and methodological background for analysis of impacts of citizen science on the social processes, structures and interactions, policy and politics (e.g. Phillips, Bonney & Shirk, 2017; Jordan, Ballard & Phillips, 2012; Conrad & Hilchey, 2011). In connection to climate adaptation, Bremer and colleagues (2019) empirically tested citizen science on weather patterns with Bangladesh communities to research the impact on citizen scientists´ capacity to support social processes for climate adaptation and on enhancement of local adaptation governance capacities. More empirical studies in this area would be desired. In order to address the introduced gaps, this thesis project tries to broaden the perspective on citizen science by extending its usage into the area of urban climate adaptation as well as extending its assessment into the scientific, policy and societal sphere. Thereby it attempts to contribute to the existing literature with empirical understanding of citizen science impacts within the realm of urban adaptation governance.

1.3 Societal and scientific relevance

At the present time approximately half of the global population are city residents with expected increase in numbers in the upcoming years (C40 Cities, 2011). Taking into consideration the urgency of climate change and vulnerability of urban residents worldwide, it is necessary to better understand the opportunities and conditions that can help to facilitate the creation and implementation of adaptive responses in urban areas (Tanner et al., 2009). Effective responses to global climate changes require effective collaboration between science and governance (van Kerkhoff & Lebel, 2015) but also public participation and support to overstep the government-policy approach (Hammer et al., 2011). The involvement of citizens in identification of urban problems and development of solutions is crucial for the cities to become adaptive and resilient (AMS Institute, n.d.). Citizen science might take the climate risks and effects closer to the civil society actors including citizens, who designate or experience implementation of adaptation responses in practice. In this regard, citizen science offers the cities and decision-makers an alternative way to engage with climate change and adaptation through participatory scientific research. The ability to produce and utilise knowledge is one of the most significant indicators of urban adaptive capacity. When rich and diversified, it is expected to enhance the robustness of actions and decisions (Williams, Fenton & Huq, 2015). Thus the motivation for cities to engage in citizen science could be the belief that building a culture of citizen engagement can foster empowerment as a knowledgeable, effective citizen, and the willingness to improve knowledge and learning capacities for climate adaptation governance that uphold accountability and

legitimacy of the resulting adaptation plans and actions (Sarzynski, 2015; Tompkins, Few & Brown, 2008).

Besides production of data and information, citizen science has the potential to nurture also other resources and capacities necessary to facilitate climate adaptation (Wildschut, 2017) as explored in this research. Better understanding of citizen science is thus important to facilitate its purposeful integration into the current governance mechanisms. From the scientific perspective, as mentioned in 1.2 it is valuable to go beyond the present academic research and examine the interaction between citizen science and the wider social context, structures, processes and interactions that steer governance. Assessment of performance of resilience-increasing and similarly targeted activities is challenging due to the multifaceted nature of urban systems, but necessary to govern adaptation and related transformative processes (Feldmeyer et al., 2019).

1.4 Research objective and questions

The objective of this research is to explore the potential value of citizen science for future climate adaptation action in cities by assessing the impact of citizen science on urban governance capacity for climate adaptation. In this matter, the notion of 'urban governance' and 'adaptive capacity' is central to this research as further described in the theoretical background of the thesis (Chapter 2). The assessment process helps to dig into the basis and assumptions around citizen science and critically analyse the results of its practical application. Secondly, this research aims to conceptualise citizen science for climate adaptation in order to support any further theoretical or practical efforts in this area. To meet the objectives, a number of citizen science projects related to climate adaptation were chosen across Europe to be described and evaluated according to two developed analytical frameworks. Based on this, certain conclusions and recommendations for governance practice could be derived and citizen science for climate adaptation could be conceptualized. Thus this research employs an exploratory practice-oriented approach investigating specific case studies on citizen science. The following central research question guided this research:

How can citizen science contribute to climate adaptation governance in European cities and urban areas?

To answer the central research question, further sub-questions were formulated:

1. What citizen science initiatives related to climate adaptation exist in Europe?
    a. To what extent are these initiatives accessible for analysis?
2. How can we assess the impact of citizen science on adaptive governance capacity, specific to the interface of science, policy and society?
3. How does citizen science impact adaptive governance capacities?
    a. How does citizen science impact the scientific dimension?
    b. How does citizen science impact the policy dimension?
    c. How does citizen science impact the societal dimension?
4. What implications does the assessment have for the potential use of citizen science for urban adaptation governance?
    a. What general recommendations can be provided to the European cities in order to potentially integrate citizen science for climate adaptation?
5. How can citizen science for climate adaptation be conceptualized for future purposes?
    a. What aims and practices would it involve to be contributive towards climate adaptation governance?

Sub-question 1 indicates that a number of representative citizen science practices had to be identified and chosen to perform as the units of analysis. For the assessment to be conducted, two frameworks were developed that would help to scrutinize the architecture of every case study and allow for analysis of its impact against urban governance capacities. This step is reflected in the sub-questions 1a and 2. The third sub-question refers to the actual assessment of the case studies. Distinction between the science, policy and society makes it more explicit in which area the impact has been shown. The results of this part point to the specific strong and weak points that need further attention when utilizing citizen science for urban adaptation purposes. According to the sub-questions 4 and 4a at this stage the main findings could be synthesized into conclusions for urban adaptation governance and further recommendations for practice could be provided. Followed by the design-oriented sub-question 5, the output of this research yields a comprehensive assessment which shows whether and how citizen science impacts specific urban adaptive capacities thus realising the extent to which it can be contributive to urban adaptation governance. Finally, the emerging field of citizen science for climate adaptation is conceptualized and operationalized based on the case study experience for its further potential utilisation in other European cities and urban areas which seek new methods to provide for climate adaptation governance. Overall, by adhering to these steps the central research question could be answered. The output of this research contributes with various types of knowledge, particularly descriptive (sub-questions 1,2), evaluative (sub-question 3), explanatory (sub-question 4) and prescriptive (sub-question 4a, 5).

1.5 Research framework

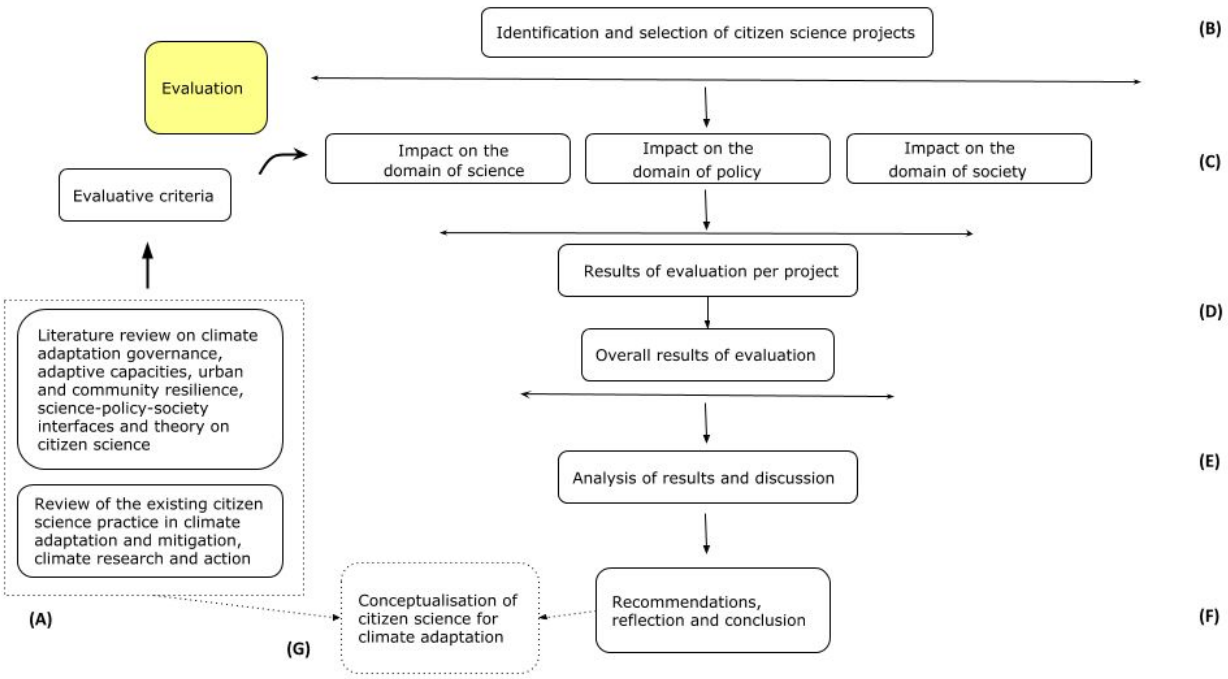

***Figure 1**: Research framework*

Figure 1 introduces the steps needed to realise the research project. Firstly, within the theoretical building block (a) the two frameworks for case study analysis and assessment were created based on the literature research on climate adaptation governance, adaptive capacities, urban and community resilience, science-policy-society interfaces and theoretical and empirical background on citizen

science. Alongside this step a representative sample of nine citizen science projects around Europe (b) relevant for climate adaptation were identified. This helped to answer sub-questions 1 and 2. The reasoning of case study selection and approach is elaborated in Chapter 3 (Methodology and research material). Next, during the evaluation process (c) the impact of the citizen science projects on the dimensions of urban adaptive capacities was assessed by means of empirical and document analysis, thus answering the sub-question 3. The outcomes of such evaluation (d,e) generated a complete picture of the performance of citizen science towards urban adaptation governance. Based on the results further recommendations (f) on better utilisation of citizen science could be provided (sub-question 4). The reflection touches upon the theoretical and methodological limitations of the research as well as validity and applicability of the results in practice. Finally, the emerging concept of citizen science for climate adaptation was conceptualised (g, sub-question 5) building on the examined empirical cases and citizen science literature, thus adding new contribution to the theoretical debate and knowledge (a).

2. Theoretical background

2.1 Climate adaptation in European cities

The European cities are prone to experience the consequences of climate change differently based on the respective geographical conditions and the city-specific adaptive capacity. The success of urban adaptation is deeply reflected in mutual coordination of adaptation strategies at the local, regional, national, EU and international level whereas the city plays a major role in the implementation ´on the ground´(Climate ADAPT, n.d.a). The main point here is that cities in Europe are not dealing with climate change alone, but are well embedded within the multi-level context. Specifically the European Union (EU) has been maintaining a supportive legal and financial framework for the cities to adapt. The EU recognizes its competence mainly in providing assistance to the most affected or disadvantaged regions and in promoting solidarity, coordination and knowledge exchange between the Member States. Since 2013 the EU Adaptation Strategy has been in effect which helps to ensure that climate adaptation is relevantly addressed in the EU legislation on various sectors, being mostly complementary with the EU action on reducing carbon emissions (EC, n.d.). Its urban-specific part named the Covenant of Mayors for Climate and Energy is a bottom-up initiative which gathers around 10 000 cities and towns committed to meet the European climate and energy objectives and to apply a joint approach towards mitigation and adaptation (Climate ADAPT, n.d.b; Covenant of Mayors for Climate & Energy, n.d.). Nevertheless, the overall current or prospective adaptation success in Europe is hard to generalize. It remains valid that cities need to acknowledge their ´stand-alone´ position likewise and actively mobilise adequate adaptation responses across scales, actors and sectors in their own responsibility (Carter, 2011). Timely and effective adaptation will lower the damage costs to the economy, environment and society and preserve the quality of life (Climate ADAPT, n.d.a).

2.2 Linking climate adaptation governance, resilience and urban adaptive capacities

The academic literature makes a distinction between mitigation and adaptation, where mitigation addresses disruptions of the carbon cycle as the primary source of anthropogenically driven climate change and adaptation aims at adjustments to the climate related impacts on social and natural systems. Thus it seems that adaptation covers 'everything', so numerous goals across levels and sectors as opposed to the one core quantifiable mission of mitigation (reduce emissions) (Huitema et al., 2016). Climate change affects both terrestrial and marine regions, various sectors (energy, agriculture, water, infrastructure, etc.), local to international levels and all types of actors. This makes adaptation a highly complex issue which requires interdisciplinarity and synergy between not only adaptation measures themselves but also with the existing governance processes and structures (Prutsch et al., 2014).

Adaptation encompasses the capacity to adjust natural and anthropogenic systems to respond to climate and other related social and natural stimuli. Adaptive governance thus broadly refers to "the collective efforts of multiple societal actors to address problems, or to reap the benefits, associated with impacts of climate change" (Huitema et al., 2016, p.1) embracing learning through creative experimentation and grounds for cooperation and collective action among multiple stakeholders across the public, private and civil society sectors (Adger et al., 2009). According to Edwards and colleagues (2019) it is crucial to acknowledge the role of individuals in this process "(e.g. leadership, trust building, vision and meaning); their social relations (e.g. actor groups, knowledge systems and social

memory); and social networks serve as the web that ties together the adaptive governance system" (p.3). The governance choices to be made encompass determination of climate-related problems that are faced, choice of administration level at which action will follow, the time frame of action implementation, choice of instruments or governance approaches through which the action can be undertaken, decision about underpinning normative principles and the practical arrangement of implementation and enforcement (Huitema et al., 2016). While global mitigation action is addressed in the centralized modes of governance, in which the incentives of state governments and supranational bodies become dominant, governance of adaptation could be recognized as 'interactive' or in some cases even 'self-governance' which allows for cooperation, greater autonomy and bottom-up steering of public, private and civil society actors (Driessen et al., 2012; Tanner et al., 2009). Thus adaptation happens rather at the regional and local scale equally comprising individual and community action (Tanner et al., 2009). Based on this, urban realities seem to be a great laboratory-like environment to see how social networks and co-management can address system complexity and effectively cope with the changing climate locally (Boyd & Juhola, 2014). Cities and urban regions constitute a crucial environment for adaptation as they "are uniquely situated to understand local contexts, raise local awareness, respond to citizens' and civil society pressures, and work to build an inclusive policy space" (IPCC, 2014, p. 577). They are starting to adopt new and more flexible governance approaches towards reducing emissions and adapting to the consequences of climate breakdown, which is more of a learning-by-doing process accompanied by gaps in knowledge and experience on how to approach abruptness of changes, uncertainty and non-linearity (Kern & Bulkeley, 2009).

Adaptation must be highly contextual as the climate consequences turn out differently relative to the vulnerabilities of the specific urban infrastructures, ecosystems and inhabitants. What varies is also the ability to understand, sense and respond to climate-related risks (Hunt & Watkiss, 2011). Hence it is necessary to design adaptive governance mechanisms tailored to the environmental, political, cultural and socioeconomic context of the given cities or urban areas. The urban level offers a unique opportunity to bring to the table reformation of local policies and practices, experimentation with new approaches, bring together local know-how and serious dedication to planning and action. At the same time collaboration of local stakeholders helps to make climate change impacts more manageable for decision-makers (Corfee-Morlot et al., 2010). Action at the local level directly supports execution of adaptation programmes, policies and strategies at higher levels of governance (EEA, 2012). Factors which determine the realization of urban adaptation are the effectiveness of the existing institutional structures, normative perception and awareness of climate change, local competence and knowledge management, vested interests or analytical capacity (Birkmann et al., 2010). Table 1 provides a summary of key building blocks of urban adaptation governance and action (Boyd & Juhola, 2014; EEA, 2012).

Table 1: *Key elements of urban governance for climate adaptation and action (Boyd & Juhola, 2014; EEA, 2012). Boyd and Juhola (2014) point out that adaptation governance is rather an idealised type of governance and its performance is hard to measure.*

GOVERNANCE Boyd & Juhola, 2014	**ACTION** EEA (European Environment Agency), 2012
Knowledge and understanding → Adaptation governance requires understanding and knowledge of the processes and dynamics to predict and respond to system feedbacks.	• Preparation and execution of local adaptation programmes, measures and strategies • Penetration of adaptation issues across policy areas • Distribution of funding and resources
Co-management and leadership → Because of the system uncertainty,	

adaptive responses and management need to be continuously enhanced through mechanisms such as monitoring, reviewing, testing, re-assessing and adjusting. This is up to the leaders and might also require alterations in social norms and values.	• Urban planning to spatially integrate adaptation related needs • Increasing resilience of infrastructure • Planning of action in case of emergency • Development of instruments and tools for knowledge dissemination • Stakeholder endorsement: development of participatory approaches to engage private and civil society actors • ...
Multi-level partnerships and networks → "Adaptive governance requires sharing of power and responsibility between user groups or communities, government agencies, and nongovernmental organisations through flexible self-organised social networks at different scales, supported by regulatory and financial institutions" (p.28)	
Ability to handle uncertainty → Adaptive governance requires long-term strategy to manage surprises and continual building of resilience. Necessary is also acceptance of uncertainty, preparedness for change or crisis and enhancement of the adaptive capacities of the system to cope with disturbance.	

When two urban areas comparable in terms of geographic location and socio-economic background are exposed to the similar climate risks, the resulting impacts might differ based on the demonstrated adaptive capacities, whereas higher adaptive capacity means lower vulnerability (Keskitalo, 2010). Urban adaptive capacity shows the awareness of the system of the need to adapt, the ability to design effective solutions and the potential that these will be successfully implemented within the existing policies, governance structures and institutional settings (EEA, 2012; Gupta et al., 2010). It can be defined as "the ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences'' (Gupta et al., 2010, p. 461). In practice, adaptive capacity reflects the available set of resources (e.g. natural, institutional, technological, cognitive, economic, human) and the ability of the system to use and apply them purposefully (Brooks & Adger, 2005). Thus successful urban adaptation governance should not be directed only towards development of short-term adaptive measures but instead support long-term building of structural conditions for adaptation that would allow to continue in the development pathway despite changing external drivers and internal processes (Keskitalo, 2010).

Adaptive capacity significantly varies across European cities but also within and between the national levels. Enhancing adaptive capacity of the cities and communities increases their resilience which should be perceived as a higher order goal of any incremental adaptation or mitigation action (EEA, 2012; Leichenko, 2011). The frequently used expression 'climate-resilient city' proposes the notion that cities, urban constituencies and systems can, after the experience of climate shocks or stresses, either bounce back to the original state, which might prove maladaptive due to returning to a business-as-usual fashion, or preferably bounce forward to the transformative state of adapting and thriving in the novel conditions, thus perceiving undesired events as the opportunity to catalyze positive changes (Manyena et al., 2011; Tanner et al., 2009). Resilience found its origin in ecology when firstly described by Holling (1973) as "a measure of the persistence of systems and of their ability to absorb change and disturbance and still maintain the same relationships between

populations or state variables" (p.14). The concept is applicable to cities as they represent complex systems which are continually adapting to changing conditions. Urban resilience can then be defined as "the ongoing capacity of cities to absorb, adapt, transform and prepare for shocks and stresses along the economic, social, institutional and environmental dimensions, with the aim of maintaining the functions of a city and improving response to future shocks" (Figueiredo, Honiden & Schumann, 2018, p.10). Following this line of thought, the concept is limited in its lack of consideration for equity and power dynamics that forms the background of how the cities function and deal with disruptions (Figueiredo, Honiden & Schumann, 2018). The desired outcome of building urban climate resilience is described for example by Bahadur, Ibrahim and Tanner (2013) or Welle and colleagues (2014) who introduce ten characteristics of a climate-resilient system: (1) **satisfied basic needs** of population in terms of food, living, health, sanitation etc. (2) **high level of** (natural and livelihood) **diversity** (3) **effective governance and institutions** marked by decentralization, flexibility and inclusiveness (4) **equitable distribution of financial resources** to deal with climate consequences (5) **strong and inclusive social capital** built on trust, existence of cohesive social networks, cooperation and norms (6) **continuous social learning** so that both individuals and organizations can anticipate future challenges and appropriately act upon them (7) **Preparedness for potential risks and uncertainty,** their acceptance and acknowledgement to stay flexible and plan ahead (8) **participation and access to relevant knowledge** whereby traditional and scientific knowledge are publicly accessible. This list is not exhaustive and could be enriched by further extensive literature review on the similar topic. In the context of this research, the introduced resilience literature highlights the importance of community participation, effective institutions, equity, knowledge, learning and sharing in building adaptive capacity.

Additionally, for the purpose of this research the societal aspect of urban adaptation governance is represented by the concept of community resilience. It can be understood as "the capacity of a community to manage current and emerging threats by addressing the ability (or lack thereof) to adapt to changing threats and challenges over time, and drive adaptation pathways towards sustainable futures'' (Sharifi et al., 2017, p.2). Communities and their empowerment is essential to urban adaptation governance as communities are where climate change impacts are felt and adaptation practices implemented (Olsson, Folke & Hughes, 2008). Inherent part of building community resilience is community learning and willingness of the members to be in charge of their future development pathways (Sharifi et al., 2017). Urban communities can be understood as "residents of a particular area who are vulnerable to similar climate impacts" (Archer et al., 2014, p. 346). These residents can be gathered based on for example administrative boundaries, common interests, participation in local organizations or activities (Archer et al., 2014). Empowering and strengthening the position of residents and their communities in adaptation governance (e.g. participatory planning to influence the direction of action) can complement local governance efforts with a bigger set of available responses, consequently increasing the overall urban resilience (Archer et al., 2014). Community resilience seems to have connections with citizen science for climate adaptation in two ways. The first one is the aspect of community, as citizen science can be also a community-led or community-involving initiative. It thus has the potential to bind the involved collective together into a cohesive network or urban community. The second connection can be found in the capacity to act and the role of knowledge in it when individuals or members of a community participate in citizen science to gain knowledge or contribute to activities related to climate adaptation and resilience building. Therefore, citizen science might provide a valuable contribution to building community resilience and increasing adaptive capacity.

2.3 Citizen science

As indicated in the Introduction, the Oxford English Dictionary provides the definition of citizen science as follows: "the collection and analysis of data relating to the natural world by members of the general public, typically as part of a collaborative project with professional scientists" ("Citizen science", 2020). The terminology found in the contemporary literature labels citizen science as 'tool', 'scientific method', 'movement', 'collaborative research', 'crowdsourcing' or 'practice', to name a few (e.g. Eitzel et al., 2017; Follett & Strezov, 2015; Tweddle et al., 2012; Bonney et al., 2009; Silvertown, 2009). The term has been also cited as a connection between research, education and agency (action) (Toomey & Domroese, 2013). In the context of this research, citizen science is understood as an alternative method, that can be employed alongside other methods, towards undertaking extended modes of science such as transdisciplinary science (Hecker et al., 2018; Funtowicz & Ravetz, 1993). The first features linkable to citizen science date back to amateur observations of weather and nature in the early 17th century. The concept has not been fully established yet as it was revived only in the 1990s in the US as a response to the deficit model of science communication implying, that public scepticism and uncertainty towards modern science and technology is resulting from a lack of its understanding, further caused by a lack of knowledge and information transfer from experts to non-experts (Irwin, 2014). Citizen science has been recently revived thanks to the emergence of extended modes of peer communities and governance, progressive approaches in education, new technologies and increased enthusiasm about open and more participatory science (Bonn et al., 2018). In the context of global environmental issues and the 'post-normal era for science', where traditional 'normal' modes of science are confounded by 'wicked problems' characterised by significant complexity, uncertainties and high stake, citizen science is seen as one extended rather than external way of conducting science on such wicked problems like climate adaptation (Funtowicz & Ravetz, 1993).

In practice, citizen science can serve many aims such as social innovation, answering certain research questions, generating knowledge, raising awareness, supporting environmental decisions and actions or informing policy. Both scientific experts and citizen scientists are ultimately supposed to gain benefits from being involved. The vision is to develop "both the "Scientific Literacy" of citizens and the "Societal Literacy" of scientists" (Kroop et al., 2017, p. 1). At the personal level, citizen scientists can benefit from learning opportunities, enjoyment and satisfaction, positive behavioral effects or changed attitudes in relation to the researched topic or to science itself (Jordan et al., 2011; Bonney et al., 2009). This raises the question on how to capitalize upon the emergent opportunity to involve the public in science while attaining broader societal desires such as enhanced environmental awareness (Jordan et al., 2011). From the opposite viewpoint, science can benefit from research outputs, increased capacities, diversity in perspectives, new approaches and promotion of social and knowledge inclusivity (Dickinson & Bonney, 2012). Scientists and leaders coordinating or actively participating in citizen science can for example be "professional scientists or leaders or coordinators of natural history groups, environmental charities, governmental agencies or non-governmental organisations" (p.1), academics or members of scientific consortium who have their primary interest in citizen science outputs for research (Tweddle et al., 2012). Citizen science in itself is perceived as any other research approach including the limitations and uncertainties inherent to the process. Here the quality of data might be compromised resulting in imbalance between research and educational goals as well as in undermining credibility and legitimacy of citizen science projects (Jordan et al., 2011). These need to be formulated differently compared to the traditional ways of doing research by applying straightforward and simplified methodologies that can improve accuracy of data collection, however at the potential expense of the scientific robustness of the results (Bonney et al., 2009; Silvertown, 2009).

Public participation in citizen science comes from self-directed motives (interest in the topic, willingness to learn, joining the community), altruistic motives (be contributive and helpful) or the combination of both (Kragh, 2016). Most of the projects follow the same pattern to be easily engaged with, require low efforts, target a wide audience and not be limited to possessing any particular skills (Turbé et al., 2019). Participation is enabled at every step of the research process however the intensity varies per citizen science project based on the degree of engagement and collaboration between the scientists and citizen science community (see Activities in Figure 2) (Boonen & Veeckman, 2017). The diversity of research activities ranges from the use of crowdsourcing when the collection of the research data is distributed among a large number of individual participants making up the crowd, through formulating research questions, designing a study, analysing and interpreting the results, up to more interactive ways such as coming up with solutions or acting upon the data (Phillips, Bonney & Shirk, 2017). Expanding on this, Bonney and colleagues (2009) developed a widely used typology of citizen science projects. *Contributory* (scientist-driven) projects are the most common form, top-down, driven by research needs and designed by scientists to which citizens contribute with large data collection over large spatial extents and/or long time spans (e.g. research on animal and plant species). *Collaborative* projects adhere to the same definition, however citizens may be involved in more research steps such as data analysis, interpretation of the results or presentation of conclusions to decision-makers (e.g. monitoring of water quality). In *co-created* (community-driven) projects scientists and members of the public work together to address some community issue (e.g. point source pollution) seeking to influence local policy and resource management. Participants are invited to take part in all the research steps thereby executing control over such projects. The co-creation type has the greatest potential to impact public understanding of science and societal relevance of citizen science. This kind of citizen science is also called 'community science' and would work in the fields such as public health or restoration of ecosystems. Wildschut (2017) adds to this by defining autonomous citizen-led projects which are completely run by citizens without academic intervention and control, or potentially only when it is needed. Figure 2 illustrates the basic architecture of a citizen science project with examples which can be adapted to the context and needs of any project.

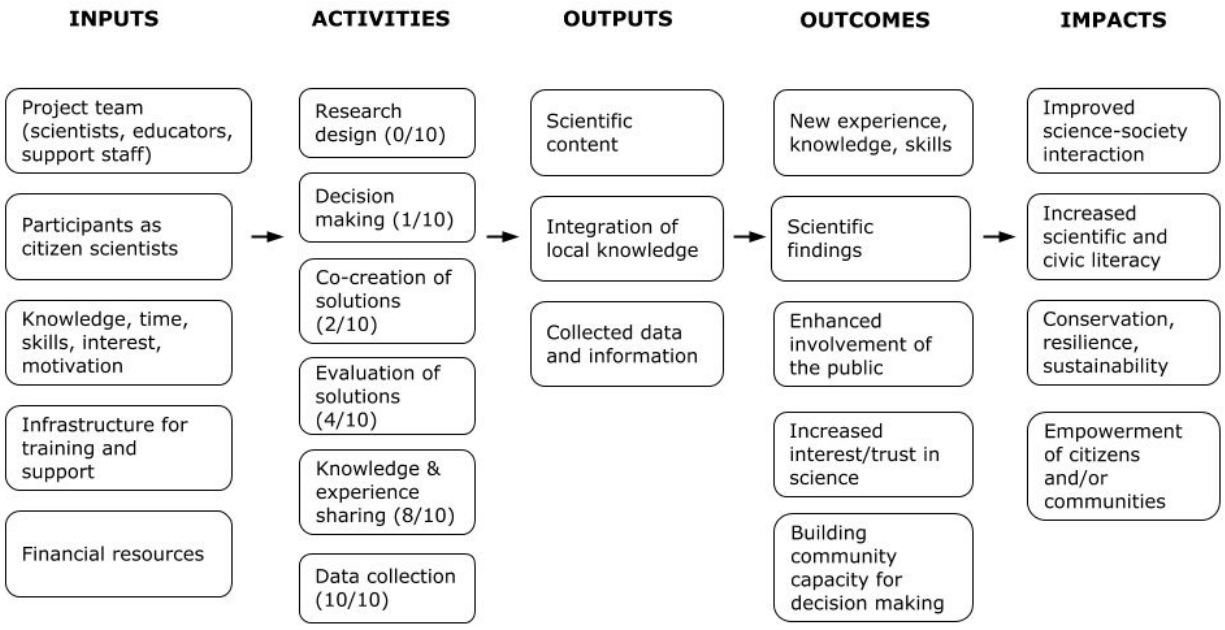

Figure 2: *The illustrative presentation of basic architecture of a citizen science project (Phillips, Bonney & Shirk, 2017; Shirk et al., 2012). The activities differ per project type (contributory/co-created/collaborative) as explained above. The desk research conducted by Boonen and Veeckan (2017) revealed how often different activities are applied among citizen science projects on the scale from 0 (least often) to 10 (most often). More description and examples on the specific components of a citizen science project are introduced in section 4.1.*

2.4 Science, policy, society and the position of citizen science

A wider theoretical background in which citizen science is embedded concerns connection between science, policy and society whereas citizen science operates at this interface (Bonn et al., 2018). The triangle "grants agency to actors in sensemaking and the interactive production of meaning, and in the political game of negotiating interests" (Dewulf et al., 2012, p.1). Citizen science is becoming increasingly acknowledged by national policy actors, European and international bodies such as UNESCO, UNEP, NASA, European Commission or European Environment Agency both in their current activities and future scientific, policy and innovation directions (Haklay, 2015). According to the EU Research and Innovation policy, the hopes for citizen science are to extend the traditional science-policy nexus into increased interchange between science and society by enhancing citizen participation as valid knowledge producers and by providing solution-based knowledge (Laine, 2018). As the name 'citizen science' indicates, the primary interaction really refers to science and society and the current transformation of the alleged boundaries between them. In this regards, the monopolistic position of contemporary traditional research institutions and universities in creation of knowledge has been changing due to continuous transition from 'closed' to 'open' science where any stakeholders are stimulated to engage in scientific processes, access knowledge resources, cooperate with professional researchers or learn from them (Gordillo Martorell et al., 2019). In this way, scientists can also experience the societal relevance of their effort and gain greater awareness of their responsibility towards society (Kroop et al., 2017). The European Commission defined the vision for Europe in science and innovation until 2030 as follows: "*The year is 2030. Open Science has become a reality and is offering a whole range of new, unlimited opportunities for research and discovery worldwide. Scientists, citizens, publishers, research institutions, public and private research funders, students and education professionals as well as companies from around the globe are sharing an open, virtual environment called The Lab*" (European Commission, 2016, p.1).

Open living labs seem to be a promising learning ecosystem "characterized by a more decentralized and open features as end-to-end architecture, peer to peer networks, open standards and platforms, or learner-centered approaches" (Gordillo Martorell et al., 2019, p. 151). In this way, the knowledge and expertise grounded in social groups can be pooled together for research and adaptive practice. There are various rationales for engaging public, private and civil society actors in co-creating research and innovation. On one hand, the complexity and uncertainty characterising many challenges facing society - including climate adaptation - means that no one knowledge system alone can claim access to the truth of the matter. Assembling a plurality of knowledge perspectives is argued to lead to a more comprehensive and nuanced understanding of wicked problems (Funtowicz & Ravetz, 1993). On the other hand, co-production processes are perceived to be a way to increase the effectiveness, public acceptance and trust in science, in light of the post-truth crisis (Kroop et al., 2017). Citizen science is positioned in this matter as an integral component being one of the five EU policy action pathways for fostering transition to open science in Europe (Nascimento et al., 2018). It is mentioned as a new approach to research and democratization of knowledge creation, science and innovation policy by offering greater public involvement in these issues and by functioning on the principle of openness to support accessible and transparent practices - open design, open-source technology and data, open access to the people and the world (Making Sense, 2018). These open-source standards enhance interoperability of citizen science data and other outputs, which can be in this way more easily discovered and reused across different settings (Williams et al., 2018). Where the influence of

science on society has been conventionally seen through publicising scientific findings, citizen science supports the interaction with any step of the research process from determining the research aims up to forming the conclusions. Another unique aspect is that citizen science can bring together multiple stakeholders that would not otherwise cooperate together, thereby creating space for innovative ideas and co-production (Nascimento et al., 2018). Thus what we can perceive as the impact of citizen science on the supposed boundaries between science and society is the increased interaction and participation of laypeople and other societal stakeholders (which is also a requirement of socially responsible science) and a potential for increased accountability, rectitude, responsiveness and relevance of science in connection to the societal challenges, values and needs (Laine, 2018). To truly reshape the science-society relations, more dialogues between the scientific and non-scientific world need to be opened up. Indeed, there is a conflicting debate if scientists should spend time on integrating and communicating science to society or rather invest their complete efforts into production of scientific knowledge. Also, the lifetime and long-term sustainability of citizen science and its established communities is still vague (Kroop et al., 2017). Because of that the existence of citizen science is prone to come under continuous scrutiny in the near future at the expense or in favour of open and more participatory science.

Although citizen science has been positioned as one of the key fostering tools towards open science in Europe, the specific ways in which citizens can influence evidence-based policy-making and decision-making processes are still absent or not sufficiently enforced (Hyder et al., 2015). At the same time, the adoption of citizen science data by public institutions and demonstration of its provided impacts are demanding. Public authorities hesitate to accept the added value of citizen science arguing that the practice is missing adequate quality standards that would be needed to generate benefits for evidence-based processes or to complement official data (Wildschut & Zijp, 2020; Nascimento et al., 2018). Reliability of citizen science data as well as synergy with governmental goals, regulations and requirements seem to be crucial to gain trust in public administration (Williams et al., 2018). Another barrier that prevents citizen science from connecting to policy is the struggle to recognize relevant policy linkages (Nascimento et al., 2018). The identification of policy linkages could be enhanced if citizen science would cover a larger spectrum of policy relevant areas where its application is currently deficient, such as resource efficiency, urban planning, waste and energy sector, land management and use or agriculture and food sector. New projects in these areas would have a potential to deliver high impact also in terms of technological contributions (Turbé et al., 2019). A further inhibiting factor is the deficiency of current governance systems in measures, legislation, funding and infrastructure to sustain citizen science in the long run or scale it up across levels and sectors, nor is it clearly linked with the existing public participation mechanisms (EU-Citizen.Science, 2020). Expanding on this, the supranational organizations and national landscapes across Europe are very disparate in handling data management, citizen and stakeholders involvement, regulatory frameworks for research and innovation and similar related issues to citizen science. More coordination across governance levels is needed to reinforce the coherence of citizen science (Nascimento et al., 2018).

Establishing connection to the policy- and decision-making sphere is a lengthy process that requires commitment to stable and reliable data inflow. Hence citizen science projects that show potential for long duration and maintainable data infrastructure are more likely to find its policy use (Turbé et al., 2019). Due to the renaissance of citizen science occurring only recently, the academic literature on its policy relevance and impact is quite scarce. Also, only a few studies pay attention to the comprehensive overview of governance, scientific and public engagement characteristics of citizen science projects that succeed in contribution to policy (Turbé et al., 2019). On the other side, since it is challenging to track the wider use of citizen science outputs, the actual contribution to science and policy might seem ´invisible´ or not attributable at times. When the complex connections between scientific evidence, citizen science and policy decisions become explicit, then the projects can earn

more representative impact and the public agents can claim to make the processes more participatory by giving space to public contributions (Schade et al., 2017). The novel meta-study of Turbé and colleagues (2019) conducted across 503 policy-relevant European citizen science projects in the environmental field (out of which only 3% covered the climate domain) that aimed to assess the landscape for potential influence on European environmental policies revealed a number of interesting points. Firstly, it found out that citizen science has the capacity to contribute to every step in the policy process, that is problem definition, policy formation, implementation and monitoring, compliance assurance and evaluation. Secondly, the assessed projects contributed to remarkably more steps of the policy process when they showcased high scientific standards, were endorsed by academics or scientists and provided easy conditions for participants to get engaged without any prerequisites related to dedication, skills or knowledge. These strong science-citizen determinants of policy relevance highlight the significance of citizen science targeting masses while contradicting the widely perceived challenge of citizen science projects to balance volunteer engagement next to ensuring scientific standards for research and policy (Williams et al., 2018). However this research suggests that the value of citizen science and engagement is still being held in data collection and monitoring over space and time in the first place (Turbé et al., 2019).

In light of the pace of climate change, the policy- and decision-makers may welcome alternative approaches to support and extend scientific knowledge and engage stakeholders including citizens in different steps of the policy- and decision-making processes. Citizen science may add to this by being a timely, spatially distributed and cost-effective source of data with the potential to assist in evidence-based processes or complement formally centralized information systems (Hecker et al. 2018; McKinley et al., 2017; Hyder et al., 2015). There is some empirical evidence when citizen science performed well in mobilising local knowledge capacities, reporting and improving the understanding of environmental problems, offering background data for policy formulation or monitoring policy implementation. Citizen science is also considered to be a useful instrument for empowering communities to become more active citizens in contrast to passive forms of participation such as voting or drivers of policy and more participatory governance regimes (Nascimento et al., 2018) but also for providing space where citizens and other actors can come closer with the local governments or other public bodies they would not necessarily meet otherwise (Irwin & Michael 2003). The aspect of empowerment gives the citizens the possibility to confront the governments with 'objectivized' data (Haklay, 2015). A potential danger might occur in alternative interpretations of environmental problems that could trigger conflicts at various levels, however this could be addressed by regular feedback mechanisms, open dialogue and governmental support with contextual knowledge (Nascimento et al., 2018).

This section would like to conclude with the key standpoints on citizen science to progress and bring innovation at the science-policy-society interface formulated at the first international conference of the European Citizen Science Association (ECSA) which took place in 2016 in Germany, based on the collected experience from the past years (Hecker et al., 2018). With regards to innovation in science, it is important for citizen science to confidently showcase scientific benefits and relevance of produced data, spread out into fields and disciplines, support knowledge exchange and networking among stakeholders and citizen science actors and use more the co-productive formats with deep involvement of participants. For promoting advances in policy, citizen science needs to increase awareness and facilitate access for decision makers and authorities to citizen science outputs and initiatives, align citizen science goals with policy goals as well as to create evaluative approaches which would support demonstration of best practices and successfully delivered impacts. From the aspect of society, it is fundamental for citizen science to involve multiple and diverse science-policy-society actors (education, industry, business, policy, etc), investigate outcomes for all the participating parties and elaborate on the transformative potential of communication of science to

society (Hecker et al., 2018). However, the growth of citizen science movement in Europe could be also facilitated by greater support from international networks as well as national and European research and innovation policy programmes and agents to allow for establishment of flourishing bottom-up or top-down initiatives (Socientize, 2014). Overall, it has been a challenging process for citizen science to become established in society, science and policy. Differences in citizen science relationship to these three dimensions will always be attributed to diversity of project goals, project designs, participants, sociocultural conditions of the specific countries and the extent to which citizen science can flourish across the world (Bonn et al., 2018; Jordan et al., 2011).

2.5 Measurement of citizen science value and impacts

The rising popularity of citizen science over the past few years has brought attention to its missing approaches for evaluation and traceability of projects. Even though it has escalated to the leading European and national research funding frameworks, there is not enough empirical evidence about its value and impact on science, policy and society to give justification to the invested resources and to sustain public engagement. Therefore it is needed to develop a sound approach towards evaluating citizen science projects according to their quality, feasibility, effectiveness, outcomes and impacts (Kroop et al., 2017). Despite the yet very early stages, promising in this topic are the ongoing scientific efforts at the European Union level to develop unified and comprehensive assessment methodologies of citizen science (Nascimento et al., 2018). In its final form, it may turn out as a set of common indicators used for self-evaluation across projects (Kroop et al., 2017). The questions it poses are whether a standardised European approach would lead to expansion and greater acceptance of citizen science, who should create the assessment tools, what to measure and how to recognise value of seemingly abstract aspects of citizen science such as social impact, open access or flexibility of the approach (Socientize, 2014). Generally, assessment of citizen science serves to enhance the existing projects, design new tailored projects to meet the needs of research and audience, but also to determine the success conditions, opportunities or barriers. Without measuring the project outcomes and impacts, the field of citizen science would suffer from a lack of understanding of its progress, possible value and effectiveness (Phillips et al., 2014). So far the measurements have been mostly focused within single projects and with emphasis on outcomes for participating individuals, education and science. The four most measured impact categories are 1) knowledge, awareness, and understanding of the primary research topic, theory or principle 2) engagement and interest in the scientific content and process 3) change of attitudes and behavior and 4) acquisition or reinforcement of the science-related skills (Phillips, Bonney & Shirk, 2017). It is emphasized here again that citizen science programmes are usually evaluated in data quality, content related scientific outputs and results or participant experience, however equally important is to accentuate the added value of such approach in terms of impact on society, economy or environment (Kroop et al., 2017). The extent to which the various outcomes and impacts are achieved depends on the goals and type of the project. The complex character of such a collective activity means that the total performance reflects more than its separate parts thus being conditioned by the sum of scientific expertise, technological and communication infrastructure, citizen engagement, networking capacities and capability to approach society, to name a few (Socientize, 2014). This thesis project is not aiming to methodologically support citizen science measurements, but explores its relevance and possibilities beyond the outcomes at the personal level.

2.6 Citizen science for urban climate adaptation: conceptual framework

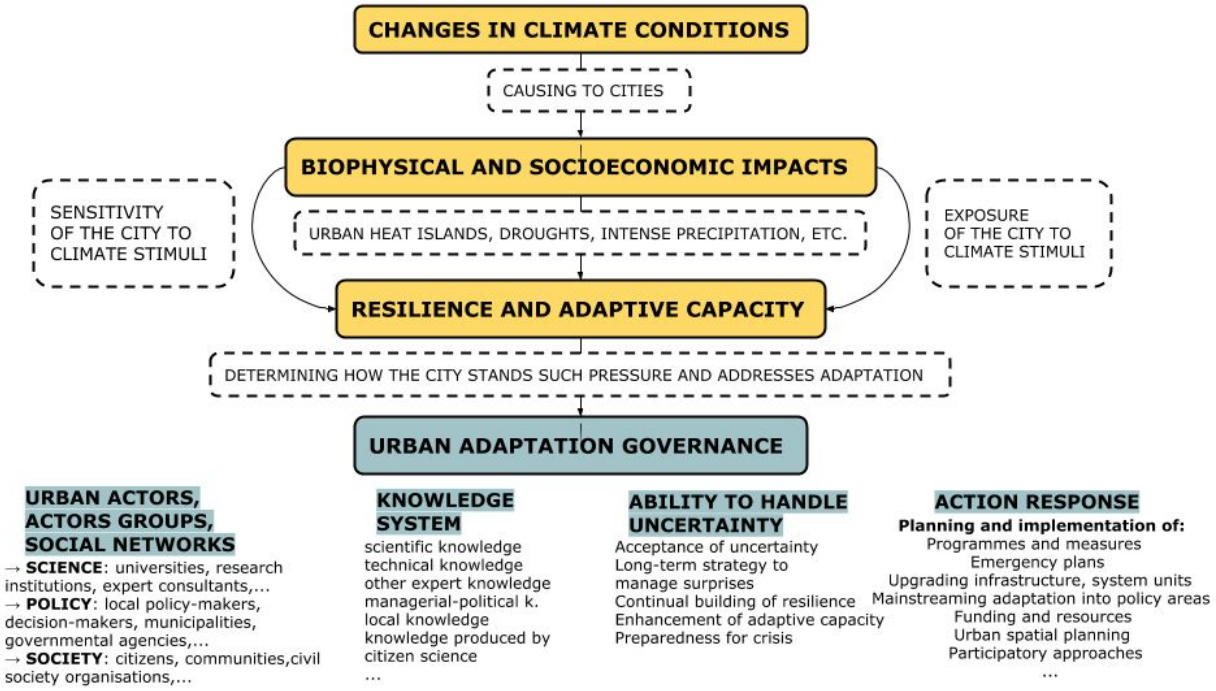

Figure 3: *Conceptual framework (based on McKune et al., 2015; Boyd & Juhola, 2014; EEA, 2012; Smit & Wandel, 2006*)

The conceptual framework (Figure 3) links up the core concepts of the theoretical background to provide the overall picture of how citizen science is approached in this research and conceptually embedded within the urban adaptation governance system. It sets the background to exploring the potential value of citizen science for future climate adaptation in the cities by assessing the impact of citizen science on urban governance capacity for climate adaptation. Based on the introduced theory, it seems that the ability of the urban system to respond, adapt and become resilient is determined by actual governance capacities, processes and choices categorized here following Smit and Wandel (2006, section 2.2) as stakeholder cooperation and partnerships, the existence of a knowledge system to support adaptation governance, long-term strategy towards uncertainty and active response 'on the ground'. According to Figure 3, citizen science may find its place within the urban knowledge system as an instrument to (co-)produce knowledge, mobilize local knowledge capacities or connect a diversity of stakeholders. Decision-making in such a high-stake issue as climate change adaptation is knowledge-intensive whereas integrating and utilising multiple sources of knowledge has potential to achieve extended outcomes (Termeer et al., 2011). Knowledge co-production is thus recognized as important to build capacity for climate adaptation and support the emergence of new possibilities in adaptation efforts (Ziervogel, Archer van Garderen & Price, 2016). Local knowledge (understanding of community contexts and experience of climate stress) is placed alongside scientific and technical knowledge possessed by the research community and managerial-political knowledge of governments and public authorities to provide first-hand insights into climate impacts and identify priorities for adaptation response (Bruckmeier & Tovey, 2008). The adaptation responses of individuals to local climate-related hazardous events such as storms or floods can concern economic (e.g. home or

property insurance), social (e.g. spreading warning signs or helping the others in neighbourhood), physical (upgrading the living spaces to resist extreme events) and ecological (plant more trees to cool down the area) actions which are oftentimes very significant and complementary for adaptation at higher levels, such as municipal (Tompkins & Eakin, 2012). As urban citizens make a number of continual decisions in view of climate-related events, they would benefit from having more recommendations to support their safety while making it easier for local administrations to cover a larger scope of their operation (Citizen Sensing, n.d.). In light of climate crisis and the beneficial potential of initiatives that enhance citizen involvement to "increase relevance, fairness and acceptance of public adaptation" (p.83), citizen science for climate adaptation could find its place as a long-term collaborative approach not driven purely by hazard occurrence (Brink & Wamsler, 2018). It could find its application for instance in monitoring changes to the environment and early detection of climate impacts (Citizen sensing, n.d.). Overall, this is the general idea upon which the assessment and conceptualisation of citizen science for climate adaptation is building in this thesis project.

3. Methodology and research material

3.1 Overall research design and strategy

This research project employs a multiple case study approach which allows for in-depth study of the variations across and within the chosen units with the purpose to generalize across these units (Gerring, 2004). In other words, each single case study (citizen science project) is firstly evaluated separately and then the results of all the acquired evaluations are compared in order to answer the central research question. The use of case studies conforms with the objective of this research to gain a holistic view of the actual citizen science practice in the urban governance settings through detailed exploration of the specific examples. The case study assessment is later introduced in Chapter 4. Here Figure 4 describes the steps of the case study approach as a foundation for the results section. The specific qualitative methods were chosen to manifest a deep yet varied insight into every case study while achieving reliability and validity of data. Firstly a desk study was conducted in order to 1) identify the existing or past citizen science projects relevant to this research (answering research sub-question 1), and 2) create two frameworks for analysis and assessment of case studies based on systematic literature review on climate adaptation governance, adaptive capacities, urban and community resilience, science-policy-society interfaces and citizen science (answering sub-questions 1a,2). The derived criteria involved in these two frameworks further steered the rest of the qualitative study. Following the selection of the citizen science projects, the respective stakeholders who are/were in charge of them were contacted in order to conduct semi-structured interviews. The acquired empirical insights were enriched by examination of available textual material related to the specific projects such as reports, publications, press material or the websites (triangulation of sources). This formed an adequate information basis to evaluate the impact of citizen science on urban adaptation capacities (sub-question 3). The outcome of this part was supposed to reveal how the citizen science projects perform in relation to the science-policy-society indicators as well as what the weak and strong points are. Following this, the implications for urban adaptation governance were introduced (sub-question 4) and citizen science for climate adaptation was conceptualised (sub-question 5) based on the practical experience of the case studies. This was further complemented by recommendations about citizen science to advise and inspire the project leaders and other parties active in future citizen science endeavors (sub-question 4a).

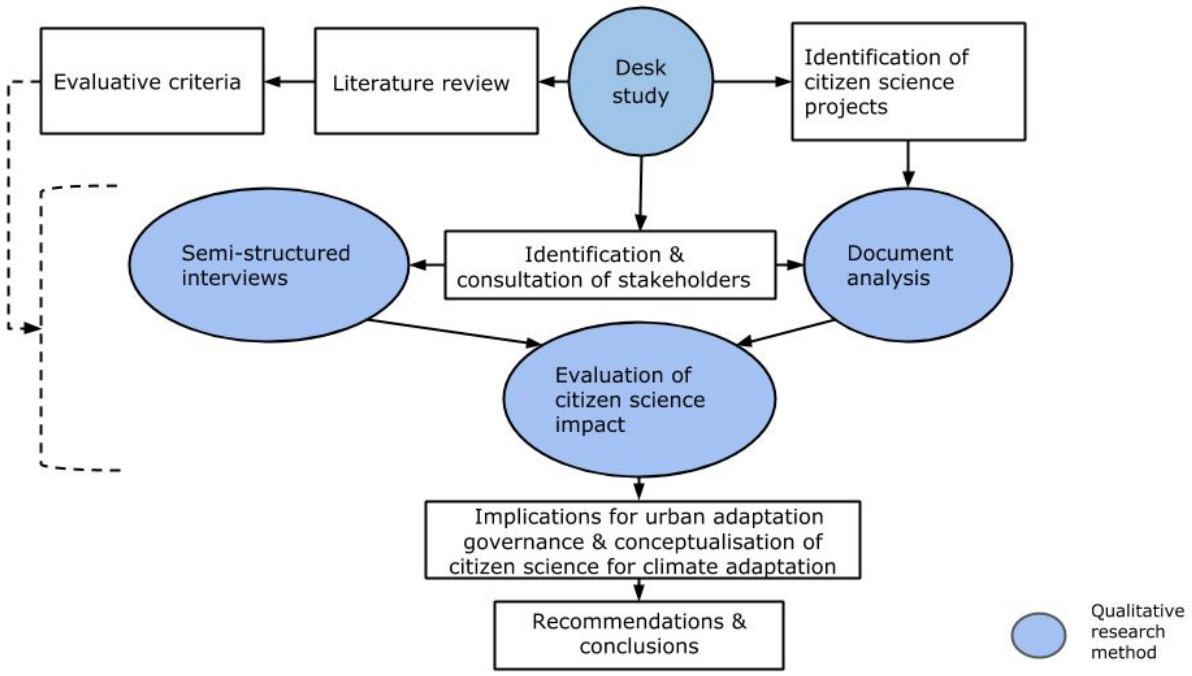

***Figure 4**: Visual representation of the research strategy. The arrow from the evaluative criteria indicates their steering role towards the qualitative research methods.*

3.2 Case study design

In methodological terms, this research follows the work of Verschuren and Doorewaard (2010) and employs a most similar case study design which compares a set of research units with a small number of different characteristics. The similarity of case studies can be understood in the way that the chosen citizen science projects have connection with climate adaptation, are practiced within but not limited to urban areas, are localised in Europe and involve citizens to a greater or lesser extent. The large amount of context specific knowledge that can be drawn from such an approach adds to internal validity (trustworthiness of the study), but can supposedly put external validity (generalizability and applicability of results to other contexts) under pressure. However, this qualitative case study research does not mean to derive universal laws, but instead aims to provide a rich and nuanced understanding of citizen science in particular urban settings and draw interesting insights as well as certain lessons from this. At the same time, the nine chosen case studies share a lot of similar characteristics while allowing for particularity of their settings. This set is big enough to find commonalities which might be well transferable to other places that share the same characteristics. Also, the results can be at later stages tested against more projects and in different cities. The emphasis was put on analysing and interpreting the case studies in a hierarchic method, thus the results gained from examination of separate case studies in the first stage were combined and used for comparative analysis of the coherent set of all the cases in the second stage. In this way the common strengths, weaknesses, correlations and differences across the citizen science projects could be determined to gain the overall picture of citizen science performance in the context of adaptation governance. The grounded nature of data generated from the case study approach hopefully makes the final results more identifiable and acceptable to potential users.

3.3 Case selection

The case studies were selected strategically being guided by the case study design to show certain similarities as described in 3.2. In terms of location, the chosen citizen science projects are meant to represent various regions of Europe that face distinct current or future climate change effects due to geographically induced variations, but may also experience influence of the national cultural, socioeconomic or political atmosphere. In terms of content, the chosen citizen science practices reflect the adaptation/urban needs particular to these regions or cities. By focusing on similar citizen science efforts in diverse European settings, this is likewise hoped to make the findings applicable in diverse settings around Europe. In terms of time, the citizen science projects were anticipated to have been in effect for a longer period so that the outcomes and impacts can be analysed, however the emergence of citizen science in Europe seems to be only a recent trend proven by the average short existence (< 10 years) of the analysed case studies. This has implications for the results further reflected in the discussion section. Nevertheless, based on the desk study research there is an abundance of citizen science initiatives around Europe with variating numbers per country. In general, the western, northern and southern regions (e.g. Germany, Spain, Sweden) seem to be more active in citizen science compared to the less engaged central and eastern part (the Baltic states, Romania, Bulgaria, Poland, etc). This did not influence the case selection as the range of citizen science topics findable in Europe is wide and many of them are relatable to climate adaptation such as weather, water, biodiversity and ecology. Instead, the limitation was the preferred urban character of the projects since many initiatives take place in other settings (e.g. nature, river basins) or are not defined by borders.

The exploration of the existing projects was done by checking the programme and speakers of the past and present citizen science conferences around Europe (e.g. ECSA), the websites of citizen science offices (e.g. Barcelona Citizen Science Office), online platforms (e.g. EU-Citizen.Science) or simple browsing guided by the key words such as citizen science, climate adaptation and concrete European countries. Meet je Stad was studied thanks to its connection to the Co-Cli-Serv project. The number of chosen case studies was not predetermined but desired to fit into the time scope of this thesis and be representative for drawing meaningful conclusions. The final set of the nine case studies illustrated in Figure 5 is similar in the core but still diverse in topics (water, weather and air, phenology, crowdmapping), locations, character, tools, level of citizen participation, the stage of implementation, and most importantly impacts on urban adaptation governance. This contributed to the possibility to generalize the results while identifying distinct nuances across the projects. Out of the nine cases, three are led by volunteers (Meet je Stad, Luftdaten), four by researchers (RiuNet, SeaWatchers, Naturkalender, CrowdWater) and two by stakeholder consortiums (BeWater, TeRRIFICA). Additionally, the latter one are transboundary projects funded by the European Union research and innovation framework programme, thereby having to meet high scientific quality and other standards which brings here enrichment to the cross-case comparison of the outcomes and impacts. The project Citizen Sensing in Norrköping (Sweden) and Porto (Portugal) was interviewed but could not be closely scrutinized due to the very nascent stage of implementation. Lastly to mention, the final set of cases is contrary to the original idea of the case study selection which was limited to three citizen science projects only, however with more added cases it is desired to keep depth of the research while increasing the external validity as well as the space for exploration of the potential variations among European regions. The overall reflection on the case study approach and choices in the context of assessment can be found in the discussion section.

Figure 5: *The case studies representing citizen science projects around Europe. Their websites can be found in the Appendix A.*

3.4 Semi-structured interviews

The aim of the semi-structured interviews was to gain a first-hand insight into the realities of the citizen science projects. This method turned out as the source of the most valuable information input thanks to the openness and detailed personal views of the interviewees, which could not be captured in another way. Overall 26 interviews were conducted and listed in the Appendix B whereas 15 of them were arranged in the online form through Skype/Zoom or written communication, and 11 in person due to reachability of the interviewees within the Netherlands. Out of the 26 interviews, 20 were relevant to the nine case studies and their assessment. These were conducted with the project leaders who were professional scientists representing the universities and research institutes. In the case of Meet je Stad and Luftdaten the interviewed project leaders were volunteers interested in citizen science and technological empowerment, whereas in the case of TeRRIFICA the interview was conducted with the representatives of the NGO (Education for Sustainable Development Association) which is in charge of project implementation in Minsk (Belarus). The names and contact details of the project leaders were found on the project websites except from Meet je Stad, where the contact information was provided through the Co-Cli-Serv network. The project leaders possessed fundamental overview and experience pertaining to the past and actual performance of the case studies. One to two interviews were conducted per case study. In the case of Meet je Stad in Amersfoort, this involved a field visit to the city of Amersfoort, so the participating members of the municipality, water board and citizens were also able to be interviewed, as well as attending one

weekly meeting of citizen scientists and one weekend conference on citizen science (with participants from Meet je Stad Bergen). It was intended to achieve a higher diversity of interviewees with a balanced representation of the science, policy and society, however it emerged as infeasible due to the limitations of time, the distance to be travelled to reach every concerned city, data privacy of participants which limited the possibility to conduct interviews with citizen scientists, and legitimacy limitations of the projects which means that only some of them involve stakeholders other than project team and participants. The implications for the results are reflected in the discussion section.

Out of the 6 remaining interviews, two were conducted with the representatives of the Dutch National Institute for Public Health and the Environment (RIVM) who are in charge of integrating high-end and low-cost sensors (by citizen science) into the national air quality monitoring network (Innovation Program Environmental Monitoring). They were reached because of their attendance at the weekend conference on citizen science in Amersfoort. Because RIVM operates between science, public administration at various levels and citizens or communities, this interview enriched the theoretical and empirical outlook on citizen science at the science-policy-society interface. Next, the interview with the academic researcher active in climate proofing of cities (especially Amsterdam) provided a scientific perspective on involvement of citizens in urban climate adaptation thus supplementing the conceptualisation of citizen science in this field (section 6.2). This interviewee was contacted intentionally due to her personal experience with citizen science, in particular with Meet je Stad in Amersfoort. The leaders of the citizen science project Citizen Sensing in Norrköping (Sweden) and Porto (Portugal) were interviewed as well, however their inputs could not be used for the assessment due to the very early stage of implementation. A few interesting points raised during the discussed 6 interviews were integrated into the conceptualisation of citizen science for climate adaptation (6.2) and the general recommendations for citizen science practice (Chapter 7). Overall, there was an unintentional right gender balance among the 26 interviewees. No other relevant details with regard to interviewee characteristics stand out of the complete list. Beyond the influence of the interviewer, the interviewees within RiuNet, BeWater, TeRRIFICA and Citizen Sensing joined the interview together at once to complement each other's answers. This actually turned out as an enriching experience triggering more detailed insight into the projects compared to single interviews.

Methodologically, the approach to the semi-structured interviews followed the publication by Alan Bryman (2012) on social research methods. Based on this, the interview guide (see Appendix C) was designed to conduct the interviews according to the same pattern whereas enough space was kept for spontaneous deviations or probing questions to elaborate more on what was already answered. This helped to get a more complete picture of the discussed case study. Screening of the grey material (e.g. project websites) related to the case study prior to the interviews helped to increase the flow of the conversation. The interview guide was designed to reflect the primary focus on interviewee´s perspectives on assessment of the case study according to the created analytical frameworks. In this respect, the interview started with introduction to the topic of this master thesis to explain the incentives for the interview. This was followed by introducing the framework for systematic analysis of the case study (4.1) and asking about its main analytical themes (aims of the citizen science project, inputs, activities, outputs, outcomes and impacts) in relation to the discussed case study. Next, the assessment framework (4.2.3) was introduced, further indicating that this (and longer) part of the interview will follow a set of science, policy and society indicators. The interviewees were asked to directly assign the scores to the indicators which were not determining the final results but were taken into consideration during the subjective cross-case assessment, as will be explained later in this work (Chapter 4: Assessment of citizen science). Finally, the interviewees were shown appreciation for participating. The majority of conversations were rounded off with talking about the outputs of this study and its later dissemination to the interviewees. Every interviewee received the interview guide prior to the interview. At the same time, a few interviewees who showed their preference to stay

within email communication filled in the interview guide and after that follow-up (prompting to elaborate on the answer) or clarifying questions could be sent to the interviewee in case of uncertainties or further concerns. Overall, this same general sequence and structure of the interview process was applied for each interview concerning case studies to ultimately secure comparability across the multiple cases. With respect to the interviews related to Citizen Sensing, the interviewees navigated the direction of the conversation as they knew which parts of the interview guide were worth discussing according to the implementation stage of the project in Sweden and Portugal based on the earlier received guide through email.

An exception were the interviews with the representatives of public authorities and citizen scientists in Amersfoort, who did not receive the interview guide in advance, however the number of questions was significantly reduced to be relevant to their position (see Appendix D). This approach was applied also to the interviews with the representatives of RIVM and climate-proof urban research, however here more emphasis was put on speculations and unconstrained thought processes to investigate the personal angles on either science-policy-society in one case or citizen involvement in urban adaptation in the other case.

The average length of each interview was one hour being held in person or online between January and May 2020. The conversations were recorded for further data analysis. In terms of ethical concerns, the interviewees were verbally asked at the very beginning of the interview for permission to record, receiving direct approval from all of them. It was not asked whether they can be named or quoted in this thesis or prefer to keep the identity and interpretations of views anonymous. To address this gap and prevent publication of potentially sensitive content, the individual interviewees are referred in this thesis as Respondents (e.g. Respondent 1, Respondent 2).

3.5 Collection and analysis of research material

The research material for analysis and assessment of the case studies was collected in two ways: 1) interview recordings (primary data source) 2) the grey literature such as project documents, plans, reports, publications, websites, media articles, dissemination materials (secondary data source). The latter one was accessed either online or in a few cases through interviewees. These two data sources generated a sizable corpus of information that needed to be reduced in order to make sense of it for the evaluation part of the thesis. With respect to the interviews, manual coding was used as an approach to qualitative data analysis of the audio-recordings (Bryman, 2012). As described in the previous section 3.4 the interviews followed a clear structure according to the two case study frameworks (4.1; 4.2.3) thus well simplifying the coding process. For this reason, the interviews were not transcribed but the recordings were played and key points for every analytical theme or indicator from the case study frameworks were written down. What was considered as 'key' was up to the subjective judgement of the interpreter, however this comprised basically everything that was not too general or too detailed but well relevant to add to the quality of the evaluation while not causing information bias. At the same time, the interviewees were navigated to cover preferably the most important perceptions in order to keep a suitable length of the interviews and ensure meaningfulness of the interview contents. Overall, manual coding turned out to be a practical and effective way of processing the interview material. In terms of documents, qualitative content analysis was conducted which encompasses looking for the underlying themes across the collected material followed by subjective interpretation and presentation of the textual content (Bryman, 2012). Here the process of identifying and extracting the important information from the available material per case study was guided again by the analytical themes and assessment indicators in the case study frameworks (4.1; 4.2.3). Finally, the pieces of information from both sources (interviews, document analysis) were compiled and merged to represent the results of this thesis (Chapter 5). The rest of the research

material includes academic articles that create the background for the theoretical foundation of this research and development of the two frameworks for case study analysis and assessment.

4. Assessment of citizen science

The assessment part of this research tries to apply a holistic view on the case studies. It evaluates the projects against certain indicators but also looks at the practices (activities) and other components so as to better understand the results as well as to easily conceptualise citizen science for climate adaptation. In this chapter two frameworks will be introduced, one for systematic description of case studies and one for assessment of case studies. Thus in practice, the basic structure of the case study is first described according to its 'inputs, activities, outputs, outcomes and impacts'. Secondly, the case study is assessed according to a number of governance-driven indicators. The information input for these frameworks is separated, thus the assessment is not based on the results from the first framework. This approach helped to get an understanding of how the project works and only then the assessment was conducted of its impacts on science, policy and society. The chapter presents thoroughly this approach to each case study which precedes the results presented in Chapter 5.

4.1 Framework for systematic analysis of case studies

The systematic analysis of every case study aimed to describe the basic architecture of a citizen science project (see Table 2). This was important in order to get a general understanding of the functioning of the case studies prior to their evaluation. Additionally, this step added to the possibility to make cross-comparisons across cases, draw conclusions and recommendations and conceptualise citizen science for climate adaptation. The systematic analysis started with making clear what the central aim of the citizen science project is (if applicable, also secondary aims). This step was purely informative to better understand why the project actually exists and in which direction it is heading. This was followed by describing the basic building blocks of the project defined here as inputs, activities, outputs, outcomes and impacts. Such an approach was inspired by so called logic models which help focus on the underlying logic of the practice in order to design interventions to reach desired outcomes and are usually demonstrated as inputs, activities, outputs, outcomes and impacts (Phillips et al, 2017). However, here the separate components were not analysed relative to the goals of the citizen science project, since the aim was just to describe and understand the project in its current form and not to assess its functioning or design interventions to reach the goals. The framework (Table 2) was used to guide the interviews and further complemented by information identified during document analysis.

Phillips, Bonney and Shirk (2017) provide a precise description of the specific components tailored to the architecture of a citizen science project. The *inputs* refer to the resources needed to carry out the project, such as human capital, knowledge, time, skills, interests or financial means. *Activities* reflect the ways in which the inputs are used and relate to the implementation of the research process in range from collection of data to acting on the results, according to the provided opportunities for participants. The *outputs* indicate deliverables - immediate results or products of the conducted activities and should be easily quantifiable. This can be for example the amount of gathered data translated into an open-source database. The *outcomes* are short-term (occurring within 1-3 years), medium-term (4-7 years) or long-term (many years after the project) measurable elements that result from the outputs. They usually reflect the achieved objectives that the project intended to meet. All the outcomes mentioned in this research refer to short-term and medium-term due to the short lifetime of the case studies. The *impacts* are difficult to measure but concern the benefits to the society in the long run (over 10 years). Impacts are considered as long-term outcomes in the broader

scope that bring sustained changes, for example improved natural resource management, resilient communities or empowered citizenry. Usually the most obvious impact is the expanded knowledge and capacity within a particular area of study. Because of the same reasoning that applies to outcomes, the impacts are referred here only as *envisioned impacts* that the projects aim to deliver after a longer period of existence.

Table 2: *The analytical framework used to systematically describe the case studies, consisting of (a) identification of the central aim and potential sub-goals (b) description of the building blocks of the citizen science project. The table also shows examples commonly found in the citizen science literature (Phillips, Bonney & Shirk, 2017; Phillips et al., 2017; Phillips et al., 2014; Shirk et al., 2012).*

(if defined) **CENTRAL AIM** **SUB-GOALS**	 secondary
INPUTS	Scientists, staff, volunteers, stakeholders Technological/research/communication infrastructure Funding Knowledge, skills, time, interests, motivation Training and support Local knowledge of community and landscapes
ACTIVITIES	Development of project design, protocol, educational materials Collection and analysis of data Observations in the field Communicating and acting on the results
OUTPUTS	Knowledge, scientific content Gathered data and information, data quality, publicly accessible databases Number of hours of training, engagement, monitored sites Exposure of project to wider audience
OUTCOMES	**Outcomes for individuals:** new skills, knowledge and understanding, increased appreciation for the natural world, increased environmental awareness, improved sense of place, increased interest and motivation, changed behaviors and attitudes **Outcomes for research:** scientific findings, publications **Outcomes for socio-ecological systems:** Policy changes, empowerment of communities, established environmental action, increased public participation in scientific research, increased public understanding of topics, improved relationships (e.g. among citizens and scientists)
IMPACTS	Conservation, improved environmental conditions, sustainability Resilient and healthy communities Improved science-society interaction, increased public support of science Responsive science More informed and attentive citizenry Increased social capital and community capacity More policy initiatives to address environmental issues

4.2 Assessment of case studies

The systematic description of a case study project was followed by assessment of its impact on the scientific, policy and societal dimension of urban governance capacity for adaptation according to the indicators introduced in the assessment framework. This section provides a brief reflection on the literature that formed a basis for the assessment framework which is introduced followingly.

4.2.1 The literature background for the assessment framework

Given the research aim and conceptual framework, the literature discussed below was examined to explore how to assess the impact of citizen science on governance capacities. The starting point was the very recent research of Bremer and colleagues (2019) who created and empirically tested the evaluation framework for measuring impact of the citizen science project carried out with communities in Bangladesh on the social adaptive capacities of citizen scientists and local adaptation governance. Unlike other adaptive capacity frameworks they operationalise the concept of 'capital' (human, social, resources and technology, political, institutional). Starting from this framework, the literature review looked at abutting literatures and assessment frameworks that share certain themes and approaches with Bremer et al., and gives a broader appreciation for this varied landscape of adaptation scholarship. This means reading along different criss-crossing lines of research work, which does not fit neatly together but goes in several interesting and oftentimes overlapping directions.

Gupta and colleagues (2010) use 'the dimensions of adaptive capacity' and introduce the Adaptive Capacity Wheel as a method to evaluate whether the characteristics of institutions from the local to national level encourage the adaptive capacity of society to cope with climate change. This is considered to be one of the most comprehensive frameworks that evaluates social factors connected to adaptation (e.g. institutions and social capital). They operationalised 22 criteria in 6 dimensions: variety, learning capacity, room for autonomous change, leadership, availability of resources and fair governance. Grothmann and colleagues (2013) extend the wheel by adding rather psychological dimensions of adaptation: motivation, which refers to the motivation of actors to deal with climate adaptation in practice, and adaptation belief, which reflects the perceptions of various actors on how realistic and effective various adaptation measures are when being implemented. Munaretto, Siciliano and Turvani (2014) apply governance lenses and link key adaptation governance principles with participatory multicriteria methods for decision-making to create a framework that would simplify adaptation decisions. Similarly, Corfee-Morlot and colleagues (2010) focus exclusively on cities and provide elaboration on the key institutional features that enhance or hinder the governance capacities of local authorities to take advantage of the urban policies and become a driver of adaptation. They agree with Cash and colleagues (2003) that management of boundaries between knowledge systems and action response tends to be more effective when it simultaneously boosts credibility, salience and legitimacy of produced information. However, Cash and colleagues (2003) view this more broadly in the context of science and technology mobilization for sustainable development, whereas Corfee-Morlot and colleagues (2010) look at science-policy interactions in local climate risk governance. Lemos and Morehouse (2005) add to this by identifying three substantial components of science-policy co-production in the context of climate-related assessments, being interdisciplinarity, interaction and participation of stakeholders and production of usable knowledge. A unique insight into urban resilience was provided by the City Resilience Framework (Arup & the Rockefeller Foundation, 2014) which scrutinizes the drivers of resilience based on the extensive examination of real urban case studies. The human and social aspect of this assessment is covered by the work of Kieslinger and colleagues (2018) who provide a holistic reflection on the outcomes and impacts of citizen science by presenting an assessment framework that combines the scientific advancement, participation of

citizens and impact on socio-ecological or economic systems. More general viewpoint on society and adaptation was gained from Kuhlicke and colleagues (2011) who created a classification of social capacities which make it possible for individuals, communities and organizations to adapt in reaction to natural hazards. Lastly, Adger (2003) contributes with a review of insights on social capital and collective action which he argues to be determinative for the adaptive capacity of society and normative underpinning of adaptation policies.

4.2.2 Operationalisation of governance capacity for climate adaptation

To be usable for the assessment, the literature review led to the choices with respect to operationalizing urban adaptation governance and its ability to contribute to adaptive capacity. Since "governance and institutions are critical determinants of adaptive capacity and resilience" (Engle & Lemos, 2010, p. 4) a number of practical governance elements across science, policy and society were identified in the explored literature that influence urban adaptive capacity and at the same time seemed to be feasible and relevant for citizen science assessment. These are labelled here as *governance determinants of adaptive capacity*. Narrowing down into governance determinants was useful as the examined adaptation scholarship includes a variety of determinants of urban adaptive capacity in relation to for example institutions, infrastructure, economic wealth, technology, social agents, information and skills, urban and spatial planning, resource dependency, equity, and others (e.g. Ford & King, 2013; Smit & Wandel, 2006; Brooks & Adger, 2005). The identified governance determinants were translated into outcome-oriented assessment indicators for citizen science, thus allowing for investigation of citizen science performance against the determinants.

4.2.3 Assessment framework

This section presents the assessment table organized according to the governance determinants of adaptive capacity and respective indicators for citizen science. Because the main research focus is on the relation between citizen science and adaptation governance, the indicators favour the social processes and structures that steer governance however still pay attention to individual enhancements of participants. In addition, the determinants are not seen as independent of each other but rather perceived as showing patterns of dynamic interaction in terms of mutual adding, limiting or conditioning. For example, if the urban institutional and political setting supports self-organization of citizen groups by establishing communication networks and cooperation among relevant actors (e.g. with NGOs or research institutes) or providing financial resources, it is believed that this would create a flourishing ground for citizen science projects to provide more credible, legitimate and salient outputs and contribute to empowerment of citizenry. Even though the determinants were chosen based on a broad literature review, it is hard to determine whether some aspect is missing in this framework, potentially making it incomplete. This gap was tried to be covered by asking Respondent 1 about feedback or missing elements in the framework, however no specific addition was raised. The feedback was not asked in further interviews because of confidence in the framework as well as to prevent inconsistency in guiding the interviews if any proposed changes would come up. However, no spontaneous comments were raised by the interviewees in this matter. Consequently, while progressing insight might add additional aspects to this framework, it seems to cover the key aspects of adaptive capacity as currently understood in the literature and among citizen science practitioners. The assessment framework (Table 3) can be understood as follows: for example political participation was identified in the literature as one of the determinants of adaptive capacity related to urban adaptation governance, therefore the indicator examines whether citizen science stimulates political participation.

***Table 3**: Overview of the assessment indicators*

	GOVERNANCE DETERMINANT OF ADAPTIVE CAPACITY	INDICATOR FOR CITIZEN SCIENCE	SOURCE
SCIENCE	**Availability of quality science**		
	Credibility: The produced knowledge shows scientific adequacy as proven by acceptable quality standards, and trustworthiness by potential users	The outputs of citizen science have been recognized by scientists or peer expert communities and are perceived to be trustworthy by prospective users.	Corfee-Morlot et al., 2010 Cash et al., 2003
	Legitimacy: The production of scientific knowledge is fair, unbiased and respectful towards diverse stakeholders	The production of knowledge through citizen science involves diversity of relevant stakeholders, their values and views.	Cash et al., 2003
	Salience and Usefulness: The produced knowledge is relevant and useful to the decision-making and other processes of all the concerned stakeholders	The outputs of citizen science are relevant and useful to the needs of decision-makers, researchers and other involved stakeholders, in the context of urban climate adaptation.	Corfee-Morlot et al., 2010 Cash et al., 2003 Lemos & Morehouse, 2005
	Usability: The produced knowledge is understandable and continuously available to the user community	The outputs of citizen science are understandable, operationally delivered and available to the users at any time and place.	Lemos & Morehouse, 2005
POLICY	**Institutional**		
	Information: Continuous accessibility to the actual information within the institutional memory; **flexibility to changing conditions** (ability of institutions to adjust when new information becomes available)	The citizen science project has established communication networks for dissemination of citizen science data and information to relevant institutions.	Gupta et al., 2010 Grothmann et al., 2013 Munaretto, Siciliano & Turvani, 2014 Arup & The Rockefeller Foundation, 2014
	Trust and cooperation: Institutions encourage trust and collaboration among various social actors, adaptive co-management	The citizen science project creates and maintains trustful and collaborative relationships between various actors.	Gupta et al., 2010 Grothmann et al., 2013 Kuhlicke et al, 2011 Munaretto, Siciliano & Turvani, 2014
	Political		

	Impact on policies and politics: Policy progress and innovation, evidence-based and participatory policy- and decision-making, integration of climate-related topics across policy areas	The citizen science project enhances policy processes and decision-making.	Bremer et al., 2019 Kieslinger et al., 2018
	Political participation: Personal access to power and shaping of public decisions, expression of opinions, influence on political outcomes	The citizen science project stimulates political participation.	Munaretto, Siciliano & Turvani, 2014 Kieslinger et al., 2018
SOCIETY	**Human**		
	Behavior and attitude: Conscious behavioral and attitudinal choices based on individual awareness and understanding of climate-related problems	The citizen science project contributes to positive change in behavior and attitude.	Kieslinger et al., 2018
	Feeling of empowerment: Empowerment of citizenry, development of competences for active citizenship, enhancement of personal knowledge and skills	The citizen science project facilitates personal self-esteem and empowerment.	Kieslinger et al., 2018
	Social		
	Social capital: Ability of institutions to increase the capacity of individuals to self-organise and innovate; foster social capital; ability to act collectively, social cohesion	The citizen science project fosters self-organisation, supports collective action and increases interaction between people in an established social network.	Adger, 2003 Gupta et al., 2010 Grothmann et al., 2013
	Knowledge and risk competence: Citizens are informed and know how to act in response to occuring or predicted undesired states or events	The citizen science project enhances knowledge and awareness about the urban climate related problems among citizenry and they know how to act upon it.	Feldmeyer et al., 2019 Arup & The Rockefeller Foundation, 2014

4.2.3.1 Indicators in the dimension of science

Climate adaptation can be understood as a social process which makes us learn more about the changing climate conditions and modify our actions and behavior accordingly. Such a process encompasses a continual effort to create a high-quality knowledge foundation for how to interpret, anticipate and act on climate uncertainty and change. Defining and measuring 'quality' indeed brings about epistemological and methodological questions as well as a plurality of contexts, perspectives or disciplines. However certain fundamental knowledge quality principles tailored to climate adaptation

have gained large attention in contemporary academia (Bremer et al., 2020). Cash and colleagues (2003) introduce the principles of *credibility, salience and legitimacy* that can be complemented with the principles of *usability and usefulness* proposed by Lemos and Morehouse (2005).
Citizen science is informally involved in research for climate adaptation as the outputs are oftentimes particular data and collected local knowledge. However, it has been a long-term challenge to ensure its scientific quality due to a simplified research process being understandable and accessible to citizen scientists (Tregidgo, West & Ashmore, 2013). Here the scientific robustness (***credibility***) is examined in the first place by questioning whether the citizen science activities and outputs are perceived as scientifically adequate by the scientists or peer communities, and trustworthy by potential end-users. While expert knowledge is undeniably significant, it is not sufficient in itself to arrange a basis for policy decisions which combine broad uncertainty and high stake for society with regard to climate adaptation. Success and political or social legitimacy of the final decisions require a special attention to the procedural questions of how the decisions are made and who is involved in the process (Corfee-Morlot et al., 2010; Cash et al, 2003). Applied to citizen science, it might prove ***legitimate*** if the production of knowledge followed an inclusive and transparent way by involving a diversity of stakeholders, their perspectives, needs and values, and the final 'products' are acceptable to them. Specifically, the indicator looks at the involvement of 1) academia and science 2) public administration 3) schools and civil society organisations (NGOs, volunteer clubs, community initiatives, etc) 4) private sector (businesses). The participation of citizens is certain in every project. The indicator is not only looking at how many categories are represented in the project, but also explores the diversity of stakeholders within the represented categories per project. Next, ***salience and usefulness*** are used here as one indicator due to their strong interrelatedness. This indicator assesses whether the outputs of citizen science are relevant and useful for the work of the decision-makers, scientific bodies or other stakeholders that can be considered as potential users. This means that the outputs address adaptation, match with the user practices and needs in this context, enhance their adaptation related work and have likeliness to be used by these stakeholders (Lemos & Morehouse, 2005; Cash et al., 2003). The information and knowledge can be useful not only when it is fitted to the stakeholders´ needs, but it has to be usable for them as well (Lemos & Morehouse, 2005). Hence another indicator is ***usability*** which is approached here as the capacity of citizen science outputs to be understandable in outputs, operationally delivered and available to the users at any time and place (open-source).

4.2.3.2 Indicators in the dimension of policy

In the policy process numerous actors moderate between local, scientific, expert and managerial-political knowledge with the intention to shape decisions about adaptation (Corfee-Morlot et al., 2010). Here the institutional and political structure is emphasized that provides the context in which citizen science action can potentially impact the agenda and influence the direction in which adaptation is heading.

Institutional

Institutions can be loosely defined as 'the rules of the game' that provide stability and predictable structure to human interaction and address cooperation problems (North, 1990). The institutional dimension is important because it represents the social structures in adaptation governance and introduces a path dependency where (often pre-existing) inherently conservative institutions shape future options. The stable and predictable nature of institutions is something that any form of collective action could not exist without. Unpredictability of climate change consequences demands institutions that actively support adaptive capacity of society and proactivity of social actors, but also allow for autonomous modifications and incremental redesign at a rate corresponding to external changes (Gupta et al., 2010). Here special attention is given to local and city authorities (particularly municipalities) as well as research universities because as shown by the results these seem to be the formal entities with the best proximity to citizen science, a strong mandate to address adaptation and

with capacity to express good understanding of the local factors that are important for adaptation decisions.

Two criteria have been used to assess the impact of citizen science on the institutional area of adaptive capacity. Firstly, in anticipation of possible threats, taking preventive measures and enabling evidence-based decision-making, the institutions (as well as other actors) require continuous incorporation and ***access to up-to-date information***. This depends on the investments in research, data aggregation and risk monitoring. The existence of multiple communication channels that are well applied helps this transfer to be more effective (Arup & The Rockefeller Foundation, 2014; Munaretto, Siciliano & Turvani, 2014). The respective indicator reflects whether communication networks or channels were established between the citizen science project and relevant authorities for dissemination of citizen science data. Thus it is not sufficient if the project maintains open-source data (indicator of usability) however stakeholders are not informed or updated about such potentially useful sources. This indicator is important also due to another determinant which is not of a primary focus here but has a strong connection to the previous one. It is the flexibility of institutions to the changing conditions, so the ability of institutions to adjust when new information becomes available. In light of climate uncertainty, decision-makers seek strategies and solutions that can perform under a variety of climatic conditions, are reversible and flexible when new reality or information becomes available. Thus supplementing the institutions with the available data and information does not only have a potential contribution to its institutional knowledge base but also to its institutional flexibility. Both access to up-to-date information and flexibility are part of institutional learning capacity (adjusted from Munaretto, Siciliano & Turvani, 2014).

Secondly, network capacity is an integral part of adaptive capacity whereas adaptive institutions should create a ground for ***trustful and collaborative relationships*** among various individual, local and organisational actors (Grothmann et al, 2013; Gupta et al, 2010). Development of trust and willingness to work together are essential prerequisites for fruitful collaborative partnerships between actors. Trust in itself involves social competences and practices such as creation of an emotional attachment, matching ambitions, predictable behavior, signalling moral uprightness and integrity. Trustful relationships between citizen initiatives and authorities also help to overcome formal obstacles more easily in relations to rules, procedures or potential regulatory mismatches (Hassink et al., 2016). Based on this, the indicator for citizen science is looking at the establishment and maintenance of trustful and collaborative relationships between various actors, for example between citizens and scientists or urban authorities. This indicator excludes relationships between citizens themselves as it is pertinent to the indicator of social capital.

Political

The political dimension investigates the potential of citizen science to ***influence policy and politics*** by supporting policy processes and public decision-making for example through agenda setting, provision of data for policy monitoring or evaluation. Also, the influence on local and urban adaptation policies, plans, strategies and other documents is assessed (Bremer et al., 2019). The second indicator evaluates whether citizen science stimulates ***political participation*** of the participants. Political participation is conceptualized as active public engagement in governance issues and political arena related to adaptation what eventually increases pluralism, transparency, accountability, flexibility, legitimacy and support for decisions, as well as more equitable distribution of benefits and burdens among the users (Munaretto, Siciliano & Turvani, 2014). Political participation is also one of the criteria to measure wider societal impact of citizen science according to Kieslinger and colleagues (2018). The indicator evaluates whether public engagement in adaptation issues changed or increased in response to citizen science for example due to the individual efforts, community pressure or the existing participatory environment.

4.2.3.3 Indicators in the dimension of society

Within the dimension of society, the impact on individual participants and social capital was measured.

Human

At the personal level the criteria are derived from the citizen science evaluation framework created by Kieslinger and colleagues (2018) who suggests to analyse the individual development during the project in addition to its wider impact on socio-ecological and economic systems. Tackling climate challenges needs alterations in people's lifestyle choices, consumption patterns and consciousness. Citizen science may facilitate ***behavioral and attitudinal changes*** for example in relation to sustainability or adaptation and environmental practices in response to increased awareness or understanding of climate related problems. Secondly, citizen science may raise empowerment among participants which is conceptualized here as the enhanced capability to realize desired outcomes and a feeling of possession of knowledge, skills and resources that can contribute to community resilience and affect a local place. This can lead to engagement in similar (citizen science or other) activities (Kieslinger et al., 2018). According to Patterson and van der Grijp (2019) empowerment can also result in motivation to promote greater climate action in the city and present a perceived shift of power towards the citizens. The ***feeling of empowerment*** is additionally connected to increased interest in political citizenship, however this is operationalised in the previously mentioned indicator 'political participation'. Originally community empowerment had an equal focus to individual empowerment, however as the results will reveal not all of the citizen science projects are functioning as community-building projects, therefore the power of the collective is reflected separately in another indicator for collective capacity and social capital.

Social

Another determinant of adaptive capacity is the ability of institutions to provide a room for autonomous self-organization and realization of citizen initiatives, encourage experimentation, innovation and proactive response to everyday opportunities or breakdowns. Gupta and colleagues (2010) and Grothmann and colleagues (2013) classify this determinant as the 'capacity to improvise'. Pelling and High (2005) make a very relevant point on what ***social capital*** can offer to assessment of adaptive capacity: "understanding adaptive capacity means understanding the generic capacities existing in a society that enable self-protection and collective action to avert or cope with stressors, as well as more hazard specific capacities" (p. 312-313). Thus at the societal level the contribution to the collective capacity is assessed, which is referred to as social capital: "features of social life—networks, norms and trust—that enable participants to act together more effectively to pursue shared objectives" (Putnam, 1995, pp. 664–665). Adger (2003) adds to this by arguing that "social dynamics of adaptive capacity are defined by the ability to act collectively" (p. 396). Therefore it is evaluated whether the citizen science project 1) fosters self-organization and mobilization of social capital 2) supports the ability to act collectively 3) supports existence of cohesive networks, when social ties such as relations and partnerships among the citizen science individuals and communities strengthen as a result of such collective action (Adger, 2003). In fact, collective action is only one of the levels of engagement in group activity according to Shirky (2010). The first and the simplest level is *information sharing* when the activity is based on creating and maintaining a shared platform where people contribute with data, pictures, opinions etc. This form of engagement resembles crowdsourcing (data and information supplied by 'the crowd') and does not require personal contact and meetings, neither the sense of belonging to a group. Information sharing is typical for contributory (scientists-driven) citizen science projects according to the typology of Bonney and colleagues (2009) introduced in the section 2.3. The second level is *collaborative production* when there is no 'owner' of the initiative, but the success is dependent on the invested efforts of many involved people and/or stakeholders. The coordination between the individual and group goals increases and the group has to make some collective negotiations. Co-production is characteristic of collaborative citizen science

projects based on Bonney and colleagues (2009). At the next level is *collective action* which requires social cohesion as a crucial prerequisite for the success of the project. Participants get involved in discussions and try to reach agreements about the purpose, shape and direction of the project. The participants themselves are the authors of the choices made in the project and should feel a binding commitment to the action and the group. Collective action requires much more coordination compared to the first two levels and may encompass governance challenges as well. Collective action connects with co-created (community-driven) citizen science projects following Bonney and colleagues (2009). Overall, information supply and sharing is the key point of information sharing, a co-creation process represents collaborative production, whereas participants in collective action are bound by shared responsibility, personal and group identity. All the three forms embrace the ability to act collectively in relation to the social capital indicator, but in different ways and to different extents. It is not prescribed which form is the best fit for citizen science, however the assessment distinguishes between these forms to allow for comparison of the projects.
Based on the resilience literature (Feldmeyer et al., 2019; Arup & The Rockefeller Foundation, 2014) the last indicator to cover the societal aspect of adaptive capacity is ***knowledge and risk competence***. In adaptation governance this refers to the information flow about urban challenges such as heat, flooding or heavy rains from the local authority or other relevant bodies to citizens. Touching upon the institutional indicator 'continual access to information', the determinant of knowledge and risk competence relies likewise on access to up-to-date knowledge and information in order to make citizenry informed and better prepared. Preparedness in this sense encompasses local understanding of risk and knowledge of possible ways how to act in the long-term or during extreme occasions. Such public awareness provides an invaluable asset to the city and empowers citizens to learn, act and adapt. This indicator also takes into consideration inherent understanding or outstanding past experience with extreme events as these contribute to enhancement of risk and knowledge competence. The impact to assess concerns whether citizen science helps to make participating citizens more aware and knowledgeable in light of potential climate risks.
Both indicators (social capital; knowledge and risk competence) reflect the potential for empowerment of communities and local knowledge which belong to essential elements of citizen science as outlined in the theoretical section.

4.2.4 Practical application of the assessment framework

The assessment framework was used to guide the interviews whereas some of the interviewees directly assigned a particular value to the indicators according to Figure 6. However, the overall assessment and interpretation of every project was done subjectively based on the compilation of information from the interviews and analysis of project documents, website and other related material. Reflection on the aspect of subjectivity is more discussed in section 6.3. The core part of the scale of measurement follows the 'traffic light system' of colour coding based simply on low, medium and high impact. Very low and very high were supposed to be used in exceptional cases to underpin the necessary gaps between levels. The additional grey colour indicates missing information on the particular indicator due to the interviewees stating that they have not investigated impact in such an area so far thus they do not feel the competence to comment on that, and additionally no supporting information was identified during the document analysis. The values were not assigned separately for every project but relative to each other, which means relative to the subjective comparison between the projects. The values were also compared against the grading provided by the interviewees to reflect on potential discrepancies. The baseline was the average of the projects. Additionally, some indicators comprise more points to look at (e.g. social capital: 1) self-organization and mobilization of social capital 2) ability to act collectively 3) social cohesion) thus higher grades reflect impact of citizen science project in majority of these points. The grading system was supposed to serve as a guiding tool to recognize similar patterns or differences among the case studies rather than being

created to express exact science. Ultimately the framework contributed to a detailed foundation for drawing conclusions.

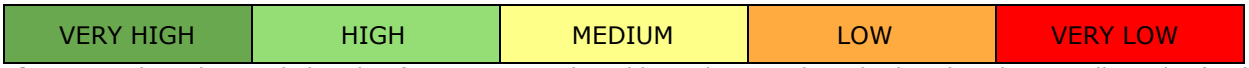

Figure 6: *The colour-coded scale of assessment. The additional grey colour displayed in the overall results (5.1) indicates missing information on the particular indicator.*

5. Results

The section starts with presenting the overall assessment results which are then further broken down into assessments of individual citizen science projects according to the introduced frameworks. This is followed by deeper cross-case analysis which provides the foundation for drawing implications from the assessment. In this way the complexity and depth of analysis over the results is gradually built up. The textual interpretation of results for every indicator per case study or across case studies differs in length respective to the amount of information gathered from the interviews and other sources.

5.1 Overall assessment

Table 4: *Overall grading of case studies*

	Meet je Stad (NL)	Meet je Stad (NO)	Luftdaten (DE)	BeWater (ES)	RiuNet (ES)	Sea watchers (ES)	Natur kalender (AT)	Crowd Water (CH)	TeRRIFICA (BY)
Credibility									
Legitimacy									
Salience and usefulness									
Usability									
Access to information									
Trust and cooperation									
Impact on policies and politics									
Political participation									
Behavior and attitude									
Feeling of empowerment									
Social capital									
Knowledge and risk competence									

Here it will be commented on the general patterns resulting from the scores (Table 4). It is not intended to analyze which performance should be improved or not, because the assessed projects were established to address different needs and produce different outcomes. The central focus is to identify weak and strong points as well as opportunities that citizen science provides in order to answer the central research question.

Interestingly, the cases present very similar patterns in most of the indicators. The results show that the citizen science projects score quite high in their contribution to science, quite low in contribution to policy and medium in contribution to society. No indicator was rated as very low (red colour).

With respect to **science**, the citizen science outputs turned out to be salient, useful and usable, however credibility appears to depend on the means of data collection and validation. It can be seen that projects led by established scientific institutions or their consortiums (score: very high) reached considerably higher credibility compared to volunteer-led initiatives. The results on legitimacy show a great variety whereas the majority of stakeholders (apart from citizens) include research institutions, schools, recreational clubs and associations or other related projects. Public authorities seem to be represented to different extents.

In the matter of **policy**, the citizen science projects do not create a significant impact on policies, politics or enhancement of individual engagement in governance issues or political arena in relation to adaptation (political participation). There is some potential to support the information and knowledge capacity of institutions, however the results show that this depends for example on credibility or interest of the specific project. Next, the case studies encourage flourishing relationships between actors especially at the science-society interface.

In terms of **society**, influence on behavior and attitude is not inherent to the projects, however they generate high levels of empowerment with respect to gaining individual skills and knowledge that can be further used for higher personal or community purposes. The assessment results for social capital are very diverse since the projects approach self-organization and mobilization, the ability to act collectively and social cohesion in a distinct way. Lastly, the projects create only medium impact on knowledge and risk competence as they raise attentiveness to potentially changing surrounding environments and natural resources, however do not contribute significantly to citizen preparedness and knowledge with regard to dealing with potential climate risks.

5.2 Assessment of individual projects

Here only the most important information is presented, thus for example description of *outcomes and envisioned impacts* is limited to the maximum of three points for each. Within the individual projects it seems for some indicators that the provided information is repeated or overlapped. However this is not seen as a diminishing factor as there are many necessary perspectives to be taken over one piece of information. The indicators enable to 'decompose' the same information from different sides. For example what served to the benefit of the empowerment of individuals may have been at the expense of credibility of the project (e.g. self-made tools for measuring climate variables, Meet je Stad). This approach allowed for more precise reflection on the assessment results for drawing conclusions.

5.2.1 Meet je Stad (Netherlands)

The city of Amersfoort starts to become more active in climate adaptation by promoting coherence between various urban initiatives and offering governance support. It joined the initiative The City Deal Climate Adaptation that enhances cooperation between the Dutch cities and their stakeholders.

The main problem is that certain areas of the city show overly high temperature during the summer season, leading to health issues of the citizens, social discomfort and degradation of infrastructure. Since 2015 the project *Meet je Stad* (Measure your City) has been active and further expanded to other cities such as Enschede, Apeldoorn, Tilburg, Utrecht or Bergen in Norway.

5.2.1.1 Analysis of the case study

According to the project leader there is no single aim because the research process is open and more parties with different goals are involved. In theory, the central aim of Meet je Stad (MjS) is to raise awareness and empower citizens to understand and deal with the consequences of climate change in their own environments by measuring local climate variables. The subgoal was identified to be a contribution to the knowledge base about weather patterns and urban heat in the city for some other purposes (e.g. policy).

Inputs

Meet je Stad was prompted by a desire of the Municipality of Amersfoort and the Vallei en Veluwe water board to make the citizens participate in investigation of urban climate change effects. To be precise, the municipality was looking for more climate data, more embedded policy among citizenry and increased public support built on knowledge, whereas the water board was struggling with the fact that it governs the public water resources without knowing how to reach the people it serves. The first meetings and coordination were organized by the Cooperative University Amersfoort (CUA), which departs from a notion of traditional university into a place for independent curiosity-driven research. Currently around 150-200 residents are involved, being recruited through newspapers, the website, by word, etc. Time-wise there are monthly meetings where citizens discuss technicalities about sensors and measurements. Once per year there is a weekend conference MeetKoppel open to any people or authorities. Funding for Meet je Stad is provided by the municipality and the water board whereas most of it is spent on the necessary material.

Activities

The project is self-proclaimed to be autonomous citizen-led science as the above mentioned actors provided only the initial facilitation (e.g. financial) and let the project work independently. The course and progress is thus in the responsibility of the participants. It employs citizen sensing which refers to the use of the self-built sensor monitoring network constructed and installed by citizens around the urban area, in the streets, gardens, neighbourhoods (Figure 7). Development and testing of open hardware and software is also up to the citizen scientists. The sensors generate and send data about location, temperature and relative humidity every 15 minutes. The research process is very open so that everybody can follow their interests, motivations and research questions. The project brought social innovation through its establishment of one of the first Internet of Things networks with the LoRaWAN system (a globally accessible wireless network, the appliances can 'communicate' between each other over long distances) which covers the area of the whole city.

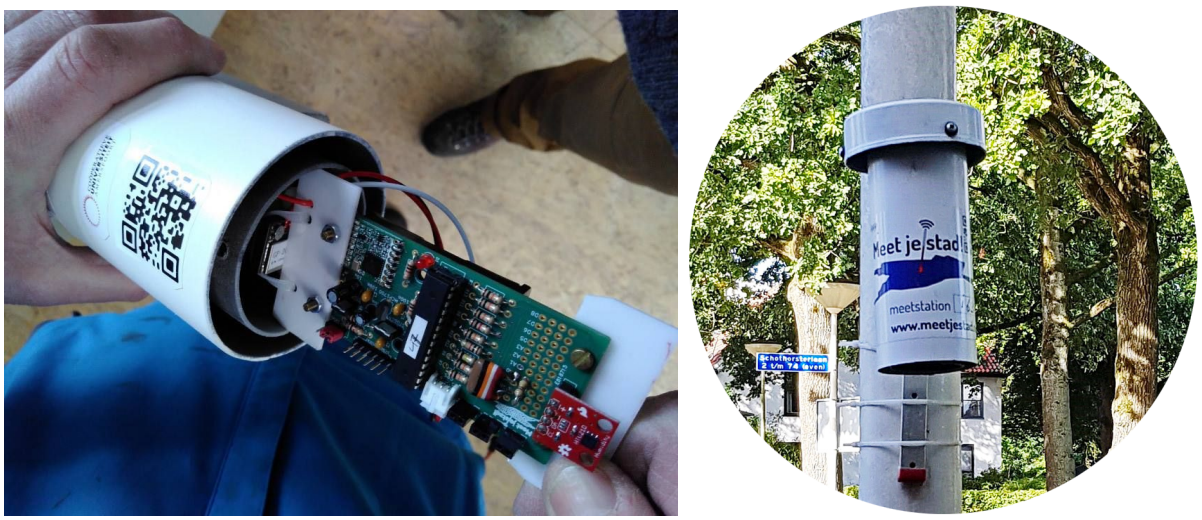

Figure 7: *Illustrative examples of the Meet je Stad sensors (left: Koppelting, 2018; right: Lekker in je Tuin, n.d.)*

Outputs

- Large amount of site-specific data from sensors
- Open data source platform (Meet je Stad website)
- Growing knowledge about local climate change patterns (e.g. overly hot spots)

Outcomes

- Outcomes for individuals: enhanced interest in surroundings and technology use
- Increased awareness about local climate effects among the involved citizen scientists
- More engagement between the citizens and the authorities (especially the municipality)

Envisioned Impacts

- More targeted urban spatial planning
- More trustful and cooperative science-policy-society relationships
- Better access of people to knowledge and technology as well as better access of authorities to local knowledge

5.2.1.2 Assessment

Credibility

According to the project leader, if quality is determined by precision and robustness, then the sensors deliver a limited performance. If it is more about being fit for function, then it can be said that the quality is high. The temperature measurements are quite accurate, whereas the quality of data about humidity is very low. In the beginning a lot of testing was self-conducted against the data of the Royal Dutch Meteorological Institute (KNMI) to find a good price-performance ratio for sensors and cater for technological precision. At the University of Bergen two of the sensors are being tested for two years to find out how long they can measure accurately and how to compensate for disparities. The project has not had success with long-term connections to academic science. The efforts to formally connect with the KNMI failed two times. Some scientists joined the project but from their personal interest, for example a pensioned meteorologist from the KNMI who does the informal quality control and used the data in the scientific publication (see Mureau, Wesseling & Zijp, 2018). Initially the municipality supported Meet je Stad because of citizen involvement, quality got the attention only when the project

was asked to help with measurements of heat islands in the Schothorst district. The municipality and the water board advise to focus more on verification of the data quality, however they are not strict about the precision of the data for their own use. It could be concluded that the citizen science data have not been fully recognized by scientists or peer expert communities, however are perceived to be trustworthy by public authorities.

Legitimacy

The project shows high legitimacy due its open-minded and inclusive approach with a diversity of stakeholders involved whose views and needs are respected. The representatives of the Municipality of Amersfoort, de WAR (laboratory for innovation), the members of the Cooperative University Amersfoort as well as of the Vallei en Veluwe water board are active in the project to different extents, especially in the area of project facilitation (funding, spaces,...). The biggest say have the citizen scientists themselves. Based on personal experience during the weekend conference Meetkoppel in January 2020, also representatives from the Netherlands National Institute for Public Health and Environment (RIVM) participated to discuss and express their stance. The project is officially not guided or in any other way intervened by an academic or research institution. It keeps being open to welcome citizens, scientists, authorities or companies.

Salience and usefulness

The measurements are not useful for serious weather predictions but are valuable as a complementary source of knowledge to the official measurements. The scope of the measurements provided by the KNMI is limited outside the borders of the cities to avoid influence of buildings, thus the project helps to deliver high resolution data inside the urban area. Moreover, it can be used for creation of real-time heat maps or for analytical purposes over a longer period. The municipality regards the data to be relevant and is actively using them in urban spatial planning of the newer neighbourhoods. For them is also vital the community knowledge aspect of the project. The citizen scientists can make the data relevant to whatever they want to do about their local environment. The water board learnt how the citizen science process works and later on started their own citizen initiative for measuring groundwater levels.

Usability

The collected data as well as overview of the performance of the sensors is openly accessible at the Meet je Stad website and presented in a way to be easily employed by end-users. The real-time data are visualized in the map (see Figure 8) whereas the archived data in the table. Respective graphs are created directly, also in comparison to the KNMI data. The data sets can not be exported. There is a plan to directly transfer the data to the meteorological institutes of the countries so that they do not have to enter the webpage manually.

Access to information

According to the project leader, "the data are open and stakeholders know it" (Respondent 1). As explained in the previous indicator of usability, the data can be reached easily by current or potential stakeholders (e.g. research and academia) who could extend the application of data to their own purposes, however the project lacks effort to create new partnerships in this area in terms of spreading awareness about such data source thus missing the opportunities for justifying its usefulness and credibility and finding new (maybe yet unknown) application and stakeholders. On the other side, the project performs well in establishing communication flow with the key urban authorities, especially the municipality.

Trust and cooperation

CUA serves as a mediator between the institutions and the participating citizens. The biggest struggle which has to do with fluctuating trust and cooperation is uncertainty about what comes out of the project and how to make use of the data. The municipality would like to improve the relationship with Meet je Stad, but the discussion will always be about achieving some goals that Meet je Stad prefers to emerge organically. At the beginning distrust from both sides was obvious, however throughout the time more acceptance can be observed and some of the citizen scientists feel more confident about the city. The shared wider goal of a healthy environment as well as personal involvement of the civil servants in the project help to overcome the trust gap. What was especially important about building the trust between (and within) both the municipality and Meet je Stad was the actual willingness of the two key project leaders and a representative of the municipality to take the time to get to know each other´s approaches and the dedication of the representative to negotiate within the municipality to support the project. Currently the interaction works in a way that if the municipality has some wishes, the project members are open to hear them and express the level of interest. The relationship with the water board reflects its low involvement in the project, however the body is generally trusted among the public.

Impact on policies and politics

Meet je Stad supported the planning of renovation of the Schothorst district to become more climate-proof. The municipality asked to identify the warmest spots, its influence and opinions of people. MjS organised some workshops in the neighborhood, added sensors to the streets, created heat maps and ran conversations at markets and events. The overall analysis was conducted in cooperation with the Amsterdam University of Applied Sciences. As a result, a set of measures was decided together with the municipality and the residents. A smaller case concerned a park that people enjoy but came under the scrutiny of a housing investment project. MjS measured the cooling effect of the green space to make a political argument against the approval of the project.

Political participation

Based on the gathered information no recognizable impact has been shown in this area. The representative of the municipality expressed that a positive influence on political participation might not turn out in Amersfoort because the involved citizens know that the authority puts efforts into doing something about climate adaptation, thus more public engagement may occur only in case it would not react fast enough to specific issues. The municipality finds the (probability of) engagement of many citizens in this project important and desirable in light of future policy decisions on climate adaptation measures.

Behavior and attitude

Changes in behavior and attitude have not been recognized yet within the project. For example the interviewed citizen scientists mentioned that their personal sustainable behavior and attitude in daily lives did not emerge from participation, but from earlier endeavors to be more environmentally responsible.

Feeling of empowerment

Within the project the citizen scientists feel prompted for curiosity and experimentation. The low-cost character of their instruments allows them to investigate deeply how to get as many good results in the most affordable way. Continuously questioning the measurement process provides a lot of opportunities for innovation and feeling of responsibility for the data. Some participants whose primary motivation to join was technology started to recognize more the climate topics which also worked the other way round. A few people stressed the empowerment of women in connection to technological work such as soldering of sensor stations. Next, asking own research questions and trying to interpret the data yielded more attention to the individual and urban surroundings as well as

basic connections, for example between concrete and accumulation of heat. Based on the interests and motivations of the participants there is more focus on the technological skills rather than on climate awareness and knowledge. Generally the project succeeds to empower the citizens as slightly more knowledgeable debate partners with the scientific and policy representatives such as in the Schothorst case. No greater adaptation or citizen science actions or ambitions were found out among the participants.

Social capital

The autonomous role of the citizens in Mjs provides a lot of space for further self-organization and attraction of more participants. However, the project keeps running into situations when it is clear that there needs to be a few people with oversight who push things when the project is in danger of a stand-still. Hence there is a bit of tension between self-organization and keeping action alive. People need to get used to the feeling that they are owners of the project as they tend to apply a wait-and-see approach. A 'democratic' boss could emerge directly from the community. Secondly, the project leader mentioned that it is challenging to keep people enthusiastic in the long term. If too few people remain engaged, the group deflates. Currently out of the 150 to 200 participants only 25 are very active, around 50 reasonably active, and then the rest just possess sensors. Meet je Stad mostly builds on collaborative production when the efforts and ideas of the participants are needed slightly beyond action of building sensors and sharing of knowledge and data. In terms of social cohesion, participants maintain good relationships among themselves, however the community feeling is not the priority for the involved individuals as they are more interested in the measurements.

Knowledge and risk competence

The project does not make the participants necessarily competent in light of dealing with potential climate risks. Neither does it introduce specific methods and ways how to increase individual or community resilience. However it makes the participants more aware about climate change in the local context by reinforcing critical thinking about connections between the measurements and the reality. The project guides to analyse the problems which are close to the citizens (e.g. hot streets) and think alone or with others about the solutions in the long run so that they can experience as few negative consequences of climate change as possible. The involved citizens further talk about these topics within their neighbourhoods and social groups.

5.2.2 Meet je Stad (Norway)

In 2018 Meet je Stad launched a spin-off group in Bergen which keeps constantly growing. Bergen with its 280 000 inhabitants is situated between the western ocean coast of Norway and natural mountainous barriers. This is reflected in usual weather patterns for this region such as increased precipitation, humidity, winds and clouds which shape the cultural and social identity of the city. The climate induced challenges that might occur can include seasonal changes, more heavy rainfalls, flooding and sea level rise, landslides and storms. Bergen possesses great capacity for climate science which is expected to be crucial for the vision of the city to become climate resilient until 2050. Climate has become one of the research pillars of the University of Bergen, the local municipality has put forward strong mitigation measures in the Green Strategy and a number of non-governmental groups actively initiate climate action. Climate change and resilience have become here an urban public discourse, enshrined in scientific and policy communities in particular.

5.2.2.1 Analysis of the case study

The citizen science group in Bergen was created with the aim to support co-creation of climate services and measure climate variables at the places that have significance for the involved citizens.

As the network is gradually more established, more attention is directed to better understanding of air quality and local climate change effects.

Inputs
The project borrowed a set-up of its Amersfoort original version in terms of technical and community infrastructure, online communication means and documentation. It was initiated by the Co-Cli-Serv team and a hackerspace in Bergen which is a community-led innovation space for people who are interested in electronics, science, technology, machines. Four public workshops (each around 30 participants) for sensor building were organized, two of them under the supervision of the Mjs leader in Amersfoort. The first participants were coming from the network of the hackerspace community, but some joined through the University of Bergen. Now the project functions in the form of loosely arranged meet-ups organized by the core citizen group. The sensors are funded under the Co-Cli-Serv project.

Activities
There are around 100 sensor stations measuring temperature and relative humidity, out of that around 60 are truly active. These are spread not only in the urban areas but also around the surrounding mountains.

Outputs
- Installed network generating a lot of detailed data about weather in Bergen

Outcomes
- Better understanding of local weather in Bergen
- Individual empowerment, primary technological

Envisioned Impacts
- Established adaptation practices at the individual level and acquirement of the "grandparents" knowledge - e.g. certain shape of clouds indicates upcoming rainfalls
- Contribution to science (weather reports, research on climate adaptation) and policy
- Individual and community empowerment, feeling of less estrangement from science, climate change and technology

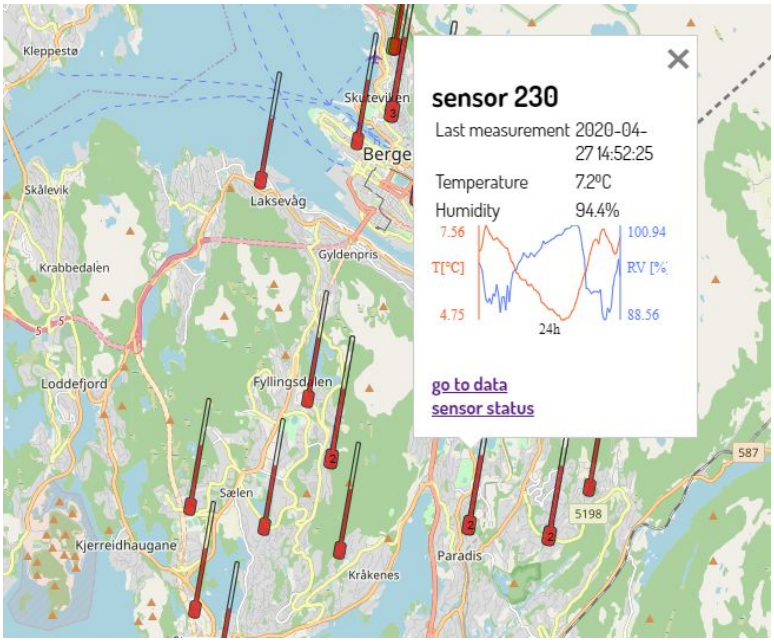

Figure 8: *Example of Meet je Stad data visualization on the map (https://meetjestad.net/index_oud2.php)*

5.2.2.2 Assessment

Credibility

The most striking climate effect in Bergen might have to do with more intense rainfalls, which cannot be measured in this way. The parameter of relative humidity is very relevant but not accurate enough. Measurements of temperature are not negligible, however they bear a different weight compared to for example Amersfoort which is dealing with the occurrence of urban heat islands. Secondly, the sensors perform well in the inner city of Bergen but the transmission of data to central gateways is more problematic from the mountainous or more distant areas of the city. There is no official provement of the quality of data. Because the Geophysical department of the University of Bergen shows strong interest in the data, it would be strongly desired by the citizen group that this department help assure knowledge quality. Two experts from this department voluntarily test a few sensor samples, suggesting solutions or additional features.

Legitimacy

MjS in Bergen is in the ownership of the citizens themselves, but the helping hands have been provided by the coordinator of Mjs in Amersfoort, the Co-Cli-Serv research team and team from the University of Bergen. The university team serves as an intermediary to supply stations and connect with technical experts. The municipality or public administration is not directly involved but supports the existence of the project. No other stakeholders interfere in the project at the moment.

Salience and usefulness

The location of Bergen in the valley makes temperature and air quality measurements in the urban area slightly problematic due to inversion layers also for official meteorological stations. Because of this, there has been a meteorological crowdsourcing program led by the weather service platform for forecasts and meteorological information in Norway (YR.no) that provided the Netatmo (more professional) sensors in citizen gardens to improve the accuracy of temperature data at the ground level. This has shown a scientific interest in such cutting edge wireless technology and its usefulness for Bergen where the institutional measurements are inaccessible. Currently there are efforts to

connect YR and MjS Bergen to embrace the citizen data provided they would be delivered in an adequate format. The strongest interest is shown by the Geophysical department which stated that given there are that many sensors the data can be used, otherwise the uncertainty of measurements would be a problem. A separate research project at the University of Bergen is interested in usage and application of MjS sensors in Sudan. The municipality is doing parallel programs with the sensor data but they hope to have more data points. The authority is very open towards community initiatives and engagement of people in adaptation measures, hence MjS might prove useful for their work in the future.

Usability

Data and performance of sensors from Bergen are transmitted to the MjS website, which means that the measurement network is integrated and harmonized with the Amersfoort group (see description of usability in MjS - Amersfoort). An illustrative example of data visualization on the map is provided in Figure 8. The current efforts are invested into putting the data into the desirable format tailored for Bergen so that it could be offered and potentially used by the interested institutions.

Access to information

Currently there are no formally established communication channels with relevant institutions for dissemination of produced data. It is highly potential that more comprehensive communication will be soon established with the Geophysical department.

Trust and cooperation

Bergen maintains a strong sense for participatory democracy, giving people opportunities and spaces for discussions and sharing about the city's climate. The society trusts the local government as well as scientific institutions. The citizen scientists expressed their willingness to support the government with the project by saying that it would be useful to have a lot of installed sensors to back up the sensors and equipment owned by the government. Similarly, the project members are willing to establish cooperation with the interested scientific bodies. No cooperation is formalized so far. Additionally, there is a lot of long distance cooperation and exchange of technical information between the Norwegian and Dutch Meet je Stad through the Riot chat room (online communication platform).

Impact on policies and politics

Based on the interview with the coordinating assistant, no impact has been shown in this area.

Political participation

The impact on political participation is absent. The people who joined the project were already interested in the climate topics or engaged in some ways. The potential is seen in writing an opinion paper for the newspapers about weather patterns or anomalies in Bergen.

Behavior and attitude

No impact has been shown on behavior or attitude based on the conducted interviews with the coordinating assistant and the citizen scientists. Regardless of MjS the citizens show concern for individual changes for example by using less cars.

Feeling of empowerment

"You feel like there is nothing you can do about it and then there is this act of measuring surroundings and contributing to science when one can get a feeling of empowerment and engagement" - Respondent 9 (coordinating assistant). Designing and building of sensors in Bergen was inspired by the existing kit of Amersfoort. This helped to avoid repetition of certain mistakes however the sense of empowerment and satisfaction behind creating own tools from the scratch was eliminated. Anyways,

the sensors must be tailored to the climate conditions of Bergen and technological empowerment generally holds a strong place in the project. The core group of participants comes from the hackerspace thus enhancing the technical knowledge is in their utmost interest. What people can learn and get out of the project depends on individual preferences. Some citizen scientists feel more familiarity with meteorology and climate change. They see bigger potential in raising individual and collective awareness about understanding and acting on local climate effects and related issues. This is where the project is slowly heading.

Social capital

The project aims to open up the conditions for the Bergen citizens to self-organize and develop new ideas or research questions together, however this is only at its very beginning. The reasons why participants take part in MjS are very diverse while taking into consideration that it is dominated by tech enthusiasts. The interests might influence the motivation for collective action. Some are interested in measuring only their own surroundings (house, garden, street) or use the results for their own purposes, some are more concerned with data analysis, technical skills, weather observations and outcomes with regard to local climate change impacts and resilience. Actually keeping people motivated to take care of their sensors is the greatest challenge. What might trigger citizens to get involved is problematic air quality when NOx from cars come down which are usually trapped at top of the mountains during temperature inversions. People are increasingly affected by this as they have to spend more time indoors, and with climate change the problem is only expected to worsen. Climate change is generally acknowledged and a popular topic among the Bergen citizens to talk about, and they are caring, thus there is potential for MjS to grow its participation and impact in providing the opportunities to contribute to solutions, start the discussions and enhance collective action. At the time being MjS in Bergen is less structured and more based on loosely arranged meet-ups to learn and exchange knowledge and skills. Social interaction is based mostly on the core hackerspace group of max 10 people. The citizen scientists expressed that the interaction for project purposes helps to create new relationships. An important part of this is that people who come to the workshops or meetings share the common interests in technology or climate.

Knowledge and risk competence

Inherent resilience of Bergen inhabitants must be emphasized as they are used to various weather patterns and have closer connection with the surrounding natural areas. In its present form Mjs does not aim to be instrumental (e.g. solve air quality) but focus is more to make people understand the local situation starting from their own surroundings. This is perceived to increase community resilience in the long run and improve preparedness for adverse climate effects. The flow of local knowledge is concentrated in the circle of participants but a word of mouth proved to be an effective instrument for raising awareness and climate knowledge beyond Meet je Stad in the neighborhoods. This indicator is rated as medium because Meet je Stad in its current form does not provide a deeper insight into responsive behavior which might be missing to make the participants competent in light of climate risks.

5.2.3 Luftdaten.info/Sensor.Community (Germany)

Air pollution is not directly related to urban adaptation, however this case study shows novelty due to the scale into which it has grown and provides a different perspective on how the same measured variables (temperature and humidity among others) can be used for a very distinct purpose and in a very distinct context in comparison to Meet je Stad. Luftdaten was initiated by a small group of concerned citizens in 2015 who wanted to measure fine dust (fine particles in the air causing health issues) in Stuttgart with 300 self-made sensors installed. Topography of the city, high numbers of cars together with a strong position of automotive industry are to blame that the European limits for

particulate matter pollution are crossed here at the alarming level. The project managed to outgrow Germany to establish a global sensor platform Sensor Community for collecting worldwide open environmental data. The primary interest of the analysis and assessment is limited to Luftdaten in Stuttgart, however some of the information as revealed during the interview or identified during the document analysis concerns also the global scale (Sensor Community) to provide a better picture of the project realities.

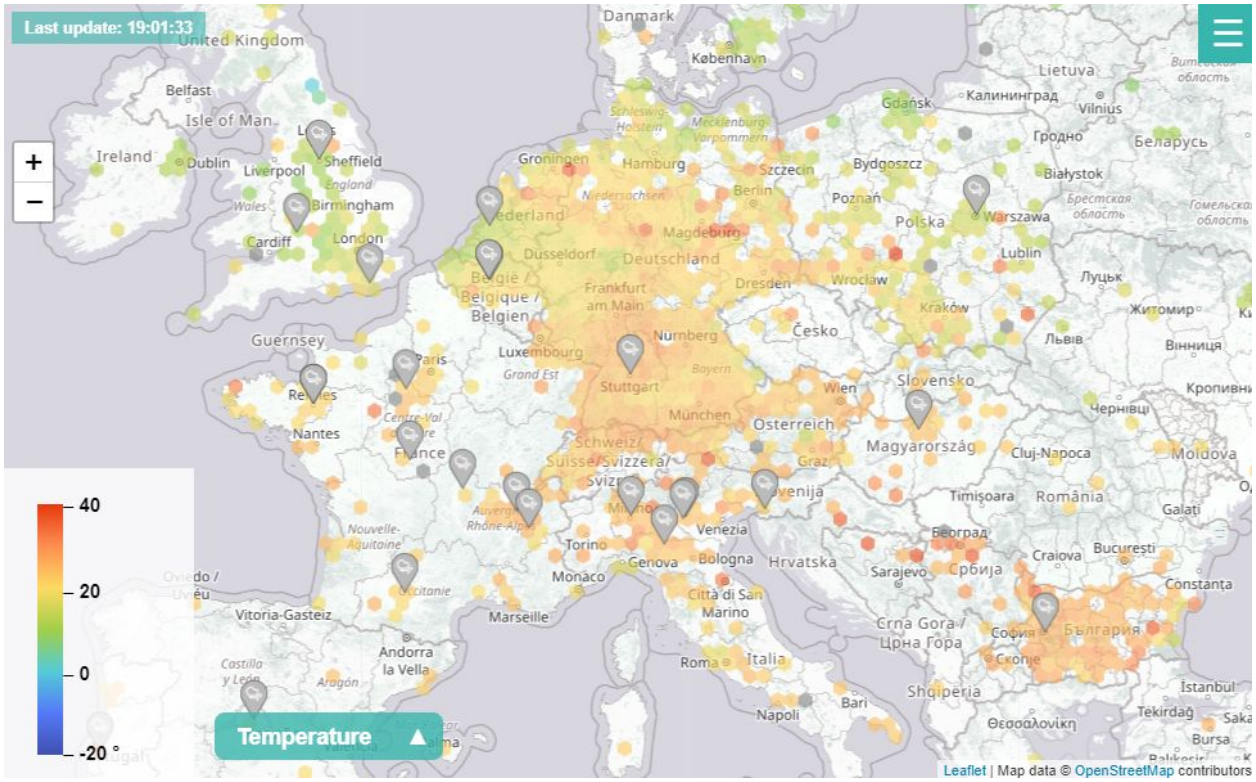

Figure 9: *Visualization of Luftdaten/Sensor Community data in real time (https://sensor.community/en/; https://luftdaten.info/)*

5.2.3.1 Analysis of the case study

The project aims to help address air quality in residential areas by providing a (global) data and community platform driven by collective curiosity. In this way it strives to contribute to better individual understanding and informed discussions about environmental and health problems in Germany but also in the urban regions around the world.

Inputs

Open Knowledge Lab Stuttgart (OK Lab) is a local volunteer group of designers, IT developers, journalists and others who have been running Luftdaten as well as Sensor Community and further work on projects related to civic tech, transparency, citizen science initiatives, open data and visualization. The Luftdaten/Sensor Community team involves ten experienced volunteers and both of them are self-paid for example through donations. In terms of Luftdaten, there are currently 754 sensors around Stuttgart. The number of citizen scientists is challenging to count, but in theory every sensor must have come from people who joined the workshop or ordered the components, set it up

and registered it to allow for data transmission. Luftdaten is only one of many projects aggregated under the newly built online platform Sensor Community which has achieved until the present time a base of more than 11 500 sensors installed by citizens in 72 countries.

Activities
The sensors measure PM10 (particulate matter with diameter smaller then 10 μm), PM2.5, temperature, relative humidity, pressure and AQI (air quality index). The data is transferred every 2,5 minutes and visualized in real time on the Luftdaten and Sensor Community website (synchronized). The platform also collects data from already established or newly set up sensor networks and clean air initiatives from all around the world. Workshops for building sensors, sharing knowledge and discussing the results are organized two times per month. The groups of engaged people who meet here are very diverse in age, gender, interests and backgrounds. Apart from that there are voluntary meetings, activities at schools or annual Personal Democracy Forum for Central and Eastern Europe where countries have free space to discuss and network.

Outputs
- Open source platform with historical (archive) and real-time data
- Visibility and publicity to 31 different regional or community projects under the Sensor Community
- Events organization as specified in Activities

Outcomes
- Improved technical infrastructure for data collection leading to higher data availability (worldwide)
- More transparency and open accessibility to data (worldwide)
- Experience and knowledge exchange between grassroots initiatives within and across countries

Envisioned Impacts
- Increased attention to air quality problems in Stuttgart and other cities
- Establishment of transnational cooperation in air quality citizen science
- Improved relationship between science, policy and society

5.2.3.2 Assessment

Credibility
Luftdaten (inc. Sensor Community) can deliver both quantity and quality. The measurements are aimed at obtaining an extensive and empirically driven data set in order to create a comprehensive picture of the overall situation with air quality. Cooperation with experts helped to achieve precise approximation of results. The inexpensive sensors produce values that have almost an identical curve profile to a professional measuring device. Their expert in the team is a retired meteorologist who previously contributed to building up the official (state) measurement stations. He brought two elements to the project: 1) expertise on weather nuances, selection of sensors and general technical approach 2) contact with a number of meteorological research institutes that assisted with selection of the best fitted sensors. These institutes also compared how citizen science sensors behave compared to the official measurement devices both in controlled and real-life environments. In the end they published a final report on performance of the sensors. Luftaden can refer to this report whenever they meet with distrust regarding the credibility of data. It is well known that the sensor stations overestimate pollution levels on occasions of high humidity, but this should be corrected with statistical models in the near future.

Legitimacy

This indicator was rated as medium because Luftdaten has the actual problems to connect with scientists and public administration despite continuous efforts, however this did not seem to discourage the project team since they managed to establish a vast (global) network of volunteers, reach to schools, libraries and numerous other community projects. The project team keeps open to welcome new individual participants, stakeholder partnerships or projects that would like to join or be established under the Sensor Community. At the present time it is desired to have a closer cooperation with the city and the federal or national authorities which seem to resist. The Luftdaten team has been making efforts for four years to 'run after' the public representatives (e.g. Mayor of Stuttgart, federal Ministry of Transportation) in the events or try to set up personal meetings. They do not express a willingness to look into the possibilities of how to act jointly, probably in light of fear to lose the power and position of being the dominant and flawless producer and interpreter of data. It could find more understanding that the administrative and citizen science efforts are complementary and not mutually eliminating. From the perspective of Luftdaten, establishing a policy-society partnership would help the project to scale up and accelerate its development and impact thanks to expertise from the public institutions. The project does not have active partnerships in the research or academic field, but is integrated within the Future City Lab at the University of Stuttgart. Respondent 10 (international community and partnership development manager) concluded that he can not imagine how they could improve diversity and outreach as they have talked to all kinds of stakeholders so far.

Salience and usefulness

The data are widely used by the research institutes inside and outside Germany that work with weather or air quality. However there are no defined rules for collaboration in this matter, some of the institutes report their usage and some do not, thus there is no precise record. Usually the project team gets informed from the third parties or involved citizens. “When we were invited to an air quality conference with scientists, companies, institutes, we taught that we need to go there and show that we are doing something good. But we saw that every single expert there used our data and map. So we do not have to advertise it, we are known and widely used” - Respondent 10. For example the Dutch RIVM fully integrated the data into their portal and publicize the project on their website. Another example is the Department of Weather and Physics at the University of Stuttgart which uses the data as a validation on the ground for the calculated data from the EU satellite. Consequently the general image of data usefulness is high especially for research purposes. In addition, the local newspapers Stuttgarter Zeitung will soon integrate the data into its online page. This is how air quality may become part of the public discussion. The data might be salient and the local decision makers are fully aware of what the project serves for, but there is no willingness to use it supposedly due to the economic importance of the automotive industry. On the other hand, this undesirable situation might in theory only underpin the actual salience of the produced data which appears to be defeated by political will.

Usability

The air quality data from Stuttgart and devices all around the world is being aggregated and displayed in real time at the open source platform Sensor Community as well as at the synchronized web page of Luftdaten. The data map (Figure 9) is graphically designed to simplify the understanding for the end-user and breaks down a complex topic of air quality into separate components (seven different indicators to choose from). The map is divided into hexagons which represent the average value of sensors located in that area. The sensors are listed after clicking on the specific hexagon. The performance of every sensor can be displayed as well. The historical data are archived thus accessible at any time. The Luftdaten and Sensor Community websites also provide the technical information about sensors together with guiding instructions on its purchase and set-up. The platform ultimately

aims to combine formal and informal data sets not only related to air quality, but also to water quality, radiation, plastics, and other environmental areas.

Access to information

No direct communication channels with institutions have been established. The project team works on external communication by creating a list of municipalities, public and scientific bodies to propose for establishment of regular information and knowledge exchange, so that the stakeholders and the project team know how to find a way to each other at any time in case of interest.

Trust and Cooperation

One of the primary concerns that the project is dealing with is the fact that no research institute which is using the data provides support in return in terms of finances, research and technical infrastructure or expertise. The researchers or other related end-users including public bodies argue with limitations of the system that does not formally allow to use such volunteer-based approach in their work practice. A closely related obstacle in the way towards trust and cooperation is an absence of awareness and defined approach on how to work with citizen initiatives. Next, despite the fact that the project is well-known in the city, there is no way how to force decision makers to build partnerships. On a more positive note, the project team has established strong partnerships with the 31 air quality initiatives aggregated under the Sensor Community.

Impact on policies or politics

Respondent 10 stated that the project does not create policy impact, but instead a several informal impacts. The example was provided from Ukraine where the partnering local sensor project used the data to force the biggest power plant to invest in filtration and facilities for reduction of air pollution. In Stuttgart, the topic of air quality has increased popularity and attractiveness among the local citizens as proven by the number of active sensors. The project has established many worldwide campaigns such as #Sensor2School and #Sensor2Library to support the notion that every school and library in the world should possess at least one sensor. Libraries and schools were chosen because they seem to be the spaces for open sharing of knowledge. Other campaigns in preparation concern the SDG Goals, Clean Air Day and current cooperation with Earth Hour. It is believed that the impact of the project is significantly dependent on data usage by others.

Political participation

Respondent 10 claimed that the project has not created impact in this area so far.

Behavior and attitude

Respondent 10 commented that changes in behavior and attitude are very small-scale among the participants but are observable in everyday adjustments to causal habits, for example the choice of a place for a walk during rush hour.

Feeling of empowerment

For Luftdaten, empowerment is perceived as the possibility for every citizen to have democratized access to reliable air quality data and ability to generate or use it themselves. The local people should understand how air quality affects their daily lives in response to growing environmental concerns. For this to achieve an individual can get familiar with air quality and related technology, data and measurement methods during the workshops, or purchase and register their own sensor station(s). During monthly meetings motivated individuals prepare their own presentations on how they handle data, participants teach each other technical definitions and manipulation with devices. The analytical thinking and tools are applied by citizens themselves, it is the engaged people that are creating the outputs and outcomes that can inform others and scale up the impact. After all, the data produced in

this project are coming from sensors of citizens. Apart from ordinary interested citizens, voluntarily engaged data scientists, IT developers, designers, teachers and others have a free ground to empower their skills and expertise for the good of the project thus contributing to its social value. On the other hand, the participating citizens in Stuttgart do not use the produced data or any acquired skills for mobilization of action towards improvement of urban air quality.

Social capital

The citizen science project can be said to foster self-organization and encourage innovation to a large extent. The OK Lab team in the role of enabler and supporter provides technical and virtual infrastructure for Luftdaten and other projects under the Sensor Community, but these in practice function on their own, cooperate and benefit from each other. Also, if there is an individual or group which would like to set up a project, they can contact the project team and will be given guidance and tools followingly. There seems to be a huge potential in this, thus the project team tries to give the globally involved community more visibility to find each other or prospective new participants, or to be findable by interesting stakeholders. The annual conference is also aimed at networking, sharing knowledge and creating partnerships. Based on the words of Respondent 10, "we are not reinventing the wheel, but allowing people to show what they are doing, it is all out there it only has to be combined". In terms of personal and community relationships, social cohesion is not a prerequisite for a success of the project in Stuttgart. The community aspect is thus not developed in the city. What is well developed and popular is the global online community platform (Mattermost) to connect, share experience and knowledge. However, it is desired to have more people active on the ground by involving them intensively in data visualizations, workshops, meetings, air quality discussions, activities in schools. The ability to act collectively translates in this case into the co-creation process when the invested efforts of individuals are needed and can shape the project, whereas the OK Lab with its team is in charge of the primary coordination.

Knowledge and risk competence

As said before, this project does not concern climate adaptation directly, thus it is not fully relevant to assess preparedness for potential climate effects. In terms of air pollution, the focus of the project lies on enhancement of individual and public understanding of air quality issues, thus the indicator was rated as medium for increasing risk-related awareness. At the same time, the project does not concern practical identification and action on risks or looking for solutions. It is up to the individual choice to adapt the behavior and attitude towards the addressed problem accordingly. This might turn out challenging as in Stuttgart everything is built with a mindset to serve the automotive industry and not the people. Spreading of awareness about air quality issues towards the general public is enhanced through the various events, campaigns and other activities.

5.2.4 BeWater (Spain)

BeWater was a 4-year long European project running in four river basins in Tunisia, Cyprus, Spain and Slovenia, whereas here the focus is on the Spanish Tordera river basin with around 157 000 inhabitants. It was also one of the citizen science projects recognized under the Barcelona Citizen Science Office even though it was not originally structured to serve this purpose but instead focused on the co-production process of various stakeholders to develop approaches towards adaptation in the river basin. The project achieved a huge success and was presented at the international conference of citizen science as an example of a good practice. The Tordera river basin has a crucial role for socio-economic development of the Catalan region. It is governed by the River Basin Management Plan for the Catalan River Basin District set under the Water Framework Directive which also includes 16 other Catalan river basins. It faces many challenges that need to be addressed in view of climate change such as lower water quantity and quality of rivers due to anthropogenic activities as well as insufficiently democractic regional and local water governance. This project does not address the urban region in itself but focuses on cooperation among around eight municipalities and other crucial actors which depend on the natural resources of the basin.

5.2.4.1 Analysis of the case study

The project addressed a sensible topic of water scarcity in Catalonia. It aimed to enhance communication, participation and coordination between a range of public, private and civil society actors for the purpose of more sustainable water management in the Tordera river basin and adaptation to climate change effects in this area.

Inputs

It was funded under the European Union framework programme for research and innovation (FP7) between 2013 and 2017 thus reaching the completion. BeWater was initiated and led by CREAF (Centre for Ecological Research and Forestry Applications), a public research center in the field of terrestrial ecology and climate change attached to the Universitat Autònoma de Barcelona. The participating stakeholders were represented by local NGOs, different levels of administration (municipal, supramunicipal, local government) and their climate change and adaptation offices, industries, public and private representatives of various sectors (agriculture, forest management, water, energy, environment, infrastructure), other experts and interested citizens.

Activities

The main focus of BeWater in practice was to facilitate a collaborative development of the Tordera River Basin Adaptation Plan (TRBAP). The whole process is illustrated in Figure 10. The research steps included diagnosis of the river basin problems and challenges in view of climate change and adaptation, formation of future visions, identification of water management options together with their implementation pathways and finally the participatory evaluation to find out which were the most preferred ones to be applied in practice. When looking closer at the involvement of citizens, this was usually conducted in a workshop setting at every part of the research process (6 workshops with 30-40 participants) or via interviews. Apart from that a number of complementary dissemination events such as exhibitions, talks, school visits, press and media events were organized to introduce BeWater concepts and approaches and to collect feedback, concerns and opinions from the general public.

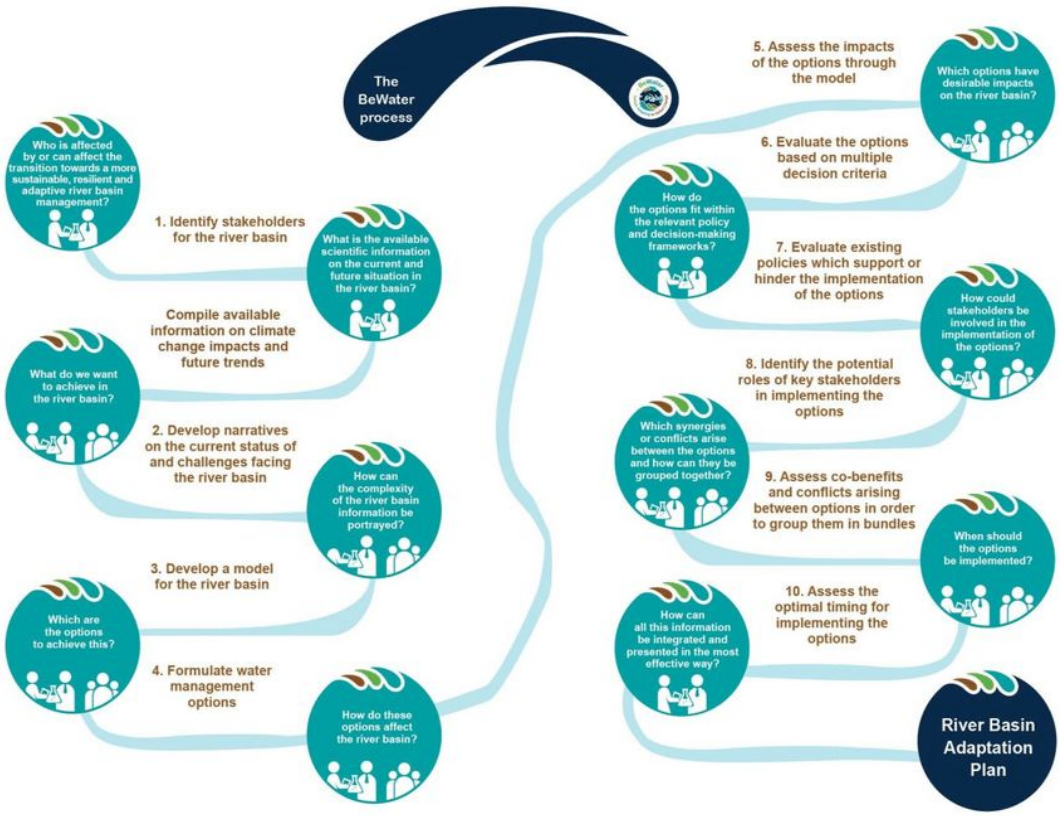

Figure 10: *Eleven action steps of BeWater (Stein et al., 2016)*

Outputs

- Tordera River Basin Adaptation Plan (TRBAP) which included 33 water management options/adaptation measures
- Handbook *Developing Participatory Adaptation Plans for River Basins* which provides lessons learned and further guidance for drafting such plans
- Development of an innovative and transferable approach and methodology for participatory water management that sets the basis or a reference point for something that is key in adaptation, and that is necessity to find solutions that incorporate different sectors, public administrations, science and society (see www.bewaterproject.eu/bewater-approach)
- Other documents: policy briefs, scientific articles, public relations material, reports, publications,...

Outcomes

- Boost of innovation in the water sector
- Mutual learning and exchange of experience and views between stakeholders
- Spontaneous self-organization of citizen platform to support one of the produced adaptation measures

Envisioned Impacts

- Continuous interaction between the participating actors
- More citizen agency and overlook of the implementation process of the outputs
- Transition towards collaborative governance and local empowerment in view of resilient and adaptive river basin management

5.2.4.2 Assessment

Credibility

The credibility of the project was rated as very high because it was not only led by a scientific team from the well-established research institute, but it was also recognized by the European Commission and a wide array of local to supramunicipal actors. Thus BeWater did not face any credibility concerns.

Legitimacy

Legitimacy was rated as very high because a participatory approach and stakeholder dialogues were key to the project. As seen in Inputs the range of stakeholders was very diverse. This brought a great deal of multi-directional learning, knowledge and information transfer into the project since the actors were trying to find common ways despite their quite distinct perspectives and ambitions. In general, the initial invitation to participate in BeWater was quite open and the participating stakeholders were involved at every stage of the research process including implementation of the final measures. The contact with local citizens, initiatives and societies was intensive according to the BeWater team. People and other actors showed strong willingness to participate based on an abundance of current problems related to water scarcity. This idea is also close to all different sectors because water is the motor for public and private development in this region. The municipalities located around the river basin were motivated by vision to create adaptation plans at their level as required by the Covenant of Mayors. Additionally, they need to guarantee safety of citizens as this area is prone to flooding, thus benefiting from gained knowledge about river morphology. More participation from the public service agencies would be desired (transport, gas, electricity) as well as more diversity from the private sector since only vulnerable businesses came up. For example a textile factory in the flood prone area took part as opposed to the bottling firm for drinking water which did not show interest in participation.

Salience and usefulness

Needless to say, the participatory process for defining and assessing water management solutions highly increased its salience and usefulness. Thus this indicator was rated as very high due to very targeted nature and preliminary knowledge of application of the outputs. Apart from addressing Tordera river basin management, the applied project approach as well as utilized or resulting adaptive management principles and tools were meant to be policy relevant and useful for integration into ordinary water management procedures, related policy design, future adaptation planning and transferable into other Mediterranean river basins.

Usability

All the diverse documentation of the project including TRBAP and other outputs is understandable and well elaborated, being available at the BeWater website. The intermediate and final deliverables were adapted to the needs of the past, current or future end-users. For example policy briefs were made to target decision-makers, scientific articles were published for the research community, public relations material was prepared for media and wider sharing, handbook and other supporting documents were meant for practitioners in this field.

Access to information

Establishing more transparent and inter-connected information flows between the relevant stakeholders was one of the key priorities of the project. During BeWater strong communication channels were created or renewed especially at the final presentation of the project results to which all the relevant public authorities and institutions were invited. Generally, every product delivered at any specific moment of the project was at all times shared with everybody participating. The actors could raise objections, additional points or modifications throughout the whole research process. Hence information flow was very much taken care of in BeWater.

Trust and cooperation

Many people were more open to participate because the project was not led by public administration but by a team of scientists to whom public trust was shown. In this way the project team feels that they made a huge favour to the public administration. It gave citizens the opportunity to interact with civil servants mainly in the process of finding the solutions together. This helped to build some foundation for mutual trust and cooperation and the results got better societal acceptance. Additionally, there was an attempt to improve communication between citizens and authorities by setting up a board of citizens (Permanent Participation Centre) to promote and follow up implementation of TRBAP. However, these official participation initiatives to which people from the basin are invited to join are not very successful as could be also seen in participation processes under the Water Framework Directive which were happening here in parallel during the project period.

Impact on policies and politics

BeWater contributed to better informed and participatory decision-making at the river basin scale. Prior to the project there were in effect rather strategic, vulnerability-related or very site specific adaptation practices in the Tordera river basin. Given that TRBAP was created under the guidance of the research institute, it was not mandatory for liable authorities to mainstream the proposed water management options into current policy development processes. Hence certain strategies were used to foster the authorities and departments of the Catalan government to take up the proposals. Some of them require longer time and a stronger political will to be implemented. Generally 22 out of 33 adaptation options were taken into consideration or mainstreamed into ordinary adaptation plans and water management planning procedures which have been already in effect or were being shaped at that time, for example municipal action plans for adaptation (e.g. in the Sant Celoni Municipality) or the Catalan River Basin District Management Plan (2016-2021). TRBAP will also allow the municipalities in the river basin to boost the political support for adaptation action at higher administrative levels. Moreover, the project made a series of policy briefs for local to EU decision-makers with the aim to provide recommendations based on the project experience that would reinforce institutional, legal and policy frameworks in the area of water management and adaption. Next, there was a high synergy between BeWater and the EU LIFE project in the Montseny Natural Park and Biosphere Reserve that took up 10 measures related to restoration of the Tordera water ecosystem. Lastly, the project supported the revision of the Catalan Strategy for Climate Change to integrate experience-based knowledge on citizen awareness. Further project proposals under the EU funding or the Spanish government are developed to implement the prioritised adaptation measures from TRBAP, such as the creation of an Integrated Plan for the Tordera Delta. Generally, the participating stakeholders show ownership of the co-produced adaptation plan and actively pursue integration of the resulting water management options into their activities. A more informal impact was delivered when the project helped to overcome a conflict about construction of the wastewater treatment plant and put forward new solutions to the debate. There was no direct impact on promotion of adaptation to higher political levels.

Political participation

Unexpectedly, a citizen-led online platform was created for promotion of one of the identified water management options (development of the Integrated Plan for the Protection of the Tordera Delta). The project leaders claimed that they are not aware of any further data to support opinion on this indicator.

Behavior and attitude

According to the project leaders, no behavior or attitude shifts were shown in this project.

Feeling of empowerment

The individual empowerment had a very special position during the project. The impact was shown in empowerment of personal voices, opinions, needs and concerns rather than certain skills. The project leaders expressed that the issues of citizens were relevant enough to be incorporated into the project outputs and to be added on the future agenda to the extent that this was possible. In other words, the collected local down-to-earth knowledge of what people are already experiencing in reality about climate change impacts in the basin was brought together with the scientific knowledge brought in by stakeholders (climate change scenarios, predictions in the water related sector) thereby increasing the knowledge needed for adaptation in this location. This follows the BeWater Society narrative to talk to local people in order to design locally relevant approaches. The indicator was rated as high (and not very high) because the citizens were provided (empowered) with resources and awareness to create the actual impact as described here (including the citizen-led platform), but probably would need more engagement, knowledge and skills to feel the empowerment and ability to use this for individual or community purposes outside of the scope and time boundaries of the BeWater project.

Social capital

It can be said that the project mobilized the social capital as well as supported further self-organization and collective action. According to the assessment of the COST Action Working Group on citizen science which sets the European framework of the citizen science concept, BeWater was categorized as a co-production/co-design project. According to the project leaders, the strongest component in mobilization and enhancement of social capital was the opportunity to talk about the most pressing issues, mutual learning between actors including citizens and scientists and the joint creation of adaptation solutions. All together there were six communities (clusters of people with interest to pursue and actively follow the project) from six different municipal areas. The project leaders consider as one of the advantages to have people participating that they feel the ownership or recognize their inputs in the final results thus trying to foster participation in the follow-up. This is also the reason why citizens created the platform to promote the Integrated Plan for the Protection of the Tordera Delta which received the highest priority in participatory evaluation of solutions but was not formally mainstreamed by a competent authority so far. This was initiated at the end of BeWater in 2017 so the project team together with CREAF offered technical advice and support to this platform on which they are working until now. The project leaders add to this that if people are not given the means and clear invitation they are not active. This was the mindset of the project team towards public participation throughout BeWater. The project is kept 'alive' by CREAF after the official completion also by fostering participation of people from the Tordera river basin in the formal participatory processes linked to European policy implementation (e.g. Water Framework Directive, biodiversity legislation), and it further keeps track of opportunities when people can raise their voice for the river basin. Regarding relationships among citizens themselves, it was very empowering to make the people from the same territory meet at one place, however this was not leading to significant impact on social cohesion. Some of them are still related, for example in promotion of agricultural areas. By far not all the people of the Tordera basin participated. The project did not reach people who were not already interested in these topics. A longer initial part of information and awareness raising before the start of BeWater probably would have helped to build a collective of participants while increasing their knowledge and trust. The project leaders conclude that where there are more people there is more space for self-organization.

Knowledge and risk competence

The local people have a strong understanding of potential climate risks as they have been experiencing water scarcity for centuries. The organized exhibitions and experience-based knowledge generated by the project contributed to public awareness of more sustainable water use and offered scientific information on climate risks. The project did not focus on dissemination of knowledge on

individual coping mechanisms or more established ways towards enhancing preparedness and risk competence, as the co-created solutions targeted the river basin management. However, the project opted for the collaborative process in order to increase societal climate resilience at the river basin scale. Additionally, the project promoted adaptive and coping capacities of stakeholders to tackle river basin challenges by exploring opportunities in further collaborations in research and innovation for example with academic institutions, civil society actors and small and medium-sized enterprises (SMEs).

5.2.5 RiuNet (Spain)

RiuNet falls under the Barcelona Citizen Science Office and was founded in 2014 by the Department of Evolutionary Biology, Ecology and Environmental Sciences at the University of Barcelona. It addresses measurement of hydrological status and ecological quality of temporary rivers in the northeastern part of Spain. Temporary rivers are typical for the Mediterranean basin and refer to waterways that have very variable and irregular water flow or are likely to dry up completely in the summer. They are very important in terms of ecosystem services and biodiversity, however face increased vulnerability due to climate change. The citizen science project is relevant for urban adaptation as the data collection is situated within the cities (e.g. Barcelona, Logroño) and their surrounding areas.

5.2.5.1 Analysis of the case study

The aim of RiuNet is to support more sustainable freshwater management by measuring ecological and hydrological status of temporary rivers. A parallel aim is to make people more aware of water resources in their surroundings with respect to quantity and quality.

Inputs

The project is coordinated by the Freshwater Ecology, Hydrology and Management Research Group at the University of Barcelona (FEHMlab). RiuNet is part of the European funded LIFE+ project TRivers which aims to develop a software tool for European river basin bodies for detection, analysis and management of temporary rivers based on their natural, climate-affected or human-impacted characteristics.

Activities

The project uses the RiuNet app (developed by the FEHMlab) which serves as an interactive educational tool that can be used by citizens at any time and place. It guides through the whole process of hydrological (natural or modified flow regime), hydromorphological (identification of riparian vegetation, substrate, water depth, velocity,...) and ecological (identification of invertebrates) assessment. Apart from the assessment report, the information about the GPS location is sent together with pictures of the analysed river stretch. Around one hour is needed to complete this whole process. The results are collected in the database of the FEHMlab research team who validate them before publishing on the data map. Currently there are more than 2000 registered users with more or less active input. A new feature will be soon added to the assessment which looks at social value and ecosystem services of the examined river. An insight into the RiuNet app is displayed in Figure 11.

Figure 11: *An insight into the RiuNet app (www.appgrooves.com/app/riunet-by-universitat-de-barcelona)*

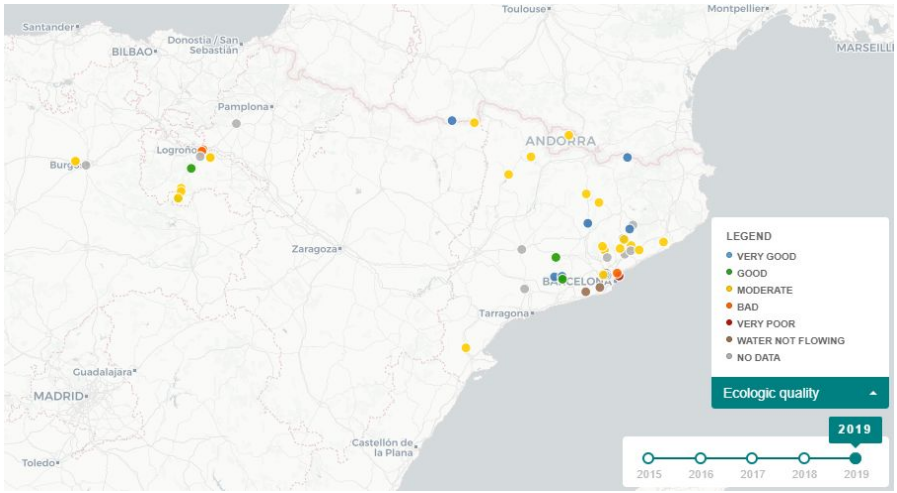

Figure 12: *RiuNet data map - the colours follow the requirements of the Water Framework Directive (http://www.ub.edu/fem/index.php/en/dades-en)*

Outputs

- RiuNet app where individuals can do the assessments and check the validation
- Data map - visualization of validated data from both urban and non-urban areas
- Reports that summarize the citizen assessments

Outcomes

- Results on the ecological status of rivers (which are most important for FEHMlab)
- Development of simplified methodology and a direct tool to measure the water quality status
- Self-education of the public about freshwater ecosystems

Envisioned Impacts

- Contribution to improved freshwater policies and management
- More citizen involvement in freshwater management

5.2.5.2 Assessment

Credibility

The project has significant credibility thanks to the coordinating scientific team from the established research institution. They validate the data according to their own freshwater research conducted in this region.

Legitimacy

The production of outputs is distributed only between citizens and scientists. RiuNet cooperates with the Municipality of Barcelona to present the project to the public or do workshops. It has further formal support from the Catalan Water Agency, The Spanish Foundation for Science and Technology (under the Ministry of Science, Innovation and Universities) and the regional Government of Catalonia. The project is open to involve various stakeholders, however the establishment of cooperation takes longer time.

Salience and usefulness

The RiuNet methodology is applicable in the whole Mediterranean region. It provides scientific data for the FEHMlab which considers them to be valid for their work but the wider usage is limited since river ecology would require more accurate identification. In research journals they are not interested in publishing data at the 'family level'. Additionally, more data would deliver more value for scientific research. The FEHMlab team plans to apply the data to policy development and water management practices of the Catalan Water Agency and other water authorities, not only science. In this area the data seems to be relevant but not used right now. The scientists try to show the validity and quality of the data for future decision-making by writing scientific publications about application of citizen science to river ecology management in prospective water governance practices. Moreover, the project is of great use to schools for learning in practice about maths, physics and other related topics at once.

Usability

The results of the citizen assessments (indicators described in Activities) together with the uploaded photographic documentation are visualized on the data map published at the project website (Figure 12). The data points are colour-coded to simplify comparison of the water status. The data is also stored in the database of the FEHMlab for their own more elaborated purposes.

Access to information

Currently the data is mostly used for internal purposes. The (potential) communication of data to institutions flows (would flow) through the FEHMlab. This is currently at the stage of mutual negotiations in particular with public administration due to high relevance of data in this area. The data is not disseminated to reach further research groups, institutions or databases.

Trust and cooperation

The citizens show a lot of trust towards the scientists behind the project as they are based at the established academic institution. Sometimes the respect towards such scientific background prevents individuals from participating as they are afraid to 'become a scientist' accordingly. However the project team develops efforts to support the public in overcoming such barriers for example by putting personal comments to their assessments or by reaching people at dissemination events. Generally

RiuNet supports cooperation and trustful relationships between the scientists and citizens, no further parties are relevant for this indicator at the moment.

Impacts on politics and policies
The project leaders claimed that such impact is not shown yet but would be desired.

Political participation
The project leaders did not feel the competence to comment on this indicator whereas the project material does not provide information beyond the scientific and educational content of RiuNet.

Behavior and attitude
The project leaders stated that what they see as contribution in this area is the strengthening of participants´ respect and value towards water resources because of increased awareness and personal experience that water is not infinite in nature.

Feeling of empowerment
On an individual basis the project performs well in enhancing knowledge on freshwater ecosystems and its scientifically-driven observations. The RiuNet tries to motivate and empower the citizens with the narrative of 'Rivers are in your hands', giving them the tool to feel the responsibility and make something about the good status of rivers by themselves. They support this narrative by running various campaigns on social media which aim to reach the wider public.

Social capital
The project mobilizes the social capital in terms of involvement in scientifically driven data collection for the benefit of nature and society. It is still far from promoting or creating the conditions for self-organization and innovation. The collective capacity here is based on information sharing when people contribute to the shared platform. Thus in this form of engagement no personal contact or a sense of belonging to a group is required or maintained. Enhancing the community aspect of RiuNet is one the future agenda of the project team.

Knowledge and risk competence
People in this region are very used to water scarcity. This is for example reflected in water consumption in Barcelona which is one of the lowest in Europe. Two or three years ago an extreme summer drought brought more understanding of potential climate risks. The influence of the project can not be seen in enhancement of knowledge and risk competence as such but rather in better personal awareness and exploration of the water places in the close surroundings where people live. The project leaders claim that especially in the cities this might turn out as a valuable asset for an urban citizen in the future.

5.2.6 Observadores del Mar (Spain)

SeaWatchers or Observers of the Sea, in the Catalan language Observadores del Mar, is the citizen science platform for marine research mostly active in Catalonia but gradually expanding to other parts of Europe and the world. It was initiated due to rapid warming of the Mediterranean sea. Together with RiuNet and a number of other projects it forms the founding group of the Barcelona Citizen Science Office. Since many Spanish and more generally European cities are located at the sea coasts which are consequently becoming more and more urbanized, it is necessary to take climate induced coastal changes into consideration in the adaptation process of these cities.

5.2.6.1 Analysis of the case study

The aim of the project is to understand the transformation of the marine environment caused by climate change. The sub-goal is to make citizens, civil society groups and other participating entities more attentive and aware of their sea surroundings and its marine life.

Inputs

The project was established in 2012 by the Barcelona Institute of Marine Sciences (under the national research agency CSIC) which is the leading marine research center in Spain but also one of the most important in the Mediterranean region. It has been in charge of Seawatchers until now together with another research center under the CSIC, The Blane Institute for Advanced Studies in the field of water ecology and hydrobiology. In total more than 50 researchers from national and international research centers coordinate the specific sub-projects of SeaWatchers. It is financed by research funds such as LIFE, Natura 2000 (European network of protected terrestrial and marine sites) and the Biodiversity Fund under the Spanish Ministry of Environment.

Activities

The citizen scientists investigate the marine species and ecosystem in terms of effects of global warming, loss of biodiversity, alteration of habitats and surface/bottom contamination. An individual chooses the sub-project, takes observations and photographs, shares it on the website, engages in the virtual dialogue and potentially acts upon the results. Currently there are around 2500 registered seawatchers (participants) in the platform, 12 000 validated observations and 13 scientific sub-projects to join. These are Coral care, Exotic fish, Jellyfish alert, Decapod crustaceans, Mediterranean fish, Sea birds, Invasive algae, Breeding seagrass meadows, Seahorses and pipefish, Nacras, Underwater deserts and Microplastic and marine litter. The participants monitor and report changes to these species or habitats with regard to expansion, mass mortality, variations in reproductive periods, distribution, abundance, health status, anomalies, alterations and so on. Observations are required at various times of the year and information can be collected both on the shoreline and in the water. An example of citizen science input is displayed in Figure 13.

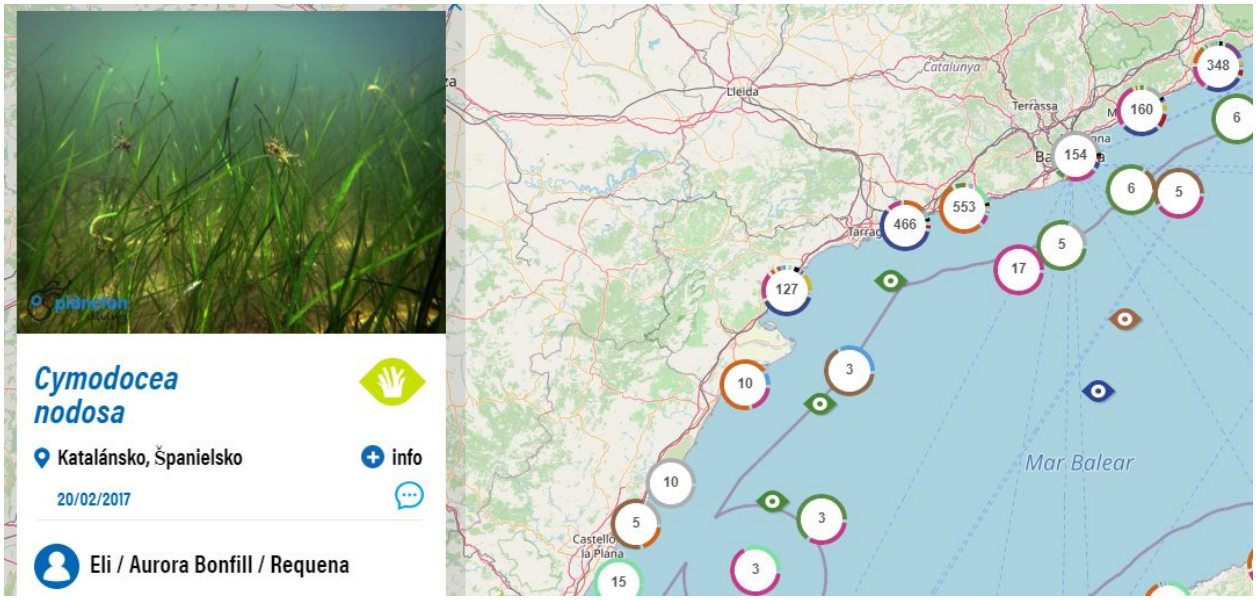

Figure 13: *An illustrative example of the citizen input (https://www.observadoresdelmar.es/Map)*

Outputs

- Extensive amount of information collected
- Web platform (the primary instrument of the project)
- Scientific papers

Outcomes

- Increased awareness on the environmental issues related to ocean health
- Enlargement of scientific observation capacities
- Support for marine research

Envisioned Impacts

- Contribution to more sustainable coastal and sea governance
- More citizen involvement in such governance practices
- Improved understanding of marine responses to human and climate impacts

5.2.6.2 Assessment

Credibility

The scientists in charge of each sub-project have the responsibility to validate and comment on the observations provided by the volunteers. The project is led by prominent institutions in their field (see Inputs) thus credibility does not receive any concern.

Legitimacy

It can be claimed that the diversity of involved stakeholders is high. The project is specific in the sense that some of the sub-projects require fishing, snorkeling and diving to be able to make the observations. Therefore apart from interested individuals (ordinary citizens, recreational or free divers, fishermen) also multiple recreational diving associations and clubs, educational centres and schools are involved. The project is in contact with public administration entities in order to establish cooperation agreements. Next, the project has established an alliance with the LIFE IP INTEMARES project which is the largest marine conservation project in Europe in order to strengthen the research network made up of scientists, professionals and citizens.

Salience and usefulness

The outputs seem to be produced and applied very purposefully. The data is useful and actively utilised in marine research. It provides improved understanding of many aspects of biology, ecology, underwater habitats, population dynamics or effects of local and global environmental disturbances such as climate change, pollution, invasions of exotic species or overfishing. The data and the project itself is especially relevant for improved monitoring and protection of marine sites under Natura 2000. It allows for design of more effective conservation and preservation techniques. Additionally, the project team identifies the practical usefulness in terms of enlargement of scientific observation capacities. So far a number of scientific papers have been published with the contribution of the citizen science data. It is also considered to be relevant for decision-makers but there is no cooperation with the policy sector so far.

Usability

The open source web platform is the main point of communication and information exchange. The citizen scientists upload here their observations, can comment on other observations and receive answers or feedback from the scientists. The interactive map displays the location and time of the specific validated observations together with taken photographs, descriptive information and answers to the scientific questions provided by the observer (citizen scientist). The observations are further

clearly categorized according to the sub-projects to which they belong. The interactive map makes it transparent how many observations have been made so far, by whom, about which topic and in which time period. The whole data package is stored with the project leaders and free to use by anyone who asks for it. Figure 13 provides an illustrative example of the citizen input as displayed on the data map.

Access to information

The attempt to establish communication channels with public institutions is in progress. The data flow in the research community is very well established. Apart from the involved research institutes, the project team started to transfer the information to international databases such GBIF (Global Biodiversity Information Facility) and the EMODNet portal (The European Marine and Observation Data Network).

Trust and cooperation

The project promotes dialogue between society and scientists on environmental and conservation problems related to the sea especially through the web platform. Based on personal observation, the coordinating scientists really invest efforts to make a personal comment on every (or majority of) citizen scientist contribution (displayed on the map) using the words that show gratitude and importance of their observation. To deepen collaboration, training and outreach days are organized for the general public and schools.

Impact on policies and politics

According to the project leader, the project has not created any policy or political impact so far within or outside Spain as the data are used primarily in research and cooperation with public authorities is only evolving.

Political participation

The project leader noted that they had not internally investigated such impact so far, adding that this would be difficult to assess.

Behavior and attitude

The project leader noted that participation does not trigger behavioral or attitudinal changes in participants to the extent of the observation of the coordinating scientists, however such changes would be a pleasant addition to the project outcomes.

Feeling of empowerment

What was mentioned by the project leader as the empowering aspect of the project is that a citizen scientist can provide a unique insight and evidence about something that is beyond the reach of the scientific community, thereby being a valuable element for expansion of scientific capacity and knowledge about the marine environment. This reflects the most occuring and known motivation of people to participate which is the process of acquiring information on the health status of the ocean and its biodiversity in order to increase individual awareness and knowledge as well as contribute to science. However, the level of enhanced awareness and knowledge per citizen scientist should not be overestimated whereas this mostly depends on the level of individual engagement in doing observations. In addition, the citizen scientists are supported to act on the results which is considered to be at least a formal attempt to increase empowerment.

Social capital

The project does not recognize its impact in enhancement of collective capacity or social cohesion. It has bigger potential in showing the possibility for self-organisation and innovation in the way that

citizens and other stakeholders can join, discuss together in the virtual environment and are supported to act on the results either at individual or group level. It can be categorized as an information sharing type of citizen science with strong dominance of the research community in shaping the project where citizens play a role of data collectors and interpreters of their observations. However the scientific community maintains fruitful relationships with the participants and supports them in the research process.

Knowledge and risk competence

Citizen scientists gain knowledge and understanding of their surroundings and climate-related issues. The project does not introduce ways to adapt or deal with climate impacts in the coastal areas, however it prompts respect and more attention to preservation of these ecosystems among the participants and the general public. The project team would like to improve its performance in the area of knowledge and risk competence, however the outcomes are hard to measure among the involved participants.

5.2.7 Naturkalender (Austria)

Naturkalender concerns the science of phenology which deals with seasonal life cycles of plants and animals. Monitoring of the climate is crucial for the survival of fauna and flora and their inherent determination of the optimum time for certain life cycle activities. Plants act as very sensitive measuring instruments of the ground-level atmosphere and react directly to the uncommon temperatures in recent years. With systematic phenological observations of the timing of budding, flowering, fruit ripening and other activities, phenology is perhaps the simplest natural process to monitor climate change effects on the ecology of species. Naturkalender covers the whole territory of Austria with such phenological observations, including cities and urban areas where the stress on species from drought, heat or pollutants is even escalated.

5.2.7.1 Analysis of the case study

The project has been designed with the main aim of aggregating high quality phenological data, thereby supporting climate monitoring based on identification of phenological trends. The secondary aspect concerns raising awareness and knowledge about climate induced phenological changes.

Inputs

The project was established by the Central Institute for Meteorology and Dynamics (ZAMG) which is the Austrian national provider of weather and geophysical service, being a subordinate research institute to the Austrian Ministry of Education, Science and Research. Apart from the governmental funding, the additional finances are received from the EUMETNET (the network of meteorological services in Europe), Austrian and European funding agencies. The project team currently involves five scientific members.

Activities

After reading the instructions on the website, the citizen scientists conduct eye observations of development of certain plant species and behavior of animals throughout seasonal cycles (10 different seasons per year) in the garden or during a walk or hike which are uploaded to the app launched in 2018. The specific species to observe (internationally recognized 'pointer' species) are divided into the categories of trees, shrubs, herbs, fruits, wine, field crops, animals (butterflies) and winter. Currently there are 200-300 registered users (a non-exhaustive number) and more than 35 000 observations. Ideally the data would be uploaded two or three times per week. What is analysed by the scientists are the phenological trends and responses in light of the warming weather pattern in Europe, for

example the earliness of spring phenological activities. An insight into the Naturkalender app is provided in Figure 14.

Figure 14: *Naturkalender app (https://play.google.com/store/apps/details?id=com.spotteron.naturkalender&hl=en_US)*

Outputs

- Naturkalender App
- Collection of the phenological data at the ZAMG
- Graphical representations of data such as "diary" of plant developments, Naturkalender interactive map, charts, diagrams
- Media reports
- Scientific publications

Outcomes

- Non-instrumental climate monitoring
- Enhancement of *observational abilities* of citizen scientists, their *understanding* of climate change and the interrelated responses of plant and animal species, and the consequent increase of environmental *awareness*

Envisioned impacts

- Selection of suited fruit and grape varieties
- Late frost damage assessment
- Ground truthing for remote sensing of phenology

5.2.7.2 Assessment

Credibility

The quality control of the phenological data is conducted by the members of the scientific project team. The project leaders emphasize the fact that it is the citizen science project, so one of the limitations of the scientific approach is limited education of citizens. The more education would be provided to them, the higher quality rank of data the project would reach. In general, the leading research institution is an important well-established Austrian body, thus no credibility concerns have been raised so far.

Legitimacy

The main core of the project involves the ZAMG and the app users - citizens. The project leaders stated that in terms of climate science and ecological questions, the production of knowledge through citizen science involves a diversity of stakeholders (rated as very high, not further specified). On the other hand, in terms of involvement of the policy or decision making sphere, the legitimacy would be low. However the project leaders emphasized that the ZAMG is one of the governmental institutions under the Ministry, thus the public sphere is indirectly integrated into the project setting. The project actively cooperates with agricultural high schools to teach and try the observations with students.

Salience and usefulness

According to the project leaders, the inputs provided by the citizen scientists are the only data source for phenological observations. For them citizen science is not an option, there are just no alternatives to the volunteer based human observations of the seasonal cycles in nature and it is impossible for professional scientists to observe plant development daily at hundreds of different locations all over Austria. Phenological data collection thus depends on volunteers and the citizen science approach is a suitable way to achieve the necessary data density in Austria. In addition phenological observation is quite simple, perfectly suited for citizen science. When comparing with weather data, relationships between the temperature profile and the natural development of wild plants and agricultural crops can be researched and the effects of climate change can be analyzed. Apart from phenology and climate research the data are of great importance for pollen prediction. The overall results are used at the research conferences and for publications in scientific journals. The data are not considered to be directly relevant for decision makers but are not even meant to be. They are used by the ZAMG which is as the national weather service impactful on the policy and political sphere in terms of scientific knowledge supply.

Usability

Savings and displays of data are provided at the Naturkalender and the ZAMG Phenowatch web page. These websites make available the information for the participants and the general public about the specific observations and developmental phases of vegetation in almost real time. More specifically, the interactive map displays citizen science inputs in the form of taken pictures, their locations, time, authors and categorization of phenological period and species. Registered users can comment on observations. Graphs, visualisations and supportive material for both professional and citizen scientists (e.g. diary of plant developments) are provided at the Phenowatch web page. There are a lot of improvements planned by the project team for upgrading the app (used for taking and uploading observations) and handling the data storage. For scientific purposes the data are also stored at the ZAMG database and its phenological observation network.

Access to information

The ZAMG is known to certain extent for its phenological research which simplifies the information exchange at the national and international level. The data is also submitted to the open-source Pan-European Phenological Database PEP725, making it available to other research and educational initiatives. The outputs in any form are not directly channeled to public administration since it is aimed to be used for policy relevant research of the ZAMG. The project team is actively looking for cooperation or advertisement at other institutions, their websites or platforms, and making efforts to reach other potential partners such as garden centers.

Trust and cooperation

The project strongly enhances the science-society relationships. The scientific team meets the citizens at the workshops organized by the ZAMG in the science centres in Vienna, Salzburg and Graz. Here the citizen scientists but also the general public can learn more about phenology, climate change impacts on ecology, raise their opinions on user needs and interests, discuss about species or just receive feedback on their observations. Such workshops have become very popular among the citizens. The project leaders provide a welcoming atmosphere by being open to host the participants at their offices at any time to show the background setting of the collective research. In the virtual sphere the project team holds the Question & Answer sessions. More workshops with people outside in nature would be desired but are limited by financial resources.

Impact on policies and politics

According to the project leaders, Naturkalender does not create direct policy impact. As mentioned before, the data from the citizen scientists are used in research conducted by the ZAMG which provides expert knowledge to public administration. In the words of the project leaders, the ZAMG would not expect to activate the society-policy interaction within this project as it is not on the shoulders of citizens to address the policy- and decision-making.

Political participation

The project leaders noted that it is difficult to answer this question due to the lack of data about the citizen scientists.

Behavior and attitude

No reasonable amount of changes in behaviour and attitude can be shown among the citizen scientists. Those who joined were already very concerned or interested in climate change adaptation, biodiversity, nature and plants. For them one of the key reasons to participate is to support science with this little action as they know it is important for the ZAMG. At the same time, they can learn something new, for example about planting certain species. So it is rather about a two-way exchange to give something and learn more in return.

Feeling of empowerment

Empowerment is perceived here in the way that the citizen scientists get more detailed understanding of phenological patterns in their own environment, can use gained information for their own purposes and compare with other reported spots from Austria based on the diary of the plant developments provided by the scientists on the Naturkalender and Phenowatch websites.

Social capital

The project is graded as medium in this indicator as it already performs well in mobilizing social capital, however more work could be done for increasing space for self-organization, collective action and connection. As will be shown, strong intentions in these areas are already set there. In its essence the project is based on information sharing to observe, photograph, upload and discuss online.

However for the project team it goes far beyond data collection for scientists. They realize that community building is very important as they see that the participating people want to talk, learn and share among each other, and find new friends. It is planned to establish offline regional groups which would not only concern phenology but also other related scientific fields such biodiversity, nature conservation, landscape planning, etc. People would become part of the group with joint interests and it is also intriguing for the ZAMG to attend such meetings. In the virtual environment "when somebody joins the app we welcome him, show appreciation to be there and connect him to the social network of observers. It's like joining the club. This approach changes a lot about social interaction" (Respondent 17 - project leader). The project team does not operate from the leadership position but strives to communicate at the same level. In the app there is a high level of interaction and dialogue between the citizens themselves in the commentary fields underneath the reported spots, they teach each other new things from which the scientists benefit correspondingly. Some of the citizens have met offline as well, but this is hard to specify further. One of the reasons why the project works well is that Austria is not too big and people feel connected to each other, which makes coordination easier for the ZAMG as well. According to the project leaders it is very much about the feeling and the people behind the project, not only the idea of the project.

Knowledge and risk competence

The participating citizens increase their understanding of climate change and the connected responses of plant and animal species. Even such small-scale personal observations for example in the domestic garden or on their own shrub become a measuring instrument for global warming. According to the project leaders the immediate reaction of plants to changing climate and its documentation via the Naturkalender smartphone app sensitize citizen scientists for global warming issues and enable them to form his/her own opinion on this topic. The project does not necessarily enhance preparedness or risk competence (in the phenological context) however is getting there gradually.

5.2.8 CrowdWater (Switzerland)

CrowdWater is a Zurich-based citizen science project for collecting hydrological data to be used in modelling of floods, droughts and streamflows both in natural ecosystems and urban areas. Its main scope of interest is on the regions of Switzerland, however the app can be used globally.

5.2.8.1 Analysis of the case study

The current objective of CrowdWater is to explore the potential of crowdsourcing for hydrological research in terms of the practical possibilities for volunteer measuring and its scientific value. In the long run the project would like to achieve an extensive database of collected data to support the predictions of extreme (droughts, floods) or other hydrological events and states.

Inputs

CrowdWater was launched in 2016 as a PhD project by members of the Hydrology and Climate Group at the Department of Geography at the University of Zurich. It is funded by the Swiss National Science Foundation.

Activities

The voluntary online CrowdWater Course explains the basis of the project and provides initial training for the interested citizen scientists. The CrowdWater smartphone app (2017) functions as a virtual measurement station. People report hydrological estimates and observations about water level, soil moisture, temporary streams, stream types and plastic pollution in the Swiss rivers. The example is illustrated in Figure 15. Currently there are 12 570 contributions. The cumulative number of

CrowdWater contributors since 2017 up to this date is more than 500. Another option is the CrowdWater game which can be entered from the computer and serves for helping with the quality check of streamflow and water level data through comparisons of photographic records.

Outputs

- CrowdWater app, game, and training course
- Data platform
- Scientific publications
- Teaching materials for high schools about water cycle, disasters and citizen science

Outcomes

- Assessment of the potential and value of the crowdsourcing approach (accuracy, data quality, usefulness,...)
- More attention of people to their surroundings

Envisioned impacts

- Accumulation of data for hydrological purposes over longer time
- Contribution to forecasts about floods, droughts and other related events and modelling
- Better understanding of monitoring opportunities and water parameters in remote places, mountains, etc.

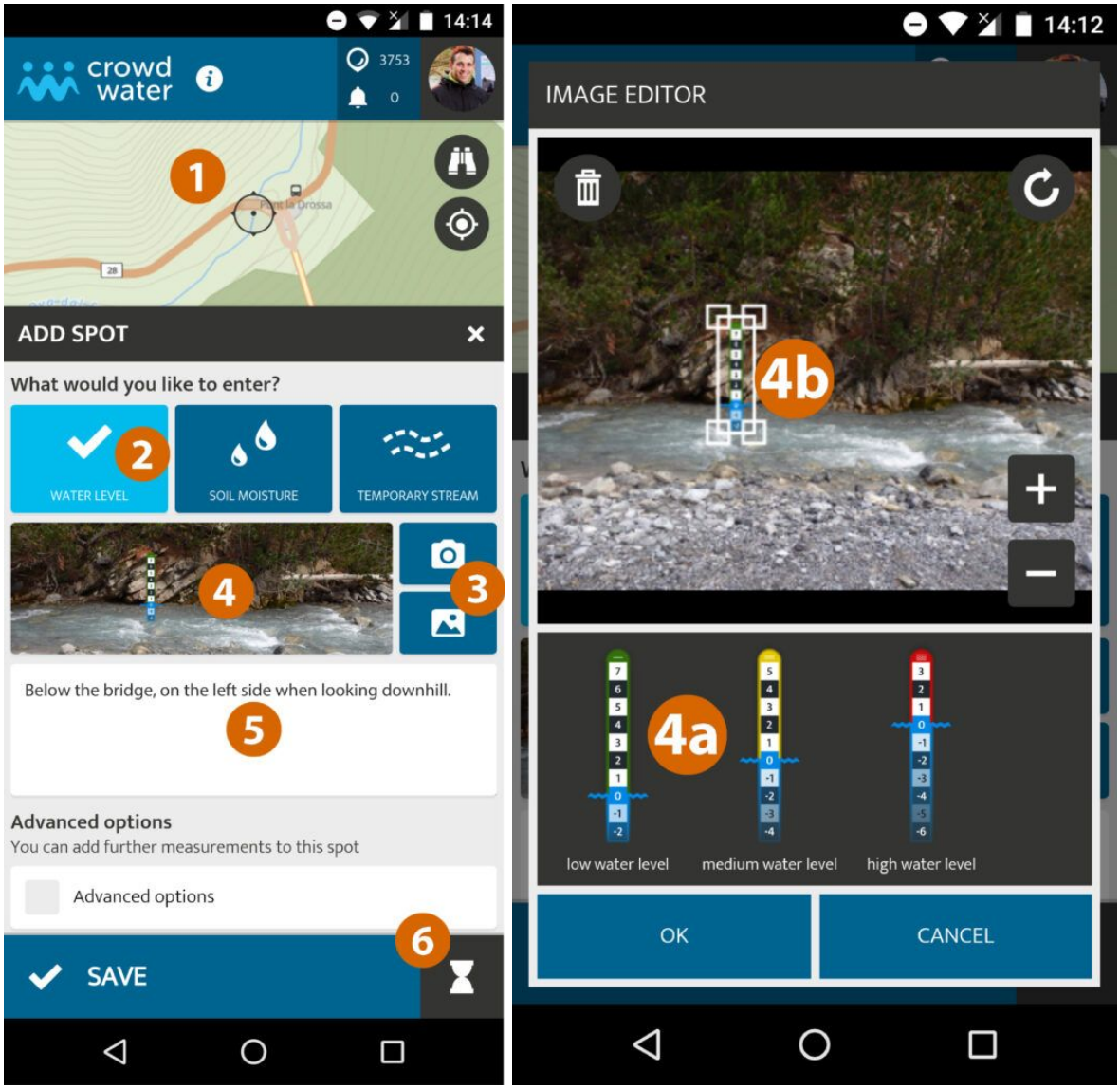

Figure 15: *Example of measuring water level in the CrowdWater app (https://crowdwater.ch/en/crowdwaterapp-en/)*

5.2.8.2 Assessment

Credibility

The quality check of uploaded observations is conducted by the project team. It is preferred if citizen scientists measure at Swiss rivers which are monitored by official gauging stations so that the conventional and crowdsourced data can be compared against reliability. The citizens can participate to certain extent in the quality check through the CrowdWater Game. The project team has delivered a number of scientific articles and empirical studies to prove the concept of crowdsourcing, accuracy of the data and its usefulness thus supporting the perceived credibility. They have analysed the value of the data by comparing it to the physical gauges and professional measurements, and have studied the ability of people to estimate the parameters such as water level and streamflow. Based on this the team suggests specific recommendations on further use of the data, specifically with respect to hydrological model calibrations, and fine-tunes the setting of the app. The project leader concluded

that the produced data is not as precise as the conventional ones, but are likely to be correct for most of its potential uses.

Legitimacy

The project scores low in terms of diversity of stakeholders as the main interaction concerns the project team and registered users. It has developed a number of informal cooperations for example with the Citizen science center in Zurich, the project Plastic Spotter in the Netherlands and the SMIRES COST Network (the European citizen science network for datasets and observations of temporary streams). The project team desires to cooperate with municipalities to spread it further, especially in places weakly monitored by the governmental agencies. Occasionally the project reaches out to high schools. Currently the project does not include other stakeholders from the science and research sector.

Salience and usefulness

Majority of the flowing water streams in Switzerland or other countries are gauged, however it is expensive to install monitoring equipment at every important or attractive location. The CrowdWater data contributes to wider spatial distribution of the traditional measurement network. For example soil moisture is very different even at very near places. The gathered data are useful for scientific purposes such as calibration of calculated hydrological streamflow models, modelling and predictions of floods and droughts or as an addition to the existing related measurements. They are especially valuable when taken during high or very low water levels and extreme occasions. The methodological part of the project was developed with respect to its potential use in developing countries which oftentimes lack proper monitoring infrastructure in remote regions. The ultimate use of the data is up to however wants to use it. The project team has shown its credibility and usefulness, but the individual end-users have to check themselves if and how this kind of data is suitable for their approach. Additionally the data is considered to be salient by the project team due to the creation of the factual basis, especially when achieving longer time series of data and abundance of images and documentation to investigate how water reacts, for example, to physical constructions up the stream.

Usability

The validated inputs from citizens are visualized on the data map available at the Crowdwater website and can be directly downloaded. Here the validated observations are displayed with their location, time, pictures, the author (observer) and certain water related categories (e.g. flow condition). The registered users and the project team can comment on other observations. Additionally, the dashboard provides graphs and other visual displays of more detailed information on contributors and individual measured water parameters.

Access to information

There have not been established communication channels with any relevant institutions as the attention was focused so far on the methodological and data collection part of the project. In the upcoming time the project team would like to start with promotion and outreach in terms of establishing partnerships with other related projects or institutions that might use the data. The project leader does not know if some institutions have used the data so far as it is publicly accessible and reporting of its usage to the CrowdWater team is voluntary.

Trust and cooperation

CrowdWater helps to establish more direct communication between scientists and citizens. The scientists are very open to meet the people, organise outreach activities and attend the science fairs. In this way citizen scientists get a better perspective on the research work of the team and why it is

important. Also, the team gets very good feedback on the project and research from the public that they would not have gotten otherwise.

Impact on policies and politics

As touched upon in the previous indicators, CrowdWater has not delivered any policy impact so far.

Political participation

According to the project leader no impact has been shown on political participation, however the potential for influence is there. "Especially when people get sensitive about extraordinary conditions such as longer droughts, they are more prone to act" (Respondent 18 - project leader).

Behavior and attitude

The project team has not observed any changes in behavior or attitude of the participants so far. The speculation (made during the interview) is that when people start to be more attentive towards their surroundings this could lead to attitudinal alterations such as greater appreciation for water resources.

Feeling of empowerment

In the eyes of the project leaders, the primary empowering factor is the open and transparent data storage which provides a solid factual base for creating personal opinions, decisions or actions. By collecting the data the participants might trigger a deeper thought process about the observations and personally reflect on them. The Crowdwater team would not conclude that the citizens gain certain knowledge as such. The increased awareness about surrounding water resources plays a much more important role. It is up to the citizen´s interest and engagement to go beyond the immediate observations, learn more and decide what to get out of the project at the personal level. They can attend the CrowdWater course and more regular observations might lead to deeper understanding of hydrological processes.

Social capital

The low impact on social capital reflects the current reality of the project to focus more on its scientific side (e.g. quality and amount of data) thereby not targeting personal or community development at the time being. Hence CrowdWater does not directly support self-organisation, collective action or social cohesion, though the team claimed that it is a nice beneficial side effect to have the community involved in the research of the University of Zurich through CrowdWater. Sharing information via the app forms the basis of the project whereas the team identified an aspect of co-production in the sense that citizens are actively asked to give feedback on everything related to the project. Social cohesion has not been developed but desired in the future. For now the interaction happens in a way that people put comments and start discussions in the app, especially the frequent contributors. The project team feels that what makes people connected together in the virtual environment is their common interest in science and their willingness to help in this area, interest in hydrology and water topics. It is considered to be a challenge to expand the app audience with those who are not that close to science.

Knowledge and risk competence

The project leader noted that when people are active in making observations they start to recognize certain patterns and trends among the data, for example longer periods without rain. This makes them start to think how far it would go or if a certain location is safe. Thus enhanced competence is seen here as gaining more awareness about the surrounding realities and potential outcomes. The project spreads basic awareness related to water risks (droughts, floods, etc) for example through the CrowdWater course. The participants are generally not guided on preparedness or coping mechanisms in case of abrupt or long-term water related challenges.

5.2.9 TeRRIFICA (Belarus)

TeRRIFICA (Territorial Responsible Research and Innovation Fostering Innovative Climate Action) started in January in 2019 as a European consortium-driven project exploring adaptation options in six pilot regions of Germany, Belarus, Serbia, France, Spain and Poland. The focus here is on Belarus and its capital Minsk which is the tenth most populated European city (2 million inhabitants). The main climate challenges at this place have to do with air pollution and a lack of green spaces. Throughout the last years Minsk has marked an increased activity around local adaptation issues at the public, private and civil society level. The project is due to completion in June 2022 and introduces an interesting perspective on collection of urban public concerns via crowdmapping. Because TeRRIFICA was launched only one year ago, some of the indicators (e.g. social capital) are assessed according to the interview, planning and future activities of the project as these show where the focus and interests lie.

5.2.9.1 Analysis of the case study

The main objective is to co-create, implement, and evaluate tailor-made adaptation solutions in Minsk with relevant local stakeholders including citizens and empower them to deal with future climate change challenges.

Inputs

The primary coordinating element is the NGO Education for Sustainable Development Association (AESD) which connects Belarusian students, academic and research communities with sustainability issues. Next to the overall project coordination in Minsk the organisation is in charge of dissemination activities and results of the project. TeRRIFICA brings together civil society, politics, public administration and science during three different phases: the knowledge phase to collect and extend the information base on climate specifications and current actions in Minsk (conferences, reflexive workshops, stakeholder analysis), the capacity building phase to formulate future visions of the city during stakeholder trainings, workshops, summer schools and field trips, and the action phase when customized adaptation approaches and practices are developed and delivered. Currently the project enters the second phase. It is funded by the EU Horizon 2020 research and innovation programme.

Activities

The core building block of the project relates to determination of local priority climate threats and hotspots through a digital interactive map (crowdmapping tool, see Figure 16) in which the population or any stakeholders put marks and descriptions of the specific locations where adverse effects are apparent or expected, or where positive and negative examples of adaptation and mitigation practices are in place concerning the temperature, water, wind, air and soil. Additionally, the participants can suggest solutions in case of negative experience. Thus the crowdmapping tool is a primary way of collecting local knowledge and spatially distributed information. This will be at later stages combined with other open data sources and used in the process of finding opportunities and co-creating roadmaps for adaptation in Minsk.

Outputs

Because TeRRIFICA has been in effect only for one year, the actual and planned deliverables until the end of the project period will be presented separately.

Actual deliverables:

- Region-specific crowdmapping tool
- Reports: stakeholder analysis, state of the art - adaptation in Minsk, institutional framework, ...

Planned deliverables:

- Development of Climate Change Adaptation Plan for Minsk
- A roadmap and performance indicators to guide the implementation of co-created adaptation and mitigation practices
- Policy recommendations, new communication strategies, tools, methodologies, innovative adaptation measures to enhance urban climate adaptation

Outcomes

- Higher participation of citizens in climate change related agenda-setting
- More tailored adaptation and mitigation measures, practices, policies
- Increased cooperation among diverse stakeholders in the urban region

Envisioned Impacts

- Integration of the concept of responsible (more transparent and inclusive) research and innovation in urban and regional policy contexts
- Social, institutional and governance changes
- More participatory climate change adaptation and mitigation processes

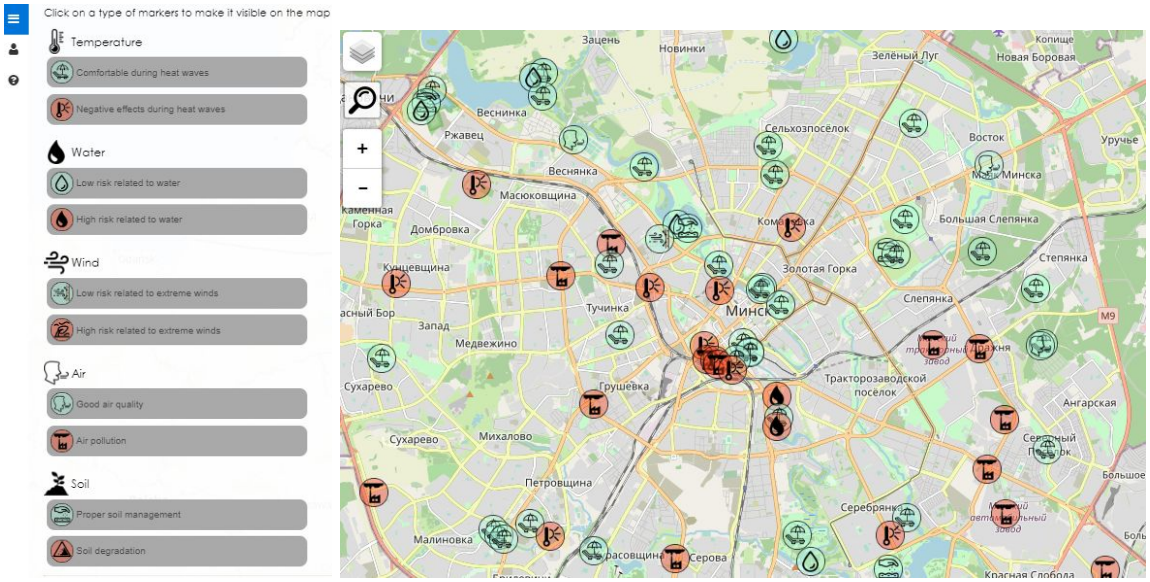

Figure 16: *TeRRIFICA Crowdmapping tool (http://belklimat.terrifica.eu/results.php)*

5.2.9.2 Assessment

Credibility

The project is recognized by the European Commission and led by a multinational research-academic-non-profit consortium with trusted coordinating organizations for every country including Belarus (AESD), thus no concerns regarding credibility have been raised.

Legitimacy

One of the project imperatives is to strengthen stakeholder cooperation and engagement in the city. Based on the conducted stakeholder mapping, there is a wide array of relevant entities in climate adaptation who will influence the project or may get influenced. Participation will be soon offered to altogether 36 key players from the four categories of business, science and education, civil society organisations and policy-makers. A parallel focus next to diversity is the inclusion of ordinary citizens,

educational and local communities. The practical aim of the stakeholder participation is to understand their opinions and interests, enhance their climate related knowledge and competencies, co-develop solutions and explore opportunities, drivers or barriers for innovation and practice.

Salience and usefulness

The participatory environment provides fruitful conditions for achieving salient and useful outputs as the stakeholders are directly involved and can influence the course according to their preferences from the very beginning of the co-creation process. This indicator was rated as very high due to very targeted and predefined outputs and their purposeful utilisation. In addition, the project aims to create outputs that will be transferable and disseminated to other cities and urban regions in Belarus.

Usability

So far it is possible to comment on the usability of the crowdmapping tool. Belarus as well as every other pilot region have their local version of this crowdsourced platform in its own language, additionally there is one international version in English. The digital map is web-based thus omitting the use of apps. Its development was guided by user-centred design and tested in more rounds with potential contributors. The layout is simple to navigate through and it can be chosen which layers (elements) of data to visualize. Some points on the map include more detailed descriptions and potential solutions recommended by a contributor. It is accessible to anyone at the climatemapping.terrifica.eu whereas at the official project website other information, updates and tangible project outputs are published. The crowdmapping tool will stay in effect after the project period is completed. A specific description of the crowdmapping tool is provided in Activities. The indicator was rated as very high because the project creates a diversity of outputs tailored to specific needs of the involved stakeholder groups (e.g. policy briefs for policy-makers, educational material for schools, etc).

Access to information

By the co-creation process, the project aims to promote not only sustainable and long-term interaction between a diversity of stakeholders, but also information and knowledge circulation to allow for innovative approaches towards climate adaptation and mitigation at all times. An open and transparent atmosphere for communication and exchange is trying to be maintained during the course of the project. The participants will have direct access to any intermediate or final outputs. According to the project leaders especially the governmental institutions will be open to receive the produced information to simplify their work in the field of climate change mitigation and adaptation.

Trust and cooperation

In itself, the project is about co-creating the solutions for the city together with citizens and civil society organisations while gathering a variety of actors on matters of climate adaptation that usually do not interact among each other. At the bottom level, discussion climate clubs are organized once per month where various stakeholders including citizens are invited to meet and talk about certain topics. Living Labs will be established where the like-minded people from any sphere including experts and citizens can come together and develop a new adaptation project. Because employees of the education sector are very active and trusted (professors, teachers,...) they mediate between academia and local authorities, academia and citizens and connect those who want to participate in crowdmapping or in development of adaptation projects within Living Labs. The research and public authorities keep slightly distant with a rather top-down approach. However, their interest goes beyond the co-creation process as they can reach groups and organizations that are not usually involved and get more familiar with education, awareness raising and scientific knowledge on climate change due to increasing societal pressure. It may rather not be generalized in which direction trust and cooperation has been or is prone to strengthen as the diversity and parallel initiatives in TeRRICA allow for a

spontaneous multi-directional beneficiation. The project leaders seem to have respect but also a big desire towards attaining some considerable impact in this area.

Impact on policies and politics

The aim of the co-creation process is to deliver numerous policy relevant deliverables such as the urban adaptation plan and roadmap as mentioned above in the planned outputs. Out of these some are predetermined and the rest is open to emerge from the co-creation. Also, the project leaders see potential in advancing the existing policy environment and integration of some of the outputs and crowdsourced data into the current development plans of Minsk. In addition, there is the potential to create impact through the involved civil society organisations and activists who can enhance their common efforts to affect the policy sphere by getting the crowdsourced data. The project leaders claim that a high amount of data in the crowdmapping tool as well as a high number and diversity of participating stakeholders can deliver better results and more influence. Additionally, the aim is to enable institutional changes within the involved institutions so that they become more open, inclusive, participatory, ethical and gender equal according to the principles of responsible research and innovation.

Political participation

The project leaders express that next to achieving practical outputs for authorities the parallel aim is to enhance active citizenship and make people feel that their voices are heard. What is unique here, also in comparison with other assessed projects, is the concept of Living Labs and discussion climate clubs where interested citizens, activists, students, representatives of civil society organizations can meet in a targeted way with experts, researchers, civil servants to discuss or create new ideas and projects. Another concept is organisation of summer schools for young researchers, activists, students or young interested people where they can get more knowledge on climate issues and generate ideas or build up their own initiatives under the expert supervision.

Behavior and attitude

The project attempts to influence behavioral patterns and climate change attitudes, however this might be challenging to estimate as those who participate only in the crowdmapping will show different impact levels compared to those engaged in additional activities.

Feeling of empowerment

Empowerment here is perceived as learning by doing and offering practical tools on how to get active. Apart from the previously mentioned opportunities, the participants can increase their awareness and knowledge about climate issues and adaptation for example during public climate workshops and lectures. By participating in the crowdmapping tool, the individuals get a better overview of the reality of the city and find the projects or initiatives nearby where there is a possibility to join. The project leaders see empowerment especially in the education sector as many schools, universities and educational communities participate, whereas students with more awareness and knowledge are more prone to develop their own smaller initiatives. The feeling of empowerment will depend on the level of engagement of the individual participant.

Social capital

The public engagement builds on the usage of the crowdmapping tool whereas further motivations for action can lead to participation in the Living Labs, discussion clubs, climate workshops, summer schools or other formats as well as specific parts of the co-creation process that allow for citizen involvement. At the very local level, the project allows to find like-minded people in the area or a neighbourhood and provide help with establishing a prospective action. "We want people to ask themselves are there any initiatives and groups that I can join? Through crowdmapping we benefit

from them and they can benefit from us" - Respondent 19 (project leader). Thus there is a prospective background for fostering self-organization, co-production or collective action. However, the engagement and motivations of people may not be overestimated nor preliminary predicted. Similarly, social cohesion is something assumed to increase but may be too ambitious. Here the project leaders point out that they are only one of many adaptation projects in the city. They rather attempt to build a network of engaged people by cooperating with other projects and organizations active in Minsk. The crowdmapping tool could become a simple social network where people can interact and find contacts, however this is not known how this will develop. It is important to motivate people by showing them that what they do is really integrated, their long-term participation is appreciated and the overall project is successful.

Knowledge and risk competence

This indicator was claimed to be also one of the desired outcomes. The practical example was introduced from the actual COVID-19 pandemic situation when the project organises online lectures about coping mechanisms based on local experience, the use of information sources and critical thinking. The second line of thought is linked to ideas how to improve the crowdmapping tool in the future so that knowledge and risk competence is taken care of, for example by connecting it with the web pages of relevant NGOs, information on climate legislation, individual adaptation practices, organization of campaigns or receiving of tailored recommendations what to do or whom to contact based on the reported problem or hot spot. This indicator is rated as high because compared to other assessed projects, TeRRIFICA has planned not only knowledge and awareness raising together with increased attention to surroundings, but also practical ways to make people more informed on responsive behavior. Surely, it is questionable how the impact will turn out when being implemented in practice.

5.3 Observations across case studies

This section builds on and synthesizes the results of the individual case studies while delving deeper into cross-case observations and highlighting the primary arguments that could form a basis for drawing conclusions in the context of the central research question.

5.3.1 Inputs, activities, outputs, outcomes, impacts

The projects are arranged in miscellaneous topics that seem to address place-based problems such as urban heat, low air quality, variable weather patterns, scarcity and quality of freshwater and marine resources or phenological changes. A majority of the projects are mostly interested in the results at their places or countries of origin whereas Luftdaten and CrowdWater are explicit about the aim to grow beyond the borders. Only a very low number of hints regarding the influence of national socioeconomic, political or cultural conditions was identified. For example in Naturkalender it was referred to the small size of Austria being stimulating towards social cohesion and feeling of connectedness among people, whereas the Spanish projects BeWater and RiuNet highlighted water scarcity as a national issue thereby justifying the aims of the projects. A stronger influence could be seen in the urban or local level contexts in which the projects are embedded. For instance, Bergen has a strong identity of the climate city which seems to provide a welcoming environment for initiatives such as Meet je Stad, compared to Stuttgart which inhibits the growth of Luftdaten within the city due to strong industrial pressure and disinterest of public authorities. The central (and secondary, if applicable) aims of the projects are profoundly corresponding across the case studies being connected to increase in societal awareness and knowledge about climate-related issues and surroundings, expansion of scientific knowledge and better understanding of climate effects and the topics at hand, and contribution to research, adaptation solutions or improved natural resource governance.

In terms of ***inputs*** the projects were established between 2012 and 2019 by volunteer groups, research institutions or stakeholder consortiums. Regarding the volunteer-led projects, the knowledge input is based on individual expertise of volunteers according to their current or previous professions or reflects the knowledge accumulated in technology-related hackerspaces where people with common interests meet to experiment. Despite the short history of the projects they managed to develop technical (e.g. sensors) and communication (e.g. web platforms) infrastructure and get participants on board in the range from around 30-100 (Meet je Stad, BeWater) up to 2500 registered users in SeaWatchers. However, the exact numbers and other information on participants for example in terms of active and non-active users does not seem to be well documented by the projects, in some cases reasoned by data privacy concerns. Apart from self-paid Luftdaten, the projects receive funding from the local, national and European Union level. In this regard BeWater and TeRRIFICA are limited to existence of 3,5 to 4 years due to being financed by the European Union framework programme for research and innovation (FP7 followed by Horizon 2020). Despite the completion of the BeWater project in 2017 the project leaders provided a deep reflection on the impacts and the continuous efforts to keep up further action. However, BeWater was not formally categorized as a fully citizen science project thus it serves here to provide enriching lenses on project functioning rather than a basis for drawing universal conclusions. The rest of the projects are still in effect, with TeRRIFICA coming to end in 2022.

With respect to ***activities***, three projects employ citizen sensing (Meet je Stad, Luftdaten), four are based on data collection through apps and/or web platforms (RiuNet, SeaWatchers, CrowdWater, Naturkalender) and two projects are approached through a more complex multi-stakeholder process of co-production (BeWater, TeRRIFICA). Additionally, TeRRIFICA developed the crowdmapping tool to collect qualitative forms of local knowledge. The projects provide guidance for data collection through simplified scientific tests (e.g. about identification of species) in the apps or on their websites. The sensor-related projects organise workshops for building measuring stations or have published online guidelines. Meet je Stad in both cities appears to be most open-minded to include citizens at more stages of the research process, especially with regard to defining the research questions and analysing the data. On a similar flexible path is Luftdaten while here a strong influence of the coordinating team on the development of the project can be identified. Next, the four above mentioned projects based on data collection (including TeRRIFICA crowdmapping tool) can be classified as contributory hence intensely driven by scientists to which citizens contribute with observations in the field. BeWater and TeRRIFICA are special with their well-structured research process in which stakeholders participate being guided by the coordinating team. Except for more demanding activities in BeWater, the projects do not pose specific requirements in terms of time, knowledge, skills and effort dedication. What seems to be quite popular among the case studies are dissemination events to boost the public outreach and citizen scientist base such as school visits, public workshops and lectures, attendance at fairs or events, meetings with recreational clubs and so on.

The ***outputs*** recognized across the projects include predominantly the amount of collected data and information, installed sensor networks, apps, open-source platforms and data maps, data archives, expansion of knowledge in the particular fields, documents and publications (plans, scientific articles, teaching materials etc.). Interestingly, BeWater presented as the output development of innovative and transferrable approach and methodology for participatory water management, whereas Luftdaten pointed out the campaigns, annual conference and visibility to gathered initiatives under Sensor Community. The ***outcomes*** are difficult to generalize as these differ in characteristic and balance per project, however some of the projects deliver more outcomes for individuals (e.g. Meet je Stad - increased awareness and technological skills), a few of them stress outcomes for research (e.g. SeWatchers and Riunet - support for freshwater and marine research), multiple cases benefit socio-ecological systems in different ways (e.g. boost of innovation, greater cooperation between

stakeholders or science-society) and Luftdaten emphasizes the instrumental outcomes such as higher availability and transparency of data worldwide. The ***impacts*** that the project envision to accomplish in the long run seem to concern mainly improved interaction at the science-policy-society interface, more citizen engagement and empowerment or contribution to place-based needs (e.g. improved water governance, urban spatial planning, increased attention to air quality problems).

5.3.2 Science

The indicators in the dimension of science reached the highest values compared to policy and society, indicating that citizen science can prove its contribution to the availability and quality of research and knowledge. In terms of ***credibility***, the projects coordinated by universities, research institutions or their consortiums do not meet obstacles with questioning the robustness of the data compared to the credibility challenges raised against volunteers-led initiatives (Meet je Stad, Luftdaten). The self-made sensors used by the latter ones seem to be a conflicting measurement tool which provides citizens with more freedom for innovation, ideas and own research questions, however gives reason to scientists and public authorities why to stay reluctant to support such initiatives due to the perception of low credibility. However this statement differs per cases based on the willingness of the specific bodies to accept and use the data, since in MjS Amersfoort the municipality is open to data however the project has difficulties in establishing long-term academic connections, the opposite happens in MjS Bergen where the research institutes show deep interest while the public authorities stay non-engaged for now, and Luftdaten needs to invest large efforts to get scientific and policy acceptance due to the industrial underpinning of the local political climate. In any way, if credibility of outputs is important for the project team, then it seems more achievable when cooperating or being coordinated by researchers. At the same time the struggle with achieving credibility does not seem to discredit volunteers-led citizen science as these projects are competent to the researchers-led citizen science in other indicators.

In terms of ***legitimacy***, the results are very diverse per project and reflect the involvement of academia and science, public administration, schools and civil society organisations, and businesses. Very high diversity was reached by BeWater and TeRRIFICA which build solely on co-production of adaptation solutions thus aiming to achieve as diverse stakeholder audience as possible. At the same time, these are the only projects that include representation of the business and industrial sector which highlights the fact that companies and industries do not show much attraction to citizen science. On the opposite side, the lowest legitimacy shows CrowdWater and Meet je Stad Bergen limited to science-citizen participation, however both projects are in their initial stage of existence paying more attention to quality of data. The public administration is generally involved to various degrees. In the two co-production projects (BeWater, TeRRIFICA) the public authorities at different levels engage directly at every stage of the research process. In the projects aimed at research contribution (RiuNet, Sea Watchers, Naturkalender, Crowdwater) the public administration is involved indirectly in the sense that the coordinating institutions are governmental subordinates or are provided with municipal, regional or national funding. In the case of Naturkalender the project leaders made a relevant point to this mentioning that its leading institution ZAMG (the Austrian national provider of weather and geophysical service) is subordinate to the Austrian Ministry of Education, Science and Research thus expected to provide policy-relevant knowledge (enriched by citizen science data) which means for them that the public sphere is indirectly embedded in the project setting. Nevertheless, despite the research targets of these projects they still make efforts to establish partnerships with the municipalities. In the case of volunteer-led projects the involvement of public authorities does not seem to be guaranteed at all times due to low stake or perceived lack of credibility. Respondent 10 from Luftdaten mentioned with regards to this that the participation of public administration is desirable to help to scale up and accelerate the project development and impact thanks to expertise of civil servants, policy- and decision-makers or other public representatives. Interestingly, the assessed

projects do not seem to cooperate much with other related citizen science projects or NGOs. Outstanding in this is Luftdaten which has grown into an umbrella initiative over air and climate measuring citizen science projects around Europe. Another common aspect across the projects is the effort to reach new citizen scientists and spread awareness through schools or recreational clubs. The last common thing is the open-minded approach towards including diverse stakeholders.

Citizen science performs high or very high with respect to ***salience and usefulness***. The projects BeWater, SeaWatchers, Naturkalender and TeRRIFICA scored very high due to their very targeted and established use of the citizen science outputs. The rest of the projects scored high as they can claim both the salience and usefulness of the data, however they need more time to find the right purpose or explore its successful application. Here the difference can be seen again between the volunteer-led sensor projects from the rest of the cases in the sense that these put more emphasis on letting the citizens find the purpose of the measurements themselves by keeping the research questions and process open for discussions and curiosity-driven exploration. It is questionable whether this has something to do with their common means of measurement (sensors) which delivers purely a general set of quantitative data that can be exploited in many ways or rather with the volunteer-based project set-up. Five contributing factors across the projects were identified for citizen science to be salient and useful. Firstly, the projects find their data or other outputs to be complementary to official measurements or scientific knowledge base as well as useful for validation of professional research on the ground. Secondly, the projects claim to benefit from expanded capacities to observe, monitor or measure at the local places which are unreachable by institutions due to capacity constraints. Thirdly, the projects collect on-the-ground knowledge as citizens conduct the activities in their surroundings and/or are expected to provide qualitative input such as opinions or more precise descriptions for example through the app or the crowdmapping tool. The fourth factor considers the fact that most of the projects create real-time graphs and archive the data thus creating a long-term basis for extracting benefits from citizen science outputs by identifying and comparing data over long time series. This was explicitly discussed for example during the interviews with the project leaders from Luftdaten, Naturkalender and CrowdWater. The fifth point is that the amount of data (or any other form of citizen science input) is crucial to realizing salience and usefulness, being guided by the principle that more data equals greater potential use. In general, the assessed projects seem confident about the usefulness of citizen science outputs particularly for research purposes (climate and meteorology, water management, marine ecosystems, etc). Meet je Stad Amersfoort, Luftdaten, RiuNet, SeaWatchers, Naturkalender and TeRRIFICA use the outputs also to spread methodological material for elementary/high schools and universities or to provide educational workshops for these. Simultaneously the citizen science outputs are something considered to be theoretically salient by all the projects rather than really shown in practice to be so, except for BeWater and TeRRIFICA which directly target salience and Meet je Stad Amersfoort which cooperates actively with the municipality. This might have to do with the fact that the aims of the projects reflect research- and people-oriented approaches thus not putting salience in the first place. It seems that the projects first explore the potential and build the foundations for citizen science and only then reach out further. However most of the projects appear to be enthusiastic or already active in trials to establish connections to policy- and decision-makers.

Citizen science performs high also in its ***usability*** which refers to understandability, delivery and availability of citizen science outputs. All the projects rely on apps and/or web platforms as the tools for collecting (in addition to sensors), displaying and storing the data. At the same time, these are openly accessible, the data packages can be directly downloaded or some of the projects claim that they can be contacted to provide them. The most common presentation of data is through interactive online maps which show for every specific point of observation its location, time, observer/registered user (anonymous or by name), photographs and textual descriptions (based on scientific questions,

categories, tests, own comments etc). These points of observation/data points are preliminarily validated by the members of the project team and provide space for commenting on other observations or receiving feedback from the coordinating scientists. In the case of sensor projects the maps show the location of the sensor and real-time values according to indicators (temperature, humidity, etc). Generally, the web platforms have supportive elements relevant to the projects, for example Meet je Stad shows performance of the specific sensors (e.g. battery), Luftdaten divides the map into hexagons which represent the average value of sensors located in that area, RiuNet colours the data points to simplify comparison of the water status or SeaWatchers categorize the data points according to sub-projects. Also, most of the projects create graphs and other visualizations to give meaning to the data. Based on a subjective opinion the web platforms are visually attractive and understandable. It is assumed that the end-users decide on the employability of data themselves according to their needs. BeWater and TeRRIFICA were graded as very high in the indicator of usability because the deliverables are very diverse (plans, reports, policy briefs, dissemination material, publications, guidelines, handbooks, articles,...) and tailored to the needs of the particular groups of end-users (the project stakeholders). However this stems from the obligations under the EU funding programme Horizon 2020.

5.3.3 Policy

Citizen science showed the lowest impact in the policy area compared to science and society, whereas the institutional indicators (access to information, trust and cooperation) were assigned with considerably higher values as opposed to the political indicators (impact on policies and politics, political participation). In terms of ***access to information*** it was assessed whether the projects have established communication networks with relevant institutions for dissemination of citizen science outputs. This indicator seems to have high correlation with the indicator of legitimacy suggesting that higher diversity of involved stakeholders simplifies the creation of communication channels with key subjects. On the opposite side, the projects that do not involve many stakeholders also do not tend to create communication channels with relevant institutions or are at the very beginning stage of such a process. Next, the projects led by researchers seem to have three advantages. Firstly, the coordinating research institution(s) itself is the institution that needs access to such information, thus shortening the way compared to for example volunteer-led projects which have to reach out purposefully to science and academia to disseminate the results. Secondly, the projects led by researchers seem to have higher competence to successfully reach public authorities to create communication channels. Thirdly, the projects led by researchers spread the data also in its national or international research communities (e.g. Sea Watchers and Naturkalender transferring the data to international databases) thus contributing greatly to dissemination of citizen science data.

The indicators of ***trust and cooperation*** show outstanding performance in the whole policy dimension. The projects support good relationships especially between science and society, or more specifically between scientists and participants. Only Meet je Stad Amersfoort and Luftdaten need to address a lack of trust between public authorities, researchers and project members mostly due to political or credibility issues. The representatives of Meet je Stad Amersfoort and BeWater explicitly mentioned that people are willing to participate because these projects are not led by public administration hence pinpointing trust concerns towards public authorities while highlighting trust of citizens towards researchers or a volunteer group as formed in Amersfoort. Some of the projects (e.g. Naturkalender, SeaWatchers) noted the motivation of people to participate in order to contribute to science. With regards to this, the leaders of RiuNet stated during the interview that too much respect towards the coordinating scientific institutions might prevent individuals from participating due to fear of being an amateur. However, almost every assessed project has its own way of supporting trust and fruitful relationships. For example in BeWater the board of citizens was established to improve communication between citizens and authorities over implementation of the adaptation plan; in

RiuNet, SeaWatchers, CrowdWater and Naturkalender the scientists show gratitude and comment on inputs of citizen scientists in the web platforms as well as organize outreach activities to meet the participants in person; or in TeRRIFICA a variety of actors are encouraged to network during climate clubs or cooperate in the Living Lab projects.

In contrast to the institutional indicators, the citizen science projects do not seem to influence policy, politics or individual participation in these. In the matter of ***policy and politics impact***, only Meet je Stad Amersfoort contributed to a more climate-proof district, TeRRIFICA has planned a number of policy-relevant deliverables and BeWater aimed for delivering a high impact in such areas as proved by the results. Neither the projects stimulate ***political participation*** conceptualised as individual engagement in governance issues or political arena in relation to adaptation. This indicator could not be assessed in three cases due to lack of information possessed by the project leaders. Nonetheless, interesting points were raised in this respect. It was claimed that in Stuttgart the establishment of the sensor network around the city well answered the increased popularity of air quality topics among the citizens. Next, it was mentioned oftentimes among the projects that the citizens can use the outputs for their own purposes including the attempts to affect the policy or political sphere. In the case of CrowdWater a personal opinion was cited saying that changing conditions push more people to act. TeRRIFICA chose quite a different way towards active citizenship by introducing the crowdmapping tool, Living Labs and climate clubs to make people feel that their voices are heard. Consequently there is some present potential for citizen science to impact policy, politics or citizen participation in these, however it seems that more time and action would be needed for the real measurable impacts to arise.

5.3.4 Society

The impact on society seems to be diversified with the lowest scores in behavior and attitude, medium in knowledge and risk competence, high in feeling of empowerment and quite varying palette of grades in social capital. Generally, the projects do not seem to stimulate ***behavioral and attitudinal changes*** towards climate adaptation, sustainability or natural resources either because the projects do not show the intention to do so or the participants joined the projects due to their preliminary interest in the field which they addressed. The leaders of RiuNet and CrowdWater expressed the idea that enhanced connection of people with water resources in these projects leads to or can lead to greater appreciation of water. Contrary to behavior and attitude, the projects induce high levels of ***empowerment*** in connection with gaining skills, knowledge or resources that can be further used for higher personal or community purposes. Actually different projects accentuate different parts of the provided definition of individual empowerment. Among the sensor projects, empowerment is perceived as the increase in technological skills, better understanding of local climate effects and the ability to measure and possibly use own data about one´s surroundings (the last point being equally featured by CrowdWater). The increase in scientific knowledge was noticed in the case of RiuNet (freshwater ecosystems) and Naturkalender (phenological patterns). In BeWater and TeRRIFICA the empowerment is seen in the opportunity to raise individual voices, opinions, needs and concerns or in support to create or engage in small actions rather than enhancing certain skills. Similarly, RiuNet and Seawatchers try to encourage the participants to feel the responsibility and act on the results. However, it may rather not be overestimated or expected that the participants necessarily act or initiate further wider engagement as no specific examples of citizen action were explicitly raised during the interviews.

With respect to ***social capital***, it was assessed whether the projects 1) foster self-organization and mobilization of social capital 2) support the ability to act collectively 3) support social cohesion among citizens (participants). The results of assessment are very diverse. In general, the projects undoubtedly mobilize social capital by getting people engaged in citizen science in different ways and to different extents, however only some of them provide further practical opportunities for self-organization or collective action such as BeWater, Luftdaten (helping to set up new sensor projects around the world), TeRRIFICA and to certain extent also Meet je Stad with its flexible open-minded functioning. This might have to do with the fact that in information-sharing projects (CrowdWater, Naturkalender, Seawatchers, RiuNet, partly TeRRIFICA with its crowd-mapping tool) the focus is on individual participation and data contributions whereas the ability to act collectively and community building are either side, envisioned/planned or not targeted impacts. On the other side in co-production projects these collective aspects are more emphasized. Here we need to distinguish between co-production in the context of volunteer-led sensor projects Meet je Stad and Luftdaten, in which the invested efforts of individuals are needed and can shape the project, and co-production in the context of research-/NGO-led BeWater and TeRRIFICA which approach the concept from the position of experts and target specific stakeholders to achieve specific outcomes. Additionally, the level of participation which refers to collective action and is characterized by a deep level of social cohesion, collective identity and decision-making, was not identified across the project set-ups. However, with respect to social cohesion, the assessed projects show that people are interested to meet and discuss either in person or virtually yet they are a long way from achieving cohesive networks. This also strongly depends on the set-up of the project, whether it is based on uploading data to apps or regular meetings and conferences, to name a few.

Lastly, the projects raise attentiveness to personal surroundings (changes of environment, natural resources) and awareness of local climate impacts, however do not contribute significantly to citizen preparedness and knowledge enhancement with regards to dealing with potential climate risks. Thus the case studies do not demonstrate full contribution to ***knowledge and risk competence***. Only TeRRIFICA has planned the specific ways towards enhancing responsive behavior and action in their project activities (especially in the crowdmapping tool). Based on subjective observation during the interviews, the topic of knowledge and risk competence was much more popular with the project leaders to discuss compared to behavioral and attitudinal changes or political participation. This may indicate that such an indicator may be likely to receive more attention in adaptation related citizen science in contrast to the other ones mentioned.

6. Discussion

This chapter will present the implications of this research for urban adaptation governance and the scientific community, reflection on research design and methodology and suggestions for further research.

6.1 Implications for urban adaptation governance - answering the research question

This research aimed to address a lack of empirical evidence of the potential contribution of citizen science to urban adaptation governance. This was met by conducting the assessment of citizen science projects against the scientific, policy and societal aspects of urban governance capacity for climate adaptation. The results reveal a number of strong and weak points as well as opportunities that could help to facilitate purposeful integration of citizen science into governance systems (Table 5). This section presents these points thus answering the central research question: ***How can citizen science contribute to climate adaptation governance in European cities and urban areas?*** In this way the conclusions at the practical level are introduced.

Table 5: *Overview of citizen science strengths, weakness and opportunities for urban governance*

STRENGTHS	WEAKNESSES	OPPORTUNITIES
Credible, salient, useful and usable knowledge production Open and transparent data and technology Expansion of scientific knowledge base and capacities to monitor and collect data or local experience Enhancement of science-society interaction Individual empowerment - increase in knowledge, awareness and skills	Low mobilization of private actors Unstable engagement of public authorities Low impact on policy- and decision-making Low steering of individual engagement in governance issues and political arena in relation to adaptation Absence of individual or collective action on the results Absent influence on adaptive behavior and attitude Low reach on people who are not interested in citizen science topic at hand	Potential to make institutions (relevant to urban adaptation governance) better informed by receiving citizen science outputs Potential to enhance social capital Potential to make citizenry informed and prepared in light of climate risks Connecting a diversity of stakeholders

Urban governance systems are suggested to experiment with this kind of citizen participation format as it can be employed for different goals related to research, urban environments and dwellers (e.g. better understanding of surroundings and climate effects), in different set-ups (e.g. co-production, information sharing) and can generate different outcomes for individuals (e.g. increased climate-related awareness), research (e.g. expanded knowledge on certain topics) or socio-ecological systems (e.g. creation of adaptation solutions). From the opposite perspective, citizens themselves show willingness to participate from their own interest or in order to contribute to the greater good. The projects can be established and coordinated for example by volunteers, research institutions or

larger groups of stakeholders each bearing its benefits and perks. In view of urban adaptation, citizen science may find application in identification of physical and biological changes, hydrology and water ecology, weather patterns, air pollution or phenology, to name a few. In other forms, citizen science can also function as a crowdsourcing project to collect local knowledge, opinions and experience of climate change effects in the community contexts and neighbourhoods of citizens. This provides insights into people's minds on what they consider important, highlights their concerns and points to the specific issues or topics which may otherwise be overseen. More on the practical side is presented in conceptualisation of citizen science for climate adaptation (6.2). In terms of governance contribution, citizen science seems to have value in advancing some of the governance capacities for adaptation (e.g. quality of science, feeling of empowerment) whereas in certain areas the impact has been weak or lacking (e.g. policy and behavioral changes).

STRENGTHS

Citizen science can contribute with credible, salient, useful and usable data and information. Credibility was achieved more easily when researchers or academics take part in the project to ensure the scientific credentials. Salience and usefulness seemed to be higher with increasing amounts of gathered data and when the projects were led with pre-defined purpose and application of the outputs. Good quality and understandability of data platforms, apps or other means together with enriching data visualizations may only further enhance usability of citizen science outputs. On top of that, archiving the data would provide a beneficial ground for its comparison and identification of trends over long time periods. The usual open source character of citizen science data and technological infrastructure supports democratization, transparency and access to anybody at any time.

The added value of participating citizens is their personal experience and reachability of very specific local and remote places thus complementing institutions with on-the-ground knowledge and larger capacities for monitoring and data collection. In connection to this, citizen science can contribute with validation or expansion of existing scientific knowledge, for example thanks to improved understanding of local climate effects. Next, citizen science can enhance science-society relationships. Supporting elements such as emphasis on direct personal or virtual contact between project teams and participants may help overcome laypersons intimidation for being engaged with expert knowledge. Also, people seemed to be more keen to participate when citizen science was led by researchers or volunteers rather than public authorities (no indications of reasoning behind). Participation in citizen science provided personal benefits in terms of empowering skills (e.g. technological) and (science-related) knowledge as well as increased awareness and sensitivity to the personal surroundings and natural resources. What might be of interest to the municipalities or other urban authorities is that in this way the citizens can become slightly more knowledgeable debate partners with public or research entities.

WEAKNESSES

Citizen science was not contributive to mobilizing companies or industries for adaptation action nor does it always manage to engage public authorities, directly or indirectly (e.g. through funding). Improved chances for the latter come for example with co-production forms of citizen science when public authorities are asked to engage or when the coordinating research institutions are governmental subordinates. Moreover, citizen science was found to have little influence on policy- and decision-making processes. Besides that, it performs low in steering individual engagement in governance issues or political arena in relation to adaptation. Thus citizen science may rather not be seen as a way towards impacting public urban adaptation issues or increasing citizen participation in these. However, it must be taken into consideration that establishing connection to the public sphere seems to be a lengthy and demanding process which requires quality and proven contributive results

from citizen science. Therefore longer existence of citizen science projects might bring about different results possibly showing higher potential to create impact in these areas.

Despite the empowering capacity of individuals to collect or generate, access and understand information and data, citizen science was not shown to trigger individual or collective adaptive action. Thus it may not be overestimated or expected that the participants necessarily act on the results or initiate further wider engagement for personal or community purposes. Similarly, citizen science does not seem to create changes in behavior and attitude in relation to climate adaptation, sustainability or natural resources. Participants rather join due to their preliminary interest in the field which citizen science addresses. Therefore it might be challenging to motivate people who do not already show interest in targeted topics or the general public. For that reason it seems important to make a more elaborated strategy on public outreach and motivation factors. In this matter, what appears to be quite popular among citizen science projects are dissemination activities such as school visits, public workshops and lectures, science fairs, outreach to recreational clubs and so on.

OPPORTUNITIES

The opportunities represent the areas of impact in which citizen science shows signs of possible contribution provided more attention would be devoted to enhancement of citizen science practice. This may depend on the aims that citizen science would be seen to deliver in the urban contexts.

Citizen science was found to contribute to better informed adaptation-related institutions by accessing citizen science outputs, however establishment of communication channels between the citizen science project and relevant institutions may not be straightforward. It seems that higher diversity of participating stakeholders can simplify the establishment of such communication channels. Thus if it is expected from citizen science to enrich the institutional knowledge base, then it might be useful to pay attention to creating structured multi-actor partnerships. Expanding on this, citizen science coordinated by research institutions directly simplified the process of dissemination by having strong competence to reach key authorities, bridge the formal and informal world, access international research databases or by using itself the citizen science outputs. With respect to stakeholder endorsement, citizen science can bring together a diversity of stakeholders in the sectors of science and education, public administration and civil society, however this seems to depend for example on the interests of both the projects and actors, invested efforts to reach stakeholders or delivered and presented quality of citizen science outputs. Greater diversity of actors could enhance in particular legitimacy of citizen science practice. The co-productive forms of citizen science are advised to reach the highest possible diversity.

Next, citizen science shows potential to enhance social capital depending on the desired outcomes for urban governance systems. If citizen participation and data aggregation are of chief importance, then information-sharing projects targeting crowds would be a suitable citizen science format. If there would be more emphasis on the collective aspect of citizen science, then co-productive forms allow for more open research process, self-organization or potentially ambitious collective action. At the same time, co-production in volunteer-led projects seems to have more potential to increase social cohesion among participants, whereas co-production in multi-stakeholder expert-based projects appears to be more contributive to stimulating partnerships among the stakeholders. However, in general it is challenging for citizen science to create a significant impact on social cohesion. It rather provides space for people to meet, discuss and share knowledge or experience in person or virtually. Therefore it may be beneficial for citizen science projects in the urban environments to establish certain communication channels, platforms or hold regular meetings. Furthermore, citizen science does not seem to be organized in the forms of collective action characterized by strong group identity, collective

decision-making and cohesive relationships, thus the ability to act collectively could be addressed either through less engaged information-sharing projects or more interactive co-production forms.

Lastly, in light of potential climate risks, citizen science could be perceived to raise attentiveness to personal surroundings and neighbourhoods as well as increase awareness of local climate impacts, however it was not seen to contribute significantly to informed and prepared citizenry. This is because participants are not usually seen as receivers of relevant knowledge and recommendations on responsive behavior. However, this opens space for experimentation and scaling up of citizen science practice in urban governance systems.

6.2 Contribution of this research

The theoretical background of this study synthesised the findings from extensive literature review to better understand citizen science as an alternative approach at the science-policy-society interface that could help to facilitate adaptive responses to climate related challenges in European cities. There is an abundance of literature sources showing a broad spectrum of citizen science contributions for individuals and scientific research especially in the various environmental fields (Bonn et al., 2018) however there is a lack of theoretical knowledge and empirical evidence to investigate its application in climate adaptation issues and its potential contribution to the processes, structures, interactions, policies and politics that steer governance in this area (Bremer et al., 2019; Wildschut, 2017; Conrad & Hilchey, 2011). This research addressed the knowledge gap and expanded the existing academic literature with empirical insights by extending the lens on citizen science impact beyond individuals into the societal, scientific and policy sphere of governance capacity for adaptation. In this way implications for urban governance as well as general recommendations for citizen science practice could be provided. Moreover, the research contributed with a general assessment framework which may serve as a benchmark for future creation of citizen science evaluation methods, and with below introduced conceptualisation of citizen science for climate adaptation which is based on the experience of the assessed citizen science projects. This research may be useful for current and future citizen science project leaders to identify and compare the performance, make improvements and learn from the lessons (see Recommendations for practice, chapter 7). Next, it may serve policy-makers, decision-makers and civil servants as an inspiration for enrichment of the science-policy interface with examined quality and impacts. Last but not least, this research project invites other cities to consider such form of participation in their future governance mechanisms in face of global climate change. The rest of this section 6.2 will provide a more detailed picture of the conceptual contribution of this research from which a global scientific community could benefit.

The initially introduced literature provides an image that citizen science has been gaining gradual influence on societal processes and structures while citizens are being legitimate actors in governance, with capacities to collect and/or produce knowledge and potentially use it themselves toward adaptive action (e.g. Bonn et al., 2018; Bäckstrand, 2003). Also, citizen science is expected to provide many benefits at the personal and scientific level such as raising awareness and learning opportunities, changes in behavior and attitude (e.g. Jordan et al., 2011; Bonney et al., 2009), increased research capacities and production of knowledge (e.g. Dickinson & Bonney, 2012), to name a few. The literature is straightforward about potentially undermined robustness of citizen science results (e.g. Jordan et al., 2011; Silvertown, 2009) and challenges for its sustained uptake by public authorities, for delivering impact on policy or for establishment of its contributing role to evidence-based decision-making (Nascimento et al., 2018; Williams et al, 2018). Yet there are scholars who see the strong potential of citizen science in providing local data as a complementary source to official databases (Hecker et al., 2018; McKinley et al., 2017; Hyder et al., 2015). These theoretical insights

were enriched by contemporary scholarship drawing on empirical evidence which has shown that citizen science is gaining its recognition in the European pathway towards open science (Laine, 2018; Haklay, 2015) and can contribute to every step of the policy process (Turbé et al., 2019), more participatory governance, cooperation among stakeholders, science-society relationship or empowerment of citizens (Nascimento et al., 2018).

The empirical results of this assessment revealed that the impact of citizen science is high on scientific impact whereas social and particularly policy impact are still difficult to achieve. This confirmed that citizen science projects struggle to live up to all of the long list of aspirations in the literature such as contribution to scientific knowledge and capacities, open science, enhancement of individual awareness, knowledge and skills and influence on policy- and decision-making processes. Contrary to the theoretical background, the empirical results did not prove behavioral and attitudinal changes in citizen scientists, nor did they provide a picture of them being active users of the data towards individual or collective adaptive action. Additionally, the results uncovered new perspectives on citizen science such as its potential for enhancement of knowledge and risk competence, improvement of access of institutions to up-to-date information or the actual salience and usefulness of citizen science outputs. The number and depth of indicators allowed for rich insights especially into the quality of science, societal capital, performance of citizen scientists and stakeholder interactions (legitimacy; trust and cooperation). However, what is perceived as the biggest contribution to the scientific community or further empirical research is the holistic reflection on citizen science being strong in scientific aspects, moderately effective in societal aspects and poorly effective in policy aspects, whereas the results distinguish (where relevant) the distinct performance in these based on the co-productive or information-sharing types of citizen science projects, or based on the leadership of volunteers or researchers. This offers a substantial opportunity to distill the strengths, improve the weaknesses, explore the uncovered potentials and ultimately make citizen science better fitted to the governance contexts to support community and urban resilience. Thereby this research demonstrated the relevance of extending methodological assessments of citizen science beyond individuals as suggested by a few authors (e.g. Kieslinger et al., 2018; Kroop et al., 2017).

Conceptualization of citizen science for (urban) climate adaptation

The theoretical section of this thesis led to development of the conceptual framework (2.6) which provided the picture of theorized embedment of citizen science for climate adaptation in urban governance systems and gave reasoning for exploring its value within this context. When comparing this with the empirically derived results and conceptualisation below, it seems that citizen science can really fit into the urban governance contexts thanks to its capacity to benefit knowledge production, mobilize people and actors with their own unique capacities and bring climate risks and effects closer to them. The aim here is to define the idea of citizen science being applicable in climate adaptation more thoroughly as drawn from the experience of the assessed case studies. It may be conceptualised as public participation in climate related research and adaptation governance practices by expanding the capacities of formal institutions to collect data, observe changes, provide local perceptions and propose solutions. Citizens are more flexible than institutions and have the ability to identify or respond to the very local phenomena. In return, citizen science can bring climate change risks and impacts closer to the society by stimulating the understanding of effects on the physical, ecological and socioeconomic systems. The activities should be relevant to the stakeholders which have different drivers to engage such as climate innovation, enhancement of public participation, enrichment of climate science etc. The involved citizens might need to recognize their contribution and benefits from participating, however the actually changing environments due to climate change seem to sensitize the individuals to become more keen to engage.

Adaptation in itself is a very broad concept which indicates that the citizen science activities can be designed in many areas. With respect to the urban systems, every citizen science project may develop its own aims, questions and tools tailored to the needs of the specific city context where it would operate. The European Climate Adaptation Platform defined the multiple sectors ("agriculture, biodiversity, buildings, coastal areas, disaster risk reduction, energy, financial, forestry, health, transport, urban and water management") and climate change impacts ("drought, extreme temperatures, flooding, sea level rise, storms, water scarcity") that can be addressed (EEA, 2018, p. 4). Next to extreme weather occasions also slow-onset events might be targeted. Seasonal observations are important to keep the participants engaged since most of the days nothing extreme is happening, however some of the natural processes alter over time such as phenological patterns. The activities can include for example monitoring, sampling, sensing, observing, mapping, measuring or co-developing adaptation pathways, measures, plans. To facilitate participation, instruments and tools such as static sensor technologies, web-based platforms or more dynamic apps for mobile devices may be developed to share knowledge and data in various forms, for instance through completion of scientific tests, photographs or simply automatic data transmission. An effective way is needed to filter and select the important and useful data. These can be compiled and incorporated into the (national, international) research databases, monitoring and forecasting systems where variations over time across data can be analysed and used for further purposes such as calibration of hydrological models or better designation of adaptation solutions.

6.3 Reflection on research design and methodology

Theoretical limitations

The limitation occurred in defining theoretical boundaries between citizen science and other forms of citizen participation. Based on the literature, citizen science refers to participation in scientific research especially in terms of data and information collection. This is in accordance with the majority of the chosen case studies that base their primary activity on sensors and apps. However, BeWater and TeRRIFICA bring a different perspective on the concept. In these initiatives citizen scientists are not central to the project but perform as providers of qualitative knowledge in terms of personal opinions and experience or are involved in the co-production process of adaptation plans and other outputs with many different stakeholders. This brings confusion whether citizen science puts primary attention to citizen scientists in the first place and if the practical realisation can go beyond scientific related research, thus not only influencing but also including activities related to the decision-making processes.

Reflection on the case study approach

The case study approach helped to ensure that the research problem would be addressed in a detailed and consistent way. The analysis within and across the case studies generated a multi-faceted and real-life outlook of the complex relation between citizen science and urban adaptation governance. The case studies are very recent considering that the oldest project was launched in 2012 (Observadores del Mar) and are at different stages of implementation. This has limiting implications for the assessment of outcomes and impacts at the science-policy-society interface which would need a longer period to unwind and shows that citizen science found its popularity only a short time ago. This was partly compensated by turning Impacts into Envisioned Impacts in order to identify the future project pathways. Anyhow, the time boundaries are not perceived to be a major drawback as they belong to the current realities of citizen science in Europe and the gained results can serve as a reference point for assessment comparisons after a longer project period. In terms of case study choices, these could be more fitted to the urban areas as more of them expand beyond the cities to wider regions or globally, or are not defined by administrative borders. However, it was challenging to

find citizen science projects tailored to adaptation activities in the urban context as further specified in the section 3.3 (Case study selection).

Reflection on the methods

As one of the methods was analysis of project material, it can be reflected that the projects are generally well documented (publications, dissemination materials etc.), however they do not often provide reports on (regularly) conducted self-assessments. Hence it would be worth further exploration if and how the projects measure their performance and progress in order to determine the value of future development of citizen science assessment frameworks. Next, more interviews with citizen scientists and representatives of public administration would bring more angles on citizen science and add to a variety of information sources. The fact that the majority of interviews was conducted with project leaders could bring biases or some aspects could be overlooked. More variety of interviews was not feasible on every occasion since many case studies do not have direct engagement with the public sector, do not hold information on citizen scientists, are not allowed to provide contact details on involved individuals such as registered users in the app or just could not be reached personally as in the case of Meet je Stad in Amersfoort. Additionally, more experimentation with methods, such as the use of focus groups, observations or surveys, would enrich the process of information gathering, however the thesis is limited in scope and time. In general, the combination of document analysis and interviews provided a rich information basis for conduction of the assessment.

Reflection on the assessment

Firstly to mention, the framework for systematic analysis of case studies provided a very useful descriptive insight into the specific project components. Next, the assessment according to one unified framework as well as generalization of the results turned out successful supposedly due to indicators being broad enough to be applied across a diversity of chosen case studies and yet specific enough to stay focused with the evaluation being unique for every project. This could encourage future citizen science assessment frameworks to apply the similar approach. Thus sufficient comprehensiveness of the framework provided a general yet diversified overview of the realities of the citizen science projects. However the attempt to use the framework for analysis across multiple case studies could unintentionally leave out some governance related determinants which are special only to one city/urban area or some cities/urban areas. The reflection on indicators has to do with its strong emphasis on different aspects of individual experience of citizen science such as political participation, behavior and attitude or feeling of empowerment. Despite their clear theoretical distinction that would eliminate overlaps while still keeping the relevance of every indicator, there were some minor uncertainties in allocating the empirical information to the right indicators. Hence more precision in allocation and theoretical distinction would be desired. Next, apart from the indicator measuring impact on policies and politics, it would be beneficial to add the indicator targeting other areas, such as impact on informal norms and structures. All in all, even though the indicators were derived according to the broad literature review, more discussion on urban adaptive capacities would be preferred to cover the necessary spectrum inherent to governance.

Reflection on the results

The results are detailed for every case study as well as a deep comparison across them is provided. Even though it was not targeted here to investigate which performance according to the indicators is good enough or should be higher, this research (in its extended version) would benefit from providing tailored recommendations to each of the assessed case studies. Next, there is a certain level of subjectivity associated with grading and interpretation of the data. Even though some of the interviewees allocated the assessment values according to their judgement, the overall results are based on the subjective one-person case study comparison and evaluation. This helped to keep consistency in using the grading scale, however may require more precise description of the choices

made. Nevertheless, the textual interpretations that accompany the results stimulate transparency of the grading process and reflect the actual positions of the interviewees and project realities. Citations of the interviewees help to highlight their viewpoints thereby enriching the dynamics of the results. In the case of TeRRIFICA, the grading might seem to be biased because the very short existence of the project prompts to base assessment on its planned functioning or deliverables rather than on the current reality. However, the interviewees expressed clearly what they perceive would turn out as more or less successful according to their perception of the project context, thus eliminating bias in grading at least to the possible extent. Generally speaking, citizen science as a participatory and interactive approach seems to be based on personal experience thus may be less feasible to be evaluated fully objectively.

Reliability, validity and reproducibility of the research

Overall, the results provide a trustworthy and meaningful outcome of this research with high internal validity due to the number and diversity of case studies, comprehensive case study frameworks and assessment process as well as triangulation of research methods and research material. This also adds to external validity of the research (generalizability and applicability in different contexts). Whereas the cases studies were chosen to cover various regions of Europe, the results of the study concerning adaptation governance were generalized to be applicable in different European urban and citizen science contexts (6.1) and the general recommendations were formulated (Chapter 7). It is up to the current or future project leaders to make inferences about transferring the results and findings to their own settings. The external validity could be further improved by more objective assessment for instance through secondary independent verification and by increasing the number of case studies. Omitting the limitations of subjectivity, the results are expected to be reproducible under the similar research set-up. However, it is acknowledged that the assessment might become outdated soon as the development of citizen science, the projects and the contexts in which they are embedded progress or change in time. Therefore the results would need a regular update to stay reliable or would require critical reflection if analysed and used in hindsight.

6.4 Further research

This research yielded a number of questions and points for further exploration. Firstly, more attention may be directed to the variability and adjustability of citizen science practice to better recognize the characteristic features of citizen science as opposed to other methods of citizen participation. Secondly, further theoretical and empirical research may explore the positive and negative implications of the various levels of citizen participation (information sharing, co-production, collective action) including self-organization for citizen science practice. Thirdly, it is suggested to investigate performance of citizen science in comparison between smaller cities and larger metropolitan areas. Actually the exploration of citizen science in urban contexts brings the whole array of research topics spanning from its integration in local governance, collaboration with authorities and other civic initiatives, participation of urban dwellers up to influence on city policies and visions. Worth exploring might be also the potential influence of the distinct cultural, political and socioeconomic conditions of the European countries reflected for instance in fluctuating trust in authorities. In the fourth place, an outstanding point for wider discussion highlighted by the assessed projects is the lack of business actors in such initiatives, though companies and other private actors could find its meaningful connection to citizen science not only in terms of financing, but also with respect to provision of research or technological equipment or space, and engagement of employees in science oriented activities. In the fifth place, the questions of ethical standards of citizen science may come under scrutiny with regard to data privacy of citizen scientists or transparency of data governance, its production and processing. The ethical viewpoint also brings attention to democratic control, autonomy of decision-making, rights and obligations between scientists as project leaders and citizens

as participants. Next, considering that each of the introduced indicators could represent one separate research in itself, this raises a plethora of questions about how to build cohesive community networks of citizen scientists, give meaning to their work, include them in solving complex problems and at more stages of scientific research, how to attract stakeholders and address their expectations, influence personal behaviors and risk competence, establish trustful relationships with authorities, increase the impact on policies and decision-making, etc. From a ´technical´ point of view, this research invites for development of widely applicable citizen science assessment frameworks that look at social, scientific and policy impacts. These could be further empirically tested and optimized to different city contexts, climate challenges and citizen science approaches. The strong interest of the interviewees in the results of this research show a promising potential of such attempts. Furthermore, continuous progress in innovation may also bring new opportunities in terms of digitalisation and technology to be used by lay researchers, opening up space for exploration how these could be utilised effectively in citizen science. Lastly, more in-depth knowledge on integration and usefulness of citizen science in governance systems would be welcomed as well as more thorough exploration of its potential use and benefits in climate adaptation inside or outside the urban areas. This, in turn, could further strengthen the integrity of citizen science assessment frameworks in the future.

7. Recommendations for practice

Based on the assessment, a number of key general findings about citizen science were identified across the projects. These may serve as learning points or advice aimed at current citizen science practitioners or leaders from the societal, scientific and public sphere who wish to develop and implement a citizen science project in the future. With respect to the conducted assessment, the learning points address areas where citizen science does not yet seem to have much impact, where the good scores could become even better or the cases could learn from each other.

1. **The aim and desired outcomes may be decided before the start of the project.**

As could be seen, citizen science can serve in many different fields, for many different aims and can deliver a great variety of outcomes. In fact, every indicator in the assessment framework could be a separate aim or outcome in itself. Therefore it may be helpful to define beforehand which direction the project should take, thus designing the research process according to the predefined ground rules and principles and emphasizing different parts of the assessment framework. The clear idea of the desired outcomes may also simplify finding the usefulness and salience for the produced data and knowledge at later stages. Does the project aim to create data and support climate research? Promote awareness and knowledge dissemination about climate change impacts? Enhance social capital and build community? Or trigger policy changes? Based on such choices, the trade-offs between data necessity and level of citizen engagement may be additionally evaluated.

2. **Citizen science works better in some fields then in others.**

The projects are advised to take into consideration the capabilities of citizens and their biggest potential ´use´, however their contribution may rather not be overestimated nor undervalued. In this sense, the participants should not be taken as ´cheap labour´ but instead a value could be added to their presence. Secondly, each place has its own context specific problems and needs which citizen science may serve well to address with the local communities. Citizen science was shown to be useful not only for tackling data scarcity and doing observations of the surroundings, but also for mapping, monitoring, on-the-ground validation of gauging, remote sensing or exploring the climate effects. This highlights the need for further investigation of its promising utilization.

3. **Citizen science could be seen as complementary rather than contradictory to governmental or scientific action.**

The concept of citizen science may not be perceived as a separate component or a trial to replace the existing practices. Because different stakeholders possess different resources in terms of time, money, power, knowledge, expertise or motivation, to name a few, citizen science can be seen as an effort to combine this diversity or contribute where institutional capacities are not sufficient. In this matter, it seems to be important to achieve matching expectations among all the involved parties for example about quality and credibility of citizen science outputs. Citizen science is well equipped to bridge the formal and informal world and help to stimulate trust between actors, be it institutions or citizens. Especially scientists and policy-makers could in this way connect to citizens, gain higher support from society or maybe increase societal acceptance of (adaptation) decisions.

4. **Citizen science is a slow process.**

Because citizen science is not a full time or strictly deadline-led activity, it may take some time until the tangible or intangible outputs, outcomes and impacts emerge. With special regard to the policy area, it takes time until policy, political and decision-making changes evolve. The way citizen science functions requires certain technical and social infrastructure to be established as well as certain learning curves to be recognized. The continuous and unpredictable unwinding of the delivered results might be challenging but not impossible to fit into the long-term planning of the public administration or scientific institutions which may provide short-term funding of 2 to 4 years according to the experience of the assessed projects. Therefore it may be worth thinking about this aspect when setting up a citizen science project.

5. **Explore more the individual and societal side of citizen science.**

When looking closer at the assessed initiatives, a number of common patterns related to the personal and societal indicators can be determined. Firstly, community creation and social cohesion do not seem to be critical to the success of the project and depend mostly on the priorities of the citizens as well as the aims of the projects. Thus it may not be perceived as a necessary need for a citizen science project to function as a community building practice. Secondly, the information and data on participants regarding motivations, demographic aspects or personal contributions (e.g. increased knowledge) are not collected in a comprehensive way in most of the case studies. This might cause a fail to point out opportunities, weaknesses or trends. Hence if it is in the interest of the specific project, it is recommended to look more into the human resource base in accordance with ethical standards and privacy rules. Thirdly, it seems relevant to think how to reach groups beyond pensioners and students in light of time and dedication flexibility of citizen science. Lastly, citizen science makes people active but not reactive in the sense that greater actions and involvement beyond the primary citizen science activity might be a positive side outcome but should not be considered a fixed rule. It may be worth thinking of ways to support and give means to people to act on the results at the individual or community level.

6. **The citizen scientists may need to see the purpose of their engagement.**

Even though the incentives of people to engage are not a primary concern in this research, it is apparent that people appreciate knowing how their contributions will be used, for example being added to a data map or processed in specific research. This might be a way of getting more participants. In addition, people value interaction in the form of feedback on their data submissions or possibility to react to other submissions. Another attraction factor seems to be when citizen science tools such as apps provide information that can not be found elsewhere, for example on risk competence.

7. **The position of citizen science at the science-policy-society interface is flexible.**

It appears that there is no one size fits all approach on how the interaction between the three aspects should be with regard to citizen science. Surely, a greater variety of stakeholders enhances legitimacy of the process provided they can benefit and engage effectively. Undeniably, the involvement of scientists from the beginning adds to the credibility of citizen science. The question might be how much time and money this should take out of the usual scope of work for scientists. The public entities could have a role be it stimulating (providing resources, urban knowledge and expertise), facilitating (giving directions) or co-producing. In general, citizen science creates a good opportunity for mutual learning and sharing as well as for overcoming the divide between the three different worlds.

8. **Uniqueness of citizen science is defined by what it is not.**

The representative of the Municipality of Amersfoort noted during the interview that what is valuable about citizen science is that it is not a Greenpeace-like campaign initiative but rather a research-based participative project to spread more knowledge about the surrounding environment. This might indicate that citizen science represents an innovative step or a small milestone in empowering people and reducing their estrangement from science, climate change and technology by following a tailor-made methodology and providing hands-on experience.

9. **Citizen science is advised to be usable both in its process and outputs.**

If the citizen science projects aim to attract a wider audience, then the realisation of activities through apps or other instruments should be designed in a user-friendly format. For citizen scientists, the activity could meet the practical convenience for example by clear guidance through the data gathering in the app and possibility for offline updates at the remote places. For the end-users, the potential usefulness of data and information may be determined by its form of delivery such as data maps, visualizations, charts, plans, roadmaps, etc. Therefore the context and extent to which the data or other outputs can be used should be considered to adjust the usability accordingly.

10. **Informal connection with individual persons is more important than formal contacts with organizations.**

The citizen science projects appear to easily identify which stakeholders may benefit or be beneficial to it, however the real cooperation only starts if there are enthusiastic individuals, experts or employees interested in the project who have the competence and willingness to engage their organization or institution. This ´bonding´ seems to be more probable when the citizen science project is touching the sustainability values of the particular staff rather than relying on sensitivity or official commitments of the organisation or institution to climate change.

8. Conclusion

Cities and urban areas have already been experiencing significant climate impacts such as heat waves, intensive rainfalls, flooding or droughts which are prone to intensify over the coming decades. Resilience of human and natural systems thus becomes of vital importance. The wide-ranging and complex nature of such challenges requires urban governance systems to depart from traditional centralised regulatory frameworks into greater distribution of responsibilities among the public, private and civil society actors to define climate goals, develop strategies and implement actions. This opens up space for alternative approaches at the science-society-policy interface and recognizes public support as a prerequisite for successful adaptation practice. Especially urban residents and communities show relevance for greater engagement as they experience both on-the-ground consequences of climate change and adaptive governance responses. Thus societal acceptance of adaptive action as well as individual adaptive choices seem to be highly determinative to adaptive capacity of cities. In this thesis citizen science was explored as one of such approaches that could enrich urban adaptation governance in Europe by involving citizens in place-based scientific research and mobilizing local knowledge capacities. The contemporary scholarship shows abundance of citizen science practice in environmental topics and defines a wide array of positive contributions especially for involved individuals and science such as learning opportunities for citizens, large-scale data collection for research or changes in adaptive behavior and attitudes. However, there might be much more that citizen science could provide when extending the lenses beyond the citizen scientist into the wider scientific, policy and societal sphere in which citizen science operates. For example, citizen science is introduced as a promising approach towards open science in Europe, enhancement of evidence-based decision-making or increasing individual empowerment. This research addressed the gap of missing theoretical knowledge and empirical experience of utilisation of citizen science in the field of climate adaptation and its potential contribution to urban governance capacity for adaptation.

Nine European citizen science projects related to adaptation in the Netherlands, Norway, Germany, Spain, Austria, Switzerland and Belarus were evaluated in their contribution to governance capacities for adaptation in order to answer the research question *How can citizen science contribute to climate adaptation governance in European cities and urban areas?* For the assessment to be conducted, interviews with project leaders and other stakeholders were held, documents related to the project were analysed and literature on urban governance, adaptive capacities, citizen science and other was examined to develop the frameworks for systematic description and assessment of a citizen science project. In terms of the latter one, governance determinants of adaptive capacity were identified in the literature to cover scientific (quality of science: credibility, legitimacy, salience and usefulness, usability), policy (access to up-to-date information, trust and cooperation, impact on policies and politics, political participation) and social (behavior and attitude, empowerment, social capital, knowledge and risk competence) sphere of urban governance for adaptation. This provided a holistic overview of strengths, weaknesses and opportunities that citizen science can deliver across these spheres thus extending its potential utilization beyond the benefits for citizen scientists and research.

The results show that citizen science currently contributes strongly to science, but less to societal aspirations and least of all to policy. With respect to science, citizen science can produce credible, salient, useful and usable knowledge, contribute to transition towards open science and bring local insights into the current scientific research. At the same time, more attention to diversity of stakeholders would benefit the legitimacy of citizen science outputs. Regarding society, citizen science appears to empower citizens with knowledge, awareness and skills pertinent to adaptation related fields of citizen science projects, however at this moment it does not influence adaptive behavior, attitude or wider individual and community action of people. Furthermore, it has potential to enhance

social capital and individual preparedness and risk competence in light of potential climate effects. In terms of policy, citizen science does not seem to influence policy- and decision-making processes or mobilize people to be active in these. Nevertheless it can improve science-society relationships and potentially improve access of institutions to up-to-date information. Thus citizen science can contribute to certain aspects of urban adaptation governance, whereas in some aspects the benefits are absent or not yet well-developed. These empirical results correspond with the literature on citizen science in many aspects, such as with regard to enhancing scientific knowledge and capacities or the struggle to establish its position in policy- and decision-making processes. Contrary to the literature, this research did not show contribution to behavioral and attitudinal changes of involved citizens or their proactive approach towards using the data for individual or collective purposes. However, the results uncovered new potential for citizen science in enhancement of (climate) knowledge and risk competence, access of institutions to up-to-date information or the actual relevance and usefulness of citizen science outputs to be used for many different research or public administration purposes. The results conclude that distilling the strengths, confronting the weaknesses and paying attention to new opportunities could make citizen science more tailored to the governance contexts thus increasing its potential to be integrated and bring benefits to urban adaptation governance.

More attention to the specific aspects that the indicators were trying to cover could enrich the outlook on citizen science impacts and its potential uses in different contexts, fields and set-ups (co-productive/collective action/information sharing projects). For this, more empirical evidence of citizen science practice in climate adaptation would be desired. This research invites citizen science initiatives to conduct self-evaluations, identify and communicate the value to scientists, policy-makers and wider public. Lastly, this research could serve as an empirical background for European cities and urban areas that seek wider public engagement, alternative ways of bridging the gap between science, policy and society, and extension of their governance capacity to facilitate adaptation and foster the resilience of the city, its communities and residents.

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Appendix A: Case study websites

Citizen science project	Website
Meet je Stad (Amersfoort, Bergen)	https://meetjestad.net/
Luftdaten Sensor Community	https://luftdaten.info/ https://sensor.community/
BeWater	http://www.bewaterproject.eu/
RiuNet	http://www.riunet.net/
SeaWatchers	https://www.observadoresdelmar.es/
Naturkalender	https://www.naturkalender.at/
CrowdWater	https://crowdwater.ch/
TeRRIFICA	https://terrifica.eu/

Appendix B: Overview of interviews

Case study interviews				
Citizen science project	**Interview respondent**	**Organization**	**Position in the project**	**Language of contact**
Meet je Stad (NL)	Respondent 1	Cooperative University of Amersfoort	Project leader	face-to-face
Meet je Stad (NL)	Respondent 2	Municipality of Amersfoort	Municipality representative	face-to-face
Meet je Stad (NL)	Respondent 3	Vallei en Veluwe water board	Water board representative	face-to-face
Meet je Stad (NL)	Respondent 4	Pensioner	Citizen scientist	face-to-face
Meet je Stad (NL)	Respondent 5	Pensioner	Citizen scientist	face-to-face
Meet je Stad (NO)	Respondent 6	Pensioner	Citizen scientist	face-to-face
Meet je Stad (NO)	Respondent 7	Meteorological Institute	Citizen scientist	face-to-face
Meet je Stad (NO)	Respondent 8	Vimond Media Solutions (product manager)	Citizen scientist	face-to-face
Meet je Stad (NO)	Respondent 9	University of Bergen	Coordinating assistant	Skype
Luftdaten.info/ Sensor.Community	Respondent 10	OK Lab Stuttgart	International Community & Partnership Development	Skype
BeWater	Respondent 11	CREAF (Universitat Autònoma de Barcelona)	BeWater Project Coordinator	Skype
BeWater	Respondent 12	CREAF (Universitat Autònoma de Barcelona)	Tordera Case Study Leader	Skype
RiuNet	Respondent 13	FEHM-Lab Research Group (University of Barcelona)	Project leader	Skype
RiuNet	Respondent 14	FEHM-Lab Research Group (University of Barcelona)	Project leader	Skype

Seawatchers	Respondent 15	Institute of Marine Sciences	Project leader	Written assessment through email exchange
Naturkalender	Respondent 16	ZAMG - Central Institution for Meteorology and Geodynamics	Project leader	Written assessment through email exchange
Naturkalender	Respondent 17	ZAMG - Central Institution for Meteorology and Geodynamics	Project leader	Skype
CrowdWater	Respondent 18	University of Zürich	Project leader	Skype
TeRRIFICA	Respondent 19	Education for Sustainable Development Association (AESD)	Project leader	Zoom
TeRRIFICA	Respondent 20	Education for Sustainable Development Association (AESD)	Project leader	Zoom
Other interviews				
Citizen Sensing (Sweden)	Respondent 21	Swedish Meteorological and Hydrological Institute (SMHI)	Project Leader - Norrköping	Skype
Citizen Sensing (Sweden)	Respondent 22	Swedish Meteorological and Hydrological Institute (SMHI)	Project Leader - Norrköping	Skype
Citizen Sensing (Portugal)	Respondent 23	University of Porto	Project Leader - Porto	Skype
-	Respondent 24	National Institute for Public Health and the Environment (RIVM)	Representative of RIVM in citizen science sensor networks in the Netherlands	face-to-face
-	Respondent 25	National Institute for Public Health and the Environment (RIVM)	Representative of RIVM in citizen science sensor networks in the Netherlands	face-to-face
-	Respondent 26	Amsterdam University of Applied Sciences, research program Climate Proof Cities	Previous experience with Meet je Stad Amersfoort - Schothorst case	face-to-face

Appendix C: Interview guide

PROJECT

What is the main climate-related risk (potentially) affecting your city? (e.g. urban heat, flooding)
Is your city active in climate adaptation?
The project is initiated by? (the order of municipality / scientists / citizens,...)
What is the aim(s) of the project?
Inputs (project team, number of citizen scientists, other stakeholders involved)

- How is the project funded?

Activities (e.g. measuring air temperature with sensors)
Outputs (immediate deliverables, e.g. open data platform)
Outcomes (max 3, e.g. increased awareness, help for scientific research)
Impacts (max 3, benefits to the society in the long-run, e.g. better adaptation measures)

ASSESSMENT

Please rate every indicator based on the scale: very low, low, medium, high, very high

SCIENCE

- ***Credibility*** **-** outputs of your project have adequate quality standards
- ***Legitimacy*** - production of knowledge through your project involves diversity of stakeholders, their values and views
- ***Salience and usefulness*** - outputs of the project are relevant and useful to the needs of decision-makers, researchers and other involved stakeholders
- ***Usability*** **-** outputs of the project are understandable, operationally delivered and available to the end-users at any time and place

POLICY

Institutional

- The project has established **communication networks** with relevant institutions to disseminate its produced outputs
- (Optional: the project supports **flexibility** of institutions to changing climate conditions by affecting practices at the institutional level, for example based on its produced knowledge)
- The project enhances **trustful and collaborative relationships** between various actors (e.g. between citizens and institutions,...)

Political

- Impact on **policies and politics**
- The project increases **political participation** of individuals (active public engagement in governance issues and political arena related to adaptation), for example because of better understanding of pressing climate-related issues

SOCIETY

Human

- The involved citizens have changed their individual **behavior and attitude**
- The project leads to **empowerment of citizens** (feeling of possession of resources, awareness, knowledge and skills to realise the desired outcomes, contribute to the individual/community resilience or affect the local place)

Social

- **Social capital**: The project fosters self-organisation, supports the ability to act collectively and increases social cohesion between people
- **Informed and prepared citizenry**: The project enhances knowledge and awareness of citizens about (urban) climate related problems and they know how to act upon future potential challenges (in the scope of your project topic)

Appendix D: Specification of interview questions for certain interviews

Respondent 2: representative of the Municipality of Amersfoort

How did the Municipality get into cooperation with MjS (Meet je Stad)?
Why does the Municipality support MjS in Amersfoort?
Credibility: Do the outputs of MjS have adequate quality standards?
Salience and usefulness: Are the outputs of MjS relevant and useful to the Municipality?
Access to information: How does MjS disseminate its outputs to the Municipality?
Flexibility: Does MjS support the flexibility of the Municipality to changing climate conditions based on its produced data and knowledge?
Trustful and collaborative relationships: Does Mjs support these among the authority and citizen scientists? How?
Impact on policies and politics: Do you see the potential impact of Mjs in this area?
Social capital: Does MjS foster self-organisation, supports the ability to act collectively and increases social cohesion between people? Is this in the interest of the Municipality?
Knowledge and risk competence: Is MjS a good approach how to make citizens better informed and prepared for climate risks in Amersfoort? Do you think it creates this impact on citizens?

Respondent 3: representative of the Vallei en Veluwe water board

How did the water board get into cooperation with MjS?
Why does the water board support MjS in Amersfoort?
Credibility: Do the outputs of MjS have adequate quality standards?
Salience and usefulness: Are the outputs of MjS relevant and useful to the water board?
Access to information: How does MjS disseminate its outputs to the water board?
Flexibility: Does MjS support the flexibility of the water board to changing climate conditions based on its produced data and knowledge?
Trustful and collaborative relationships: Does Mjs support these among the authority and citizen scientists? How?
Impact on policies and politics: Do you see the potential impact of Mjs in this area?
Social capital: Does MjS foster self-organisation, supports the ability to act collectively and increases social cohesion between people? Is this in the interest of the water board?
Knowledge and risk competence: Is MjS a good approach how to make citizens better informed and prepared for climate risks in Amersfoort? Do you think it creates this impact on citizens?

<u>Examples of the spontaneous follow-up questions:</u>
When you don't use the data but learnt some lessons from MjS, how do you apply these?
Is the water board publicly trusted? Does it have potential to be fully involved in citizen science?
Once citizen science becomes more established, what could be the role of the water board in it?
How to get people motivated to participate? How to find out what they are interested in?

Respondents 4-8: citizen scientists (MjS Amersfoort/Bergen)

How did you get into this project?
Why do you participate in this project?
What is/was your field of occupation?
Activities: How regularly do you participate? (measure/go to meeting, etc)
Outputs: Do you use the results for any purposes?
Outcomes for individuals: What does participation bring to you? Do you want to achieve something by participating?
Trustful and collaborative relationships: Has your feeling of trust towards any stakeholders in the project changed during participation?
Political participation: Do you see any increase?
Behavior and attitude: Did you change your behavior or attitude in relation to adaptation and sustainability because of your participation in the project?
Empowerment: Do you see any personal increase in awareness, knowledge or skills? Have you realized any wider individual or community action?
Social capital: Does MjS foster self-organisation, supports the ability to act collectively and increases social cohesion between people? Did you establish or improve relationships with other citizens?
Informed and prepared citizenry: Does your participation influence your understanding of local climate challenges? Do you feel more knowledgeable and prepared on how to act in light of potential climate risks?

Respondents 24-25: representatives of RIVM

Could you please describe the role of RIVM at the science-policy-society interface?
How do you perceive the interaction of these three aspects in the Netherlands (both national and local level)?
Do citizens understand and accept your institutional role? Do they trust you?
What do you think is the current role of citizen science at this interface?
What do you think could be the future role of citizen science at this interface?
If there was some other participatory method to experience, learn, measure, but not citizen science, do you think citizens would be interested?

<u>Examples of the spontaneous follow-up questions:</u>
Why public bodies do not put more effort into citizen initiatives (and citizen science) for the sake of increasing trust and cooperation if not for the sake of data and usefulness?
Who are mostly the people involved in citizen science?
Is citizen science becoming a children's hobby or senior activity?

Respondent 26: researcher in climate-proof cities

Could you please describe the research programme Climate Proof Cities?
Is your work connected with the concept of adaptive capacity of the city? If yes, how? How is the concept understood in the scope of your research?
Do you have any experience with citizen engagement as part of your research work?
Could you please name some urban climate change challenges that you think are the most important to address in Europe, the Netherlands or other scope that you prefer?

How was the cooperation between the Amsterdam University of Applied Sciences and MjS in the Schothorst case? What do you think about the credibility and usefulness of MjS data? What is your perspective now on citizen science after this experience?
How could citizens contribute to urban climate adaptation? How could this work through citizen science? What would be the role of the university such as UvA in this?

Examples of the spontaneous follow-up questions:
When you work with the public bodies, do you feel that they would be open to involve citizens in their adaptation solutions? How do they make people participate or collect their thoughts?
What do you see as more effective approaches to urban adaptation than citizen science?
How could then citizen science stimulate people to adaptive behavior?