Bridging the Science-Society-Policy Interface

A Comparative Case Study on Citizen Science for Policies

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A Comparative Case Study on Citizen Science for Policies

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Executive Summary

Background

The rise of citizen science has drawn policymakers' attention. With a shift towards participatory and transparent governance, linking policies to citizen science can contribute to create the evidence base and social acceptance for policymaking, and further counter-play populism and post-truth politics. However, the adoption of citizen science is still slow. Incorporating citizen science into the policy domain implies involving diverse stakeholders of whom the background and motivation vary, and their expectations may not often coincide. Furthermore, citizen science may be money- and time-consuming if not well designed, causing concerns over policy failure in terms of budget or timing. Concerns regarding quality and interoperability of citizen-generated data and obstacles faced in project implementation have also been hindering the acceptance of citizen science.

Objective

The research objective of this study is *to gain empirical understanding on how citizen-generated data from citizen science initiatives can contribute to political decision-making and problem-solving in different contexts*. More specifically, we aim to explore how a citizen science initiative is formed, what opportunities and challenges are for citizen-generated data and what role citizen-generated data plays in the initiatives, how such initiatives lead to a citizen-driven solution of political decision-making and problem-solving process, and how the contextual settings and actors' perceptions and actions interplay and potentially play a part along the process.

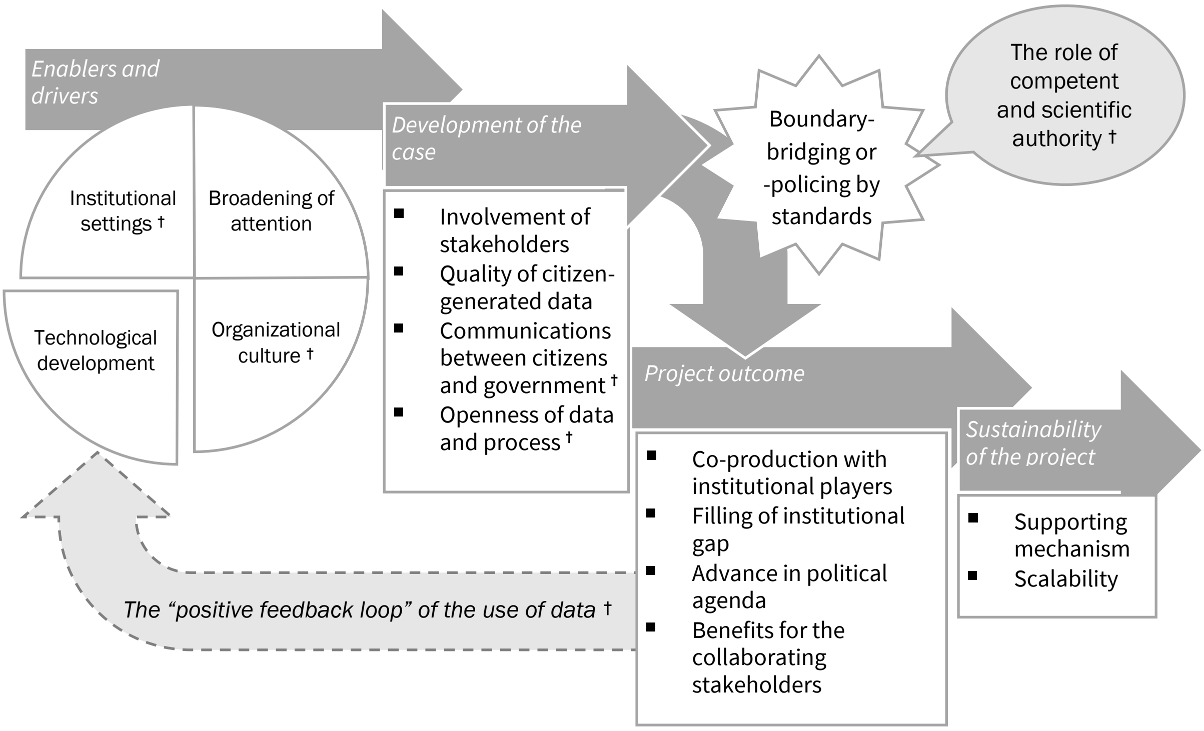
Methods

To attain the abovementioned research objective, three research questions are formulated. The first research question seeks to explore citizen science in the political domain by asking: *How are citizen science initiatives linked to political decision-making and problem-solving?* A systematic literature review was conducted with the aim to set up a conceptual model that describes the case where citizen science initiatives are linked to political decision-making or problem-solving. The second research question then investigates the role of citizen-generated data in citizen science initiatives and intends to capture the ambiguous reality of social interactions involved, and thereby asks: *How does citizen-generated data contribute to political problem-solving in citizen science initiatives, in particular as a mode of "socio-technical governance"?* Using the developed conceptual model as a guideline for analysis, case studies were performed on two citizen science initiatives — the case of Dutch Skies in the Netherlands and the case of AirBox in Taiwan — in different contexts. The findings from the case studies were then compared and synthesized, and put forward as a revised, empirically enhanced model of citizen science for policies, which answers the third research question: *How is the contribution of citizen science initiatives to political problem-solving shaped by the contextual settings and dynamics of the actors involved?* Finally, the insights gained from the revisions were translated into policy recommendations for the main actors involved in citizen science.

RESULTS

A conceptual model was set up through a systematic literature review to describe how citizen science initiatives are linked to political decision-making and problem-solving. The model is composed of five major stages, which depicts how such cases are initiated ("enablers and drivers"), how such initiatives lead to a citizen-driven solution of political decision-making and problem-solving ("development of the case"), how contextual settings and actors' perceptions and actions interplay and potentially play a part in such process ("boundary-bridging or boundary-policing by standards" and also previous stages), what results were produced by such initiatives ("project outcome"), and how such initiatives sustain and continue to bring influence to the society ("sustainability of the project"). Each stage further contains elements to specify the factors involved, which serve as the guideline for the subsequent case studies.

In this study, two cases — the case of Dutch Skies in the Netherlands and the case of AirBox in Taiwan — were analyzed to gain empirical insights on linking citizen science initiatives to policies, and more specifically, to explore the role of citizen-generated data in such process and capture the ambiguous reality of social interactions involved. Based on the findings from the case studies, a revised, empirically enhanced model was proposed, as shown in the figure below. The revisions consist of four major parts. First, two additional enablers — *institutional settings* and *organizational culture* — were added, and the interwovenness of driving factors was identified from the case studies. Second, two additional dimensions of co*mmunications between citizens and the government* and *openness of data and process* in the development of the case was added to capture the dynamics within the actor network. Third, the influence of *the dual role of competent authority and scientific authority* was discussed. Finally, the *"positive feedback loop" of sensor data use in driving sensor development* was added to link the project outcome back to the element of technological development in the stage of enablers and drivers.



The revised, empirically enhanced model of citizen science for policies. Additional dimensions added and revisions to the conceptual model are denoted by the † symbol.

Policy Recommendations

Policy recommendations were formulated for policymakers in government based on the empirically grounded insights gained from the case studies. First, it is suggested to involve stakeholders in the co-production process towards problem-solving as evidenced by the various benefits brought to the project and the collaborating stakeholders. Second, starting to listen and empowering citizens are crucial towards building a trusted dialogue with citizens. Finally, as resonating with the advocacy in existing literature, attaining openness of data is key to the trust building process.

Scientific and Societal Contributions of This Research

In this research, we addressed three identified scientific knowledge gaps through a comparative case study on citizen science initiatives for policies. First, we enhanced the limited empirical understanding in existing literature on how citizen-generated data from citizen science initiatives affects political decision-making through empirical evidence collected from case studies. Second, the ambiguous reality of social interactions involved in citizen science initiatives was further investigated with an attempt to clarify the blurred boundaries between different forms of such interactions through in-depth analysis of the cases studied. Third, we furthered the understanding on how political decision-making and problem-solving (partly) led by citizen science initiatives are induced and shaped by contextual settings in citizen science initiatives through a comparative analysis between the cases.

The society contribution of this study lies in the experiences and lessons learned drawn from the case studies. Based on the empirically grounded insights gained from the cases, we formulated policy recommendations to inform policymakers in government on how citizen science could be incorporated into the policymaking process or exercise as a mode of governance, and thereby contribute to problem-solving around societal issues of public concern.

Limitations

The major limitations identified for this study are the selection of case, the comprehensiveness of data collection, and the advisable adoption of the concept of boundary-bridging or -policing by standards. While the first two limitations were mainly resulted from the given, limited time and resources of this research project, we recognize that the aforementioned concept brings more insightful analysis to cases which to a greater extent fit the definition of *social movement-based citizen science*, although in this study the concept has indeed provided guidance for the case studies and has led to fruitful investigations on the cases.

Suggestions for Future Work

Building upon the findings retrieved from this study, we identified three suggestions for future research on citizen science for policies. First, we recommend to further investigate the "positive feedback loop" between the development of sensor hardware and the improvement on the quality of sensor data. Second, we propose future studies on an in-depth analysis of linking citizen science towards the problem-solving of societal challenges taking into account the complexity of governance. Finally, we suggest future research to address the challenges of the representative of citizens in citizen science initiatives.

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Acknowledgement

The thesis marks the end of my journey at the MSc Engineering and Policy Analysis program in the Netherlands. The thesis work was unexpectedly not frustrating as I've always imagined and, in fact, it was rather fun. I wish to acknowledge the assistance of the many that has made this possible.

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Cheng Hsin (程心)

Kaohsiung, July 2020

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List of Abbreviations and Terms

General

CGD	Citizen-generated data
IoT	Internet of Things
PM	Particulate matter
STS	Science and Technology Studies

Dutch context-specific

GGD	Municipal and Regional Health Service (Gemeentelijke Gezondheidsdienst)
GS	Provincial Executive (Gedeputeerde Staten)
Hollandse Luchten	The “Dutch Skies” project
IPEM	The Dutch Innovation Program for Environmental Monitoring
LML	National Air Quality Monitoring Network (Landelijk Meetnet Luchtkwaliteit)
Omgevingswet	The Environmental and Planning Act
RIVM	National Institute for Public Health and the Environment (Rijksinstituut voor Volksgezondheid en Milieu)
Samen Meten	The “Measuring Together” program

Taiwanese context-specific

AirBox	A collective term referring to small-sized, low-cost real-time air quality micro-monitoring sensors developed from various non-governmental projects (e.g. LASS AirBox) (空氣盒子)
Campus AQ project	The project of air quality micro-sensing on campus (校園空品微型感測計畫)
Civil IoT Taiwan	The Civil IoT Taiwan program (民生公共物聯網計畫)
Dept. EM&IM, EPA	Department of Environmental Monitoring and Information Management, EPA (環保署 環境監測及資訊處)
EPA	Environmental Protection Administration (環保署)
EPB	Bureau (or Department) of Environmental Protection (環保局)
Forward-looking Program	Forward-looking Infrastructure Development Program (前瞻基礎建設計畫)
LASS	Location Aware Sensing System (環境感測器網絡系統)
Smart U&R project	The project of smart air quality micro-sensing in urban and rural areas (智慧城鄉微型感測計畫)

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1

INTRODUCTION

It is widely acknowledged that tackling the world's "grand challenges" (George et al., 2016) requires policymakers, scientists, businesses and citizens to work together and find new ways of collaborating. *Citizen science* is, among many initiatives, a rapidly evolving field with various promissory benefits through promoting public participation in scientific research (Strasser et al., 2019). The concept and practice of citizen science emerge from citizens as tools for data collection in assisting scientific research; for instance, the famous case of "eBird" (Sullivan et al., 2009), where citizens or bird lovers help record and collect data from bird watching, has helped advance biological scientific research. The field then gradually shifts to include the advocacy of democratizing science for the "lay people" beyond the hierarchy as well as serving for public goods. The rise of citizen science has therefore also drawn policymakers' attention (Haklay, 2015; Nascimento et al., 2019; Taeihagh, 2017). With a shift towards participatory and transparent governance, linking policies to citizen science can contribute to create the evidence base and social acceptance for policymaking (Hecker, Bonney, et al., 2018; Nascimento et al., 2019), and further counter-play populism and post-truth politics (Schade et al., 2017).

However, the adoption of citizen science is still slow (Blaney et al., 2016; Hecker, Bonney, et al., 2018; Nascimento et al., 2019). Incorporating citizen science into the policy domain implies involving diverse stakeholders of whom the background and motivation vary, and their expectations may not often coincide. Furthermore, citizen science may be money- and time-consuming if not well designed, causing concerns over policy failure in terms of budget or timing (Hecker, Garbe, et al., 2018; Schade et al., 2017). Concerns regarding the quality and interoperability of citizen-generated data and obstacles faced in project implementation have also been hindering the acceptance of citizen science (Hecker et al., 2019; Nascimento et al., 2019).

In this chapter, we first set out the definition of citizen science and its adjacent concepts in section 1.1. Based on the introduced settings, in section 1.2 we identify the scientific knowledge gaps in citizen science research in the policy domain, from which the research objective is defined in section 1.3. We then further the research design by deriving the research questions and the respective research methods in section 1.4. In section 1.5, we elaborate on the scientific and societal relevance of this research. Finally, the outline of this thesis is presented in section 1.6.

1.1 CORE CONCEPTS

Citizen science is a broad and flexible concept (Eitzel et al., 2017; Robinson et al., 2018; Strasser et al., 2019). Although many efforts were done to review, define, contextualize and develop typologies of citizen science (e.g., Eitzel et al., 2017; Kullenberg & Kasperowski, 2016; Strasser et al., 2019; Wiggins & Crowston, 2011), the term is ill-defined as being used in diverse ways throughout its rapid growth in popularity — both as a notion and as a practice (Fan & Chen, 2019). It is therefore necessary to clarify the meaning of the term and its many and often ambiguous usages. In this section, we elaborate on the characteristics of citizen science and briefly set out the typologies of citizen science proposed in existing studies, followed by introducing its adjacent concepts through a literature review.

1.1.1 Citizen Science

The continuously evolving concept of citizen science has been adapted and applied within diverse situations and disciplines (Eitzel et al., 2017; Kullenberg & Kasperowski, 2016; Strasser et al., 2019). Often, citizen science is characterized instrumentally "as a tool, method or form of research collaboration" (Eitzel et al., 2017, p. 7), whereby citizen science is defined as a mode of public participation in science where "*amateurs* ('general public') can contribute to the *production* of *scientific* knowledge, with education as an associated goal or a by-product" (Strasser et al., 2019, p. 54). In such cases, citizen science is often situated in the context of traditional, hierarchical science and policymaking processes, where citizens participate in the scientific production as a supporting role (e.g. Bonney et al., 2009). By contrast, citizen science may in turn be characterized as "part of a movement that democratizes the scientific research process" (ibid.) advocating for a greater inclusion for the public to set research agendas, conduct analysis and communicate the results along with "professionals". This type of citizen science can be considered as "a form of resistance to elitism" (Eitzel et al., 2017, p. 9), which resonates with the open science movement (Eitzel et al., 2017; Kullenberg & Kasperowski, 2016).

Alongside the development towards a more evidence-based, transparent and inclusive policymaking process, citizen science can also be characterized as "a knowledge-producing capacity of society and a path to evidence-based decision-making" (Eitzel et al., 2017, p. 9). In these cases, citizen science initiatives aim at examining a problematic situation in the society in order to provide evidence for addressing the identified issue through influencing political decision-making. The initiatives often involve a collaborative process between scientists and citizens and rely heavily on scientific standards or methods for the validation of results, although scientific output is typically not the primary goal of the initiatives (Kullenberg & Kasperowski, 2016, pp. 13–14; Ottinger, 2010b). In this study, we adopt this perspective to emphasize the link of citizen science initiatives towards the policymaking and risk problem-solving processes. In this sense, citizen science is "embedded in the triangle of science, society and policy" (Hecker & Wicke, 2019, p. 1) or situated at the science-society-policy interface, around which the main actors and their roles are depicted in Figure 1-1 — i.e., in principle, policy supports citizen science, members of society contribute to citizen science, and the scientific or research communities runs citizen science projects (Hecker & Wicke, 2019).

Typologies of citizen science. The diverse practices of citizen science is portrayed with a wide variety of projects (Kullenberg & Kasperowski, 2016). The projects have been classified based on attributes such as the level of citizen's engagement (Haklay, 2013; Shirk et al., 2012), the type of knowledge practices (Strasser et al., 2019), and the environment where the project takes place (Wiggins & Crowston, 2011). A summary of abovementioned classifications is shown in Table 1-1. It is worth noting that, despite the wide variety, the landscape of citizen science shows a very uneven distribution with the majority of cases is about data collection and classification by citizens,

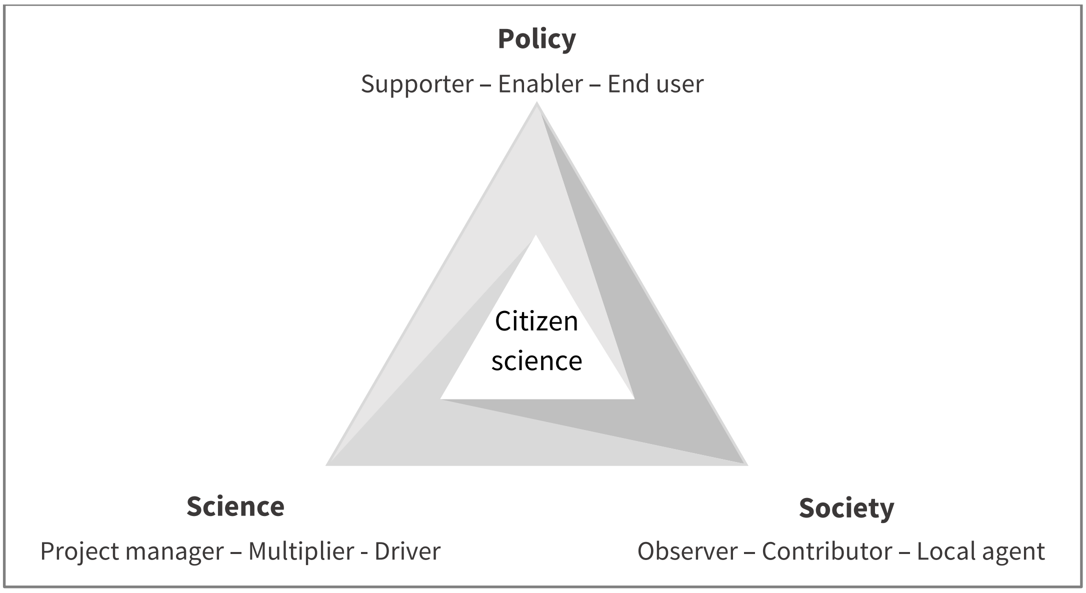

Figure 1-1. Main roles in citizen science at the science-society-policy interface (Hecker & Wicke, 2019, p. 8). Adapted by the author.

particularly in the domain of ecology, environmental sciences and geography (Hecker et al., 2019; Kullenberg & Kasperowski, 2016; Nascimento et al., 2019).

Shirk et al. (2012) investigate how public participants interact with scientists and thereby develop five types of citizen science projects, ranging from lower degree of public participation — for instance, citizens request professional researchers to conduct specific scientific investigations ("contractual") or are asked to assist scientists in data collection ("contributary") — to higher degree of participation, where citizens further engage in analyzing data, disseminating findings and/or refining project design ("collaborate") or even more actively involved in most or all aspects of the research design ("co-created"). While all above types of citizen science projects are primarily designed by scientists, in the cases of "collegial" contributions, citizens may also independently conduct research that advances scientific knowledge. Similarly, Haklay (2013) distinguishes four types of citizen science initiatives based on the level of participation with a specific focus on projects that involve data collection, or more specifically, *volunteer geographic information* (VGI). From a minimal to a maximal level of cognitive engagement, citizen science projects are categorized as crowdsourcing ("citizens as sensors"), distributed intelligence ("citizens as basic interpreters"), participatory science (citizens participate in problem definition), and extreme citizen science (collaborative science) (Haklay, 2013, p. 11). It should be noted that these typologies do not imply a hierarchical interpretation in the degree of participation but rather as a representation of a *spectrum* (Haklay, 2013; Shirk et al., 2012; Strasser et al., 2019). Meanwhile, the designation of such typologies presents a clear political agenda of the use of citizen science: "to encourage projects fulfilling citizen empowerment, rather than exploitation while ensuring that they contribute to science, as defined by scientists" (Strasser et al., 2019, p. 55).

Wiggins & Crowston (2011) complement the prior work that focuses primarily on the integration of public participation in scientific research, and further propose a typology based on the project goals and the environment where the citizen science project takes place. They distinguish five types of citizen science projects, namely: citizen science initiatives that intervene in or respond to local concerns ("action"), those with an objective of natural resource management ("conservation"),

Table 1-1. Typologies of citizen science. Note: (a) linear, grayscale elements indicate a spectrum-like typology; and (b) gaps between neighboring elements indicate the mutual exclusiveness of types devised, and vice versa.

Dimension		Types derived				
Level of citizen engagement or participation	**Shirk et al. (2012)**	Contractual	Contributory	Collaborative	Co-Created	Collegial
	Haklay (2013)	Crowdsourcing	Distributed intelligence	Participatory science	Extreme citizen science	
Environment where project takes place (Wiggins & Crowston, 2011)		Action	Conservation	Investigation	Virtual	Education
Type of knowledge practices (Strasser et al., 2019)		Sensing	Computing	Analysis	Self-reporting	Making
Notions of citizen and citizenship, and the social and political goals of scientific activities (Fan & Chen, 2019)		Cosmopolitan community of knowledge	Science, state, and citizen	Democracy and justice	Civic commons and techno-social infrastructures	
Action and justification (Ottinger, 2017)		Scientific authority-driven	Social movement-based			

projects which focus on data collection from the physical environment ("investigation"), online scientific research projects that are entirely ICT-mediated ("virtual"), and projects with the primary goals on scientific education in formal and informal settings ("education"). In this typology, the unique characteristic of virtuality in citizen science projects is specified, highlighting the differences between projects take place in the physical world and those carried out online.

Strasser et al. (2019) analyze citizen science initiatives based on the type of knowledge practices involved, with an agenda to "capture the greater diversity of participatory practices" (p. 55) and to avoid a presupposition of the label of "citizen science" on the practices. Five types of citizen science practices are distinguished: "sensing" or observing as well as measuring, donating idle computational power for parallel "computing", assisting in "analyzing" scientific data, "self-reporting" information that are then pooled for research purpose, and "making" instruments. By conceptualizing "citizen science" as a specific type of relationship between science and the public, this typology situates citizen science and its activities at a broader context of participatory contribution to scientific research.

Fan & Chen (2019) argue that using the term *citizen science* — unlike the use of terms such as popular science, public science and amateur science — is by itself making a *political statement* since "citizen is a political concept, category, and entity" (p. 182). Through a closer look at citizen science initiatives in East Asia, they point out that current discourse on citizen science is often based on Western (and in particular Anglo-American) experiences and thus assumes participatory liberal democracy as the default, reference political framework. They suggest that citizen science research "can benefit greatly from a historically informed and socio-politically sensitive view" (ibid.) and therefore propose four modes of citizen science: citizen science as a form of collaborations between professional scientists and amateurs ("cosmopolitan community of knowledge"); citizen science projects which are "implicated in traditional macro-politics" [1] (Fan & Chen, 2019, p. 185), in which the state has historically been a powerful force in shaping science and citizenship ("science, state, and citizens"); citizen science which strongly advocates public participation in science and whereby democratizing science and policymaking process ("democracy and justice"); and citizen science which emerges from the expansion of new technoscience ("civic commons and techno-social infrastructures"). It is worth noting that although the differences between the proposed types or modes are significant, they are not mutually exclusive nor static; furthermore, the different modes were distinguished to "highlight the various notions of citizen and citizenship built into the formulations of citizen science" (Fan & Chen, 2019, p. 183).

Finally, Ottinger (2010b) proposes two distinct traditions of citizen science — namely, "scientific authority-driven" and "social movement-based" — by investigating the power relations between citizens and scientific authorities in citizen science initiatives. A more detailed description of the two types is presented below along the discussion on the use of different dichotomies related to the social interactions involved.

Bottom-up vs. grassroots vs. social movement-based citizen science. In addition to the abovementioned typologies, some dichotomies are used — very often in an interchanged manner — to describe and capture the ambiguous reality of social interactions involved in citizen science initiatives. The dichotomies are listed in Table 1-2.

The dichotomy of "top-down" vs. "bottom-up" is frequently used to describe a more experts-led vs. a more citizens-led citizen science project, with Liu et al. (2014) further specify the determinant as the direction of "strategies of information processing and knowledge ordering" (pp. 6–7). Another dichotomy that more specifically distinguishes citizen science initiatives by the initiators is "institutional" vs. "grassroots", where the former being powered by competent authorities and the latter being launched by citizens (Berti Suman & van Geenhuizen, 2020). It is worth noting that a "bottom-up" citizen science initiative is not necessarily fully "grassroots" as citizen science projects could be initiated or organized by institutions or government in a collaborative manner where discussions and decision-making are done in a "bottom-up" fashion (e.g. Jiang et al., 2016).

Lastly, Ottinger (2017) differentiates two traditions of citizen science based on the action and justification relate to the initiative, namely "scientific authority-driven" vs. "social-movement based". The latter stresses that the initiative being driven by an aim towards influencing political decision-making in response to a problematic situation or identified issue in the society, and often involves criticizing and challenging existing standard settings and authorities. A comparison of the two citizen science types is summarized in Table 1-3. In this sense, social movement-based citizen science initiative is almost always both bottom-up and grassroots with a strong motivation on addressing an issue in the community or society.

[1] For instance, the citizen science project "Operation Moonwatch" was rolled out in the times of Cold War and space race, and was therefore of huge political significance and symbolized scientific nationalism. In such cases, science, state and citizens are mutually constituted.

Table 1-2. Dichotomies on citizen science initiatives

Dichotomy	Distinguished by
"Bottom-up" vs. "top-down"	The direction of "strategies of information processing and knowledge ordering" (Liu et al., 2014, pp. 6–7): ▪ *Bottom-up* — a synthesis of information and knowledge; often initiated by different groups or citizens, i.e. grassroots-driven. ▪ *Top-down* — a "synonym of analysis or decomposition" of information and knowledge; typically research-led by experts or the authorities.
"Grassroots" vs. "institutional"	The authority and legitimacy of the initiators (Berti Suman & van Geenhuizen, 2020, p. 1): ▪ *Grassroots-driven* — "initiatives launched by citizens". ▪ *Institutional* — "interventions powered by competent authorities".
"Social movement-based" vs. "scientific authority-driven"	The action and justification of the initiative (Ottinger, 2017): ▪ *Social movement-based* — research question awareness raised by citizens in response to a problematic situation or identified issue in the society. ▪ *Scientific authority-driven* — research question designed by scientific professionals. See Table 1-3 for more detail.

Table 1-3. Comparison between scientific authority-driven and social movement-based citizen science. Original source: Tu et al. (2017); translated and adapted by the author.

Type of citizen science	Scientific authority-driven	Social movement-based
Problem structuring	Research question designed by scientific professionals.	Research question awareness raised by citizen scientists in response to the care for the society.
The role of citizens in knowledge production	Led by scientific professionals. Citizens participate as a supporting role in the established process of knowledge production.	Citizens are active participants in research in a collaborative partnership with experts of scientific backgrounds. ICT and/or open sourced community may also be involved depending on the research question.
Process of knowledge production	Citizens help produce knowledge that meets existing scientific standards. Citizens' participation in this type of citizen science is mainly to assist in data collection or data analytics.	Citizens provide interpretations of data, formulate arguments on causal relations, and question the choice and justifiability of existing standards. Information and knowledge are produced by using innovative, DIY sensors or tools.
Relation to science	*"…Extends its authority to scientist-led research projects that incorporate the efforts of uncredentialed individuals"* (Ottinger, 2017, p. 356)	*"…Critiques the universalizing, values-denying model of science that is currently institutionalized in academic and policy sphere"* (Ottinger, 2017, p. 356)
Flaws	Strengthening of the authority of the existing knowledge production system.	Data collection may be fragmented and less accurate. May involve the collection of "incorrect data." Research are considered *political* and thus induced criticisms on its objectivity.

1.1.2 *Adjacent Concepts*

Several concepts share similarity or relevance with the notion of citizen science. ***Crowdsourcing***, for instance, likewise refers to general public's participation and collaboration in science but "often without fully understanding the concepts or implications motivating a research project" and "rarely determine the questions or initial motivations of research" (Eitzel et al., 2017, p. 10). It can therefore be seen as a form of citizen science of lowest level of engagement and usually with an emphasis on sensing or data collection (Haklay, 2013). A few similar terms were used to describe such practice specifically in some disciplinary contexts, for instance, ***volunteer geographic information*** in geography or ***community-based participatory research*** in public health and environmental justice (Eitzel et al., 2017). The term ***citizen sensing*** *or* ***participatory sensing*** is also often used in similar regard. Derived from *volunteer geographic information*, a term which is later considered too narrow, citizen sensing describes a bottom-up or grassroots-driven citizen participation in monitoring and measurement activities with "the reliance on some form of sensor technology" (Berti Suman & van Geenhuizen, 2020, p. 552). Noteworthily, as pointed out by Berti Suman & van Geehuizen, "citizen sensing and citizen science are increasingly converging" (Berti Suman & van Geenhuizen, 2020, p. 552) as the latter continuously evolves and becomes increasingly linked to policymaking.

Other similar concepts include ***citizen engagement*** or ***public engagement***, which refers to the involvement of the public and is more often used in political science research (for instance, see Carpini, Cook, & Jacobs, 2004). The term, unlike citizen science, does not have an emphasis on the participation in scientific activities or production of scientific knowledge. Lastly, ***data collaborative*** is also a relevant notion regarding cross-sector partnership with a focus on data-related activities. Defined as "cross-sector (and public-private) collaboration initiatives aimed at data collection, sharing, or processing for the purpose of addressing a societal challenge" (Susha et al., 2017, p. 2691), data collaborative underscores the collaboration among parties who own valuable data — in particular, the involvement of the private sector (Susha et al., 2017), whereas citizen science emphasizes the participation or engagement of citizens.

1.2 PROBLEM STATEMENT

Citizen science provides opportunities to connect citizens and policies and has therefore drawn great interest to researchers and policymakers (Hecker, Bonney, et al., 2018). However, the adoption of citizen science is still slow (Blaney et al., 2016; Hecker, Bonney, et al., 2018; Nascimento et al., 2019). Incorporating citizen science into the policy domain implies involving diverse stakeholders of whom the background and motivation vary, and their expectations may not often coincide. Furthermore, citizen science may be money- and time-consuming if not well designed, causing concerns over policy failure in terms of budget or timing (Hecker, Garbe, et al., 2018; Schade et al., 2017). Concerns regarding the quality and interoperability of citizen-generated data and obstacles faced in project implementation have also been hindering the acceptance of citizen science (Hecker et al., 2019; Nascimento et al., 2019). In this section, the scientific knowledge gaps for this study are identified and discussed.

1.2.1 *Empirical Evidence on Linking Citizen-generated Data to Political Decision-making*

Citizen science is assumed to bring many benefits when linked to policies, with most focus on citizen science as a novel tool for data collection and classification (Kullenberg & Kasperowski, 2016).

Examples show that citizen science can be a cost-effective approach in acquiring data in particular at high resolution or over large spatial and temporal scale, which is often too expensive to achieve with conventional measurements (Hyder et al., 2015; McKinley et al., 2017). The acquired data, or *citizen-generated (open) data* (Charalabidis et al., 2018, p. 185), can further serve as the evidence base for underpinning policies and informing policymaking (Hecker, Bonney, et al., 2018; Nascimento et al., 2019).

Despite the described benefits, many studies have also pointed out that the adoption of citizen science for policymaking remains stagnant (Blaney et al., 2016; Hecker, Bonney, et al., 2018; Nascimento et al., 2019). While most attribute this to concerns regarding data quality, little is known about the use of citizen-generated data for policymaking in practice (Nascimento et al., 2019). More investigations are needed to understand the practical matters on how the inflow of citizen-generated data may affect policymaking process.

Knowledge gap 1. *The empirical understanding of how citizen-generated data from citizen science initiatives affects political decision-making is limited.*

1.2.2 *The Ambiguous Reality of Social Interactions Involved in Citizen Science Initiatives*

While many typologies have been devised to distinguish between different types of citizen science projects in terms of the degree of public participation or citizen engagement, the environment where the project is carried out, and the type of knowledge practices, there are alongside different dichotomies attempting to capture the ambiguous reality of social interactions involved in citizen science initiatives. The diversity of the typologies and dichotomies used to distinguish citizen science initiatives are discussed earlier in section 1.1.1. The different forms of social interactions involved in citizen science initiatives are observed to heavily shape the modes of how the initiatives are linked to political decision-making and problem-solving or how *governance* is done with the citizen science initiatives (Berti Suman & van Geenhuizen, 2020; Göbel et al., 2019; Ottinger, 2010b). However, it is not always clear in practice what the boundaries between different forms of social interactions are, as evidenced by the interchanging use of terms such as “bottom-up”, “grassroots”, “activists”, “citizens-led”, etc., and how these interactions are linked to different modes of governance.

Through situating citizen science in the context of “governance” from the perspective of Science and Technology Studies (STS), which provides insights into the political dimensions of citizen science by describing “an expanded network of influential actors and organisations that drive the development and uptake of science and technology through society” (Göbel et al., 2019, p. 3), Göbel et al. (2019) distinguish four governance modes of citizen science as a resource for the policymaking processes. We further introduce and discuss the governance modes later in section 2.2.1. Among the identified governance modes, the concept of “socio-technical governance” is proposed to describe the citizen science initiatives emerging not via established policy channels but through the use of technology; for instance, citizens measuring air quality in their living environment using self-made, low-cost sensors. This governance mode often appears around topics of people’s concern which involves the emerging technologies, and has a direct impact on the society without being reliant on any explicit policy support — as contrasted to the remaining modes where citizen science is “initiated” by policymakers or used as a policy instrument. Despite its depth of scientific and policy engagement, this form of citizen science is largely neglected within existing literature on citizen science.

Knowledge gap 2. ***The investigations into the ambiguous reality of social interactions involved in citizen science initiatives — particularly in the form of citizen science as a mode of "socio-technical governance" — are lacking, and the boundaries between different forms of social interactions in citizen science initiatives are blurred and understudied.***

1.2.3 Citizen Science as Governance in Different Contexts

In addition to the complexity and diverse dynamics constituted of actors' perceptions and actions, as elaborated previously in the second knowledge gap in section 1.2.2, how citizen science initiatives are linked or contribute to political decision-making and problem-solving is also induced and shaped by the distinct contextual settings (Berti Suman & van Geenhuizen, 2020; Fan & Chen, 2019). However, as resonated with the first knowledge gap defined earlier in section 1.2.1, the empirical understanding on citizen science initiatives — specifically how such initiatives are influenced by or interact with different contexts — is still limited. Moreover, current discourse on citizen science is dominated by studies concerning Western (particularly Anglo-American) experiences, which tend to overlook the variety of socio-political contexts (Fan & Chen, 2019). In short, there is a lack of more in-depth analysis into how the political decision-making or problem-solving (partly) led by citizen science initiatives is induced and shaped by the contextual settings and how such influences play a role in the dynamics within the actors' arena.

Knowledge gap 3. *The understanding on how political decision-making and problem-solving is induced and shaped by the contextual settings in citizen science initiatives is limited.*

1.3 Research Objective

Citizen science is a rising concept with many promissory benefits, and a growing attention has been devoted to linking it to the policy domain. Studies have been investigating the potential benefits as well as challenges faced for the adoption of such practice, with most focusing on using citizen science as a novel data collection tool, and the attained data by citizens as an evidence base for informing policymaking. However, empirical understanding of how citizen-generated data may influence political decision-making is still limited. This study therefore aims to explore citizen science in the policy domain and to address the challenges taking into account the variety of contextual settings. The research objective of this study is hereby,

To gain empirical understanding on how citizen-generated data from citizen science initiatives can contribute to political decision-making and problem-solving in different contexts.

1.4 Research Questions and Methods

In this section, the research design for the aforesaid problem setting is presented. We start by introducing the three research questions proposed to attain the identified research objective for this study, based on which we then elaborate on the corresponding research methods and expected outcomes for each of the research questions.

The objective of this study, as presented in section 1.3, is to gain empirical understanding on how citizen-generated data from citizen science initiatives can contribute to political decision-making and problem-solving in different contexts. Accordingly, three research questions are proposed,

1. *How are citizen science initiatives linked to political decision-making and problem-solving?*

The first research question intends to investigate the link or the pathway from a citizen science initiative to the institutionalization of political decision-making and problem-solving. We conduct a systematic literature review, through which we first discuss and explore how a citizen science is formed and what opportunities and challenges are for citizen-generated data in such initiatives. Building upon the findings of what a case of citizen science composes, we set up a conceptual model which describes how such cases are initiated, how such initiatives lead to a citizen-driven solution of political decision-making and problem-solving, and how the contextual settings and actors' perceptions and actions interplay and potentially play a part in such process. The conceptual model further serves as the basis of an analytical framework which guides the case studies for answering the following research question.

2. *How does citizen-generated data contribute to political problem-solving in citizen science initiatives, in particular as a mode of "socio-technical governance"?*

The second research question seeks to gain empirical insights on the role of citizen-generated data in citizen science initiatives. More specifically, it attempts to probe into how citizen-generated data complements or fills in the institutional gaps in official data, how citizen-generated data situates at the open (government) data movement, and how such data was used by policymakers in political decision-making or problem-solving process to address the issues related to the citizen science initiatives. We emphasize on investigating the cases of citizen science as a mode of "socio-technical governance" since — as elaborated earlier in the second knowledge gap in section 1.2.2 — it is much less discussed in the existing literature of citizen science. We conduct case studies using the previously developed conceptual model as a guideline to synthesize the findings from the empirical cases, which further grounds the case comparisons for answering the third research question.

3. *How is the contribution of citizen science initiatives to political problem-solving shaped by the contextual settings and dynamics of the actors involved?*

The third and last research question aims at exploring how citizen science initiatives are shaped empirically by different initial enabling conditions as well as perceptions, actions and interactions of the actors involved and thus leads to varying outcomes in the influence on political decision-making and problem-solving. We conduct a comparative case study analysis of two citizen science initiatives to gain insights on the interplay of the contextual settings and the actions of stakeholders and its implicit causal relation to an institutional response. Together with the findings from the previous research question, a revised, empirically enhanced model is proposed. The model depicts different stages of citizen science initiatives as a resource of governance. Building upon the insights gained from the revisions, we further draw out policy recommendations for policymakers in government on how citizen science initiatives could be integrated into the policymaking processes and contribute to problem-solving for societal issues.

An overview of the research questions and their corresponding method and expected result is shown in Figure 1-2. First, in chapter 2, a systematic literature review is conducted on citizen science research related to the policy domain, which allows a conceptualization of citizen science initiatives on informing policies or contributing to political decision-making or problem-solving process. Subsequently, case studies are performed to investigate into the role of citizen-generated data in citizen science initiatives, and how governance is done throughout the process. Chapter 3 sets forth the case study research design and introduces the selected cases in this study. The cases are examined using the proposed conceptual model, from which the findings are presented in chapter 4. In chapter 5, the findings from case studies are then synthesized and translated into a revised, empirically enhanced model describing how citizen science initiatives contribute to political decision-making or problem-solving and what and how contextual settings and actors' perceptions interplay and play a part along the process. Based on the insights gained from the case studies, policy recommendations are formulated. Finally, we conclude the thesis report with a recap of

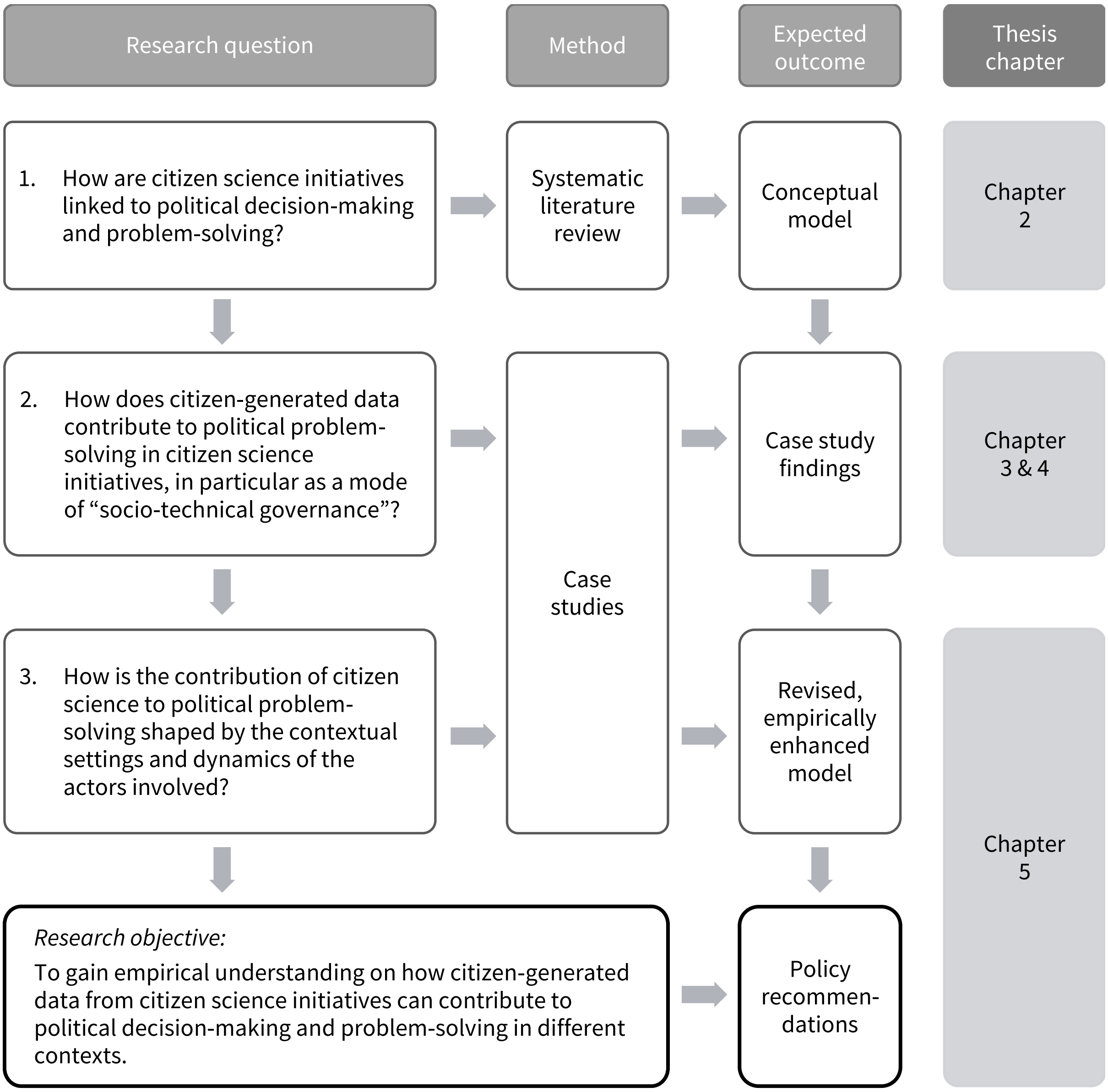

Figure 1-2. Overview of the research flow

research questions and answers, the contributions and limitations of this research, and suggestions for future research in chapter 6.

1.5 Scientific and Society Relevance of This Study

In this study, we seek to address the three scientific knowledge gaps identified and introduced earlier in section 1.2 through a comparative case study on citizen science initiatives for policies. First, we aim at enhancing the limited empirical understanding in existing literature on how citizen-generated data from citizen science initiatives affects political decision-making through empirical evidence collected from case studies. Second, the ambiguous reality of social interactions involved in citizen science initiatives would be further investigated with an attempt to clarify the blurred boundaries between different forms of such interactions through in-depth analysis of the cases studied. Third, we seek to further the understanding on how political decision-making and problem-solving (partly) led by citizen science initiatives are induced and shaped by contextual settings in citizen science initiatives through a comparison analysis between the cases.

The society relevance of this study lies in the experiences and lessons learned potentially drawn from the case studies. Based on the empirical evidence collected from the cases, we strive to formulate policy recommendations to inform policymakers in government on how citizen science could be incorporated into political decision-making and contribute to problem-solving around societal issues of public concerns.

1.6 Thesis Structure

The thesis is outlined as followed. In chapter 2, a systematic literature review is conducted, whereby a conceptual model is developed and presented. Chapter 3 sets forth the case study research approach, whereby two cases of citizen science initiatives on air quality monitoring using low-cost sensors in the Netherlands and Taiwan are selected and introduced. Based on the research approach, chapter 4 elaborates on the findings of the case studies. In chapter 5 the cases are compared and the findings from the case studies are translated into a revised, empirically enhanced model, whereby policy recommendations are formulated. Finally, chapter 6 draws the conclusions for this study. The research flow and the structure of the thesis are depicted in Figure 1-2.

2

A Conceptual Model of Citizen Science for Policies

In this chapter, a systematic literature review is conducted to the aforementioned problem settings in order to answer the first research question: *how are citizen science initiatives linked to political decision-making and problem-solving?* We first set out the systematic literature review approach in section 2.1, where we develop the literature search questions and queries, define the criteria for study inclusion and exclusion, and present the preliminary search results. We then discuss the findings derived from the systematic literature review for each of the search questions in section 2.2. Finally, the findings are synthesized and translated into a conceptual model of citizen science initiatives for policies in section 2.3. A summary of the chapter is provided in section 2.4.

2.1 Systematic Literature Review Approach

To develop a conceptual model of citizen science initiatives for policies in answering the first research question — *how are citizen science initiatives linked to political decision-making and problem-solving?* — a systematic literature review is conducted. We follow the guideline by Kitchenham & Charters (2007) to perform a systematic literature review. We adopt the search strategy of a database search complemented with additional snowballing. Two research databases — Web of Science and Scopus — were used to perform the article search.

In this section, we first define the literature search questions and their respective search queries in section 2.1.1. The inclusion and exclusion criteria for study selection are then specified in section 2.1.2. From the systematic literature search performed based on the described settings, the results are listed in section 2.1.3. In the next section, we present the findings synthesized from the systematic literature review, whereby the conceptual model is derived.

2.1.1 Literature Search Questions and Queries

Since concepts such as *citizen science* and *bottom-up*[2] are either continuously evolving or depicted by general terms, we develop a combination of alternative keywords based on the understanding of adjacent concepts and terms introduced in section 1.1 as well as via initial search for each concept to ensure that the final literature research yields inclusive results.

[2] We use the term "bottom-up" here to refer to the citizen science initiatives that are citizen-led instead of those that are designed by the professional scientists and citizens participate in the project merely as "sensors" or only provide assistance in data collection. The use of relevant terms was discussed earlier in section 1.1.1.

Table 2-1. List of concepts and respective combination of keywords

Concept	Search string, i.e., a combination of keywords
Citizen science	`("citizen science" OR "citizen sensing" OR "crowdsourcing")`
Citizen-driven or citizen-led	`("social movement-based" OR "bottom-up" OR "activism" OR "grassroots")`
Citizen-generated data	`("citizen-generated data" OR "citizen-gathered data" OR "citizen science data")`
Policymaking	`("policy" OR "politics" OR "decision-making")`

Three search questions and their respective search queries are listed below. We first inquire a basic understanding on what a citizen science initiative encompasses or is comprised of. A second inquiry concerns the aspect of citizen-generated data from a citizen science initiative, where we seek to find out the opportunities and challenges. Finally, we investigate the link on how a bottom-up citizen science initiative may influence political decision-making. A summary of the search strings used for each of the concepts in database search is shown in Table 2-1.

a) *What is a citizen science initiative as a mode for governance?*

» ("citizen science" OR "citizen sensing" OR "crowdsourcing") AND ("social movement-based" OR "bottom-up" OR "activism" OR "grassroots")

b) *How are citizen-generated data from citizen science initiatives used?*

» ("citizen science" OR "citizen sensing" OR "crowdsourcing") AND ("social movement-based" OR "bottom-up" OR "activism" OR "grassroots") AND ("data" OR "monitoring" OR "measurement") AND ("process")

c) *How can citizen science initiatives inform political decision-making?*

» ("citizen science" OR "citizen sensing" OR "crowdsourcing") AND ("social movement-based" OR "bottom-up" OR "activism" OR "grassroots") AND ("policy" OR "politics" OR "decision-making") AND ("government")

2.1.2 Criteria for Study Selection

The following criteria were applied for the inclusion of articles resulted from database search,

1. The article is an empirical study.
2. The study involves citizen science characterized by bottom-up, grassroots-driven, or citizen-led initiatives.
3. The study involves citizen-generated data, i.e. data actively generated by citizens around the issues of their concerns.
4. The study suggests that the generation of data is to serve the public good (e.g. measuring the quality of air and water) and has (potentially) been used to inform policymaking or influence political decision-making.

Studies that meet the following criteria are excluded from the selection,

1. The citizen-generated data involved in the study is generated as a by-product of digital (social) media use and lifelogging.
2. The citizen science initiative involved in the study is primarily for educational purpose or limited to awareness raising only.

In addition, the studies have to be qualified to the quality standards; more specifically, the articles have to be peer-reviewed and/or the journal or proceeding conference where the article is published is of good quality.

2.1.3 Results

The literature search was conducted using the queries defined in section 2.1.1 between April 13–15, 2020. The articles were further included or excluded per the criteria presented in section 2.1.2. A summary of the search process and number of results is shown in Table 2-2. The literature search results in 15, 6 and 9 articles for the three search questions respectively. Six duplicates are eliminated from the searched results; therefore, at last a selection of 24 articles was yield from the search, as listed in Table 2-3. It should be noted that some articles found from a specific query may (also) be useful for answering other search question(s).

In the next section, insights synthesized from the literature are discussed in order to answer the search questions. The findings from answering the search questions then form the basis of developing a conceptual model of linking citizen science to political decision-making.

2.2 Findings from the Systematic Literature Review

In this section, the findings for the search questions introduced in section 2.1.1 are presented. In sequence, we first discuss the insights gained from the empirical cases of citizen-driven citizen science initiatives found from the literature search in section 2.2.1. We then elaborate on the role of citizen-generated data and its related opportunities and challenges in section 2.2.2. Finally, we present the findings from existing studies on how citizen science initiatives can contribute to or inform political decision-making in section 2.2.3. In the next section, the findings are synthesized and translated into a conceptual model of bottom-up citizen science initiatives for policies.

2.2.1 Composition of Citizen Science for Governance

This section answers the first search question: *what is citizen science as a mode for governance?* with the aim to gain a basic understanding of what a citizen science initiative encompasses or is comprised of as a mode for governance. A search is conducted by using a query combining keywords that are related to the concepts of citizen science and the characteristics of bottom-up initiatives, as previously shown in section 2.1.1. Below we discuss the composition of a bottom-up citizen science from the aspect of stakeholders and activities and processes.

Stakeholders. Citizen science initiatives encompass a broad spectrum of stakeholders. Identifying the relevant stakeholders involved and their interests in the initiative is critical to the understanding of the complexity (Geoghegan et al., 2016; Skarlatidou et al., 2019). Skarlatidou et al. (2019) propose a method of stakeholder mapping to identify the level of power and interest regarding the identified issue. In this study, we adopt the classification of six stakeholder groups identified by Göbel et al. (2016): (a) civil society organizations, informal groups and community members; (b) academic and research organizations; (c) government agencies and departments; (d) participants; (e) formal learning institutions such as schools; and, (f) businesses or industry.

Attributes and processes. The processes or stages of activities involved in citizen science initiatives are extensively discussed and well-described in the literature, although not all rest on the

Table 2-2. Summary of search process

Search query #	0. Per search engine		1. After removing duplications	2. Excluded per criteria	3. Results
	Web of Science	Scopus			
(a)	134	179	203	188	**15**
(b)	29	65	73	67	**6**
(c)	80	103	116	107	**9**

Note: Searches were conducted in April 13–15, 2020.

Table 2-3. List of articles/report reviewed

#	Article/report	Source	Domain		
			(a) Empirical case	(b) Citizen-generated data	(c) Informing policies
1	Berti Suman & van Geenhuizen (2020) [†]	J of Environmental Planning and Mgmt.	■		■
2	Buckland-Nicks, Castleden & Conrad (2016)	J of Science Communication	■		
3	Conrad & Hilchey (2011) [†]	Environmental Monitoring and Assessment	■		■
4	Carlson & Cohen (2018)	J of Environmental Management		■	■
5	Carton & Ache (2017)	J of Environmental Management	■	■	■
6	Gabrys et al. (2016) [†]	Big Data and Society		■	
7	Göbel et al. (2016)	Woodrow Wilson International Center for Scholars		■	■
8	Göbel et al (2019)	Citizen Science: Theory and Practice	■		■
9	Hoover (2016)	J of Science Communication	■	■	■
10	Jiang et al. (2016)	J of Sensors	■	■	
11	Kenens, Van Oudheusden, Yoshizawa & Van Hoyweghen (2020)	Palgrave Communications	■		
12	Kimura (2019)	Science as Culture	■	■	
13	Lämmerhirt et al. (2019)	Global Partnership for Sustainable Development Data	■	■	
14	McCormick (2012)	Ecology & Society	■	■	
15	Meijer & Potjer (2018) [†]	Government Information Quarterly		■	■
16	Ottinger (2010a)	Surveillance and Society	■	■	■
17	Ottinger (2010b)	Science, Technology, & Human Values	■	■	■
18	Ottinger (2018)	J of Science Communication			■
19	Ponti & Craglia (2020) [†]	Ispra, European Commission		■	■
20	Rickenbacker, Brown & Bilec (2019)	Sustainable Cities and Society		■	■
21	Schade et al. (2017) [†]	Joint Research Centre, the European Commission		■	■
22	Shirk et al. (2012) [†]	Ecology and Society	■		■
23	Tu (2019)	East Asian Science, Technology and Society	■	■	■
24	Van Brussel & Huyse (2019)	J of Environmental Planning and Mgmt.	■		■

Note: The article/report found via additional snowballing method is annotated by the [†] symbol.

perspective chosen for this study, i.e. characterizing as “a knowledge-producing capacity of society and a path to evidence-based decision-making” (Eitzel et al., 2017, p. 9) as discussed previously in section 1.1.1. Nevertheless, common characteristics and attributes can be retrieved from such cases and be used as findings for constructing a conceptual model for the bottom-up initiatives in this study. Below we discuss a five-stage framework designed by Shirk et al. (2012), a four-stages performance matrix by Berti Suman & van Geenhuizen (2020), and an analytical framework by Ponti & Craglia (2020).

Shirk et al. (2012) suggest that the outcome of citizen science initiative is influenced by negotiations and interactions between scientific interests and public interests, whereby proposing a five-stage model describing the complex process of public participation in scientific research — inputs, activities, outputs, outcomes, and impacts. The element of outcome is further divided into three categories: those for science, those for individual participants, and those for social-ecological systems. While the framework resonates with the view on the importance of stakeholder’s perceptions in shaping the outcome of citizen science initiatives, the complexity of the path towards political decision-making or problem-solving — i.e. how outputs are linked to impacts — is less emphasized in the study.

Similarly, Berti Suman & van Geenhuizen (2020) propose a four-stage model by investigating two cases of grassroots citizen sensing initiatives where citizen-generated sensor data of noise measurement were used to campaign against the expansion plan of airport. Two types of stakeholders are identified in this study: citizens and institutions. The model describes degree of “performance” of the case by four stages: initial conditions enabling problem-solving; steps towards problem-solving; partial problem-solving; and full problem-solving. Each of the stages are detailed with relevant perceptions and/or actions of the citizens or the institutional players. A more detailed description of the model is provided in section 2.2.3. While the model provides a clear picture of the interactions of actors involved and the path towards a citizen-driven solution, the involvement (and thus perceptions) of the researchers — which is often present in the case of citizen science — absent in the studied cases.

A similar set-up of stages can be found in the framework introduced by Ponti & Craglia (2020), where the aspect of citizen-generated data (CGD) is emphasized. In the framework, the attributes are categorized into five main categories: data governance; setup and development of the project (corresponds to initial conditions enabling and steps towards problem-solving); project outcomes (corresponds to partial or full problem-solving) ; sustainability of the project; and CGD use by the public sector. Common elements such as participation of the citizens are present in corresponding stages. The parts of data governance and CGD use by the public sector are further discussed in the next section of 2.2.2.

2.2.2 The Use of Citizen-generated Data in Citizen Science for Governance

This section answers the second search question: *how are citizen-generated data from citizen science initiatives used?* with the aim to investigate the use of citizen-generated data from citizen science initiatives, and the opportunities and challenges encounter. A search is conducted by using a query combining keywords that are related to the concepts of citizen science as a governance mode and of citizen-generated data, as previously shown in section 2.1.1. Below we elaborate on the relevance of citizen-generated data to citizen science initiatives.

As discussed in section 1.1.1, existing studies often characterize citizen science instrumentally, or particularly as a tool of data collection (Eitzel et al., 2017). In this context, literature typically identifies citizen-generated data as a source of evidence in the development or implementation of regulations or inputs for modeling. As a result, complying with scientific or regulatory standards becomes the major concern of citizen-generated data, with existing studies primarily focusing on examining, questioning or improving the quality of citizen-generated data (e.g. Kosmala et al., 2016). In many cases, citizen-generated data are challenged by institutions and regulators and even excluded from the policymaking or political decision-making processes for their validity and accuracy (e.g. Ottinger, 2010b; Berti Suman & van Geenhuizen, 2020).

Reflecting on this perspective, Gabrys et al. (2016) put forward the concept of "just good enough data", arguing that the use of citizen-generated data is beyond regular use for regulation, compliance and modelling; therefore, the relevance of citizen-generated data should not be examined solely through absolute criteria or alignment to the corresponding official data, especially considering that "these criteria can often shift depending upon modes of governance, location, and available resources" (Gabrys & Pritchard, 2018, p. 6). Pinpointed by their observations of the participatory environmental sensing project of Citizen Sense in northeastern Pennsylvania, USA, they point out that the use of citizen-generated data serves not for "raising public awareness" as what earlier conceptions of public science or citizen science suggests, but rather "communicating public awareness to regulators" (Gabrys & Pritchard, 2018). In this sense, citizen-generated data are understood as "entities that transform" (Gabrys & Pritchard, 2018, p. 6) depending upon their uses or the ends to which the data might be "good enough" to achieve. Data quality is assessed with respect to the "fitness for intended use" (Wiggins & He, 2016, p. 1549).

Table 2-4 showcases a summary of the use of citizen-generated data from a selection of the empirical cases of citizen science initiatives retrieved from the systematic literature review. The cases are described by an adaptation of attributes related to citizen-generated data (CGD) listed in Ponti & Craglia (2020), including the type of data collected and the purpose of data collection, the owner of CGD, and whether CGD is used to complement official data or used by policymakers. It can be observed that, in alignment with the concept of "just good enough data", in most cases citizen-generated data are not directly used by the institutions or regulators, a response from the institutional actors was present (e.g. a governmental program which further to the identified issue in Berti Suman & van Geenhuizen, 2020). It should be noted that, however, the information from the literature itself is too limited to infer that citizen-generated data do contribute to such responses and to determine to what extent the contribution is in the cases.

It is also worth noting that, as Hoover (2016) observed in a case where blood samples were collected in a Native American tribe in Canada, privacy concerns regarding the data collected could be a crucial factor shaping the process and outcome of citizen science projects. Since blood samples of the indigenous people are sensitive information in the studied case[3], distrusts against the authorities were observed alongside with the privacy concerns throughout the project. This element of privacy concerns on citizen-generated data is also incorporated in the proposed conceptual model, which is introduced later in section 2.3.

[3] The community's concerns were that the government might misappropriate the blood samples — more specifically, distort the information and use the collected blood samples — to "prove" that the indigenous people are no longer Indians (Hoover, 2016).

Table 2-4. A selection of empirical cases of bottom-up citizen science initiatives from the systematic literature review, and the use of citizen-generated data for the cases

Article	Country where the initiative took place	Type of data collected and purpose for data collection	Owner of collected and processed data	Is CGD used (by citizens) to complement gaps in official data	Is CGD used by policymakers (or institutional actors)	Whether there is an institutional response to the initiative
Berti Suman & van Geenhuizen (2020)	The Netherlands	Sensor data for noise measurement	Informal groups and community members	Yes, specifically to fight against "information monopoly"	No	Yes
Berti Suman & van Geenhuizen (2020)	UK	Sensor data for noise measurement	Informal groups and community members	Yes, specifically to challenge official data	No	Yes
Hoover (2016)	USA	Blood sample data to examine health impacts	Academic and research organization	Yes, specifically to challenge official data	Unclear	Yes
Jiang et al. (2016)	The Netherlands	Sensor data for air quality measurement	Civil society organization	Yes	Yes	Yes
Kimura (2019)	Japan	Sensor data for radiation measurement	Informal groups and community members	Yes, specifically to challenge official data	Unclear	Unclear
Ottinger (2010b)	USA	Bucket[4] measurement data for air pollution	Informal groups and community members	Yes	No	Yes
Tu (2019)[5]	Taiwan	Photographs showing the quality of air.	Civil society organization	Yes	No	Yes

2.2.3 *Citizen Science on Informing Political Decision-making*

This section answers the third and last search question: *how can citizen science initiatives inform political decision-making?* with the aim to probe into the path from citizen science initiatives to policymaking or political decision-making. A search is conducted by using a query combining keywords that are related to the concepts of citizen science and of policymaking or political decision-making, as previously shown in section 2.1.1. Below we present the findings from existing literature.

Typically, the role of citizen science in the policy context is identified as a data source for the development, implementation or monitoring of regulation or a supporting tool for science policy (Gabrys & Pritchard, 2018; Göbel et al., 2019). This perspective is often based on the assumption that policymakers are central to the policymaking process and that "policy" and "science" are separate spheres, and often sees policymaking as a linear process where policymakers structure the way citizen science is incorporated. In recent studies, the concept of "governance" is introduced to broaden the view of policymaking process beyond the public sector by "capturing non-hierarchical

[4] A simple, inexpensive sampling device for ambient air. See Ottinger (2010b).
[5] The case of the KS 100 Plan.

modes of coordination, for instance through networks or markets, as well as roles of non-state actors in public policymaking and implementation" (Göbel et al., 2019, p. 3). The concept is further enriched by Science and Technology Studies (STS), which highlights the intertwined nature of science and politics. In this view, science and politics are mutually dependent and interlinked, and governance is a multi-directional process rather than a linear, top-down one.

In light of this view, Göbel et al. (2019) develop four modes of governance for citizen science: (a) source of information for policymaking, (b) object of research policy, (c) policy instrument, and (d) socio-technical governance. While the first three inherit the view of "citizen science as a tool of policymakers", the last mode of "socio-technical governance" describes the cases where citizen science functions as governance mode "without involving political representatives or established policy channels" (Göbel et al., 2019, p. 30), or as we consider in this study — as discussed in section 1.1.1 — the cases of *grassroots citizen science*. In this governance mode, citizen science often appears around a problematic situation or issue in the society and tackles the problem without relying on any explicit policy support; however, less is discussed in the literature on how socio-technical governance is structured towards its influence on the identified issue. It is worth noting that, as pointed out by Göbel et al. (2019), this form of citizen science is largely neglected within existing literature of citizen science.

A more detailed investigation into citizen science initiative and its connection to problem-solving is provided by Berti Suman & van Geenhuizen (2020), who studied two cases of grassroots citizen science initiatives measuring noise pollution to campaign against the expansion plan of airport. They suggest that citizens measuring, although by itself does not mean already solving the problem, provides an opportunity that "creates a trigger for the solving" (Berti Suman & van Geenhuizen, 2020, p. 559) — as in line with the point of view of Gabrys et al. (2016) previously discussed in section 2.2.2. From the observations and comparison on the cases, a four-stage model is proposed to detail the path from a bottom-up citizen science initiative towards "full problem-solving", i.e. practical interventions by the institutional actors to mitigate the problem: (1) *initial conditions enabling problem-solving*, as evidenced by the perceived "malfunctioning and dogmatic attitude of the institutional response to the risk problem" and "inconsistencies in the institutional approach to the problem" by the citizens (Berti Suman & van Geenhuizen, 2020, p. 560); (2) *steps towards problem-solving*, where mutual understanding on a shared problem is achieved through, for instance, the broadening attention of the public towards the problem and citizen-generated data; (3) *partial problem-solving*, where a trusted dialogue is achieved by "co-production with institutional players", i.e. integrating the citizen initiative with institutional governance system; and finally, (4) *full problem-solving*, where practical interventions are implemented as well as citizen's contribution is acknowledged by the institutional players.

The concept of the boundary-bridging or boundary-policing function of standard settings or standards (Ottinger, 2010b) is frequently used in citizen science-related studies in STS. As evidenced by her close observations of the cases where residents measure air quality using "buckets"[4], Ottinger demonstrates that standards play a dual role in shaping the success of "social movement-based" citizen science initiatives, as previously introduced in section 1.1.1. Ottinger argues that, on the one hand, standards "bridge the boundaries" and thereby offer citizens or non-scientists the opportunities "to render their challenges recognizable to experts and to claim the right to participate in expert-dominated discussions of technical issues" (Ottinger, 2010b, p. 251). On the other hand, standards "police the boundaries" between science and non-science, making them "a resource for experts who wish to resist non-scientists' challenges" (ibid.).

The varying outcome is also shaped by the diverse contexts of the citizen initiatives. As Tu (2019) observed from the case of citizen science initiatives measuring air quality in Taiwan, "citizen groups in Taiwan often prioritize their demands for tightening regulations and overall pollutant quantity control rather than directly targeting the polluters" (p. 252) as compared to the US's cases. She notes that the differences could be explained from a broader, historical context, as part of the results of the industrial agglomeration patterns, rapid urbanization and mismanaged, mix land use in Taiwan.

2.3 Towards a Conceptual Model of Citizen Science for Policies

In this section, the proposed conceptual model describing how citizen science initiatives are linked to political decision-making and problem-solving is derived from the findings of the systematic literature review. The proposed conceptual model is illustrated in Figure 2-1. The model is composed of five major stages:

(1) *Enablers and drivers* — how such cases are initiated;

(2) *Development of the case* — how such initiatives lead to a citizen-driven solution of political decision-making and problem-solving;

(3) *Boundary-bridging or boundary-policing by standards* — together with the elements from previous stages, how contextual settings and actors' perceptions and actions interplay and potentially play a part in such process;

(4) *Project outcome* — what results or outcomes were produced by such initiatives; and

(5) *Sustainability of the project* — how such initiatives sustain and continue to bring influence.

Each of the stages contains elements or factors involved, which are further introduced later in the following sub-sections. A summary of the explanations of each of the elements are presented in the corresponding analytical framework, as shown in Table 2-5.

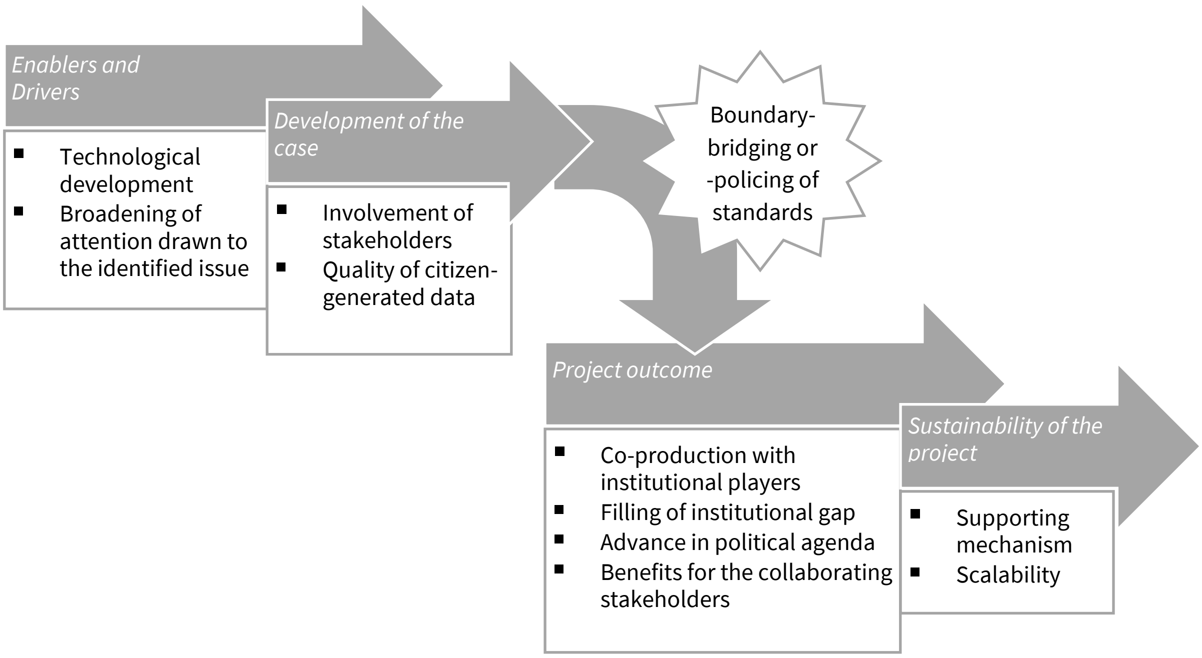

Figure 2-1. The proposed conceptual model for bottom-up citizen science initiative.

2.3.1 *Enablers and Drivers*

In the first stage are the enabling conditions and driving factors which induce the bottom-up citizen science initiatives. Two elements are identified in this stage: the *development of technology* and the *broadening of attention drawn to the problematic situation*. Below the two elements are introduced.

Table 2-5. The analytical framework corresponding to the proposed conceptual model

Stages	Element	Description of the element
Enablers and drivers **[Initial conditions enabling problem-solving]**	Technological development	Advances in technologies such as the development of low-cost sensors and Internet of Things.
	Broadening of attention drawn to the identified issue	Broadening of pressure exerted on the government, possibly associated with a monopoly of information or citizens' distrust in authorities (Berti Suman & van Geenhuizen, 2020).
Development of the case **[Steps towards problem-solving]**	Involvement of stakeholders	The involvement of stakeholders (other than citizens) and the relationships among them.
	Quality of citizen-generated data	The "fitness of intended use" of data, or whether the data is "good enough" for the purpose of the citizen initiative (Gabrys & Pritchard, 2018).
Boundary-bridging or boundary-policing function of standard settings		Whether standard settings act as a boundary-bridging or a boundary-policing function to the citizen-generated data so that it is either accepted or disapproved by the authorities (Ottinger, 2010b).
Project outcome **[Partial or full problem-solving]**	Co-production with institutional players	Co-production of solutions to the identified problem, e.g. citizens play a more active role in examining the problematic situation or taking actions in political decision-making process, whereby new relationships between citizens and the government is established (Berti Suman & van Geenhuizen, 2020; Ponti & Craglia, 2020).
	Filling of institutional gap	The filling of the information needed for policymaking or political decision-making, or if citizen-generated data is used to complement official data. In this dimension we also include the "ordinary use" of data, namely the use of citizen-generated data as a source of information or evidence-base for policymaking or as input for modelling and simulations.
	Advance in political agendas	The use of citizen-generated data as an instrument to advance political agendas through communicating the need of the citizens (Gabrys & Pritchard, 2018).
	Benefits for the collaborating stakeholders	If the collaborating public organization has gained something and what they have gained from the project. This also covers potential benefits for other involved stakeholders (except citizens).
Sustainability of the project	Supporting mechanism	Initiatives in place to support and thus sustain the project, such as potential or actual sources of contribution to fund a project.
	Scalability	Whether the projects have or could be scaled up.

Technological development. The advances in technoscience or technologies could be a strong enabler for citizen science initiatives (Berti Suman & van Geenhuizen, 2020; Fan & Chen, 2019; Göbel et al., 2019). The emergence and the spread of new technologies may provide opportunities or serve as tools for citizens to resolve an identified societal problem. For instance, in the bottom-up citizen science initiative of "Airplane Monitor Schiphol" (Berti Suman & van Geenhuizen, 2020; Carton & Ache, 2017), technological progress in low-cost sensors and Internet of Things (IoT) is crucial to enable citizens to measure noise pollution in a self-organized manner to confront the government with the information monopoly on environmental measurements.

Broadening of attention drawn to the identified issue. The broadening of attention drawn to the identified societal issue, and often accompanied with pressure exerted on the government or the institutions, is also often observed as a powerful driving factor for citizen science initiatives (Berti Suman & van Geenhuizen, 2020). This factor is often associated with a monopoly in information or citizens' distrusts against the authorities, which may be further linked to the "perceived malfunctioning and dogmatic attitude of the institutional response to the risk problem" (Berti Suman & van Geenhuizen, 2020, p. 560) and/or "perceived inconsistencies in the institutional approach to the problem" (ibid.).

2.3.2 Development of the Case

The second stage of the model describes the development of the case by introducing two elements of the initiative: *whether the case involves its stakeholders* based on mutual understanding of the identified issue, and whether the *quality of citizen-generated data* is "good enough" for the ends to which the citizen initiative is hoping to achieve. Below the two elements are elaborated.

Involvement of stakeholders. As resonated the arguments on the need for involvement of multi-stakeholder collaboration for governance system, whether stakeholders are involved in the citizen science initiatives as well as the relationship among the involved stakeholders other than citizens are crucial to the progress and development of such initiatives (Ponti & Craglia, 2020).

Quality of citizen-generated data. The quality of citizen-generated data is investigated and interpreted from several different aspects: the "fitness of intended use" of data (Wiggins & He, 2016); whether the data is "good enough" for the purpose of the citizen initiative (Gabrys & Pritchard, 2018); and, as discussed earlier in section 2.2.2, privacy concerns regarding the collected data.

2.3.3 Boundary-bridging or Boundary-policing of Standards

The concept of "boundary-bridging" or "boundary-policing" function of standards (Ottinger, 2010b) underlines the significance of standards and standardized practices on influencing the effectiveness of citizen science initiatives and thus the outcomes. As elaborated earlier in section 2.2.3, Ottinger (2010b) demonstrates that standards play a dual role in shaping the outcomes of social movement-based[6] citizen science initiatives. Based on her close observations on the cases where residents measure air quality using "buckets"[4], she argues that, on the one hand, standards may "bridge the boundaries" and thereby offer citizens or non-scientists the opportunities "to render their challenges recognizable to experts and to claim the right to participate in expert-dominated discussions of technical issues" (Ottinger, 2010b, p. 251). On the other hand, standards may "police

[6] For explanations on social movement-based citizen science, see section 1.1.1.

the boundaries" between science and non-science, making them "a resource for experts who wish to resist non-scientists' challenges" (ibid.).

In this stage, we thereby adopt the notion of *boundary-bridging or -policing by standards* — alongside with the factors introduced in pervious stages — to elaborate on how contextual settings and actors' perceptions and actions interplay and potentially play a part in the process of linking citizen science initiatives to their outcomes; more specifically, whether standard settings bridge or police the boundaries between science and non-science for citizen-generated data so that it is either accepted or disapproved by the authorities, and thus contributes to or hinders the progress towards political decision-making and problem-solving.

2.3.4 Project Outcome

The fourth stage examines the project outcome by four elements: (a) the co-production with the institutional players towards a solution to the problem, whereby establishes a "trusted dialogue" as well as a new relationship between citizens and government; (b) the filling of institutional gap such as the use of citizen-generated data to complement official data; (c) advance in political agendas through, for instance, communicating the need of citizens; and (d) (potential) benefits for the collaborating stakeholders. Below the four elements are further explained.

Co-production with institutional players. The co-production of solutions or problem-solving strategies between citizens and institutional players (i.e. the government or institutions) to the identified problem symbolizes the *institutionalization* of the citizen science initiatives (Berti Suman & van Geenhuizen, 2020; Carton & Ache, 2017; Ponti & Craglia, 2020). The co-production of solutions is embodied by, for instance, citizens playing a more active role in examining the problematic situation together with the institutional players or taking actions in political decision-making process. The stage is often achieved on the basis of an institutional recognition of the problems or societal issues — and potentially also a recognition of the citizens' initiatives — and thereby brings about the mitigation of such issues through practical interventions. The co-production may contribute to the set-up of a trusted dialogue between citizens and institutional actors, whereby new relationships between the two were established (Berti Suman & van Geenhuizen, 2020; Ponti & Craglia, 2020).

Filling of institutional gap. The "filling of institutional gap" (Berti Suman & van Geenhuizen, 2020, p. 561) refers to the bridging of the information gap needed for policies, or more specifically, the use of citizen-generated data to satisfy the need of information for political decision-making or policymaking process or to complement official data. This includes the traditional or ordinary way of using those data — namely, as a source of information or the evidence-base for policymaking and/or as inputs for the official modelling and simulations for the support for policymaking.

Advance in political agenda. Citizen-generated data may influence policies and politics in more implicit ways beyond the direct use as a source of evidence-base for policymaking or inputs for modeling and simulations, as elaborated in the filling of institutional gap above. As suggested by the concept of "just good enough data" (Gabrys et al., 2016), citizen-generated data could be "good enough" and thus useful for communicating people's concern to the regulators (Gabrys & Pritchard, 2018). In this sense, citizen-generated data from citizen science initiatives may serve as an instrument and whereby contribute to the advances in political agenda.

Benefits for the collaborating stakeholders. Citizen science may bring not only benefits for the citizens but also for the involved or collaborating stakeholders (Ponti & Craglia, 2020). In this dimension, whether the collaborating stakeholders have gained from the citizen science initiatives and what such (potential) benefits are involved are examined.

2.3.5 *Sustainability of the Project*

Finally, the fifth and last stage assesses the sustainability of the project by whether a supporting mechanism presents and whether the project could be further scaled up. Below the two elements are introduced.

Supporting mechanism. The supporting mechanism refers to ways by which the citizen science initiatives are supported and thus ensured the viability and continuity (Ponti & Craglia, 2020). In other words, this dimension examines whether there are initiatives — for instance, potential or actual sources of contribution — in place to fund such projects.

Scalability. The scalability of the project is an important aspect of examining how citizen science initiatives would sustain. From assessing whether the projects have or could be further scaled up, this dimension investigates on the possibilities or potential of the expansion and thereby the sustainability of such citizen science initiatives.

2.4 SUMMARY

In this chapter, a conceptual model which describes how citizen science initiatives are linked to political decision-making and problem-solving was set up through a systematic literature review. The proposed conceptual model is illustrated in Figure 2-1, and the explanations of the elements and factors involved are summarized in Table 2-5. The model is composed of five major stages:

(1) *Enablers and drivers* — how such cases are initiated, including the elements of (a) technological development and (b) broadening of public attention drawn to the identified issue;

(2) *Development of the case* — how such initiatives lead to a citizen-driven solution of political decision-making and problem-solving, including the elements of (a) involvement of stakeholders and (b) quality of citizen-generated data;

(3) *Boundary-bridging or boundary-policing by standards* — how contextual settings and actors' perceptions and actions interplay and potentially play a part in such process (together with the elements from previous stages);

(4) *Project outcome* — what results or outcomes were produced by such initiatives, including the elements of (a) co-production with institutional players, (b) filling of institutional gap, (c) advance in political agenda, and (d) benefits of the collaborating stakeholders; and

(5) *Sustainability of the project* — how such initiatives sustain and continue to bring influence, including the elements of (a) supporting mechanism and (b) scalability.

The proposed conceptual model is later used as a basis or framework to guide the case study analysis in chapter 4 and chapter 5.

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3

Case Study Research Design

In this chapter, we set forth the research design for case studies in order to answer the second and the third research question, namely: *how does citizen-generated data contribute to political problem-solving in citizen science initiatives, in particular as a mode of "socio-technical governance"?* — in chapter 4; and *how is the contribution of citizen science initiatives to political problem-solving shaped by the contextual settings and dynamics of the actors involved?* — in chapter 5. We present the case study research approach in section 3.1, where we follow Yin (2014) on developing a case study protocol, followed by identifying the criteria for case selection and methods for data collection. A holistic, multiple-case design is adopted for this study. Upon the case selection criteria, two cases are selected: the case of Dutch Skies in the Netherlands and the case of AirBox in Taiwan. The two cases are then introduced in detail in section 3.2. A summary for this chapter is provided in section 3.3.

3.1 Case Study Research Approach

Case study research is a suitable research method for answering the second and third research questions for several reasons. First, the research questions are "how" questions, which are of a more explanatory form of research questions and often lead to the use of research methods such as experiments, history research or case study. Second, citizen science is a rising field or a contemporary phenomenon over which the researchers have very limited or no control. Experiments and history research are therefore inadvisable for studying such events: the former requires manipulations of behaviors, and the latter deals with the "dead" past. Third, the boundaries between the phenomenon of citizen science and its context are not clearly evident. Case study is therefore an appropriate strategy for studying the behaviors of citizen science events.

A multiple-case design is selected for this study as it is in general preferred over single-case design: the former may yield more substantial analytical benefits, while the latter is more vulnerable to criticisms regarding the case's uniqueness and requires extremely strong arguments in justifying the choice for the case (Yin, 2014, pp. 56–57). We thus adopt a holistic, multiple-case design for the case study, as depicted in Figure 3-1. In the following sub-sections, the case study protocol is defined according to Yin's (2014) five components of a case study research design. We then specify the criteria for selecting the cases for this study and identify the methods for data collection for the cases. The selected cases are further introduced in the next section of 3.2.

3.1.1 Case Study Protocol

We follow Yin (2014) on developing the case study protocol by defining the five components of a case study research design: (a) a case study's questions; (b) its propositions; (c) its case(s); (d) the

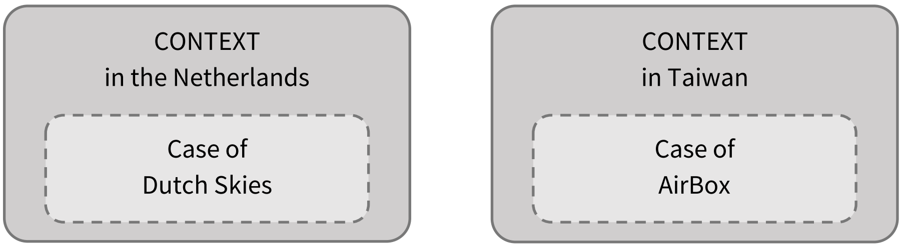

Figure 3-1. Illustration of the design of a holistic, multiple-case study.

logic linking the data to the proposition; and (e) the criteria for interpreting the findings. The first three components indicate what data are to be collected, while the last two describe how the data collected would be processed (Yin, 2014, pp. 36–37). Each of these components is elaborated below.

(a) Study questions. The first component concerns the question to which the case studies aim to answer. The research questions that the case studies aim to answer are, as introduced in section 1.4, the second research question — *how does citizen-generated data contribute to political problem-solving in citizen science initiatives, in particular as a mode of "socio-technical governance"?* — and the third research question — *how is the contribution of citizen science initiatives to political problem-solving shaped by the contextual settings and dynamics of the actors involved?* We therefore derive the study questions for the case studies as,

1. What are the contextual settings of the case?
2. How do the stakeholders involved in the case interact with one another?
3. How is the data generated from the case (i.e. citizen-generated data) used or linked to policies?
4. How are the communications with citizens done in the case?
5. What are the major challenges faced in the case?

(b) Study proposition. The second component "directs attention to something that should be examined within the scope of the study" (Yin, 2014, p. 30). The proposition adopted for the case studies is that citizen science initiatives — which emerge around a problematic situation or a societal issue and thus a topic of public's concerns — are induced and shaped by the interplay between contextual factors and actors' perceptions and actions, and further lead to different outcomes in political decision-making and problem-solving. Based on the proposition, we aim to identify the enablers and/or disablers of bottom-up citizen science projects in different contexts, and how these contextual factors interact with the actors involved in the case.

(c) Unit of analysis — the "case." The third component identifies what the "case" is to be studied and can be further divided into two steps: defining the case and bounding the case (Yin, 2014, p. 31). Following the study questions and proposition defined above, in this study we take a *bottom-up citizen science project* as the unit of the case study. The project involves a group of citizens initiating and participating in scientific research, usually in collaboration with scientists or experts, with a political aim on influencing a certain decision made by the government. The described stakeholders and the entire lifecycle of the project is within the boundary of the case study.

(d) Linking data to propositions. The fourth component "foreshadows the data analysis steps in the case study" (Yin, 2014, p. 35). We follow the *pattern-matching* logic to examine the pre-post patterns from the conceptual model described in section 2.3. Additionally, we adopt the techniques of *explanation building* and *cross-case synthesis* to build a general explanation and aggregate findings across individual case studies.

(e) The criteria for interpreting the findings. The fifth component concerns the criteria for assessing or interpreting the strength of a case study's findings and is done by specifying the potential rival theories and explanations for the findings. In this study, we examine the findings using the conceptual model developed in section 2.3 as the guideline of case study analysis.

3.1.2 Case Selection

Four criteria were used to select the case study groups:

1. The cases involve citizen science initiatives as a mode for "socio-technical governance", or more specifically, a citizen initiative that appeared around the topic of citizens' concern with an aim to examine the problematic situation.
2. There were data collected by the citizens (i.e., "citizen-generated data") involved in the cases.
3. The citizen-generated data from the case had been or potentially been used in policies or political decision-making, or has potentially contributed to the solving of the problem.
4. The case is from the environmental domain.
5. Both the coordinator(s) of the case and their government counterpart(s) were willing to participate in the study. This criterion ensures that this study has access to information of the selected cases.

According to the above criteria, two cases are selected for this study: (a) the case of AirBox, Taiwan, and (b) the case of Dutch Skies, the Netherlands. The selection of the cases follows the *replication logic*; more specifically, the logic of a theoretical replication (Yin, 2014, pp. 56–62). The cases are further introduced in detail in section 3.2.

3.1.3 Data Collection

As suggested by Yin (2014), case studies should rely on the triangulated data from multiple sources of evidence to "overcome the deficiencies and measures associated with any given source" (pp. 46–47). In this study, a convergence of two sources of evidence — documentation and interviews — was used to obtain information for the cases studied. The documentation used includes project websites, news clippings and articles in the mass media, administrative documents (such as proposals and progress reports) as well as formal research studies which concern the same cases studied. An overview of the documents used for the case studies is summarized in Table 3-1.

For data triangulation, interviews were conducted with representatives from each of the three stakeholder groups: the government, the researchers and the citizens or the community. In this study, three interviews were conducted per case — i.e. in total six interviews were conducted, as summarized in Table 3-2. The interview transcripts are supplemented in Appendix A.

3.2 Case Descriptions

Case studies were used in this study to gain insights on how the citizen-generated data could inform policies or contribute to political decision-making and problem-solving in different contexts. Following the research approach developed earlier in the section 3.1, the case of AirBox in Taiwan and the case of Dutch Skies in the Netherlands were selected for the case studies. In this section, a general introduction to the two selected cases is presented. The introduction touches upon the contexts and settings of each of the cases, as well as the main actors involved in the cases. We first present an overview of the abovementioned contents for the two cases in section 3.2.1. After that, the cases of AirBox and Dutch Skies are further introduced in section 3.2.2 and section 3.2.3, respectively. The cases are then investigated, discussed and analyzed based on the introduced settings in the next chapters of 4 and 5.

Table 3-1. Overview of documentation data sources for case studies

Documentation	Type of documentation	Case
Waag (2019)	Project website	Dutch Skies
RIVM (n.d.)	Project website	
Wesseling, Blokhuis, et al. (2019)	Official report	
Wesseling, van Alphen, Volten, & van Put (2016)	Official report	
Wesseling, de Ruiter, et al. (2019)	Research studies	
Veenkamp et al. (2020)	Research studies	
Volten et al. (2018)	Research studies	
de Jonge (2017)	(Documented) interview	
Wesseling (2017)	(Documented) interview	
RIVM (2018)	News clipping and articles	
van Zoelen (2019)	News clipping and articles	
NOS (2019)	News clipping and articles	
NH Nieuws (2019)	News clipping and articles	
EPA (2019)	Project website	AirBox
Civil IoT Taiwan (n.d.)	Project website	
LASS Community & Academia Sinica (2019)	Project website	
Taipei City Government (2016)	Project website	
EPA (2015)	Official report	
EPA (2016)	Official report	
MoST (2018)	Official report	
MoST, EPA, MoT, MoIA, & MoEA (2017)	Official report	
EPA (2017)	Presentation slides	
EPA (2018)	Presentation slides	
Chen L.-J. (2016)	Presentation slides	
Lee (2017)	Research studies	
Tu (2019)	Research studies	
Wang & Walther (2017a, 2017b, 2017c)	Research studies	
Walther et al. (2017)	Research studies	
Walther et al. (2018)	Research studies	
Chen W.-H. (2015)	News clipping and articles	
Chen W.-Z. (2015)	News clipping and articles	
Chen W.-Z. (2017)	News clipping and articles	
Lin & Chang (2017)	News clipping and articles	
Liu & Chang (2020)	News clipping and articles	
Lu (2017)	News clipping and articles	
Xie (2020)	News clipping and articles	

Table 3-2. List of interviews

Interview #	Interviewee	Case
HL1	Project team member from Waag	Dutch Skies
HL2	Researcher at RIVM	
HL3	Officer at Province of North Holland	
AB1	Founding member of LASS community	Airbox
AB2	Researcher at the Institute, Taiwan[8]	
AB3	Officer at Department of Environmental Monitoring and Information Management (Dept. EM&IM), EPA, Taiwan	

3.2.1 *Overview of the Cases*

The cases of AirBox and Dutch Skies are both bottom-up or citizen-led citizen science initiatives measuring air quality — more specifically, particulate matter in ambient air — using low-cost sensors. While the case of AirBox emerged initially from activities initiated by an online, "Maker" community, the case of Dutch Skies was a program launched mainly by the provincial government of North Holland, yet within the project, citizens or participants were given much room to discuss and make decisions on strategies in a bottom-up or co-created fashion. In addition, both cases are further associated to a larger movement or a governmental program on linking the citizen science to the development of the IoT sensing network.

An overview of the roles of the main actors involved in the two cases is illustrated in Figure 3-2 based on the triangle of science, society and policy around the concept of citizen science. On the side of policies, the Environmental Protection Administration (EPA), Taiwan and the provincial government of North Holland, the Netherlands are the competent authorities for the respective two cases. For the roles of science, in the case of AirBox, the Institute[8] possesses expertise particularly in data analysis and IoT techniques, while EPA is the scientific authority for air quality measurement. In the case of Dutch Skies, RIVM and GGD Amsterdam are the experts in air quality measurement at the national and regional level respectively. It should be noted that, however, because of RIVM's assignment to offer policy advice to the government based on the research results, they have a

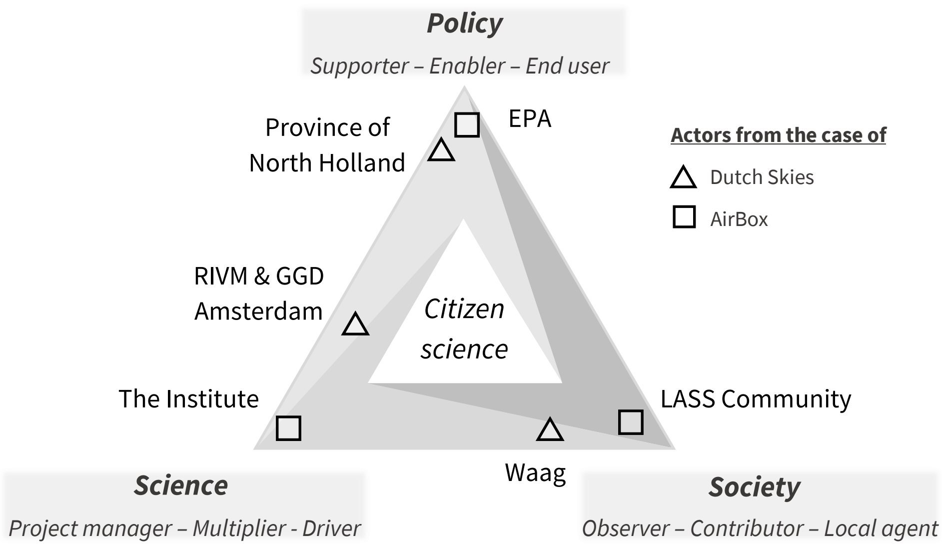

Figure 3-2. Main actors involved in the two cases. Created by the author; adapted from Hecker & Wicke (2019), pp. 8.

stronger tie with policymaking and are therefore relatively leaning towards the policy side in the diagram as compared to the role of the Institute in the case of AirBox. Finally, on the side of society, the case of AirBox was partly initiated and carried out by the online, "maker" community of LASS, who was one of the first to advocate the use of self-assembled, low-cost sensors for measuring particulate matter in ambient air. For the case of Dutch Skies, Waag, a non-governmental foundation in Amsterdam, is in charge of community management for the project — more specifically, they are the main contacts of the citizens or participants. We therefore select Waag as the actor representing the society or the citizens participating in the project in the case studies. More detailed descriptions on the main actors involved in the cases of AirBox and Dutch Skies are set forth in section 3.2.2.1 and 3.2.3.1 respectively.

3.2.2 *The Case of AirBox, Taiwan*

"AirBox" is a small-sized, low-cost real-time air quality micro-monitoring sensor (or simply referred to as "microsensor") that comes in various versions developed by different groups and projects (for instance see Figure 3-3). The initiatives can be dated back to the period of 2014–2016 when poor air quality — in particular, the emissions of particulate matters — was the heated debate in Taiwan. Around the same time, the "Maker" movement, led by the spread of low-cost, open-sourced hardware, was rapidly growing. The most well-known case is the "LASS AirBox" developed by the LASS (abbreviated from Location Aware Sensing System) Community. Building upon the prototypes developed by citizen groups as well as researchers and scientists, the Environmental Protection Administration (EPA), the competent authority for environmental protection in Taiwan, has adopted the idea of micro-sensing and put forward a program to build an air quality monitoring network.

Figure 3-3. Different versions of AirBox in Taiwan. Original source: "Several common air quality micro-sensors with open data infrastructure and data upload feature: upper left and lower left: LASS AirBox; top right: MAPS by Academia Sinica; lower right: Edimax AirBox." by Chen W.-Z. (2017), licensed under CC BY-NC-ND 3.0 TW.

One major part of the program is the "Smart Micro-sensing in Urban and Rural Areas" (hereafter referred to as "Smart U&R") project, whereby air quality microsensors will be installed by EPA and local Environmental Protection Bureaus (EPB) in areas that are vulnerable to air pollution, e.g. industrial zones and heavy-traffic roadways (EPA, 2018, p. 6). In addition, as a minor part of the program, the "Air Quality Micro-sensing on Campus" (hereafter referred to as "Campus AQ") project aims at incorporating air quality sensing with environmental and information education as well as public participation (*ibid.*). The Campus AQ project is implemented by a national research institute[8] (hereafter referred to as "the Institute") in collaboration with the Ministry of Education (MoE) to install microsensors in primary schools throughout the country. The construction of the air quality monitoring network also plays a part in the umbrella program of "Civil IoT Taiwan", commissioned by the Ministry of Science and Technology (MoST), to fuel the growth of the digital infrastructure towards an environmental Internet of Things (IoT) sensing network (MoST, EPA, MoT, MoIA, & MoEA, 2017). In the following sub-sections, we further elaborate on the main actors involved as well as the context of the case of AirBox.

3.2.2.1 Main Actors Involved

LASS Community. The LASS community is a non-profit online community founded in around 2015 by a former electronic engineer from the semiconductor industry who was interested in the Maker movement. The community consists of people with various kinds of background — e.g. engineers, researchers, environmental groups and even people from the public sector — yet all with a common concern for the quality of their living environment. The members collaborate mostly remotely via group discussions on social media site. LASS is currently also working with Water Resources Agency (WRA)[7] on developing a partnership for water level monitoring using microsensors.

The Institute[8]. The Institute is a national research institute subordinated to the central government of Taiwan. Its participation in the AirBox-related projects is mainly led by one of its researchers who joined the LASS community in around 2015. The Institute was involved in the AirBox project for Taipei Smart City Summit and Expo in 2016, which was a big success and thereby paved the way for the Campus AQ project, where the Institute implicitly played the bridging role between EPA and the LASS community.

Environmental Protection Administration (EPA). EPA is the governmental agency responsible for protecting and conserving the environment. They are the official competent authority for the control and regulation of air pollution, which are implemented according to the results from the official measurement stations. Following the development of micro-sensing technologies, EPA is aiming at building a multi-layered air quality monitoring system, as shown in Figure 3-5. The Smart U&R project and the Campus AQ project are a part of the efforts to construct the micro-monitoring network, i.e. the lower levels of the system.

[7] The Water Resource Agency (水利署) is the administrative agency responsible for water-related affairs. It is a subordinate agency of the Ministry of Economic Affairs, Taiwan.

[8] We avoid explicitly indicating the name of the national research institute in this study in order to prevent the interviewee from being easily identifiable. A national research institute in Taiwan could be, for instance, Academia Sinica, National Chung-Shan Institute of Science and Technology (NCSIST), Industrial Technology Research Institute (ITRI), etc.

3.2.2.2 *The Context*

The development of micro-monitoring of air quality in Taiwan is denoted by several projects that take place in a relatively simultaneous manner, as illustrated in Figure 3-4. For this reason, AirBox is often used as a collective term referring to small-sized, low-cost real-time air quality microsensors developed from different projects. It is worth noting that, in some cases, the term "AirBox" is used specifically to refer to the air quality microsensors deployed in primary and secondary schools in Taiwan from the Campus AQ project.

The very first micro-monitoring project in Taiwan was a research pilot study carried out by the Department of Geography, National Taiwan University (NTU) in 2012. Commissioned by EPA, the pilot experimented air quality monitoring using low-cost microsensors around the campus of NTU. However, it was until the period of 2014–2016 when poor air quality — in particular, the emissions of particulate matters — was a heated debate in Taiwan that the earliest bottom-up initiatives emerged. The most well-known cases are the PM2.5 micro-monitoring in Puli, Nantou and the case of LASS AirBox. Following a grassroots initiative emerged in Puli township, Nantou county in around 2014, and later resulted in an air quality micro-monitoring network in central Taiwan. Meanwhile, the LASS community was founded first within the Maker community, and later expended as an ecosystem consisting of engineers, environmental groups, researchers and scientists. By collaborating with the Institute, a major breakthrough was the debut of AirBox at the Taipei Smart

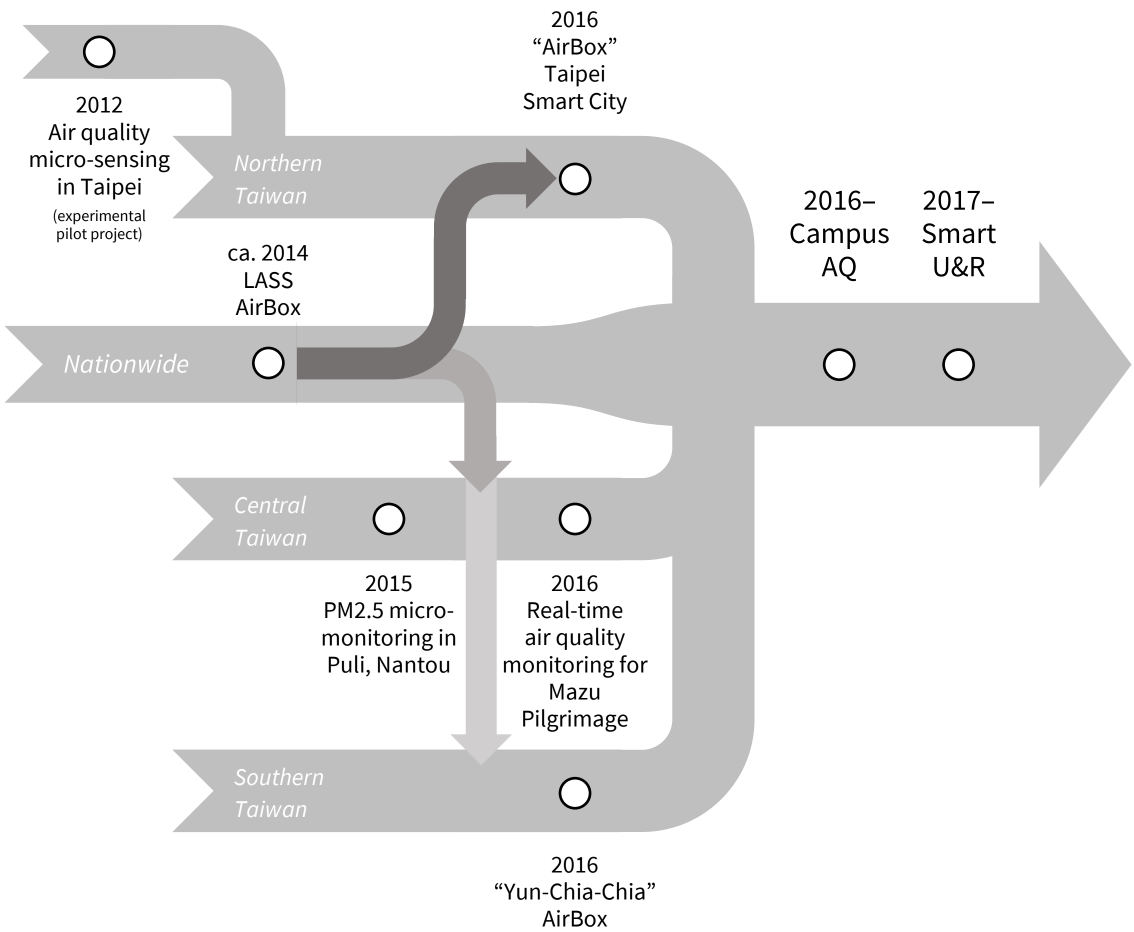

Figure 3-4. Context of air quality micro-monitoring initiatives in Taiwan. Created by the author.

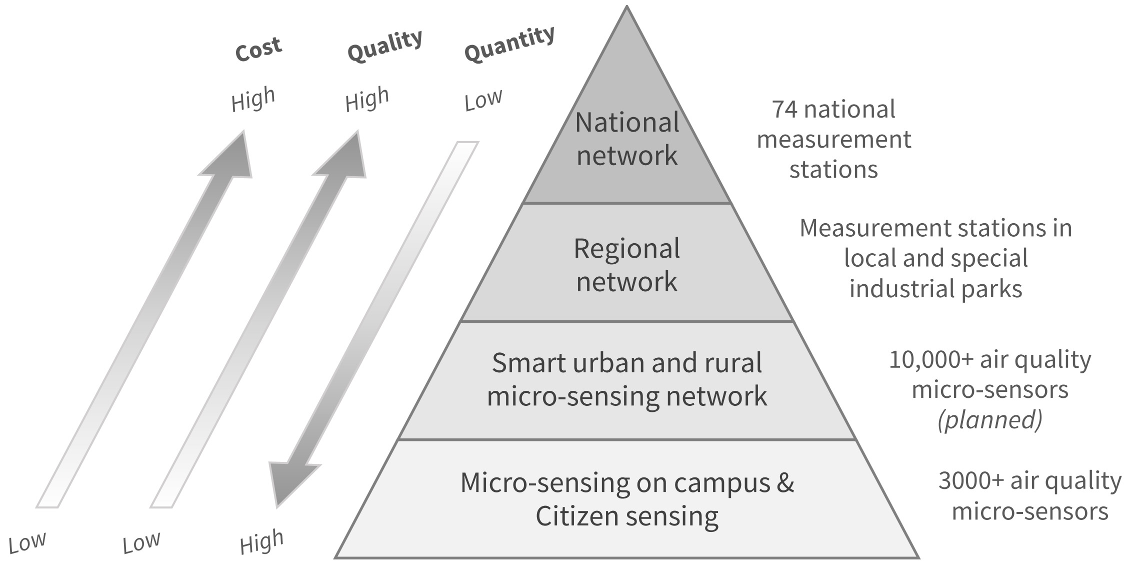

Figure 3-5. The multi-level air quality monitoring system in Taiwan. Translated and adapted from originals from EPA (2016), Fig. 1-3 in pp. 290 and EPA (2018), pp. 9.

City Summit and Expo in 2016, where around 300 microsensors building on LASS's prototype were installed in primary schools throughout the city.

Seeing the rapid growth and potential of environmental micro-sensing network, the central government has put forward the Civil IoT Taiwan program to promote the construction of digital infrastructure of IoT network. As part of the efforts, EPA is responsible for building a multi-layered air quality monitoring system, as illustrated in Figure 3-5. The successful experience with Taipei and other five cities then drives the Campus AQ project, where over 2,000 microsensors were further deployed in primary and secondary schools around the whole country (EPA, 2018). Meanwhile, EPA has started its own air quality microsensor deployment in the Smart U&R project, where microsensors were put specifically in areas that are vulnerable to air pollution, such as industrial zones and heavy-traffic roadways. Below the projects are further elaborated on each of its background and contents.

PM2.5 micro-sensing in Puli township, Nantou county. The initiative in Puli township, Nantou county can be traced back to the local anti-pollution campaigns by the residents in around mid-2014. A small town with no heavy industry and typically known for its surrounding beauty of nature, Puli was unexpectedly found to be one of the towns with the worst air quality countrywide, with an annual average PM2.5 value of 33.3µg/m^3 in 2013 — the highest record among all towns of the year (Tu, 2019). Accordingly, a group of five concerned mothers founded the Puli PM2.5 Air Pollution Reduction Self-Help Group, which soon attracted hundreds of members. The Self-Help Group advocated for a cleaner air in their neighborhood by organizing regular meetings, lectures on the air quality issue as well as street protests (Liu, 2019). The actions then inspired a researcher at the neighboring National Chi Nan University (NCNU), who later joined the Self-Help Group's efforts by developing low-cost PM2.5 microsensors and mobile app used to monitor the particulate matter. The efforts soon caught EPA's attention, and help paved the way for the pilot project of air quality micro-monitoring, namely the regional air quality micro-monitoring network in Central Taiwan[9]. Puli township was designated as the first trial zone of EPA's pilot project in collaboration with NCNU

[9] Project website: airq.org.tw.

(EPA, 2015, p. 5; Chen W.-H. , 2015). The network has also integrated the results from the experimental mobile-PM2.5 sensing project for the Mazu Pilgrimage, an annual folk event that takes place around Central Taiwan. The data collected from the microsensors were incorporated into the data portal of Civil IoT Taiwan afterwards. For more details about the case of PM2.5 micro-sensing in Puli, Nantou, see also Tu (2019) and Walther et al. (2017).

LASS AirBox. The LASS Community is an online community formed in the then rapidly rising "Maker" movement to promote the do-it-yourself culture with open-sourced hardware. The community was founded in around 2015 by a former electronic engineer from the semiconductor industry who was curious about the Maker movement and therefore decided to make something oneself. Shortly after its initiation, the LASS community got connected via social network with a researcher at the Institute, who has too been developing microsensors, and the two began working together in the domain of air quality measurement, which resulted in several prototypes of LASS AirBox (Xie, 2020). The microsensors developed by the LASS community are all open-sourced and can be easily set up by the people. Around a year after the community was founded, there were more than 1,000 LASS AirBox installed throughout Taiwan (Chang, 2017).

"AirBox" Taipei Smart City. Building upon the prototype developed by LASS and the Institute, "AirBox" was debuted at the Taipei Smart City Summit and Expo in 2016. The pilot project was commissioned by the Department of Information Technology of Taipei City Government in collaboration with the Institute and the LASS Community as well as private companies, i.e. Edimax Technology Co. Ltd. and Realtek Semiconductor Corp. (Taipei City Government, 2016). In the project, 300 AirBox sensors — manufactured by the companies — were installed in the primary schools in Taipei City, serving as an educational program of environmental and information education. The data collected from the sensors were linked and visualized on the data portal, mapping out the air quality around the city. The pilot turned out to be a success, and therefore the experience with Taipei City Government has served as a model for the Campus AQ project.

The Campus AQ project. The success of AirBox's debut at the Taipei Smart City Summit and Expo has attracted attention of the other major cities in Taiwan, and therefore led to the initiation of the Campus AQ project. In the project, AirBox sensors were further installed in primary and secondary schools in other cities and counties — in cooperation with the local governments — following the model established with Taipei City. The project, as a part of the Civil IoT Taiwan program as well as a minor part of the EPA's micro-sensing network program, was implemented by the Institute in collaboration with the Ministry of Education and Edimax. The data collected from the microsensors were also incorporated into the data portal of Civil IoT Taiwan.

The Smart U&R project. The Smart U&R project was initiated by EPA also as a part of the Civil IoT Taiwan program. In the project, air quality microsensors were installed by EPA and local Environmental Protection Bureaus (EPB) in areas that are vulnerable to air pollution, more specifically, industrial zones and heavy-traffic roadways (EPA, 2018, p. 6). With the project, EPA aims to deploy over 10,000 microsensors throughout the country (Chang, 2017). The microsensors installed in this project were specifically produced with regulated inspections and maintained by the EPBs under standard processes to ensure that the measurement data are with good quality. The data collected from the microsensors were mainly published on EPA's website of air quality monitoring IoT network (see Figure 3-6) and were also incorporated into the data portal of Civil IoT Taiwan.

Figure 3-6. The Smart U&R sensor data visualized on the Web of Air, EPA. Screenshot from wot.epa.gov.tw (July 2020).

3.2.2.3 Summary of the Case

AirBox is a small-sized, low-cost real-time microsensors that comes in various versions developed by different groups and projects. It is therefore important to clarify the scope of the case to ensure that the actors and activities of interest were included in the analysis. In this study, we include the three major, ongoing projects of the development of air quality micro-monitoring in Taiwan — LASS AirBox, the Campus AQ project and the Smart U&R project — into the scope of the case of AirBox, as illustrated in Figure 3-7. The main actors involved, as described in section 3.2.2.1, are LASS community (society), the Institute (science) and EPA (policy). Note that while LASS AirBox is a case of bottom-up citizen science project, the projects of Campus AQ and Smart U&R are both initiated by the scientific authorities as a part of EPA's ambition to construct an air quality micro-monitoring network.

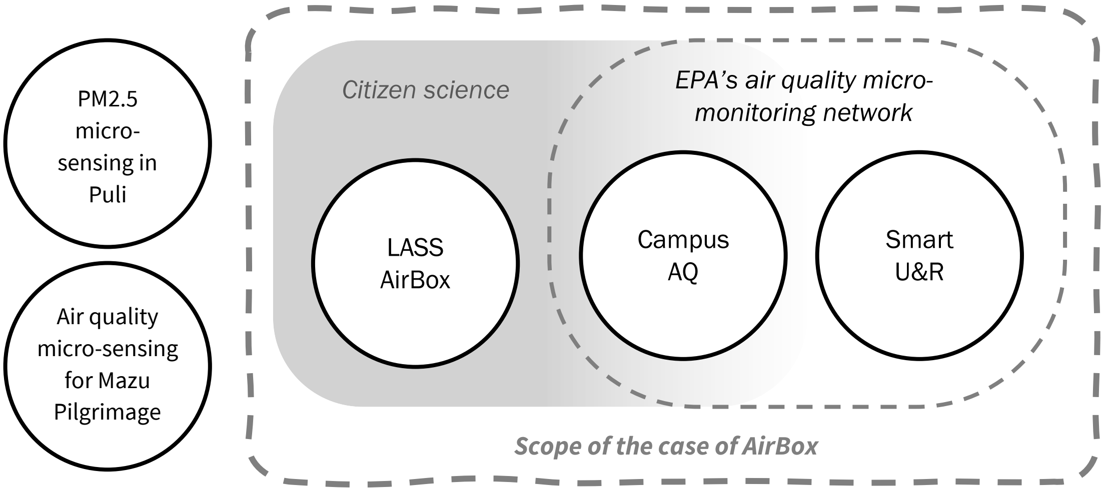

Figure 3-7. The scope of the case of AirBox, where the three major projects are included.

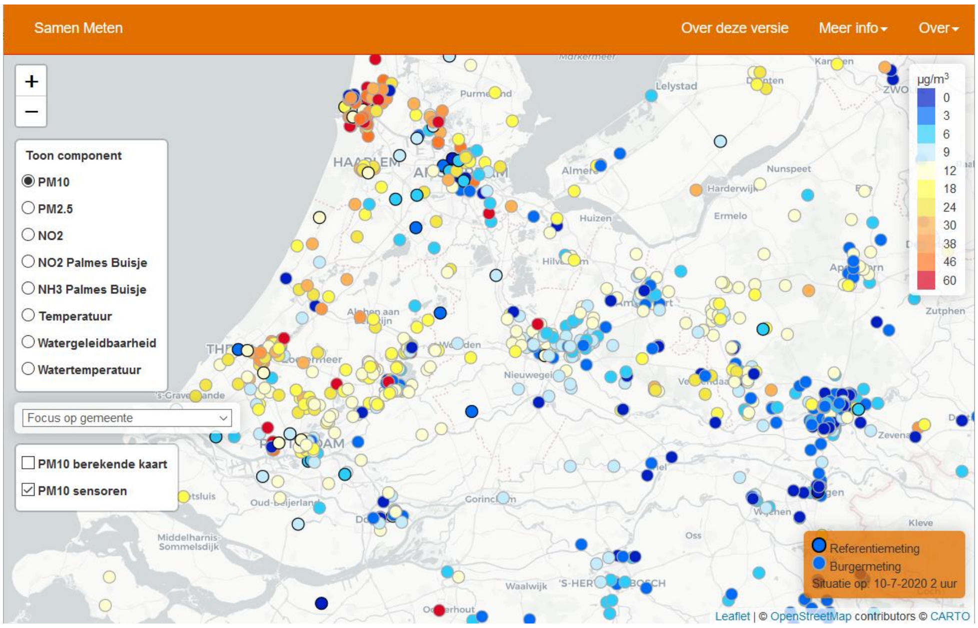

Figure 3-8. Map of sensors from RIVM's "Measuring Together" website. Screenshot from samenmeten.rivm.nl (July 2020).

3.2.3 *The Case of Dutch Skies, The Netherlands*

The Hollandse Luchten project[10] ("Dutch Skies") is a citizen science project that involves residents in the province of North Holland to measure the air quality in their living environment using low-cost, self-assembled sensors. The project is commissioned by the provincial government, and together with Waag, RIVM and GGD Amsterdam are the four major parties or actors involved in the case. Since 2019, three pilots were carried out in the IJmond region, Zaandam and Buiksloterham (Waag, n.d.). For each pilot, meetups were held where citizens meet, discuss and assemble the sensors together with the aforementioned parties. Citizens are able to see the measurement not only on their sensors but also via the data portal (see Figure 3-8). In this section, we further introduce the Dutch Skies project by elaborating on the main actors involved and the background and context of the case.

3.2.3.1 *Main Actors Involved*

The Dutch Skies project is commissioned by the provincial government of the North Holland, who later asked various stakeholder groups to join and participate in the project. Together with Waag, RIVM and GGD Amsterdam are the main actors involved in the case. Below the actors are briefly introduced.

Waag. Waag (or previously also known as Waag Society) is a non-governmental foundation based in Amsterdam, with its work focuses mainly on using the emerging technologies as instruments of social change. Citizen science is hence one of the topics of their focus. Waag has been running the Smart Citizen Lab program (Waag, n.d.), where they explore tools and applications that help make sense of the living environment and work with citizens and designers to tackle environmental issues. They were therefore asked to join the Dutch Skies project for their expertise in communications and community management. In the project, Waag organized the meetings with citizens in a bottom-up fashion: they provide technical and logistical supports such as help organizing meetups, where

[10] The project website: hollandseluchten.waag.org.

residents who are interested in air quality issues gather to discuss, define their research questions, assemble sensors, and measure air quality themselves. They were also involved in the development of technology, which was built on earlier experiments and pilots, such as the Making Sense project and Smart Citizen Kit (Veenkamp et al., 2020).

RIVM & GGD Amsterdam. Dutch National Institute of Public Health and the Environment (RIVM) and Regional Health Service of Amsterdam (GGD Amsterdam) are the experts of air quality measurement in the Dutch Skies project from the national and regional level, respectively. They were therefore asked to join the Dutch Skies project, where they served as the authority of knowledge. The Dutch Skies project is also under the umbrella program of Samen Meten ("Measuring Together") initiated by RIVM, with which they experiment the innovative ways of measuring the living environment. It should be noted that, in this study, the term RIVM is used to specifically refer to an innovation group subordinated to the Centre for Environmental Quality in RIVM, who researches on new ways of doing air quality monitoring.

Province of North Holland. The province of North Holland is the initiator as well as the sponsor of the Dutch Skies project. The initiative of Dutch Skies can be dated back to around 2016, when the province of North Holland first had discussions about having a citizen sensing program, which were later put into the farther proposal of the project in 2017. As the proposal was accepted by the provincial executive (*Gedeputeerde Staten, GS*), the province started the preparations, such as finding partners to participate in the project. The measurement with citizens started in 2018, and its first phase of the pilot project is expected to be wrapped up in summer 2020.

3.2.3.2 The Context

The development of micro-monitoring of air quality in the Netherlands is a process consisting of several major citizen sensing projects in a relatively successive or linear manner, as illustrated in Figure 3-9, which embodies the path from "ad hoc citizen science projects towards national measurement network" (Volten et al., 2018, p. 339) for environmental monitoring in the Netherlands. One of the first projects is the iSPEX project. Initiated in 2012, in the iSPEX project citizens measured the properties of particulate matter (aerosols) with iPhones supplemented with a small add-on for the camera (Snik et al., 2014). Following several citizen science initiatives that took place later on, the significance of the citizen science movement was gradually recognized by RIVM, who later launched the Innovation Program for Environmental Monitoring (IPEM), aiming at developing an innovative national air quality measurement network (LML) (Volten et al., 2018). The ultimate goal is to have the national monitoring network evolve towards a hybrid, flexible system, using high-quality reference base supplemented with a vast amount of data from different types of sensors

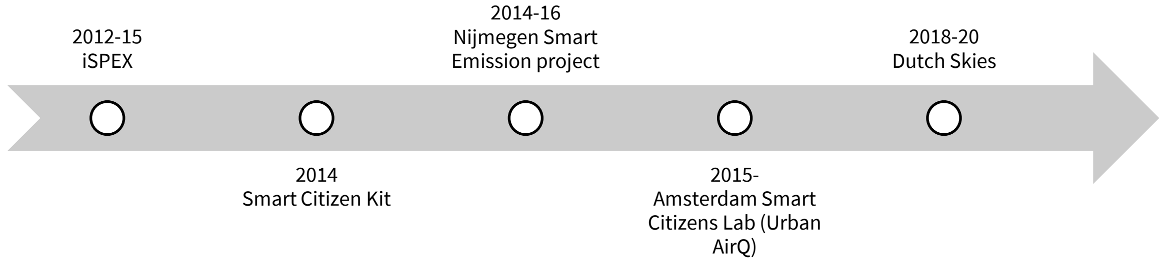

Figure 3-9. Context of air quality micro-monitoring initiatives in the Netherlands.

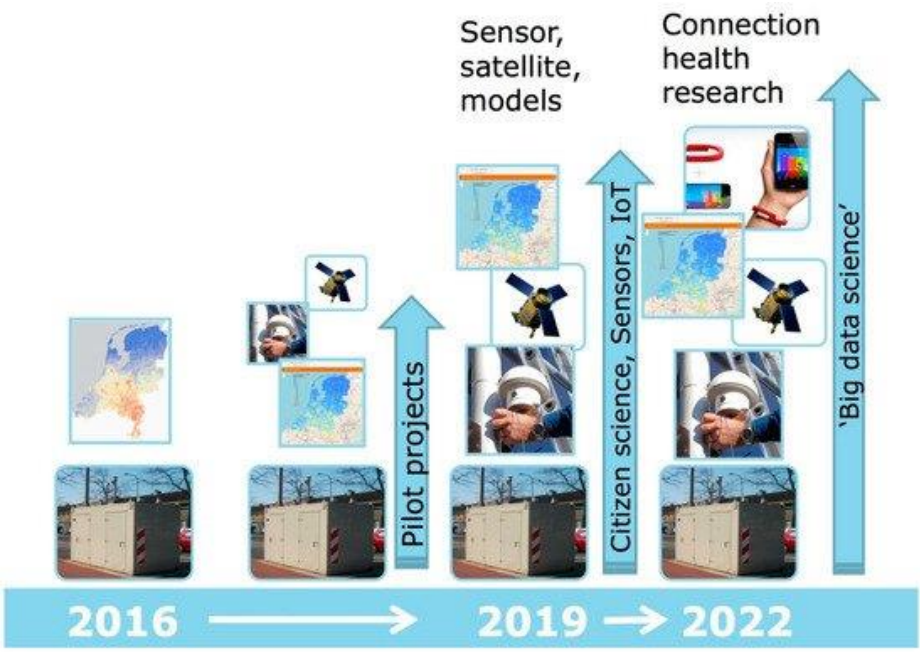

Figure 3-10. The roadmap of the Dutch Innovation Program for Environmental Monitoring (IPEM). Original source: Wesseling et al. (2019), p. 3, licensed under CC-BY 4.0.

(Volten et al., 2018; Wesseling, de Ruiter, et al., 2019). For more details, see Volten et al. (2018) and Wesseling et al. (2019).

Figure 3-10 depicts the roadmap of the Innovation Program for Environmental Monitoring (IPEM) and its associated milestones. The development of an innovative national monitoring network is anticipated to be done through integrating citizen science as well as citizen-generated data. More specifically, the program consists of four building blocks: the development of a knowledge portal, the innovation of new calibration approaches for low-cost sensors, the creation of a data portal with visualizations of the sensed data, and modelling and assimilation techniques for incorporating the sensor data of higher uncertainty into official models (Volten et al., 2018; Wesseling, de Ruiter, et al., 2019). Below we briefly introduce the relevant citizen science initiatives on air quality monitoring in the Netherlands to set out the contexts for the Dutch Skies project.

The iSPEX project[11]. In the iSPEX project the properties of particulate matter (aerosols) were measured with iPhones supplemented with a small add-on for the camera. The project was initiated in 2012, primarily by the University of Leiden alongside RIVM and many scientific as well as societal partners. It is one of the earliest projects where RIVM experienced the new way of measuring air quality using the citizen science approach. Through the use of state-of-the-art technology together with the concept of citizen science, the project was carried out on an unprecedented scale for environmental monitoring — "with more than 3,000 participants and over 10,000 contributed measurements" (Volten et al., 2018, p. 342) — and whereby "played a decisive role in changing RIVM's views on the way that citizen science can contribute to environmental science" (ibid.).

Smart Citizens Kit Amsterdam[12]. The project of Smart Citizens Kit in Amsterdam is a three-months pilot project carried out by Waag, Amsterdam Smart City and the Amsterdam Economic Board,

[11] Project website: http://ispex.nl/
[12] Project website: https://waag.org/en/project/smart-citizen-kit/

using a sensor kit developed at Fab Lab Barcelona (Waag Society Amsterdam, 2014). During the project, a temporary air quality monitoring network was created in the city of Amsterdam on an experimental basis. The project succeeded in attracting and involving a fairly large amount of citizens, although the quality of sensed data was an issue in the case (de Jonge, 2017; Waag Society Amsterdam, 2014). The project paved the way for the succeeding Amsterdam Smart Citizens Lab program.

Amsterdam Smart Citizens Lab[13]. The program of Amsterdam Smart Citizens Lab was initiated by Waag — in collaboration with Amsterdam Smart City, TNO, RIVM among other minor partners — in 2015 to further experiment with the concept of citizen science and sensing with the use of self-assembled, low-cost sensors. During the four-year program, RIVM experts initially intended to purely be observers, but "soon became motivators and trusted sources of information" (Volten et al., 2018, p. 344). As observed from the project, the support from RIVM experts was appreciated and welcomed provided that the citizens were taken seriously by the experts. It was also learned from the project that timing is crucial — more specifically, sufficient amount of information is needed for citizens at early stages, although too much information may limit the space of creation of the citizens (Volten et al., 2018).

Nijmegen Smart Emission project[14]. The Smart Emission project in the city of Nijmegen was a pilot project initiated by Radbound University and the municipality of Nijmegen in 2016. RIVM also participated in the project as a partner. The project aims to test the concept of citizen sensing network, which incorporates bottom-up planning processes and includes a "feedback loop of information" from the participants to the sensors. During the project, the plans were continuously adapted to various needs from the stakeholders and participants as well as limitations on the hardware. The key takeaway for RIVM from this project is to stay flexible and transparent throughout citizen science projects (Volten et al., 2018).

It is worth noting that, in the Netherlands, governmental planning and policies for air quality related issues are formulated *only* based on calculations and simulations of air quality models. In other words, from a legal point of view, "only the calculations count" (de Jonge, 2017), and the measurements taken by RIVM and the GGDs from their official measurement stations are used as input and control for the models (ibid.).

3.2.3.3 Summary of the Case

The development of air quality monitoring in the Netherlands is a process consisting of several major citizen sensing projects in a relatively successive or linear manner, which embodies the path from "ad hoc citizen science projects towards national measurement network" (Volten et al., 2018, p. 339) for environmental monitoring in the Netherlands. The significance of the citizen science movement was gradually recognized by RIVM following the development of several citizen science initiatives. The Innovation Program for Environmental Monitoring (IPEM) was later launched by RIVM with the ultimate goal of constructing a national monitoring network composing of a hybrid, flexible system — namely, using high-quality reference base supplemented with a vast amount of data from different types of sensors. The Dutch Skies project is commissioned by the provincial government of the North Holland, who later asked various stakeholder groups to join and participate in the project. As introduced in section 3.2.3.1, the province of North Holland (policy),

[13] Project website: waag.org/en/project/smart-citizens-lab
[14] Project website: smartemission.ruhosting.nl

together with Waag (society), RIVM and GGD Amsterdam (science) are the main actors involved in the case.

3.3 Summary

In this chapter, the case study research design was presented. Case study research is a suitable research method for answering the second and the third research questions for several reasons. First, the research questions are "how" questions, which are of a more explanatory form of research questions and often lead to the use of research methods such as experiments, history research or case study. Second, citizen science is a rising field or a contemporary phenomenon over which the researchers have very limited or no control. Experiments and history research are therefore inadvisable for studying such events: the former requires manipulations of behaviors, and the latter deals with the "dead" past. Third, the boundaries between the phenomenon of citizen science and its context are not clearly evident. Case study is therefore an appropriate strategy for studying the behaviors of citizen science events.

A holistic, multiple-case design is adopted for this study. The case study protocol was developed following Yin (2014) and the case selection criteria were specified, whereby two cases are selected: the case of Dutch Skies in the Netherlands and the case of AirBox in Taiwan. The contexts and main actors involved for two selected cases were introduced in section 3.2.

In the next chapters, the selected cases are then investigated and discussed using the proposed conceptual model as a guideline in chapter 4, based on which the findings are then translated into a comparative case study analysis in chapter 5.

4

Case Study Findings

In this chapter, an investigation into the two cases described previously in chapter 3 is conducted based on the conceptual model developed from chapter 2. We first examine the enabling conditions and factors that drive the citizen science initiatives in section 4.1, and then discuss the setups and interactions during the development of the case in section 4.2. We investigate how standard settings exercise the boundary-bridging or a boundary-policing function for the initiatives and how this influence, together with the factors from the previous stages, shape the outcomes in section 4.3. The project outcomes and its sustainability are then examined respectively in section 4.4 and section 4.5. A summary of the chapter is presented in section 4.6. The findings from the case studies further serves as the base for the case comparison and analysis in chapter 5.

4.1 Enablers and Drivers

The enablers and drivers of citizen science initiatives describe how such cases were initiated and enabled. We examine the enabling conditions and driving factors for the two cases based on the dimensions of the conceptual model derived in section 2.3, namely the *technological development* and the *broadening attention drawn to the identified issue*. Although in both cases the two aforementioned factors present, the democratization of power (Berti Suman & van Geenhuizen, 2020) that leads to a shift to participatory problem-solving is only observed in the case of Dutch Skies, whereas in the case of AirBox the institutional response is a top-down solution without involving the citizens. The disparities may be explained by — as highlighted by the interviewees — the *institutional settings* and *organizational culture* in the cases, which are therefore added as two additional enablers and driving factors.

In this section, we elaborate on the technological development in section 4.1.1; the broadening of attention drawn to the identified issue in section 4.1.2; the institutional settings in section 4.1.3; and organizational culture in section 4.1.4 for the two cases.

4.1.1 Technological Development

Technological development — more specifically, the development of low-cost sensors and the wave of Internet of Things (IoT) — is a powerful driver for both projects. The rapid development of sensing technologies has served as a strong push towards the realization of a smart sensing network of the living environment, and has further led to RIVM's initiative of the "Measuring Together" program in the Dutch case (Wesseling, Blokhuis, et al., 2019) and the establishment of the "Civil IoT Taiwan" program in the Taiwanese case (EPA, 2018) respectively. The development has also drove the democratization of sensing, as evidenced by everyone can easily buy cheap sensors and conduct measurements themselves. As the researcher at RIVM explained,

> *And for us as an official institute, the question is: okay, do we want to be in this development, and do this together with the people? Or do we want to ignore it, and then it will not stop but it will go on without us, and we will have no control over it and have no influence on it.*
>
> *— Researcher at RIVM*

It is worth noting that the "Civil IoT Taiwan" program, one of the programs under the construction of digital infrastructure in the Forward-Looking Program, was initiated by the Ministry of Science and Technology, Taiwan[15]. Therefore, in contrast to the Measuring Together program, Civil IoT Taiwan is almost fully technology-led by nature. As a result, EPA's Smart U&R project — as a child project of the Civil IoT Taiwan program — is highly driven by the technological development, with one of its main goals being to drive the development of the IoT industry (MoST, EPA, MoT, MoIA, & MoEA, 2017, p. 4). As an officer at EPA explained,

> *When we were drafting the [Smart U&R] project... because the Forward-Looking Program is a technology-led program, it is about some new development ... though there were non-governmental initiatives of low-cost micro-sensing like LASS and AirBox, we thought ... this [i.e. micro-sensing] could be an application in the industry.*
>
> *— Officer at Dept EM&IM, EPA (translated)* *[original quote, B.2.a]*

The development of technology also plays an important role in the initiative of LASS as well as the Campus AQ project. As pointed out by the founding member of LASS, it was first decided for the community to "measure with microsensors" before diving into the domain of air quality measurement and thereby developing LASS AirBox. Similarly, the researcher at the Institute was at the beginning motivated by the trend of IoT development in addition to the concept of participatory sensing. It is interesting to note that both the founding member of LASS and the researcher of the Institute are of a background in either information, electrical or mechanical engineering, in contrast to the case of Dutch Skies where the scientists and researchers involved are mostly experts in air quality measurements and with a background in physics-related fields.

4.1.2 Broadening of Attention Drawn to the Identified Issue

As Berti Suman and van Geenhuizen (2020) argue, citizen science or citizen sensing potentially drives a shift towards a participatory problem-solving or a more democratic decision-making process, which entails the democratization of power. The broadening of attention drawn to the problematic situation or the identified issue, which is likely induced by a perceived "malfunctioning and dogmatic attitude of the institutional response to the risk problem" or "inconsistencies in the institutional approach to the problem" by the citizens (Berti Suman & van Geenhuizen, 2020, p. 560), serves as a strong push for this democratization.

The broadening of attention drawn to the air quality issue is observed in both cases. In the case of Dutch Skies, according to the officer at the province of North Holland, one of the major changes

[15] For more details, see Appendix 0 for descriptions on the relevant projects for the case of AirBox.

which drive the initiative is that “people are more aware of the quality of their living environment.” This is partly led by the democratization of information and thus knowledge resulted from the development of mobile phones, as per the researcher from RIVM, “everyone can google information.” For the case of AirBox, the concerns of the public on the air quality issue is obvious as the issue was a heated debate at the time (Lin & Chang, 2020; Chen W.-Z. , 2015). This can also be seen in one of the motivations of EPA’s Smart U&Q project, namely the need of information to respond to citizens’ demand (MoST, EPA, MoT, MoIA, & MoEA, 2017, p. 4).

The distrust in authorities — resulted from the perceived “malfunctioning and dogmatic attitude of the institutional response to the risk problem” and/or “inconsistencies in the institutional approach to the problem” by the citizens (Berti Suman & van Geenhuizen, 2020, p. 560) — is clearly present in both cases. As noted by the officer at the province of North Holland, the citizens complain about the province particularly *“because we are the ones giving the permits [for emissions], they [i.e. citizens] think that we should do more.”* Similarly, in the case of AirBox, EPA has experienced a lot of conflicts with the citizens. It should be noted, however, that in many citizen science initiatives the distrust is observed not only of citizens in the authorities. Many experts or officers are also suspicious of the idea of citizen science for various reasons: citizens might be installing sensors in places that are not in accordance to the requirements, citizens might diddle the sensor data, or merely because of a perceived distrust from the citizens. As indicated by the researcher at RIVM on the challenges faced in the development of the Measuring Together program,

> “ *This was really a struggle in the beginning ... I got a lot of opposition from my nearest colleagues ... being so opposed to this whole citizen science [project]... also from the idea — and this is something that a lot of experts have — that citizens doing measurements, are doing this measurement to criticize them, because they [i.e. citizens] don't trust them [i.e. experts].*
>
> *— Researcher at RIVM*

It is interesting to note that the broadening attention and pressure exerted on the government does not always serve as a positive driving force towards an institutional response to the issue. Rather, the impact of the driving factors is the result of the mixed interactions among the factors. As observed by the researcher at the Institute from the experience of working with the city of Taichung in Campus AQ project,

> “ *The city of Taichung is less friendly to us at first ... We were actually quite afraid of travelling to Taichung at that time because it happened to be around the local elections ... Then we decided to install the sensors after the election ends, to distance ourselves from that ... [because] air pollution was the heated topic of debate in that election ... Everyone was talking about air quality, and some blamed AirBox for being a drag on the government because the information was disclosed ... So it was more difficult to communicate and work with them at that time [i.e. before the election].*
>
> *— Researcher at the Institute, Taiwan (translated)* *[original quote, B.2.b]*

Although in both cases the push for democratization of power (Berti Suman & van Geenhuizen, 2020) presents, it only leads to the shift to a participatory problem-solving in the case of Dutch Skies, whereas in the case of AirBox the institutional response is a top-down solution without involving public participation. As suggested by the interviewees, we seek to explain the differences from the influence of the two additions of drivers, i.e. institutional settings and organizational culture, in the following sub-sections of 4.1.3 and 4.1.4 respectively.

4.1.3 Institutional Settings

The influence of institutional settings on driving the citizen science initiative is observed particularly in the case of Dutch Skies. As highlighted by the officer of the province of North Holland, one of the major changes that drive the initiative is *"how the province sees its role in the issue"*, which is to a large extent driven by the introduction of the new *Environmental and Planning Act* (*Omgevingswet*). The new national law, which was initially expected to take effect in 2018, integrates lots of different separate pieces of legislation on the environment and planning with an aim to extend the deliberation space to a more decentralized governance (Rijksoverheid, VNG, IPO & UvW). The new law allows more room for regional or area-specific customization of planning as well as specifies public participation as a key element in the policymaking process, and therefore became a strong boost for the province to start experimenting with more citizen engagement.

Traditionally, as the officer explained, the province has a very strict interpretation of its role. From their perspective, air quality management in the Dutch system is mainly up to the national government, and together with the municipalities they take the measures. With the introduction of the new law, as the province kept receiving increasing demands on taking actions for the air quality issue, they have started to think that *"we should also make policies for things that are perhaps not our direct responsibility, but that we still do and feel responsible for."* The province thus was hoping to start a monitoring program to have a more detailed view of the air quality in some parts of North Holland. For the province, it is important to first collect more data and information so that they *"can make policies based on those data."*

The introduction of the new law has also led to a discussion on whether the province should move forward to a more participatory strategy, for which the province decided to experiment with the idea of citizen science and put forward the proposal of the Dutch Skies project. The decision was heavily influenced by the introduction of the new *Environmental and Planning Act* and the fact that "*everybody knew it [i.e. the new law] was coming*". As pointed out by the officer at the province of North Holland,

> *This kind of proposal has been there before, but then the other governors are very skeptical .... And in this day, they knew and that killed that discussion because we know we have to do something with it. And for that reason, they accepted it.*
>
> *— Officer at Province of North Holland*

In the case of AirBox, the relevant institutional settings are mostly aiming at "fueling in the growth of IoT industry", as illustrated by the construction of digital infrastructure in the Forward-Looking Program. The Campus AQ project and the Smart U&R project are both initiated within the umbrella program, as discussed previously in section 4.1.1.

4.1.4 Organizational Culture

In both cases organizational culture — more specifically, the (shared) beliefs and values established by the head of government — was found to be crucial to the citizen science initiatives. The influence of organizational culture on the results of the initiatives is mainly evidenced by the example of the provincial government in the Dutch Skies project as well as EPA in the case of AirBox, but can also be exemplified by the varying experiences of working with different local governments experienced by both RIVM and the Institute respectively in the two cases.

The Dutch Skies project is launched by the provincial government. Per the officer at the province of North Holland, a key person for pushing forward this initiative is one of the governors or the representatives of provincial executive (*Gedeputeerde Staten, GS*), who was in charge of environmental policy for the province. The governor was a very *"activist person"*, very open to the idea of citizen science, and thereby provided a strong support for the proposal of Dutch Skies. As the officer stated, despite that the institutional settings were ready, *"if you don't have an activist governor who really wants to do something, then you just wait."*

The influence of organizational culture can also be seen from RIVM's varying experiences with different municipalities on measuring with citizens. One most significant example was a pilot citizen science project in the municipalities around Rotterdam, where the citizens measure nitrogen dioxide together with RIVM using diffusion tubes. As narrated by the researcher at RIVM,

> *One city participates, the other doesn't, for the same reason. One city participates because 'maybe we can find a source of pollution that we didn't know about ... and we can take measures.' And the other city, for the same reason not participating ... 'yeah, we are not going to participate because maybe we find some sources of pollution that we didn't know about.'*
>
> — *Researcher at RIVM*

Another interesting case is the citizen science project of "Arnhems Peil"[16] in the city of Arnhem, which was initiated by the municipality in parallel with another local, grassroots citizen science initiative called "Arnhem-air"[17] that took place earlier. As the researcher at RIVM described, *"So there were 200 people building their own sensors, and then the city of Arnhem came, 'okay, hmm... these people are very activist, we want other people than activists to do the measurement, so we are starting to build another citizen science here with sensors next to the already existing sensors.'"* How government responds to the citizens' demand can be very different from one to another as demonstrated by the cases in North Holland, Arnhem, and municipalities around Rotterdam.

Similar experiences are also observed by the Institute in the Taipei Smart City air micro-monitoring project and the Campus AQ project for the case of AirBox. It was noted by the researcher at the Institute that whether importance is placed on by the head of government *"really plays a very big role in whether our project would succeed or fail."* This is exemplified by their experiences of installing sensors with different local governments in Taiwan, for which their main contacts are the Bureau of Education (BoE) and in some cases the Bureau of Environmental Protection (EPB) in the municipal government. Since the Campus AQ project is commissioned by the Ministry of Education, the BoEs are obligated to cooperate with the Institute in implementing the project, whereas the EPBs are the local competent agencies for air quality measurement and therefore are in general more critical of the project. Although the project was in the end implemented in all cities and counties around

[16] The project website: arnhemspeil.nl/acties/luchtdata-project.html.

[17] The project website: arnhem-air.nl.

Taiwan, the process of working with different local governments is much more smoothly — specifically, less questions were faced by and more resources are provided for the Institute — when the department heads are more open to new things and changes as well as more willing to confront with pressure exerted from local citizens. The most significant example given was the case of air micro-monitoring in the Taipei Smart City summit, the pilot project which later inspires the Campus AQ project. As suggested by the researcher at the Institute, the pilot project was made possible primarily due to the fact that Taipei City Government *"allows possible failures"* instead of the "embracement of the idea" of participatory sensing.

4.2 Development of the Case

The development within the case is examined from two dimensions, namely the involvement of stakeholders and the quality of citizen-generated data, as defined in the conceptual model shown in Figure 2-1 and Table 2-5. As informed by the cases, two additional dimensions are added to the analysis. The dimension of *communications between citizens and the government* is added to capture the dynamics among the actors involved towards a mutual understanding of the problem — more specifically, how the use of citizen-generated data for "communicating public awareness to regulators" is done in practice and how the limitations of sensors or other difficulties are communicated to the public — as in alignment with the concept of "just good enough data" by Gabrys & Pritchard (2018). Another additional dimension on the *openness of data and process* highlights the transparency in facilitating the trust building process in citizen science initiatives.

In this section, we elaborate on the involvement of stakeholders in section 4.2.1; the quality of citizen-generated data in section 4.2.2; the communications between citizens and the government in section 4.2.3; and the openness of the cases in terms of data and process in section 4.2.4.

4.2.1 Involvement of Stakeholders

The involvement of stakeholders in the "institutionalization" (Carton & Ache, 2017) of the initiative, or the solution within the institutional framework as converged from the bottom-up citizen science initiatives, describes the engagement of stakeholders and the relationships among them. This aspect is notable in the case of Dutch Skies, where a wide range of stakeholders were invited by the province of North Holland to join the project either as a major partner in the development of the project (including Waag, RIVM and GGD Amsterdam) or a minor participating role (such as Tata Steel). By having diverse stakeholders on the table and in the discussion facilitates in building a "trusted dialogue" between the concerned citizens and the government, which would not have been the case *"if it were purely from the government"*, in particular considering the some residents' distrust in the province (see section 4.1.2). The officer at the province of North Holland highlighted the involvement of RIVM and GGD Amsterdam for their role as the scientific authorities in air quality measurement,

> "
> *...with Waag Society, RIVM, GGD... I think that helps, too. Because RIVM and GGD are the experts in this field in the Netherlands. People perceive them as objective.*
>
> *— Officer at Province of North Holland*

It is noteworthy that the objectivity perceived by the citizens is not solely due to the attendance of the experts in the project meetups, but more as a result of the experts explaining about technology and how measuring air quality works scientifically so that *"people control the technology ... [and] people* *understand it."* As pointed out by the officer at the province of North Holland, it was the *"information and knowledge"* gained by the citizens from the experts that *"changed the discussion"*. The involvement of stakeholders was also facilitated by the openness of the process — more specifically, the receptiveness to stakeholders' opinions and ideas, for which we further discuss later in section 4.2.4.

In contrast to the case of Dutch Skies, the "solutions" within the institutional framework as converged from the LASS AirBox initiative, namely the Campus AQ project and the Smart U&R project, did not involve LASS community or citizens in the institutional response. Although in a broader sense, the Campus AQ project can be viewed as a form of institutionalization of the citizen initiative with the participation of citizens — considering the dual role[18] of the researcher at the Institute as both an institutional actor and a participant in the LASS community, the project itself is mainly targeting at the participation of students in primary and secondary schools as an *object* of environmental and Maker education. From this perspective, the two projects are both implemented in collaboration within institutional players such as EPA, the Institute, the Ministry of Education and local governments. Note that the lack in involvement of stakeholders in the two projects may also be partly explained by the difficulties in *identifying who the stakeholders are* — as part of the difficulties in identifying the specific source(s) of air pollution (Tu, 2019), attributed to the complexity of air quality governance in Taiwan. As Tu (2019) suggests, the complexity is characterized by "Taiwan's dense industrial agglomeration patterns, rapid urbanization, and mismanaged mixed land use" (p. 252) resulted from the socio-political contexts.

4.2.2 Quality of Citizen-generated Data

The quality of citizen-generated data is an important aspect frequently discussed in literature on citizen science. As elaborated on in section 2.2.2, the quality of citizen-generated data is typically assessed with respect to the regulatory or scientific standards in the context of "instrumentally characterizing citizen science" whereby citizen-generated data is used as a source of evidence in the development or implementation of regulations or inputs for modeling. In contrast to the typical view, we adopt the concept of "just good enough data" (Gabrys et al., 2016) where citizen-generated data are considered "good enough" when they are "useful" for achieving the ends related to the citizen science initiatives — such as communicating public awareness to regulators — beyond the regular use in regulations, compliance and modelling. In this section, we discuss the quality of citizen-generated data of the two cases in this view. In this section, we first briefly set forth the controversial nature of data quality in air micro-monitoring. We then introduce the pattern of data quality improvement from a view of the "positive feedback loop" driven by sensor development as informed from the case studies. Finally, we elaborated on the privacy concerns related to the cases.

The controversial nature of data quality in air micro-monitoring. In the case of air quality measurement using microsensors, the quality of data is influenced by several aspects, including the quality of the sensor itself, the conditions under which the sensors work, and the calibration methods applied to the *raw data*, or the data directly produced from the sensors (Gerboles et al., 2017; Karagulian et al., 2019). An illustration on the factors which potentially influence the quality of sensor data is shown in Figure 4-1.

It is worth noting that, at the current stage of sensor development, the calibration for sensor-outputted raw data is a key element in ensuring data quality because it helps reduce or potentially

[18] For more descriptions for the "dual role" of the researcher at the Institute, see section 3.2.2.1 where the main actors involved in the case of AirBox are introduced.

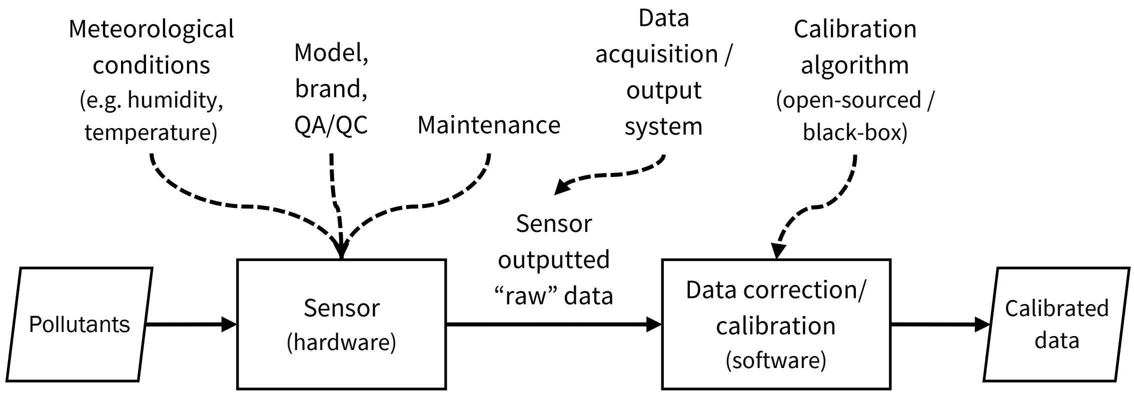

Figure 4-1. The factors which potentially influence the quality of data. Note that the sensor indicated in the diagram is referring to the sole sensor detector produced by Original Equipment Manufacturer (OEM)[20]. Created by the author.

bridge the gap between non-standardized and standardized (or referenced) air quality data — given that the measurements done by the sensors and by the official measurement stations are *essentially* different in terms of their working principles[19] (EPA, 2019). In certain well-defined situations, the uncertainty of measuring with low-cost sensors may *approach* the level of the "official" measurement methods; however, this is not always possible due to the influence of meteorological parameters (Gerboles et al., 2017). Moreover, the existing regulatory standards are established based on the exposure of either annual or 24-hour averaged value of particulate matter, while the human health impact of instantaneous particle pollution (e.g. on the scale of 1-hour or a few minutes) is still understudied (EPA, 2019). In short, high level of uncertainties were involved in both the measurement and the actual effects of particulate matter.

These uncertainties are reflected in the examination of data quality, which is central to the conflicts emerged in the case of AirBox. As noted by the member of LASS,

> *At the beginning, EPA ... or those people from the field of environmental engineering ... very much despise this micro-monitoring thing. They consider these microsensors toys which are inaccurate and useless ... In their view, sensors ought to be accurate, and have to be calibrated. These are what they've learned from their textbooks ... For us ... PM2.5 ... these fine particles ... they are inherently unpredictable and uncertain. Furthermore, you cannot explain the causal relation between PM2.5 and health. And you [i.e. EPA] keep requiring the measurement to be 'accurate' ... with respect to some kind of standardized stuff, which is not comprehensive ... So it's like you're asking a thing ... which is*

[19] The official measurement stations monitor the longer-term trend in air composition on a larger (regional) scale, while the sensors measure the short-time (or instantaneous) change in air pollutants on a smaller (local) scale. The air monitoring techniques used by official measurement stations are for instance Tapered Element Oscillating Microbalance (TEOM) or Beta Attenuation Monitoring (BAM), while low-cost sensors often use optical methods for measuring, for instance, particulate matters.

[20] Low-cost sensors encompass two categories: OEM sensors, or the sole sensor detector produced by Original Equipment Manufacturer (OEM), which is often open-sourced; and sensor systems (SSy), which include OEM sensors, data acquisition software, data calibration, etc. and are therefore ready-to-use. Most commercial sensors are SSys where black-box calibration algorithms are often used (Karagulian et al., 2019, p. 5). For more information, see Karagulian et al. (2019) for a review on 112 sensors used in European Union member states.

impossible to be measured accurately ... to be measured accurately, and if the measurement were not accurate, you can do nothing. This is unrealistic.

— Founding member of LASS community (translated) [original quote, B.2.c]

In the case of Dutch Skies, concerns on the quality of measurement data of the institutions are present in a similar manner as in the case of AirBox, as evidenced by the skepticism and oppositions from air quality measurement experts at RIVM and GGDs at the very beginning of the citizen science initiatives (de Jonge, 2017).

The positive feedback loop of sensor development and the use of sensor data. The quality of sensors has improved significantly in a short period of time through what the researcher at RIVM described as "*a self-fulfilling prophecy*" when being asked about the "usefulness" of the measurement data. As the researcher explained,

> "
>
> *Right now they are really useful, but in the beginning they weren't. So... we started taking up the citizen science program and the citizen science infrastructure... sort of in the expectations that in a few years, the sensors would be better, and when the sensors have improved, also the usefulness of the measurement would increase. And this is a kind of self-fulfilling prophecy. Because by taking this sensor data, doing something with the sensor data, you create a market. And by creating a market, you create better sensors. And this has really materialized very rapidly with the particulate matter sensors.*
>
> *— Researcher at RIVM*

In this view, the pattern of data quality improvement is depicted by a positive feedback loop where the development of sensors improves the quality of sensor data and drives the use of data, which in turn drives the development of sensors and thereby improves the quality of sensors (Rothwell, 1992), and the citizen science initiatives serve as a "push" which drives the process. A similar pattern can also be observed in the case of AirBox, where the push was mainly given by private sector, the academics and citizen groups such as LASS. We further discuss the feedback loop in section 5.2.4.

Privacy concerns. Privacy concerns were less significant in the two studied cases. The most evident one is the location of sensors publicly shown on the visualized air quality map. The concern was taken care of by purposely shifting the data point around a little bit on the map, making the data point less accurate; therefore, one can see not in which house but in which neighborhood the sensor is located. The measures taken to protect privacy were not to the citizens' concern — in fact, there were some complaints from the citizens that the locations were not accurate enough and that the sensor *"is in a different place each time"*. In general, the citizens are enthusiastic about seeing where their own sensors are and showing that *"it is my sensor."*

4.2.3 Communications between Citizens and the Government

As informed by the cases as well as the concept of "just good enough data" by Gabrys & Pritchard (2018), the additional dimension of *communications between citizens and the government* was added to the conceptual model to capture the dynamics among the actors involved towards a mutual understanding of the problem — more specifically, how the use of citizen-generated data for “communicating public awareness to regulators” is done and how the limitations of sensors or other difficulties are communicated to the public.

The communications with citizens were in two very different forms in the cases of Dutch Skies and AirBox. While in the case of AirBox the exchange of information between LASS and EPA were mostly channeled via the researcher from the Institute, who is both working with EPA on the Campus AQ project and also a participant in LASS. In the case of Dutch Skies, the province of North Holland as well as other stakeholders are directly confronted with the citizens at the project meetups, where *“lots of difficult discussions”* took place. As the officer at the province of North Holland explained, *“in the end it [i.e. the project] all went smooth ... but it was not always an easy process”*. It was emphasized by the officer that openness is *“a very vital point”* throughout the process, for which we discuss more in-depth later in section 4.2.4. A similar view was held by the project team member from Waag, as noted by the member,

> *The province actually is quite open about involving the citizens in this case ... And yeah, of course, the citizens can be critical, but we never really experienced a point where there was a big conflict. I think the two parties can listen to each other and during the project, we have different conversations with each other to see how they can match and how we can involve the citizens more in the province.*
>
> *— Project team member from Waag*

The difference between the two case may be also partly explained by the motivation of the initiatives, as communicating with residents was one of the main goal of the province of North Holland when initiating the Dutch Skies project, as well as one of the major reasons for which RIVM launched the “Measuring Together” program. For the case of AirBox, the motivations of the initiatives are mainly technology-driven, as previously explained in section 4.1.1.

Citizen science is recognized by the RIVM as an effective way of communicating with citizens as underlined by the attentions and publicity the initiatives could create. It was first demonstrated by one of the earliest citizen science pilot projects of RIVM in around 2016, where they experimented the idea of “measuring with citizens” through measuring the peak of emissions from the new year fireworks in the Netherlands. At that time, the sensors were much less accurate; in fact, the sensor were so crude that they can also be used to measure the huge peaks emitted from fireworks and were therefore called “firework sensors”. To RIVM’s surprise, almost all 70 sensors that they handed out to the citizens later went online and the measurement has led to a lot of discussions in the society. As the researcher at RIVM explained,

> *So newspapers were writing, ‘citizen science are measuring... finally the fireworks are being measured...’ which was very frustrating for my colleagues, who are doing the official measurements and who were writing a press release every year about how high this peak is. And no, no newspaper picks it up.*
>
> *— Researcher at RIVM*

The powerfulness of citizen science in facilitating communications, as resonating with the process of empowering citizens with information and knowledge described in section 4.2.1, is built on the basis of *“starting to listen”* and *“taking them [i.e. the citizens] seriously”*. As pointed out by the researcher at RIVM, while many scientists and experts question the "objectivity" of citizen science conducted by "activist" citizens (see also Ottinger, 2018), those citizens *"still want to have high quality measurements"* even though having "political" or activists' ideas. The researcher further argued that, as opposed to the typical impressions of many experts, it is more challenging to *"find the experts who want to trust the citizens"* than finding the citizens who are willing to participate in the projects: *"The citizens are ready for it. They want to participate, and they also want us [i.e. RIVM] to be involved."* In fact, from their experience of the Measuring Together program, the hostility from citizens against the institutional authorities could be gradually resolved once the conversation started; in particular, when the institutions started to listen to the citizens' concerns and needs. As noted by the researcher at RIVM,

> *It really is a matter of starting to listen. So what we have often seen with the Samen Meten program, we also do Twitter, for example ... And what we've noticed that as soon as we started to talk to the citizen scientists, so they were pretty anti-government and anti-RIVM, but as soon as we started to say, you know, 'hey, I'm from RIVM, I'm from Samen Meten, I'm interested in your measurement, show me what you've got.' As soon as we started to do that, or do it on Twitter ... instead of being hostile, they started to defend us. And this happens quickly, very quickly.*
>
> *— Researcher at RIVM*

It was also noted by the researcher at RIVM that the communications have to be "framed" — more specifically, to *"tell all the positive things you can do with the measurement, and at the same time, implicitly explaining what the limitations are."* This was a lesson learned for RIVM from an earlier case of the iSPEX project, where a huge disclaimer was placed on the project website, explaining everything that one cannot do with the measurement mainly to appease the fellow colleagues at RIVM, but *"for the citizens, it's not very nice to hear all the limitations."* A similar experience was encountered by the LASS community, as the member of LASS explained their relationship with EPA and recalled how EPA responded to people's questions and requests on air quality micro-sensing in the earlier days of LASS's initiative,

> *We [i.e. LASS] weren't doing projects for them [i.e. EPA], we don't rely on them, so we just ignore them... but then people would go to them with the sensors, so they were very annoyed by that and thought that our sensors were shit. And then they'll have to make some public announcements, emphasizing that people should not completely trust those AirBox things. They're actually telling the truth, but for us... it sounds so irritating, that they're always openly criticizing that our stuff was wrong.*
>
> *— Founding member of LASS community (translated)* [original quote, B.2.d]

In contrast to the case of Dutch Skies, where citizen science initiative is considered an instrument to facilitate the communications with citizens, in the case of AirBox there were very limited direct communications between the citizens and EPA. As the member of LASS further explained, the relationship between LASS and EPA was more like *"an two men ride of a horse"* [21], with a dialogue established in an implicit, loose manner via the researcher from the Institute. The implicit competition between LASS and EPA is also evidenced by the use of citizen-generated data by EPA for *"internal validation"*, as explained by the officer at EPA, to *"understand how the citizens are monitoring ... and see if there were any differences with our results"* and there was no other use of citizen-generated data beyond this usage. While it is acknowledged by the officer that the competitive relationship with LASS to some extent inspires or urges EPA to implement the official air quality micro-sensing network, there were little direct engagement with the citizens' initiatives from EPA throughout the case of AirBox. As the officer explained how EPA reacted to people measuring with microsensors,

> *We did not ban or tell people that you cannot do it ... So people are developing this thing [i.e. air quality micro-sensing], we are quite open to it. Because you have your own purposes. We were just reminding the people that the measurements from microsensors cannot be used as the only reference of the air quality of your living environment. Of course, they can still install sensors, at different locations ... and they will take care of the calibration for sensors with whatever methods they think is necessary. And of course, they can also come to EPA for calibration in reference to our measurement stations ... per my understanding this was also the case [of interaction with people].*
>
> *— Officer at Dept. EM&IM, EPA (translated)* *[original quote, B.2.e]*

In the case of AirBox, the limitations of sensors appeared to be communicated in a few years of process where conflicts with LASS were gradually resolved. When being asked about EPA's communications with the citizens on the limitations of AirBox, the researcher at the Institute commented,

> *They [i.e. EPA] have their difficulties because of their role, so whatever they said ... it will be something that is not very nice for the people to hear ... Moreover, the language that people can understand, and what the government is speaking, they are not completely the same. They need someone in between to pass on the information. And LASS is actually a quite nice platform for that.*
>
> *— Researcher at the Institute, Taiwan (translated)* *[original quote, B.2.f]*

As inspired by the cases, we seek to further explain the differences in the two cases from a comparison of the role of EPA and RIVM; more specifically, whether the dual role of competent authority and scientific authority has an impact on the outcomes of the citizen science initiatives. We further discuss this perspective in section 5.2.3.

4.2.4 Openness of Data and Process

The criticality of openness — in terms of both data and the overall process — was highlighted in both cases in facilitating the trust build process with citizens as well as among the stakeholders involved in the project. In both cases, the data generated from the projects are all publicly accessible via data

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[21] The original words used in the conversation were "王不見王" (Wáng bú jiàn wáng), literally translated as "a king shouldn't meet another king".

portals partly as a result of discussions on resolving the concerns of public sector. In this section, we elaborate on the openness from the aspect of transparency and of the receptiveness to opinions observed in the two cases.

Openness in terms of transparency. Transparency is essential to citizen science initiatives. In the case of Dutch Skies, as discussed previously in section 4.2.3, the communication with citizen was "*not always an easy process*" where "*a lot of difficult discussions*" took place, mostly on questioning the province for the ultimate, actual use of the citizen-generated data. As the officer at the province of North Holland explained, "*people are cynical, people think that this was never going to work*" given that the data were not official data and therefore cannot be used in the court (de Jonge, 2017). For instance, one of the main questions asked by the citizens is "*why are we doing that if you can't use it against the companies?*" — for which the officer underlined the importance of being honest and transparent about the plan,

> *We can't make any promises ... [about] what we're going to do with it, because we don't even know what the results will be. We can make no guarantees for it. The only guarantee that we committed is that we are going to measure, is that we make sure the quality is as good as this can be, and that all the information is open and shared. That's the only thing that we can do. And we don't know what the rest of the process will be, so we're not going to make any promises ... Because people want to ... the question we often get... 'what are you going to do with this?' So you also have to tell people what you're not going to do. And you have to be honest about it, you have to be open about it. So people have to know what they can expect.*
>
> *— Officer at Province of North Holland*

It was highlighted by the officer that transparency is especially important considering Tata Steel's participation, "*there has to be some kind of trust*" to have the citizens and Tata Steel both consented to a dialogue. Transparency was achieved also through the opening of data. In both cases, all sensor data were made accessible to the public, yet the decisions to publicize the data were not made in an easy, straightforward process as a result of concerns regarding the quality of data. In the case of Dutch Skies, GGD Amsterdam was initially opposed to the opening of data considering that they are responsible for air quality measurement and their situation being closer to the people, "*so if there were a high peak in the PM10, which is not realistic, ... they get all the calls.*" The GGD later consented to the decision as RIVM agreed to help with answering the questions from the citizens. As the researcher at RIVM described,

> *The GGD Amsterdam said, 'okay, we should perhaps not publish the PM10 data, because the PM10 data is not very good. We don't trust it. We should keep it out...' And we said, the RIVM, we said, no fucking way. Because this is open data, this is data from the citizens, and it has to be there. If it's shitty data, we have to explain that it is not good, and*

> *people have to be able to see that it's not good ... And we are not going to... sort of exclude it from the results, because then, we will lose trust.*
>
> *— Researcher at RIVM*

It is worth noting that, as indicated by the researcher, *"it also means that working with companies is more difficult because they are often, you know, in favor of black boxes[20]."* Similarly, in the case of AirBox, the opening of data was a major step forward taken by EPA finally *"after lots of discussions"*, stated by the researcher at the Institute. The decision was even more difficult in this case because for the Smart U&R project, the sensors were installed and maintained by EPA and therefore the sensor data were in some sense "official". Thus, EPA has the responsibility to ensure that there were no abnormal behaviors seen in the data because, *"it is a matter of their credibility"*. In fact, as the researcher pointed out, in the beginning EPA was hoping to complete the calibrations for the measurement on the hardware side, i.e. on the sensor itself, so that *"the sensor-outputted data were already calibrated"* to avoid publishing "incorrect data". The proposal was however rejected by the researcher because in this way EPA runs the risks of losing trust. As the researcher explained,

> *Because I was telling them [i.e. EPA], people can buy those detectors inside your assembled sensors, so if the sensor-outputted data were different from those DIY-ed by the people, you're in big trouble. So you have to release those raw data outputted from the sensors, and then you tell people how those raw data were calibrated.*
>
> *— Researcher at the Institute, Taiwan (translated)* [original quote, B.2.g]

Eventually, EPA has accepted to open and release the sensor-outputted raw data provided that the data passed the quality assessment and control (QA/QC) process. It is worth mentioning that, in both cases, the calibration models were also scheduled to be opened to the public soon (Lin & Chang, 2020).

Openness in terms of the receptiveness to opinions. The openness in the process lies also in the engagement with stakeholders in the case of Dutch Skies. At the preparation stage, all collaborating stakeholders were asked by the province to define their own project plan — more specifically, to answer questions like: *"what is important for you? What do you want to add to the project? What role do you see yourself playing in the project?"* — and accordingly, the province *"gave everybody room to create their own project, and also become an owner of the project in their own right."* For instance, Waag suggested to start the communities in a certain way. In this sense, the openness and receptiveness to stakeholders' opinions during the project is crucial to creating involvement that pushes forward the project. As noted by the officer at the province of North Holland, *"everybody really felt involved"* and thereby has made *"a very high level of commitment"* to the project.

In both cases, the importance of the opening of data as well as the data processing methods in attaining transparency and therefore facilitating the trust building process is underlined by the involved actors. In addition, openness is key to making citizen science initiatives transformative and more widely accessible to science, policy and society at large and thereby improve the scalability of the project (Göbel et al., 2016, pp. 7–8; Ponti & Craglia, 2020). We further elaborate on the aspect of scalability later in section 4.5.2.

4.3 Boundary-bridging or Boundary-policing by Standards

As Ottinger (2010b) argue, standards play a dual role in boundary-bridging or boundary-policing function in shaping the ultimate impact of citizen science initiatives. Regulatory standards and standardized practices, on one hand, can "bridge the boundaries" between citizens and expert communities, offering citizens or non-scientists the opportunities "to render their challenges recognizable to experts and to claim the right to participate in expert-dominated discussions of technical issues" (Ottinger, 2010b, p. 251) . On the other hand, standards can "police the boundaries" between science and non-science, providing grounds for excluding non-scientists from the decision-making process. In this section, we demonstrate how standards shape the different outcomes in the two cases.

In the case of AirBox, standardized process was clearly observed to police the boundaries between citizen science initiatives (i.e. LASS) and scientific authorities (i.e. EPA) as evidenced by all sorts of "standards" imposed on the sensors installed by EPA in the Smart U&R project. As the researcher at the Institute explained,

> *At first their sensors were actually the same as ours, and the only difference is that they applied the same standardized procedures for EPA's official measurement stations on their microsensors. So their microsensors have to be stored somewhere for a few months before going online ... to be observed and calibrated, and then put on site. And then, once in a while they sent technicians to check if the sensors were okay, to do some cleaning, and also put another sensor next to it for paired comparison ... So they are maintaining their low-cost sensors with high maintenance costs.*
>
> *— Researcher at the Institute, Taiwan (translated)* *[original quote, B.2.h]*

In the case of Dutch Skies, the citizen-generated data are "RIVM-approved" and therefore were "boundary-bridged" and attributed with validity and credibility. As the researcher at RIVM explained,

> *Because if they do the measurement, and they said, 'yeah, and RIVM is helping us, is putting this measurement on the data portal. This are official measurement from the RIVM.' Then the local government goes, 'hmm ... these are not the local lunatics, we have to take it more seriously.' So this is also for us a surprise. We didn't realize this beforehand. But we give weights to the citizen science projects.*
>
> *— Researcher at RIVM*

The difference in how standards were "harnessed" in the two cases also suggests that the institutional actor plays the role of competent authority and scientific authority at the same time creates difficulties for the actor and makes it harder to bridge the boundaries, as resonated with earlier discussions in section 4.2.4. We discuss this perspective further later in section 5.2.3.

4.4 Project Outcome

As Göbel et al. (2019) and Berti Suman & van Geenhuizen (2020) suggest, citizen science initiatives engage with political processes and are linked to policies and political decision-making as modes of governance, whereby influence and contribute to the problem-solving process of identified issues in the society. In this section, the outcomes of the two citizen science cases are analyzed based on the conceptual model derived in section 2.3 on four dimensions, namely co-production with institutional player (section 4.4.1), filling of institutional gap (section 4.4.2), advance in political agendas (section 4.4.3) and the benefits for the collaborating stakeholders (section 4.4.4).

4.4.1 Co-production with Institutional Players

The dimension of co-production with institutional players was identified by Berti Suman & van Geenhuizen (2020) in citizen sensing and citizen science initiatives. As they argue, the initiative itself "creates a trigger for the solving" (Berti Suman & van Geenhuizen, 2020, p. 559) and further leads to a shift towards a "democratization in power" in the co-production phase, which forms the basis of the ultimate "full problem-solving", or practical interventions by the institutional actors to mitigate the problem. In this study, the case of Dutch Skies itself is a co-production with institutional players where the province of North Holland explored how the sensors could be used together with the citizens and stakeholders, while in the case of AirBox the dimension of co-production was nearly absent. In this section, we elaborate on the outcomes of the two cases from which we present the reflections from the perspective of the co-production with institutional players.

The aspect of co-production in the case of Dutch Skies was illustrated by the involvement of citizens as well as other stakeholders, as described earlier in section 4.2.1. Since the initiative itself was already an effort made by the institutional actors (i.e. RIVM and the province of North Holland) to start a dialogue and figure things out together with citizens, the component of co-production in this case was more like a process *within the project* rather than a *project outcome*. Nevertheless, as discussed earlier in section 4.1, the initiative of the Dutch Skies project did not appear out of thin air; instead, the co-production was enabled by the influences of intertwined factors working along in the context.

It is worth noting that, in the case of Dutch Skies, although the co-production with institutional actors was present in the case, the citizens participating in the Dutch Skies project are seeking for an even more active role in such projects beyond mere participation. More specifically, the citizens are eager to engage in the project on a more strategic level with more transparency in the process. As observed by the project team member from Waag from the feedback they received from the participants,

> "*And they really want to be involved more in a project, also about the strategy and the ideas of how we can do it better. And not really be only a participant.*
>
> *— Project team member from Waag*

It should however also be noted that, almost all participants in the Dutch Skies project are above the age of 50 years old, well-educated and there are "*more men than women*", as the typically seen in many citizen science initiatives (Haklay, 2013; Nascimento et al., 2019).

In contrast to the case of Dutch Skies, co-production was nearly absent in the case of AirBox. As discussed earlier in section 4.2.1, the "solutions" within the institutional framework as converged from the LASS AirBox initiative, namely the Campus AQ project and the Smart U&R project, did not involve LASS community or citizens in the institutional response. However, in a broader sense, the Campus AQ project can also be viewed as a form of institutionalization of the citizen initiative with the participation of citizens — considering the "dual role" [18] of the researcher at the Institute as both an institutional actor and a participant in the LASS community. In this sense, to some extent co-production was implicitly achieved as converged from the citizen initiative. As commented by the researcher from the Institute,

> *They [i.e. EPA] have their difficulties ... Well, you know, we had a lot of conflicts with them ... but later I realized that in essence we should actually be friends, because we have the same goal, and are both getting to know this new technology. So we know what their difficulties are, we should be helping each other ... So now we are on the same page ... If there were any disagreements, we have found a way to communicate and work together to resolve the issue.*
>
> *— Researcher at the Institute, Taiwan (translated)* [original quote, B.2.i]

A similar view was adopted by the member of LASS. Although there have been numerous clashes between LASS community and EPA in the beginning, the member of LASS emphasized that, within the community, it should always be stressed that *"we are here to help, not to rock the boat."* On the surface, it seems that LASS and EPA are working in parallel with some sense of implicit competitions; however, LASS is essentially cooperating with EPA by experimenting the new technologies, building pilots "for the government". By making use of their flexibility, LASS is able to try out many novel things in time and are "allowed to make mistakes", which is often much more difficult if not impossible for the government: *"if we did something wrong yesterday or before, we just make a post right away acknowledging that 'we're wrong', but this is not the case for the government."* In the end, they were hoping to achieve the same end. As the member of LASS explained,

> *If the government could have things done well, why would I have to do all these things? ... All these people from the community ... none of those was paid. Why are they doing these? They were hoping that the government could do something nice. So when the government copied our things, we're actually very pleased. We don't want the government to create something awful, so we demoed how it's supposed to be done for them.*
>
> *— Founding member of LASS community (translated)* [original quote, B.2.j]

4.4.2 Filling of Institutional Gap

The "filling of institutional gap" (Berti Suman & van Geenhuizen, 2020, p. 561) refers to the use of citizen-generated data to satisfy the need of information for policymaking or political decision-making or to complement official data. In this dimension, we also include the "ordinary way" of using those data as a source of information or the evidence-base for policymaking and as inputs for the official modelling and simulations for the support for policymaking. In this section, we first elaborate on the use of citizen-generated data as input for RIVM's model in the case of Dutch Skies, followed by briefing the use of sensor data in the "smart auditing" application in the case of AirBox. It should be pointed out that, however, in the latter example, the data used were not citizen-generated data but rather the "official" data produced from the Smart U&R project, as a result of boundary-policing by standards as explained earlier in section 4.3.

Use of citizen-generated data in RIVM's model. In the case of Dutch Skies, the citizen-generated data were put into RIVM's model and has helped "improved the model." This was a milestone achieved in supporting the citizen science initiatives for RIVM, as the researcher at RIVM pointed out, "*apart from the other things it [i.e. citizen science project] does, it also has to be useful for us.*" We further discuss the aspect of sustainability of the citizen science initiatives in section 4.5.1.

"Smart auditing" for EPA. In the case of AirBox, one major use of the sensor data is the "smart auditing" policy (EPA, 2017), where micro-sensed data were analyzed and shared with the local Environmental Protection Bureaus (EPBs) as "*informants*" to support the audit of air pollution. As the officer at EPA describes, the analysis of sensor data assists EPBs in identifying the "*crime hotspots*" so that EPBs "*crackdown on*" illegal emissions of air pollutants. It should be note that, however, the sensor data were not legally binding even though they were generated from EPA's sensors, and were therefore not directly used as "evidence" but rather as "informants" in the application.

4.4.3 Advance in Political Agendas

Besides the ordinary, direct use of data mentioned above in section 4.4.2, the data generated from the citizen science projects were also influencing policies and politics in more implicit ways. As suggested by the concept of "just good enough data" (Gabrys et al., 2016), citizen-generated data could be "good enough" and thus useful for communicating people's concern to the regulators (Gabrys & Pritchard, 2018). In this section, we exemplify how citizen-generated data could contribute to advance in political agendas by the pre-derating policy in the case of AirBox and the use of citizen science initiative to "avoid potential crisis" in the case of Dutch Skies.

Pre-derating of power plants based on air quality forecasts. The pre-derating policy was an outcome of continuously communicating the concern of the public to regulator as a result of the rising public awareness (Lin M.-J. , 2016; Tsou, 2016). The effects of derating of power plant on the quality of air were already known to the policymakers: by launching a derating, the emissions of air pollutants were temporarily reduced and the quality of air would potentially be improved or kept at an acceptable level. Yet, in the past, the derating policy was only launched based on "mutual understanding" between the government and the power plant, and only after the quality of air indeed worsened (Lin M.-J. , 2016). Alongside the AirBox initiatives and anti-air pollution movement, more information on air quality were disclosed and public awareness on air quality issues was also growing, which later formed the basis of *pre-derating* policy, namely launching derating of power plant *in advance* if air quality were forecasted to be worsen. The pre-derating policy was later proved to be "effective" in reducing the worsening of air quality and therefore was institutionalized into the regulations (Chu, 2017). As noted by the researcher at the Institute,

> "*In the past, pre-derating was like a grant from the government, people had to beg for it. Now they are forced to ... under some specific conditions the power plant is forced to derate. Or even when the specific conditions were not yet met, people would say that the air quality would definitely worsen, you have to listen to us ... So now they know they have to derate ... when the forecast says the air quality would worsen.*
>
> — *Researcher at the Institute, Taiwan (translated)* *[original quote, B.2.k]*

Avoidance of potential crisis. As mentioned earlier in section 4.2.3, citizen science could be a powerful, effective way to communicate with citizens. In this sense, the researcher at RIVM stressed the importance of the use of citizen science initiatives as a policy instrument to avoid potential crisis. As the researcher argued,

> *And I think, if we start doing this now, around this topic of noise, we can sort of avoid a crisis that will happen in five years .... Well, you've seen the farmer protest in the Netherlands ... I think if we had, five years ago, gone to these farmers and said, 'okay, you don't agree with us, let's do measurements together?' This, they would not have been, you know... they would still have been angry, they would still have been in Den Haag with protests, but they would not have been at RIVM with protests.*
>
> *— Researcher at RIVM*

4.4.4 Benefits for the Collaborating Stakeholders

Citizen science brings not only benefits for the citizens but also for the involved or collaborating stakeholders (Ponti & Craglia, 2020). This dimension was observed in the case of Dutch Skies particularly for the participation of Tata Steel. Although we cannot speak for Tata Steel or confirm that Tata Steel themselves has perceived benefiting from their involvement in the project given that the deficiency in relevant information, it was suggested by the officer at the province of North Holland that a better, trusted dialogue between Tata Steel and citizens was established during the project because of their involvement. As the officer noted,

> *And you see that the attitude of Tata is changing, and Tata has put some of our sensor stations at their area... and they have also official measuring stations on their [area] ... and before they didn't share this information. They started sharing information from their own measurement station. So you see that they're involved in a dialogue. And that's exactly what we wanted ... Because we wanted to be able to start a dialogue with Tata Steel ... and that's what you see, that more realism in the discussion because, of course, the companies... lots of people work there, and the company's aim is also not polluting the environment ... and they have taken measures.*
>
> *— Officer at Province of North Holland*

This dimension is however not applicable for the case of AirBox due to the absence of involvement of stakeholders, as explained previously in section 4.2.1.

4.5 Sustainability of the Case

In this section, we discuss the sustainability of the case from the dimension of support mechanism of the project and its scalability (Ponti & Craglia, 2020).

4.5.1 Supporting Mechanism

The supporting mechanism indicates whether there are initiatives in place to support and thus sustain the project, such as potential or actual sources of contribution to fund a project. In the case of Dutch Skies, the mechanism has been achieved as the citizen-generated data are proved to be useful and were already used in RIVM's atmospheric model and even "helped improved the model". As the researcher at RIVM explained,

> *We have to able to say to the ministry, because the ministry is really giving us the money to do this, we have to be able to say to the ministry, look, we have to support citizen science, because then we can give you this nice model with all these details. And this is what citizen science is giving us. So to put it very, very strongly, we have to make ourselves dependent on citizen science, in our procedures. And then we can support citizen science, and continue to support it*
>
> — *Researcher at RIVM*

It is not clear that whether there is a supporting mechanism for the Smart U&R project, or whether the sensors installed will be continuously functioning and maintained, especially considering the relatively high maintaining costs (see section 4.3). As commented by the LASS member,

> *I think the point is the usefulness … From what we have now, the government is installing sensors in industrial zones, and we're doing this with the citizen science approach … If this mode could continue to work, I think it's nice. But the [Smart U&R] project was some four-year project … perhaps it just ended after four years. I think it would be a pity if it ended after the project is done. After all, it has a lot of positive impacts on the society.*
>
> — *Founding member of LASS community (translated)* [original quote, B.2.l]

4.5.2 Scalability

Scalability indicates that whether the projects have or could be scaled up. This dimension is observed in both cases, and particularly in the case of AirBox from both LASS and the Institute. Currently, LASS is working with the Water Resource Agency on expanding their work to the water-level sensing and through which establishing a "public-private partnership". Furthermore, LASS is working with the Institute on plans to scale up the AirBox initiative to a global level. The researcher at the Institute again emphasized the importance of openness in this step, indicating that *"some companies are developing their own, closed system, which will not sustain as soon as there is no more money"* and that *"openness is key"*. For the case of Dutch Skies, the citizen science pilots will be further expanded to more communities within the province. In the longer term, sensors installed from citizen science projects will be used to construct a flexible, hybrid system of a national monitoring network, as explained earlier in section 3.2.3.

4.6 SUMMARY

In this chapter, the two cases — the case of AirBox in Taiwan and the case of Dutch Skies in the Netherlands — were examined and investigated as guided by the proposed conceptual model. Findings from each of the five stages were summarized below,

(1) *Enablers and drivers* — Technological development was found to be a powerful driver for both cases. The broadening of public attention to the identified issue was also observed in both cases; however, it only led to a shift to participatory problem-solving in the case of Dutch Skies. As informed by the case studies, *institutional settings* and *organization culture* were added as two additional enablers and driving factors with an attempt to explain such differences.

(2) *Development of the case* — In the case of Dutch Skies the building of a trusted dialogue was noticed to be facilitated by the presence and involvement of diverse stakeholders, while in the case of AirBox, citizens were excluded in some sense from the institutionalized response to the initiative. For the quality of citizen-generated data, a "positive feedback loop" — i.e. the quality of sensors was improved through the use of sensor data, which in turn improved the quality of sensors — was observed from both cases. Two additional dimensions were added to this stage: *communications between citizens and the government* was employed to further capture the dynamics among the actors involved, and the *openness of data and process* was added to emphasize the importance of transparency and receptiveness to opinions within citizen science initiatives.

(3) *Boundary-bridging and boundary-policing by standards* — Standards was observed to shape the distinct outcomes in the two cases. In the case of AirBox, standardized process policed the boundaries between citizen science initiatives (i.e. LASS) and scientific authorities (i.e. EPA) as evidenced by all sorts of "standards" imposed on the sensors installed by EPA in the Smart U&R project. By contrast, in the case of Dutch Skies, the citizen-generated data are "RIVM-approved" due to the involvement of scientific authorities in the project and therefore were "boundary-bridged" and attributed with validity and credibility.

(4) *Project outcome* — The co-production of solutions with institutional players was present in the case of Dutch Skies, whereby benefits for the collaborating stakeholders were produced — for instance, the change in attitude of Tata Steel. In the case of AirBox, although there was no direct involvement of citizens in the institutionalized response to the air quality issue, a rather implicit mode of co-production has emerged: citizens or non-governmental groups such as LASS community, who are more flexible and allowed to make mistakes, experimented new technologies and built pilots in some sense "for the government". In the case of Dutch Skies, citizen-generated data were used in both the filling in institutional gap and the advance in political agendas, while in the case of AirBox, citizen-generated data were more useful for "communicating the public's concerns" and had to some extents contributed to the institutionalization of the "pre-derating policy".

(5) *Sustainability of the project* — In the case of Dutch Skies, a supporting mechanism was more solidly established through successfully incorporating citizen-generated data into the official air quality models, while in the case of AirBox it is relatively unclear whether such mechanisms exist for relevant projects. In both cases, there are plans to further scale up the current project to either regional, national, or even global level.

The findings from the case studies form the basis of the case comparison and discussions in the next chapter of 5, whereby a revised, empirically enhanced model is developed.

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5

Towards a Revised, Empirically Enhanced Model

In this chapter, we perform a comparative case study analysis based on the findings derived from the previous chapter, based on which a revised, empirically enhanced model of citizen science for policies is developed. We first analyze and compare the findings from the two case studies in section 5.1. The results are synthesized and translated into a revised, empirically enhanced model, which is further elaborated in section 5.2. Building upon the insights gained from the case studies, we formulate the policy recommendations in section 5.3. A summary of this chapter is presented in section 5.4.

5.1 Case Study Analysis

In this section, we perform a comparative case study analysis for the two cases drawing upon the findings derived from the previous chapter of 4. A summary of the comparison of the two cases is presented in Table 5-1. We discuss the distinctions between the two cases, based on which revisions on the conceptual model are proposed towards an empirically enhanced model. The revised model is further presented in the next section of 5.2.

5.1.1 Enablers and Drivers

As elaborated earlier in section 4.1, the enablers and drivers of citizen science initiatives describe how such cases were initiated and enabled. For the two cases, technological development was found to be a powerful driver, in particular for the case of AirBox. It is worth noting that, unlike the case of Dutch Skies — where experts communicating the methods and results to citizen audience is "equally important" (Wesseling, de Ruiter, et al., 2019, p. 2) as with the development of sensing technologies and IoT network, the relevant projects in the case of AirBox are almost fully technology-driven. This aspect, together with the influence of other enabling conditions and driving forces elaborated below, may help explain the differences observed in communications between citizens and the government, which we discussed later in section 5.1.2.

The broadening of public attention to the identified issue was also observed in both cases. It only led to a shift to participatory problem-solving, however, in the case of Dutch Skies. In this study, we suggest that such differences to be explained by the distinction in the role of scientific and competent authorities. We further elaborate on this argument later in section 5.2.3. In addition, as informed by the case studies, *institutional settings* and *organization culture* were added as two additional enablers and driving factors with an attempt to explain such differences.

Table 5-1. A comparison between the cases

Main category	Dimension	Case studies	
		Dutch Skies	**AirBox (including LASS, Campus AQ & Smart U&R)**
Enablers and drivers	**Technological development**	Strong driver for RIVM	Strong driver for all actors, namely EPA, the Institute and LASS community
	Broadening of pressure exerted on the government	A relatively proactive approach to problem-solving partly driven by ▪ Pressure exerted on the province NH from residents' distrust in the province, particularly for Tata Steel-related issues ▪ The need of new ways of communicating with citizens (RIVM)	A relatively passive approach to problem-solving partly driven by ▪ A mismatch in official air quality data and people's experience ▪ The need of information to respond to citizens' demand ▪ Competition with LASS AirBox
	Institutional settings †	The introduction of the new Environmental and Spatial Planning Act — to facilitate public participation	The initiation of the Civil IoT Taiwan program — to press ahead the emerging IoT industry
	Organization culture †	▪ Strong support from the provincial executive of North Holland ▪ Varying experiences with different local governments in RIVM's Measuring Together program	▪ Open-mindedness of Taipei City Government (LASS/Campus AQ) ▪ Varying experiences with different local governments in the Campus AQ project
Development of the case	**Involvement of stakeholders**	Stakeholders (including Tata Steel) were invited to join project meetings	▪ *Campus AQ & Smart U&R* — not involved ▪ *LASS* — open to all participation in its discussion group
	Quality of citizen-generated data	▪ Fitness for the use in RIVM's model after calibration ▪ Privacy concerns were less significant: Geolocation of the sensors is shifted around a little bit on purpose to protect privacy	▪ Excluded from institutionalized solution because not meeting regulatory standards ▪ Privacy concerns were less significant: Same as the Dutch case
	Communications between citizens and the government †	▪ "Framing" — tell all the positive things while implicating explains the limitations of sensors ▪ Listening to the citizens' needs and establishing a trusted dialogue	▪ Single-way, top-down communicating the limitations of sensors ▪ Implicit dialogue established via the researcher at the Institute
	Openness of data and process	▪ Transparency attained by the opening of data and calibration model ▪ Receptiveness of stakeholders' opinions	▪ Transparency attained by the opening of data and calibration model

Note: Additional dimensions added to the revised, empirically enhanced model are denoted by the † symbol.

Table 5-1. A comparison between the cases (continued.)

Main category	Dimension	Case studies	
		Dutch Skies	**AirBox (including LASS, Campus AQ & Smart U&R)**
Boundary-bridging / boundary-policing by standards		*Boundary-bridging*: The presence of RIVM and GGD Amsterdam in the project gives the credibility of citizen-generated data	▪ *Boundary-bridging:* The involvement of the Institute in the Campus AQ project ▪ *Boundary-policing*: The standardized procedures for official measurement stations were applied to microsensors in Smart U&R to safeguard the quality of measurement
Project outcome	**Co-production with institutional players**	Empowerment in a bottom-up fashion: ▪ Citizens can make their own decisions on some strategies ▪ Citizens can discuss with the various stakeholders on the table Establishing new relationships between citizens and the government: ▪ Citizens measuring air quality have an impact on the local political agenda ▪ Measuring with citizens could help avoid potential crisis. E.g., for new development plans the province will measure with citizens in the planning phase	No explicit co-production with institutional players: ▪ Implicit competition between LASS and EPA: Collaboration of EPA and the Institute (also in some sense representing LASS) within the institutional framework; the LASS community that is not within the institutional framework was excluded from the government's projects ▪ Citizens measuring air quality have an impact on the local political agenda
	Filling of institutional gap	Used in RIVM's numerical model and has helped improved the model	Use in "Smart Auditing" — the use of data as an (extra) informant of pollutant emissions to inform audits.
	Advance in political agendas	Citizen science as a policy instrument to avoid crisis	The pre-derating policy of power plants depending on air quality forecasting — as a result of campaigning by citizens using the micro-sensing data
	Benefits for the collaborating stakeholders	Tata Steel joins the measurement and opens their measurement data	Did not collaborate with stakeholders.
Sustainability of the case	**Supporting mechanism**	Yes, with an aim to "making the model dependent on citizen science"	Unclear
	Scalability	Will be expanding to other locations in the province (and in the Netherlands).	▪ Unclear for Smart U&R ▪ LASS / the Institute is aiming at further expanding to a global level

It is also interesting to note that, as elaborated earlier in section 4.1.2, the broadening attention and pressure exerted on the government does not always serve as a positive driving force towards an institutional response to the issue. Rather, the impact of the driving factors is the result of the mixed interactions among the factors. This is evidenced by the experience of Campus AQ project in Taichung city in the case of AirBox, where the pressure exerted on the Taichung government actually in some sense hindered the progress of the project since air quality issue was the most heated debate and thus a sensitive topic around the time of local elections.

Although varying organizational cultures and distinct experiences are observed for different municipalities in both cases, the influence of organizational culture on the projects is intertwined with affects brought by other drivers such as the broadening of attention drawn to the identified issue and the institutional settings, as particularly evidenced by the example of Taichung city in the case of AirBox as well as the case of Dutch Skies. We discuss the interwovenness of enablers and driving factors further later in section 5.2.1.

5.1.2 Development of the Case

The stage of the development of the case describes how citizen science initiatives lead to a citizen-driven solution of political decision-making and problem-solving. In addition to the initially proposed elements of the *involvement of stakeholders* and the *quality of citizen-generated data*, two additional dimensions — *communications between citizens and the government* and *openness of data and process* — were added to the model as informed by the case studies. Below we discuss the differences between the two cases from each of the four aspects.

As elaborated previously in section 4.2, the establishment of a trusted dialogue in the case of Dutch Skies was facilitated by the presence and involvement of diverse stakeholders, particularly the participation of RIVM and GGD Amsterdam as they are the experts in air quality measurement and are perceived as objective. It is noteworthy that the objectivity perceived by the citizens is not solely due to the attendance of the experts in the project meetups, but more as a result of the experts explaining about technology and how measuring air quality works scientifically. This view resonates with the findings from the communications between citizens and the government, which we further discuss below in the same section. As for the case of AirBox, citizens were in some sense excluded from the institutionalized response to the initiative. This lack of involvement of stakeholders may be partly explained by the difficulties in *identifying who the stakeholders are* — as part of the difficulties in identifying the specific source(s) of air pollution (Tu, 2019), attributed to the complexity of air quality governance in Taiwan. As Tu (2019) suggests, the complexity is characterized by "Taiwan's dense industrial agglomeration patterns, rapid urbanization, and mismanaged mixed land use" (p. 252) resulted from the socio-political contexts.

The quality of citizen-generated data was observed in both cases to be improved through a similar pattern depicted by a positive feedback loop, where the development of sensors improves the quality of sensor data and drives the use of data, which in turn drives the development of sensors and thereby improves the quality of sensors (Rothwell, 1992). Citizen science initiatives serve as a "push" which drives the process. While in the case of Dutch Skies this pattern was in some sense materialized through a "self-fulfilling prophecy" by the RIVM, in the case of AirBox the development of such pattern was mainly driven by private sector, the academics and citizen groups such as LASS. A recap on this revision on the proposed conceptual model of this positive feedback is later presented in section 5.2.4.

The communications between citizens and the government were in two very different forms in the two cases. While in the case of AirBox the exchange of information between LASS and EPA were mostly channeled via the researcher from the Institute, who is both working with EPA on the Campus AQ project and also a participant in LASS. In the case of Dutch Skies, the province of North Holland as well as other stakeholders are directly confronted with the citizens at the project meetups, where "lots of difficult discussions" took place. The significance of openness throughout the process was emphasized, which we further discuss below in the same section. The difference in communications between the two case may be also partly explained by the motivation of the initiatives. As discussed earlier in section 5.1.1, communicating with residents was one of the main goals of the province of North Holland when initiating the Dutch Skies project, as well as one of the major reasons for which RIVM launched the "Measuring Together" program, while for the case of AirBox, the motivations of the relevant projects and initiatives are mainly technology-driven.

The criticality of openness — in terms of transparency (through open data) and the receptiveness to opinions (for overall process) — was highlighted in both cases in facilitating the trust build process with citizens as well as among the stakeholders involved in the project. In both cases, the data generated from the projects are all publicly accessible via data portals partly as a result of discussions on resolving the concerns of public sector. In addition, openness is key to making citizen science initiatives transformative and more widely accessible to science, policy and society at large and thereby improve the scalability of the project (Göbel et al., 2016, pp. 7–8; Ponti & Craglia, 2020).

5.1.3 Boundary-bridging or Boundary-policing by Standards

Standards was observed to shape the distinct outcomes in the two cases. In the case of AirBox, standardized process policed the boundaries between citizen science initiatives (i.e. LASS) and scientific authorities (i.e. EPA) as evidenced by all sorts of "standards" imposed on the sensors installed by EPA in the Smart U&R project. By contrast, in the case of Dutch Skies, the citizen-generated data are "RIVM-approved" due to the involvement of scientific authorities in the project and therefore were "boundary-bridged" and attributed with validity and credibility. The difference in how standards were "harnessed" in the two cases also suggests that the institutional actor plays the role of competent and scientific authorities at the same time creates difficulties for the actor and makes it harder to bridge the boundaries. In light of this, a revision on the conceptual model was set forth on the distinction of the role of competent and scientific authorities. The revision is presented later in section 5.2.3.

5.1.4 Project Outcome

The stage of project outcome describes what results or outcomes were produced by such initiatives. The stage is composed of four dimensions: (a) co-production with institutional players, (b) filling of institutional gap, (c) advance in political agenda, and (d) benefits of the collaborating stakeholders. Below the findings from case studies, as discussed previously in section 4.4, are analyzed and compared from these four aspects.

The co-production of solutions with institutional players was present in the case of Dutch Skies, whereby benefits for the collaborating stakeholders were produced — for instance, the change in attitude of Tata Steel. In the case of AirBox, although there was no direct involvement of citizens in the institutionalized response to the air quality issue, a rather implicit mode of co-production has emerged: citizens or non-governmental groups such as LASS community, who are more flexible and allowed to make mistakes, experimented new technologies and built pilots in some sense "for the government". The distinct outcomes were shaped by the interplay of different dynamics among actors as well as the contextual settings, as elaborated earlier in sections 5.1.1 and 5.1.2.

The use of citizen-generated data was examined based on two dimensions: the filling in institutional gap, or the traditional, "ordinary" ways of direct data use as an evidence-base for policymaking and parameter inputs for official models; and the advance in political agendas, or the implicit data use for "communicating public's concerns" to the government or institutions. In the case of Dutch Skies, citizen-generated data were "RIVM-approved", and thereby "boundary-bridged" with the official measurement data, as discussed earlier in section 5.1.3. Accordingly, citizen-generated data were successfully incorporated into the official air quality model and contributed to "improve the model", and therefore wield a direct influence on policies. By contrast, as a result of the boundary-policing function by standardized process, in the case of AirBox citizen-generated data were excluded from the traditional policymaking processes. This was particularly evidenced by EPA's "smart auditing" program, where sensor data *generated by the government* were used as "informants" to support the audit of air pollution. Nevertheless, citizen-generated data were useful in both cases for "communicating public's concerns" and to some extents contributed to the advances in political agendas, as highlighted by the "avoidance of potential crisis" in the case of Dutch Skies and the "pre-derating policy" of power plants based on air quality forecasts in the case of AirBox.

5.1.5 Sustainability of the Case

The sustainability of citizen science initiatives was embodied by mechanisms to continuously sustain or support such initiatives — for instance, financially. In the case of Dutch Skies, a supporting mechanism was more solidly established through successfully incorporating citizen-generated data into the official air quality models, as elaborated above in section 5.1.4. By contrast, it is relatively unclear in the case of AirBox whether such mechanisms exist for relevant projects. There were plans, however, for both cases to further scale up the current project to either regional, national, or even global level.

5.2 Revisions on the Conceptual Model

In this section, revisions on the proposed conceptual model — as described earlier in section 2.3 — are elaborated drawing upon the insights gained from a comparison of the cases. The revised, empirically enhanced model is illustrated in Figure 5-1. The revisions are composed of four major parts, which we present in the subsequent sections: the addition to two enablers — *institutional settings* and *organizational culture* — and the interwovenness of driving factors in section 5.2.1; two additional dimensions of *communications between citizens and the government* and the *openness of data and process* in the development of the case in section 5.2.2; the influence of the overlaid or distinct role of competent and scientific authorities in section 5.2.3; and the "positive feedback loop" of sensor data use in sensor development in section 5.2.4. On the basis of the insights attained from the revisions, we formulate the policy recommendations in the next section of 5.3.

5.2.1 The Interwovenness of Enablers and Driving Factors

The enablers and driving factors, as discussed earlier in section 4.1, are the enabling conditions of the citizen science initiatives which made the initiative possible. As informed by the case studies, the influences of the enablers and driving factors are interrelated. The interwovenness of factors is depicted by replacing the list-like with ring-shaped illustration of the elements involved. Moreover, two additional enablers and drivers, namely institutional settings (section 4.1.3) and organizational

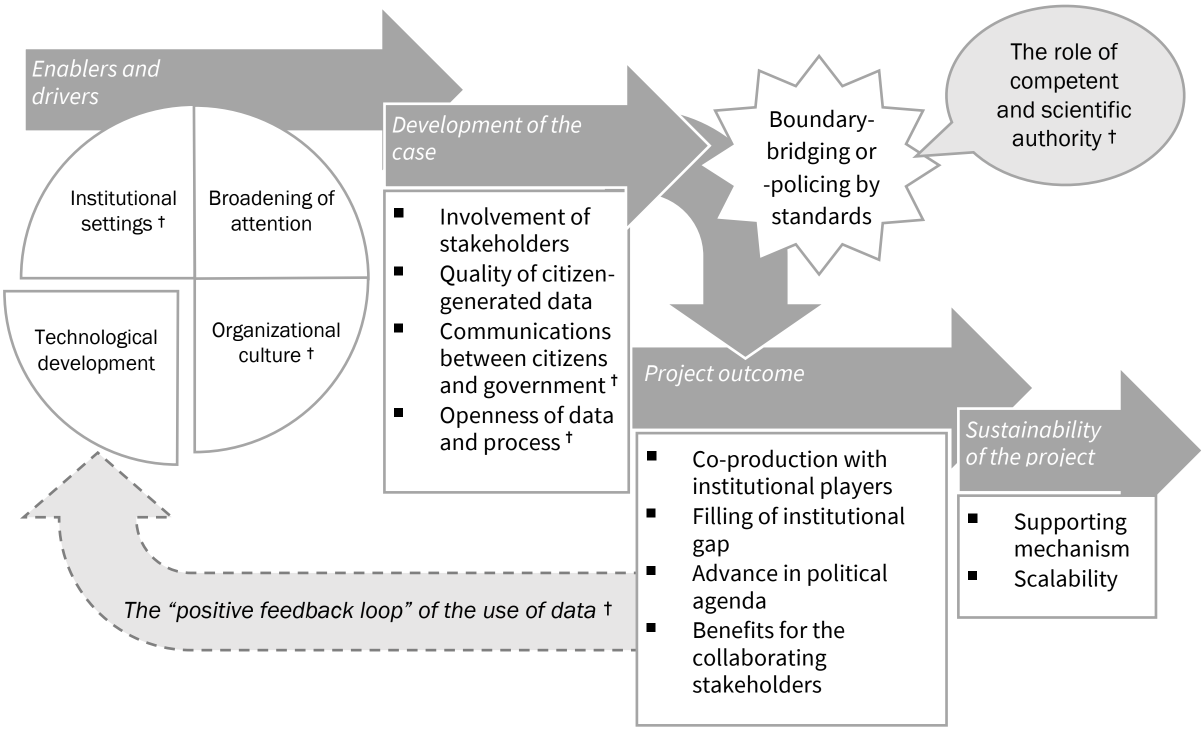

Figure 5-1. A revised, empirically enhanced model of citizen science for policies. Additional dimensions added and revisions to the conceptual model are denoted by the † symbol.

culture (section 4.1.4), were found from the case studies. In this section, we elaborate on the interwovenness of the enablers and driving factors and the influence of this interwovenness on enabling the citizen science initiatives.

The interwovenness among factors is evidenced mainly by the interrelation of institutional settings and organizational culture and their interplay with the broadening attention drawn to the identified issue and thus pressure exerted on the government. As observed from the case of Dutch Skies, the project was made possible mainly because of the simultaneous presence of the change in institutional settings (namely the introduction of the new *Environmental and Spatial Planning Act*) and the "activists" beliefs and values owned by the representative of provincial executive, who provide strong support and push to the launch of the project. It was, however, also the democratization of information led by the development of smart phones that allow people to become "more aware of the quality of their living environment", and thereby gave shape to a public consensus driving the two aforementioned changes.

In the case of AirBox, the institutional setting was more a technology-led, industry development-driven proposed program and was less relevant to the initiative. Yet the influence of organizational culture — specifically, the values established by the heads of the governmental agencies — was equally found crucial in determining whether a project was enabled. As also seen in the case, the broadening awareness on the air quality issue and the pressure exerted on the government are strong drivers for the institutional response. It is worth noting, however, that the broadening of public attention is not always a positive driver, as evidenced by the experience with Taichung in the case of AirBox (see section 4.1.2).

5.2.2 *The Significance of Communications and Openness on Establishing Trusted Dialogues*

As informed by the cases as well as the concept of "just good enough data" by Gabrys & Pritchard (2018), the additional dimension of *communications between citizens and the government* was added to the conceptual model to capture the dynamics among the actors involved towards a mutual understanding of the problem — more specifically, how the use of citizen-generated data for "communicating public awareness to regulators" is done and how the limitations of sensors or other difficulties are communicated to the public. As discussed in section 4.2.3, citizen science initiatives could be effective in facilitating communications — and thereby establishing a trusted dialogue — as observed in the case of Dutch Skies. Specifically, the dialogue is both "communicating the concerns and need from the citizens" as well as "communicating the limitations from the authorities". In contrast to the Dutch Skies project, the communication was done in an implicit, less straightforward manner via the researcher at the Institute, who was both working with EPA for the Campus AQ project and a participant in the LASS community.

The significance of openness throughout the project was emphasized by the actors in both cases, and was therefore also added as an additional dimension to the conceptual model. Openness comprises two parts: openness in terms of transparency — through publicizing the collected data as well as calibration methods; and openness in terms of the receptiveness to opinions — for the overall process. This significance was highlighted in facilitating the trust build process with citizens as well as among the stakeholders involved in the project. In addition, openness is key to making citizen science initiatives transformative and more widely accessible to science, policy and society at large and thereby improve the scalability of the project.

5.2.3 *Citizens' Perceptions on the Role of Competent and Scientific Authorities*

As discussed earlier in section 4.3, standards played a distinct role in the two cases, for which we seek to explain the disparity from the distinction in citizens' perceptions on the role of competent and scientific authorities. In the case of Dutch Skies, the boundaries between non-science (i.e. citizen-generated data) and science are bridged by the involvement of scientific authorities — RIVM and GGD Amsterdam — in the project. The citizen-generated data from the case is "RIVM-approved" and therefore were attributed with validity and credibility. In contrast to the case of Dutch Skies, regulatory standards and standardized process police the boundaries between science and non-science in the case of AirBox, where the sensors later installed by EPA in the Smart U&R project were applied with sophisticated standardized quality checks and maintenance procedures to ensure that the sensor quality are in compliance with referenced measurements. We seek to explain this difference by analyzing the citizens' perceptions to the involved actors. An illustration of the stakeholders involved in the two cases with respect to citizens' perceptions to them is shown in Figure 5-2.

In the case of Dutch Skies, the major concerns of the participants are related to pollution issues around Tata Steel, for which the competent authority is the province of North Holland, who is responsible for issuing the emission permits and therefore perceived distrust by the citizens. The scientific authorities in the case — namely, RIVM and GGD Amsterdam — are perceived as objective, and therefore their presence and involvement added trust to the process and helped bridge the gap of trusts between the province and the citizens. In addition, the involvement of Waag — a non-

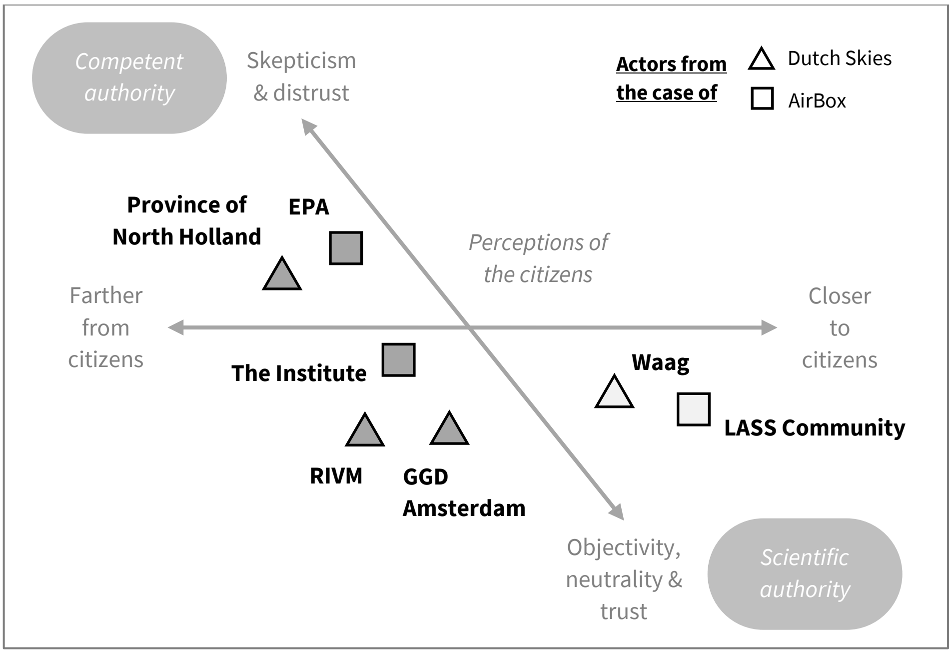

Figure 5-2. Stakeholders involved in the cases by citizen's perception.

governmental organization that is perceived closer to the people by the citizens — also helps bring the authorities and citizens closer to each other.

In the case of AirBox, however, EPA is at the same time the competent authority of air quality issue as well as the scientific authority in air quality measurement — or, in other words, the regulators and the monopoly of knowledge — all in one. The dual role in EPA adds to the difficulties for EPA to bridge the boundaries between science and non-science; furthermore, tensions and disagreements emerge between the citizens and EPA especially from the high level of distrusts against EPA as perceived by the citizens, which further adds to the difficulties from their role.

5.2.4 A Positive Feedback Loop of Sensor Data Use and Sensor Development

A positive feedback loop was observed in both case studies on the improvement of the quality of sensor data or citizen-generated data, and was therefore added to the revised model to link the project outcome back to the driving factor of technological development. As discussed earlier in section 5.1.2, the pattern of data quality improvement is depicted by a loop where the development of sensors improves the quality of sensor data and drives the use of data, which in turn drives the development of sensors and thereby improves the quality of sensors (Rothwell, 1992). In this view, citizen science initiatives serve as a "push" which drives the process, where citizens measuring and generating data creates a market of sensors, which further creates better sensors and improves the quality of sensor data. While this process was described by the researcher at RIVM as a "self-fulfilling prophecy" in the case of Dutch Skies, the cycle was also observed in the case of AirBox, where LASS community, the academics and also the private sectors pioneered the use of low-cost sensors and thereby stimulated further development of sensors in a cyclic pattern.

5.3 Policy Recommendations

In this section, the empirically grounded insights gained from the case studies are translated into policy recommendations for policymakers in government on incorporating citizen science into the policymaking process or, in a broader sense, the governance of an identified societal issue. The policy advices comprise three major parts: first, we encourage policymakers to move towards a co-production of solutions through engaging more stakeholders in the citizen science initiatives. Second, we advise policymakers to initiate a dialogue with citizens first by taking them seriously — more specifically, to start with listening to their needs and concerns, followed by communicating the methods and findings as well as empowering citizens with information and knowledge. Third, we emphasize the significance of attaining openness of data and process on trust building between citizens as well as among stakeholders. Below we further elaborate on the three recommendations.

Involving more stakeholders in the citizen science initiative. As resonated with the arguments on the need for involvement of multi-stakeholder collaboration for governance system, we encourage policymakers to move towards a co-production of solutions through engaging more stakeholders in the citizen science initiatives. In this study, we argue that citizens' perceptions — more specifically, citizens' perceived distance as well as trust or distrust towards institutional actors — are affected by the roles of those actors. For instance, as evidenced by EPA's dual role in the case of AirBox as both the regulator and the monopoly of knowledge, it could be extremely difficult for the government to practically adopt the concept of citizen science and the uptake of citizen-generated data. The situation is especially difficult when tensions and disagreements exist between citizens and the government, which often lead to high level of distrusts against the authorities. In such cases, involving different stakeholders is particularly crucial in facilitating the (re)building of trusts. As observed in the case of Dutch Skies, the participation of stakeholders such as RIVM, GGD Amsterdam and Tata Steel has fostered the trust building process during the project, which would not have been possible if the project were implemented solely by the provincial government.

Taking citizens seriously — start with listening, communicating and empowering. One of the most important steps forward for the government towards building a trusted dialogue with citizens is to take citizens seriously. In practice, this means to first "starting to listen" to the needs and concerns of the citizens. In this premise, citizen science could be a powerful instrument to communicate the scientific methods and findings — which are central to the problem-solving of the identified issue yet often quite complicated to understand — with citizens considering the publicity it creates, as evidenced by RIVM's experience in the case of Dutch Skies. Moreover, we advise to establish the dialogue with citizens on the basis of empowerment of citizens, or more specifically, to fill the citizens with information and knowledge. This was a lesson learned from the case of Dutch Skies, where information and knowledge gained by the citizens from the experts explaining how science and technologies work really "changed the discussion". In summary, all these above aspects have their roots in taking citizens seriously, which is crucial to the establishment of a trusted dialogue with citizens.

Attaining openness of data and process for transparency and the receptiveness to opinions. We emphasize the significance of openness on facilitating the trust build process with citizens as well as among the stakeholders involved in the project. Openness comprises two parts: openness in terms of transparency — through publicizing the collected data as well as calibration methods; and openness in terms of the receptiveness to opinions — for the overall process. This significance was highlighted in. In addition, openness is key to making citizen science initiatives transformative and more widely accessible to science, policy and society at large and thereby improve the scalability and thus sustainability of the project.

5.4 SUMMARY

In this chapter, the revised, empirically enhanced model on citizen science for policies was developed based on revisions on the previously proposed conceptual model. The revised model was illustrated in Figure 5-1. The revisions, which were formulated from the findings of the comparative case studies, comprised four major parts:

(1) *The interwovenness of enablers and driving factors* — As evidenced mainly by the interrelation of two additional factors — institutional settings and organizational culture — and their interplay with the broadening attention drawn to the identified issue, the influences of enablers and drivers on the development of citizen science initiatives were found to be intertwined among factors. The interwovenness of factors was depicted in the graphic illustration of the revised model by the ring of elements.

(2) *The significance of communications and openness on establishing trusted dialogues* — Two additional dimensions were introduced, as informed by the case studies, to the development of case in the revised model: communications between citizens and the government was added to further capture the dynamics among the actors involved; and the openness of data and process to emphasize the importance of attaining transparency and the receptiveness to opinions throughout the initiatives.

(3) *Citizens' perceptions on the role of competent and scientific authorities* — With the attempt to explain the differences in the two cases on whether boundaries between science and non-science were bridged or policed by standards, the influence of citizens' perceptions on the role of competent and scientific authorities was introduced. It was argued in this study that citizens' perceived distance as well as trust or distrust towards institutional actors were affected by the roles of such actors, and that the outcomes of citizen science initiatives were further shaped by these perceptions.

(4) *A positive feedback loop of sensor data use and sensor development* — The improvement in the quality of sensor data or citizen-generated data was realized through a positive feedback loop, where sensor development improves the quality of sensor data and drives the use of such data, which in turn fosters the development of sensors. In this view, citizen science initiatives could serve as a "push" which drives the abovementioned processes.

The empirically grounded insights gained from the case studies were further translated into policy recommendations for policymakers in government. The policy recommendations comprise three major parts: first, we encourage policymakers to move towards a co-production of solutions through engaging more stakeholders in the citizen science initiatives. Second, we advise policymakers to initiate a dialogue with citizens first by taking them seriously — more specifically, to start with listening to their needs and concerns, followed by communicating the methods and findings as well as empowering citizens with information and knowledge. Third, we emphasize the significance of attaining openness of data and process on trust building between citizens as well as among stakeholders.

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6
CONCLUSIONS

In this study, we focus on the enhancement of empirical understanding on how citizen-generated data from citizen science initiatives can contribute to political decision-making and problem-solving in different contexts. More specifically, we seek to explore how a citizen science initiative is formed, what opportunities and challenges are for citizen-generated data and what role citizen-generated data plays in the initiatives, how such initiatives lead to a citizen-driven solution of political decision-making and problem-solving process, and how the contextual settings and actors' perceptions and actions interplay and potentially play a part along the process. Based on empirically grounded insights, we aim to formulate policy advices to government policymakers for incorporating citizen science into the policymaking processes and, in a broader sense, the governance system for the "grand challenges" encountered in the society.

This chapter concludes the thesis report by providing the key findings from this study. In this chapter, we first recap the research questions proposed and the corresponding findings for this study in section 6.1. Accordingly, the key findings from this study are set forth in section 6.2. A summary of the contribution of this study is then presented in section 6.3 and the limitations are discussed in section 6.4. Finally, we conclude the thesis with suggestions for future research in section 6.5.

6.1 RECAP OF RESEARCH QUESTIONS AND FINDINGS

In this study we examined, analyzed and compared two empirical cases of citizen science initiatives in order to attain the research objective,

> *To gain empirical understanding on how citizen-generated data from citizen science initiatives can contribute to political decision-making and problem-solving in different contexts.*

Three research questions are formulated to attain the objective, for which we recap the findings respectively in the following sections.

6.1.1 Linking Citizen Science to Political Decision-making

The first research question was proposed as — *how are citizen science initiatives linked to political decision-making and problem-solving?* — with which we investigated the link or the pathway from a citizen science initiative to political decision-making and problem-solving of an identified issue. We applied a systematic literature review method to answer this question, whereby a conceptual model was proposed, as depicted in Figure 2-1. A summary of the explanations of elements and factors involved in the model was provided in Table 2-5. More details on the model were elaborated earlier in section 2.3. The proposed conceptual model describes how citizen science initiatives as a mode of governance are linked to political decision-making and problem-solving. Five major stages were identified in the model:

(1) *Enablers and drivers* — how such cases are initiated, including the elements of (a) technological development and (b) broadening of public attention drawn to the identified issue;

(2) *Development of the case* — how such initiatives lead to a citizen-driven solution of political decision-making and problem-solving, including the elements of (a) involvement of stakeholders and (b) quality of citizen-generated data;

(3) *Boundary-bridging or boundary-policing by standards* — how contextual settings and actors' perceptions and actions interplay and potentially play a part in such process (together with the elements from previous stages);

(4) *Project outcome* — what results or outcomes were produced by such initiatives, including the elements of (a) co-production with institutional players, (b) filling of institutional gap, (c) advance in political agenda, and (d) benefits of the collaborating stakeholders; and

(5) *Sustainability of the project* — how such initiatives sustain and continue to bring influence, including the elements of (a) supporting mechanism and (b) scalability.

The conceptual model further served as the guideline for the subsequent case studies for answering the second and the third research questions.

6.1.2 The Role of Citizen-generated Data in Linking Citizen Science to Policies

The second research question was proposed as — *how does citizen-generated data contribute to political problem-solving in citizen science initiatives, in particular as a mode of "socio-technical governance"?* — from which we sought to gain insights on the role of citizen-generated data in a citizen science initiative. More specifically, we attempted to probe into how citizen-generated data complements or fills in the institutional gaps in official data, how citizen-generated data situates at the open (government) data movement, and how such data was used by policymakers in decision-making or problem-solving process to address the identified issues around which the citizen science initiatives emerged. Case studies were performed as guided by the proposed conceptual model. Two cases — the case of AirBox in Taiwan and the case of Dutch Skies in the Netherlands — were examined and investigated. Findings from each of the five stages were summarized below,

(1) *Enablers and drivers* — Technological development was found to be a powerful driver for both cases. The broadening of public attention to the identified issue was also observed in both cases; however, it only led to a shift to participatory problem-solving in the case of Dutch Skies. As informed by the case studies, *institutional settings* and *organization culture* were added as two additional enablers and driving factors with an attempt to explain such differences.

(2) *Development of the case* — In the case of Dutch Skies the building of a trusted dialogue was noticed to be facilitated by the presence and involvement of diverse stakeholders, while in the case of AirBox, citizens were excluded in some sense from the institutionalized response to the initiative. For the quality of citizen-generated data, a "positive feedback loop" — i.e. the quality of sensors was improved through the use of sensor data, which in turn improved the quality of

sensors — was observed from both cases. Two additional dimensions were added to this stage: *communications between citizens and the government* was employed to further capture the dynamics among the actors involved, and the *openness of data and process* was added to emphasize the importance of transparency and receptiveness to opinions within citizen science initiatives.

(3) *Boundary-bridging and boundary-policing by standards* — Standards was observed to shape the distinct outcomes in the two cases. In the case of AirBox, standardized process policed the boundaries between citizen science initiatives (i.e. LASS) and scientific authorities (i.e. EPA) as evidenced by all sorts of "standards" imposed on the sensors installed by EPA in the Smart U&R project. By contrast, in the case of Dutch Skies, the citizen-generated data are "RIVM-approved" due to the involvement of scientific authorities in the project and therefore were "boundary-bridged" and attributed with validity and credibility.

(4) *Project outcome* — The co-production of solutions with institutional players was present in the case of Dutch Skies, whereby benefits for the collaborating stakeholders were produced — for instance, the change in attitude of Tata Steel. In the case of AirBox, although there was no direct involvement of citizens in the institutionalized response to the air quality issue, a rather implicit mode of co-production has emerged: citizens or non-governmental groups such as LASS community, who are more flexible and allowed to make mistakes, experimented new technologies and built pilots in some sense "for the government". In the case of Dutch Skies, citizen-generated data were used in both the filling in institutional gap and the advance in political agendas, while in the case of AirBox, citizen-generated data were more useful for "communicating the public's concerns" and had to some extents contributed to the institutionalization of the "pre-derating policy".

(5) *Sustainability of the project* — In the case of Dutch Skies, a supporting mechanism was more solidly established through successfully incorporating citizen-generated data into the official air quality models, while in the case of AirBox it is relatively unclear whether such mechanisms exist for relevant projects. In both cases, there are plans to further scale up the current project to either regional, national, or even global level.

We adopted the concept of "just good enough data" (Gabrys et al., 2016), and from the case studies, we observed that the use of citizen-generated data serves not for "raising public awareness" as what earlier conceptions of public science or citizen science suggests, but rather "communicating public awareness to regulators" (Gabrys & Pritchard, 2018) as resonated with the adopted concept. It was observed in the case studies that citizen-generated data have played a diverse range of roles in contributing to linking citizen science initiatives to political decision-making or problem-solving. For instance, in the case of Dutch Skies, citizen-generated data were used as a direct source of data input into RIVM's official atmospheric model and had helped improved the model. Citizen-generated data have also been used beyond regulatory use, as observed in the case of AirBox, in communicating concerns of the public and advancing political agendas. In addition, a "positive feedback loop" was identified from the case studies, where the quality of sensor data rapidly improved through the use of those data and thereby created a market and improved the quality of sensors.

The findings from the case studies formed the basis of the case comparison and discussions, which further guided the answer to the third research question.

6.1.3 Citizen Science Initiatives towards Political Decision-making in Different Contexts

Finally, the third research question was proposed as — *how is the contribution of citizen science initiatives to political problem-solving shaped by the contextual settings and dynamics of the actors involved?* — from which we aimed to explore how citizen science initiatives are shaped empirically by different initial enabling conditions as well as perceptions, actions and interactions of the actors involved and thus leads to varying outcomes in the influence on political decision-making and problem-solving.

We conducted a comparative case study analysis of two citizen science initiatives to gain insights on the interplay of the contextual settings and the perceptions and actions of stakeholders, and its implicit causal relation to an institutional response. Based on the findings from the previous research question, a revised, empirically enhanced model was proposed. The revisions comprised four major parts:

(1) *The interwovenness of enablers and driving factors* — As evidenced mainly by the interrelation of two additional factors — institutional settings and organizational culture — and their interplay with the broadening attention drawn to the identified issue, the influences of enablers and drivers on the development of citizen science initiatives were found to be intertwined among factors. The interwovenness of factors was depicted in the graphic illustration of the revised model by the ring of elements.

(2) *The significance of communications and openness on establishing trusted dialogues* — Two additional dimensions were introduced, as informed by the case studies, to the development of case in the revised model: communications between citizens and the government was added to further capture the dynamics among the actors involved; and the openness of data and process to emphasize the importance of attaining transparency and the receptiveness to opinions throughout the initiatives.

(3) *Citizens' perceptions on the role of competent and scientific authorities* — With the attempt to explain the differences in the two cases on whether boundaries between science and non-science were bridged or policed by standards, the influence of citizens' perceptions on the role of competent and scientific authorities was introduced. It was argued in this study that citizens' perceived distance as well as trust or distrust towards institutional actors were affected by the roles of such actors, and that the outcomes of citizen science initiatives were further shaped by these perceptions.

(4) *A positive feedback loop of sensor data use and sensor development* — The improvement in the quality of sensor data or citizen-generated data was realized through a positive feedback loop, where sensor development improves the quality of sensor data and drives the use of such data, which in turn fosters the development of sensors. In this view, citizen science initiatives could serve as a "push" which drives the abovementioned processes.

The empirically grounded insights gained from the case studies were further translated into policy recommendations for policymakers in government. The policy recommendations comprise three major parts: first, we encourage policymakers to move towards a co-production of solutions through engaging more stakeholders in the citizen science initiatives. Second, we advise policymakers to initiate a dialogue with citizens first by taking them seriously — more specifically, to start with listening to their needs and concerns, followed by communicating the methods and findings as well as empowering citizens with information and knowledge. Third, we emphasize the significance of attaining openness of data and process on trust building between citizens as well as among stakeholders.

6.2 Main Conclusions

This study aims to explore how citizen science initiatives are linked to political decision-making and problem-solving with a focus on the use of citizen-generated data generated from such initiatives. The study drew first on a systematic literature review on developing a conceptual model describing the process from a citizen science initiative to its influence on political decision-making, and then on case studies to explore how contextual settings and actors' perceptions and actions interplay and potentially play a part in the process. It was found from the case studies that the different "set-ups" such as institutional settings and organizational culture played a crucial role in enabling the citizen science initiatives, and that several factors such as the openness of data and the process along the development of the initiatives have shaped the outcome in different ways.

We probed into the aspect of the quality of citizen-generated data, and sought to explain the disparities found in the two cases by adopting the concept of boundary-bridging and boundary-policing by standards (Ottinger, 2010b). The difference in how standards were "harnessed" in the two cases suggested that it was more difficult to bridge the boundaries of science and non-science when the institutional actor was at the same time both the competent authority and the scientific authority, as observed in the case of AirBox. By contrast, in the case of Dutch Skies, the citizen-generated data were "RIVM-approved" and therefore were attributed to validity and credibility. The involvement of the scientific authorities, namely RIVM and GGD Amsterdam, in the project has helped in providing citizens with a sense of objectivity and thus facilitated the trust building process with other stakeholders involved.

6.3 Contributions of This Study

In this section, we elaborate on the contributions of this study. The scientific contributions are first set forth in section 6.3.1, as followed by the societal contributions in section 6.3.2.

6.3.1 *Scientific Contributions*

In this study, we addressed three identified scientific knowledge gaps through a comparative case study on citizen science initiatives for policies. First, we enhanced the limited empirical understanding in existing literature on how citizen-generated data from citizen science initiatives affects political decision-making through empirical evidence collected from two case studies. Second, the ambiguous reality of social interactions involved in citizen science initiatives was further investigated with an attempt to clarify the blurred boundaries between different forms of such interactions through in-depth analysis of the cases. Third, we furthered the understanding on how political decision-making and problem-solving (partly) led by citizen science initiatives are induced and shaped by contextual settings in citizen science initiatives through a comparative analysis between the cases.

A revised, empirically enhanced model was developed to describe how citizen science initiatives are linked to policies. We mobilized the findings from cases studies by Berti Suman & van Geenhuizen (2020), the notion of "just good enough data" (Gabrys et al., 2016) and the concept of "boundary-bridging or boundary-policing by standards" (Ottinger, 2010b) to explain the differences between the two selected cases. The two studied cases in this study are the state-of-the-art, bottom-up citizen science initiatives in the domain of air quality micro-monitoring, and have potentially served as a mode of socio-technical governance (Göbel et al., 2019), which is highly neglected in existing citizen science literature.

6.3.2 *Societal Contributions*

The society contribution of this study lies in the experiences and lessons learned drawn from the case studies. Based on the empirically grounded insights gained from the cases, policy recommendations were formulated to inform policymakers in government on how citizen science could be incorporated into the policymaking process or exercise as a mode of governance, and thereby contribute to problem-solving around societal issues of public concern. The policy advices were elaborated earlier in section 5.3.

6.4 LIMITATIONS

In this section, the limitations for this study are discussed. This thesis research was conducted within a period of five months by a single researcher; therefore, with limited time and resources, various limitations were present in the research. Below we describe three major limitations identified for this study, namely the limitations on case selection in section 6.4.1, data collection in section 6.4.2, and the use of the concept of boundary-bridging or -policing for social movement-based citizen science in section 6.4.3.

6.4.1 *Case Selection*

Case selection was one of the major limitations for this study mainly due to the limited time and resource for survey on candidate, existing cases. The two citizen science initiatives selected for this research were both relevant to the development of sensing technology and IoT techniques, both in the domain of air quality measurement and have both achieved impacts on political decision-making or problem-solving. However, the two selected cases were less comparable in terms of, for instance, the way through which the project was initiated and organized, and whether the involvement of stakeholders exists for the case.

6.4.2 *Data Collection*

Another major shortcoming identified in this study was the limitations regarding data collection. In this study, as mentioned in section 3.1.3, a total of six interviews was conducted in addition to the use of secondary data sources to provide information for the case studies. The collected data were considered too narrow and limited for determining what the organizational culture of the institutional actors is, considering that organizations and institutions are by nature very heterogeneous. A more comprehensive triangulation of data could be further achieved by, for instance, conducting more interviews. In this research, although more potential interviewees were identified through snowballing during the project, the interviews were eventually left unconducted due to time limitation. As a result, the access to more comprehensive information was not fully possible during this study.

6.4.3 *The Use of the Concept of Boundary-bridging or -policing for Social Movement-based Citizen Science*

In this study, we mobilized the concept of boundary-bridging or boundary-policing by standards, as argued by Ottinger (2010b), to explain the differences between the distinct outcomes of the two studied citizen science initiatives. Although the concept has indeed provided guidance for the case studies and has led to fruitful investigations on the cases for this study, more insightful analysis could be conducted using this concept for cases that to a greater extent fit the definition of *social movement-based citizen science*.

As elaborated in section 1.1.1, social movement-based citizen science emerges from the awareness on an identified issue in the society, and are developed and enacted by citizens to address such problematic situation; moreover, this tradition of citizen science aims at "fostering collective action and political change" (Tu, 2019, p. 240) and "critiques the universalizing, values-denying model of science that is currently institutionalized in academic and policy sphere" (Ottinger, 2017, p. 356). In this context, whether the boundaries between science and non-science are bridged or policed by standards becomes crucial to whether the results and findings from such initiatives qualify or are recognized as *science*, and further guides the reflections on what after all qualifies as science. In this study, the two selected cases did not meet such requirements of social movement-based citizen science, as they were not initiated or enacted by concerned citizens to address the societal issue: specifically, the case of Dutch Skies was carried out more as an inclusive mode of governance, while the case of AirBox was more technology-driven. This limitation is in some sense resonated with the limitations on case selection, which was discussed earlier in section 6.4.1.

6.5 Suggestions for Future Research

In this section, building upon the findings retrieved from this study, we identify three suggestions for future research on citizen science initiatives for policies.

6.5.1 *Investigation into the Positive Feedback Loop on Improving Data Quality*

In this study, a "positive feedback loop" — i.e. the quality of sensors was improved through the use of sensor data, which in turn improved the quality of sensors — was identified as informed from the case studies. While this process was described as a "self-fulfilling prophecy" in the case of Dutch Skies, the loop was also observed in the case of AirBox, where LASS community, the academics and also the private sectors pioneered the use of low-cost sensors and thereby stimulated further development of sensors in a cyclic pattern. This cyclic pattern, however, requires further investigation to more specifically describe how the development of sensor hardware interacts with and improves the quality of sensor data.

6.5.2 *Investigation into the Governance Aspect of Citizen Science*

We recommend future studies on citizen science research for an in-depth analysis from the aspect of governance, given that governance could be of complexity. In this study, we sought to investigate the link between citizen science and policies based on empirical evidence from citizen science initiatives which measure air quality — more specifically, particulate matter — with the use of low-cost sensors. Although the use of citizen-generated data on "doing" governance, such as the filling of institutional gaps and advances in political agenda, were identified in the case studies, to what extent was the identified issue "resolved" through incorporating citizen science into the governance system remains understudied. For instance, for the case of air quality management, the actual governance of air quality issues is much more complicated in practice. First, the quality of air is influenced not only by particulate matter but also other substances such as ozone and nitrogen dioxide. Moreover, there were no clear, explicit casual relations established between air quality and its impact on human health in existing studies. In addition, the governance of air quality issues often requires collaboration across different regions. In summary, more in-depth investigations into the governance aspect are needed to provide more concrete connections from citizen science to the problem-solving of many societal challenges.

6.5.3 *Representativeness of Citizens in Citizen Science Initiatives*

The representativeness of citizens or participants in citizen science initiatives is also an interesting aspect for future research on citizen science. As observed in both two cases in this study, the participants in the citizen science initiatives are almost all middle-aged, well-educated and mostly male — a situation which is very typically seen in citizen science research, yet hardly represents the population of citizens. We thereby recommend future research to address the challenges of this representative of citizens in citizen science initiatives.

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Appendix A. Interview Transcripts

The interview transcripts were documented in the form of anonymous summaries and all personal identifiable information were excluded to ensure that the transcripts are anonymous.

List of Interview Transcripts

A.1 Interview with a Project Team Member from Waag (Dutch Skies)

1. Brief introduction to Waag

Waag is a non-governmental foundation based in Amsterdam which operates at the intersection of science, technology and art and believes in the values of fairness, openness, inclusivity. Waag's work focuses mainly on using the emerging technologies as instruments of social change. Citizen science is one of the topics of their focus. Waag has been running a program called the Smart Citizens Lab, where they explore tools and applications that help make sense of the living environment, and work with citizens and designers to tackle environmental issues, ranging from air and water quality to noise and pollution.

2. Partners in the Dutch Skies project

RIVM, GGD Amsterdam, Waag and the Province of North Holland are the four major parties in the project. The Province is the client of the project — they paid for the project, searched for different parties who have an expertise in some certain fields to join the project, and were also linked to all the strategies and the data analysis. The RIVM and GGD Amsterdam are more focused on the air measurements in addition to analyzing the data. For instance, RIVM has developed a data platform and a Shinny App during the project. Waag is in charge of the development of sensor technology as well as the communication and community management: they built the sensors and the Dutch Skies website, developed the data flow, and were the most in contact with the citizens. There are also other minor partners involved in the project, as listed on the project website, such as Omgevingsdienst, as well as some local, smaller partners, such as Brak! and Pieter Vermeulen Museum, yet they are not working on the project on a daily basis.

3. Participants of the project, and the *Dutch heroes*

Waag uses a mix of different approaches to find their participants. For every pilot, Waag started with organizing two meetups together with their partners, where participants discussed and decided their measurement strategies. So Waag had help from the Province, the other partners (e.g. the museum) and also the municipalities in the area to find active citizens. Waag also uses local newspapers and social media, as well as setting up events on the online meetup platform.

There were around 120 participants in the Dutch Skies project, among which there was a small group of around ten participants called the "Dutch heros" (in Dutch, *Hollandse Helden*). The Dutch heroes were more actively involved and spending a lot of time with the project, which was *"amazing"* for Waag as they *"never thought that the participants wanted to be involved in such a way as the Dutch heroes are doing that now,"* according to the interviewee.

Almost all Dutch heroes involved in the project until now are over 50 years old — some of them had already retired, and there were more men than women in general. They were all very concerned about their living environment, and some of them have already been doing some things about air quality. The level of technical knowledge and skills, however, varies among the participants: some were with a rich technical background and can understand a lot about the hardware, and therefore were keen to develop some parts of the sensors themselves; others were less technical, and Waag has organized technical trainings for them.

In general, the participants were motivated by different goals for each of the three pilot projects in Dutch Skies. For the first pilot in IJmond region, citizens are concerned about the air pollution of the neighboring Tata Steel. For the second pilot in Amsterdam and the Buiksloterham area, the participants have another concern. And for the third pilot in Zaanstad–Kogerveld, people are more concerned about the car pollution because the area is very close to a highway.

4. Communications with citizens

Waag makes uses of a few different channels to communicate with the participants: On the Dutch Skies website as well as via newsletter, Waag always shares news and posts about the sensors or the technology. Besides that, Waag also gives updates to the Dutch heroes, who sometimes further communicate things to the other citizens in their area. And for the rest, Waag also communicates via email a lot because still many people find it very handy.

There were no big conflicts between the citizens and the government experienced in the Dutch Skies project. According to the interviewee, although the citizens were critical, *"the two parties can listen to each other."* They've had different conversations with one another to see how the two parties can match, and how to involve citizens more in the province. Per the interviewee, the Province is very open for the voices of the citizens, although the project is also something very new for them.

5. Challenges and lessons learned

As the Dutch Skies project is one of the first citizen science projects in the Netherlands on this scale, everything is very new for all the partners involved and there was no blueprint for it. For community management, it was quite a challenge for Waag on setting up a local community, distributing the technology and on dealing with participants with various levels of technical knowledge and skills. They learned that it is important to have contacts with the local community, and that it is more valuable to use the existing social networks instead of building a network themselves. And for the second phase of the project, more technical trainings will be provided to participants with less technical knowledge. From a technical aspect, Waag has also faced quite some challenges on developing the technology, in particular on setting up the LoRa network in different cities.

At the time of the interview, Waag was working on an evaluation of the first phase of the Dutch Skies project with some participants. From what Waag has learned from their feedback so far, the participants were hoping to be more involved in the decision-making process or the whole strategy of the project, rather than being only a participant doing the measurements.

A.2 Interview with a Researcher at RIVM (Dutch Skies)

1. The context

RIVM has an innovation group who researches on new ways of doing air quality monitoring. One of the first citizen science projects was the iSPEX project — initiated in 2012, the project was the "ticket" for the researcher and also RIVM to citizen science. Together with the University of Leiden, RIVM developed the plan for citizens to do measurement on air quality with their mobile phones. In light of the development of sensing technologies, for RIVM as an official institute, the question became: *"Do we want to be in this development, and do this together with the people? Or do we want to ignore it, and then it will not stop but it will go on without us, and we will have no control over it and have no influence on it."* This then resulted in the Samen Meten ("Measuring Together") program, and Hollandse Luchten ("Dutch Skies") is one project focusing on the measurement of air quality under the umbrella program.

It is worth noting that the democratization of information, (partly or perhaps mainly) resulted from the development of smartphones, is driving the development citizen science. Because *"everyone can google things even if they are not experts,"* today experts need to explain things much more. The need of new ways of communicating with citizens is one of the major motivations for RIVM to dive into citizen science. While social interactions are considered important, the scientific part of the results — the air quality measurements themselves — also have to be useful.

Nevertheless, RIVM's recognition on the significance of citizen science was not a smooth and easy process; rather, it was *"a process of a number years of very softly moving and carefully moving"*. As noted by the researcher, most oppositions against citizen science at the early stages were from their colleagues at RIVM, namely from the experts themselves: *"The citizens are not the problem. The experts are the problem. How do you find the experts who want to trust the citizens?"* It took around three to four years before the opposed experts started to change their conceptions on what the measurement meant for them, and started to accept it as a fact that RIVM is now measuring together with citizens using the citizen science approach.

2. Partners in the Dutch Skies project

The project was initiated by the Province of North Holland. RIVM was one of the partners along with the municipalities, GGD Amsterdam, Waag and many other parties. RIVM was asked to join the project for several reasons: their knowledge of the quality of the sensors and the interpretation of data, as well as their expertise in citizen science.

GGD Amsterdam and RIVM both have their expertise in air quality measurement. Together with the DCMR[22], their measurement stations form the official air quality monitoring network in the Netherlands. RIVM has around 50 national measurement stations that are according to European regulations all over the Netherlands. Around the Port of Rotterdam and the Port of Amsterdam, there are extra measurement stations owned by DCMR and GGD Amsterdam respectively, that are of the same quality as the national measurement stations.

[22] DCMR Milieudienst Rijnmond is the joint environmental protection agency of the province of South Holland and 15 municipalities in the Rijnmond region. For more details, see its official website: dcmr.nl.

3. The link to politics and policies

The citizen-generated sensor data were now used in RIVM's modelling and helped improved the model. This was an important and meaning step for RIVM on its investments in citizen science, as explained by the researcher, *"because the ministry is really giving us the money to do this, we have to be able to say to the ministry, look, we have to support citizen science, because then we can give you this nice model with all these details."*

Citizen science could contribute to changing local politics — more specifically, to change the agenda of political parties — as it creates a lot of publicity, and *"there's no politicians in that area who cannot take this into account in the politics."* It is worth noting that RIVM also played a role in this process: because the citizens are measuring with RIVM, local governments have to take them more seriously since they *"are not local lunatics."* It is worth noting that, however, the attitude of local government towards the acceptance of citizen science can vary widely from one to another, and the attitude may also change over time. The varying attitudes are evidenced by the experience of measuring with citizens using NO2 tubes in municipalities around the city of Rotterdam, as well as the case of the city of Arnhem.

As the researcher argued, measuring with citizens could help *"avoid a crisis"*. For instance, RIVM is currently working on measuring noise pollution with citizens, for which *"if we start doing this now, around this topic of noise, we can sort of avoid a crisis that will happen in five years."* Noise is a hot debated, politically sensitive topic at the moment: all the policymaking is done based on models by regulation, yet the modelling results are to some extent inconsistent with the living experiences of the citizens, who are suffering from the noise pollution.

4. Communications with citizens

Citizen science is considered an effective tool to communicate with citizens because of the wide publicity and thus huge impacts it creates. This was evidenced by the measurements with the "firework sensors" — sensors of poor quality that they could only be used to measure the huge peaks resulted from the new year fireworks — in the early stages of citizen science projects: *"So newspaper were writing, citizen science are measuring... finally the fireworks are being measured... which was very frustrating for my colleagues, who are doing the official measurements and who were writing a press release every year about how high this peak is. And no, no newspaper picks it up."*

The researcher highlighted the criticality of *"taking citizens seriously"* — which is particularly done by *"starting to listen"*. In addition, to facilitate the communications, RIVM also makes use of Twitter to spread information. As noticed by the researcher, even if the citizens were anti-government or anti-RIVM, they became much less hostile *"as soon as we started to talk to them."* As the researcher further explained, *"even have all kinds of politics or activists' ideas, they still want to have high quality measurements. So give them a bit of trust."*

5. Challenges, lessons learned and next step

The quality of citizen-generated data is crucial to RIVM since their ultimate goal is to incorporate such sensor data into their official models. The data is now very useful because its quality has improved a lot throughout the years, which was materialized very rapidly with the particulate matter sensors through a kind of "self-fulfilling prophecy". As explained by the researcher, *"because by taking this sensor data, doing something with the sensor data, you create a market. And by creating a market, you create better sensors."*

One of the challenges which RIVM encountered was to advocate the publicizing of citizen-generated data, especially in the cases where the data were of less good quality. In the Dutch Skies project, for instance, GGD Amsterdam was initially opposed to the opening of PM10 measurement data because of the poor data quality. As described by the researcher, *“we are not going to... sort of exclude it from the results, because then, we will lose trust.”* For RIVM, it is important to explain the results and deal with crappy data through calibration techniques. The calibration model used is also planned to be open to public.

A.3 Interview with an Officer at the Province of North Holland (Dutch Skies)

1. The context

The initiative of Dutch Skies can be dated back to around 2016, when the province of North Holland first had discussions about having a citizen sensing program, which were later put into the farther proposal of the project in 2017. The discussions were driven by two major changes. One was in the society, that people are more aware of the quality of their living environment, in particular air quality. The other was the change in how the province sees its role in the issue. Traditionally, the province has a very strict interpretation of its role. From their perspective, air quality management in the Dutch system is mainly up to the national government, and together with the municipalities they take the measures: *"…we didn't see a big role for us, in ourselves… before that, we said, well, that's not really our thing."* Over the years, as the province kept receiving increasing demands on taking actions for the air quality issue, they have started to think that *"we should also make policies for things that are perhaps not our direct responsibility, but that we still do and feel responsible for."* The province thus was hoping to start a monitoring program to have a more detailed view of the air quality in some parts of North Holland. For the province, it is important to first get the data and information so that the provincial government *"can make policies based on those data."*

This has also led to a discussion on whether the province should move forward to a more participatory strategy, for which the province decided to experiment with the idea of citizen science and put forward the proposal of the Dutch Skies project. The decision was heavily influenced by a mix of two important factors. The first is the introduction of the new *Environmental and Planning Act* (*Omgevingswet*), a national law that integrates lots of different separate pieces of legislation on the environment and planning. Public participation is a key element in the new law. The new law was initially expected to take effect in 2018, and therefore became a strong boost for the province to start experimenting with more citizen engagement: *"I mean, that law was coming, everybody knew it was coming. So you have a good reason to do it."* The second factor is the organizational culture of the province, especially the (shared) beliefs and values established by the provincial executive (in Dutch, *Gedeputeerde Staten, GS*). One of the representatives of GS or the governors, who was in charge of environmental policy for the province, was a very *"activist person"* and was very open to the idea of citizen science, and thereby provided a strong support for the proposal of Dutch Skies: *"…if you don't have an activist governor who really wants to do something, then you just wait."* Therefore, the institutional settings and the personal values of those who are in office together played a crucial role in the enablement of the Dutch Skies project: *"The personal aspect is very important, but also the setting. Because otherwise… this kind of proposal has been there before, but then the other governors are very skeptical. So why should we do this? Is this necessary? Why would you make this more difficult for ourselves than it already is, so to say, more or less? And in this day, they knew and that killed that discussion because we know we have to do something with it. And for that reason, they accepted it."*

As the GS accepted the proposal of Dutch Skies, the province started with the preparation in 2017. In 2019, although a new GS was formed after the provincial elections, the Dutch Skies project continued with little frictions as the representative for environmental policy from the previous period stayed in office. The project later became a part of the Healthy Living Environment Program (*Programma Gezonde Leefomgeving*), which is a part of the province's environmental policy established in the new Coalition Agreement (*coalitieakkoord*).

The project started with five communities: three of them are around Tata Steel in the IJmond region, one in Zaandam, and another one in the north of Amsterdam. In total, they have 200 sensor stations running at the time of the interview. In the coming years, the province plans to expand the project.

2. Partners in the Dutch Skies project

The province of North Holland has selected some parties as their partners for the Dutch Skies project: RIVM and GGD Amsterdam were asked to join the project because of their expertise in air quality measurement and their control of the official measurement stations; Waag was asked to organize the communities for the project; and also with some other municipalities, organizations and companies. It is worth noting that, throughout the project much room were provided to the collaborating stakeholders, as explained by the officer, *"so I gave everybody room to create their own project, and also become an owner of the project in their own right. And I think that's worked because everybody really felt involved."*

3. The link to politics and policies

It is not yet clear how the data collected will be used in province's policymaking process in practice. While many citizens were enthusiastic about doing measurements around Tata Steel, the province is more looking forward to using the sensor data in areas where the current development plans take place. For the province, the data collected from these projects might further serve as the evidence-base for decision-making.

4. Communications with citizens

The distrust from citizens was mainly against the province rather than RIVM or GGD because the province is the one who is responsible for issuing the pollution permits, and therefore the citizens *"think that we should do more."* The officer emphasized the cruciality of openness throughout the process especially when confronted with such difficult situation. In the Dutch Skies project, citizens were provided with much freedom on making decisions regarding the measurement strategies: *"they [i.e. citizens] were the ones deciding what you're going to measure, and have all these different, independent parties who offer the experience and knowledge. And I think that helps to not make it the government's project."* Also being honest and transparent with the citizens about the project goals so that *"people have to know what they can expect."* As the officer explained, *"we can make no guarantees for it. The only guarantee that we committed is that we are going to measure, is that we make sure the quality is as good as this can be, and that all the information is open and shared. That's the one thing that we can do."*

The importance of involving of diverse stakeholders is also underlined by the officer. For instance, the participation of the experts in air quality measurement in the Netherlands, i.e. RIVM and GGD Amsterdam, helps establish trusts among the participants because *"people perceive them as objective."* As the officer commented, *"with Waag Society, RIVM, GGD... I think that helps, too."* And that the project would not have been successful *"if it was purely from the government."*

Another crucial part in establishing a trusted dialogue with the citizens is that *"people control the technology, that people understand it. So they get explanation about the technology, and then the experts from RIVM gave explanations about measuring air quality, how that works. So also feeding them with information and knowledge. So that also changes the discussion."*

5. Challenges, lessons learned and next step

For the next step, the province is planning to expand the monitoring network, and therefore to have a good understanding of the living environment. The main goal of is to ensure that this knowledge is available for everyone, i.e., the local governments, the province as well as the citizens — everyone can use the information in their own planning.

A.4 Interview with a Founding member of LASS Community (AirBox)

1. The context

The origin of LASS initiative was the interviewee's interests in the "Maker movement", which later motivated the interviewee to start making things in the "do-it-yourself" approach. Air quality measurement was selected as the domain for this application work since it was the most heated topic at the time. The functioning of LASS community is "contribution-based" and in a rather distributed mode, and almost everything happens online — no regular, face-to-face meetings were hosted, yet all discussions were opened to and accessible for everyone. The members in LASS community encompass a wide range of occupations and backgrounds, including makers, engineers as well as people from private companies, academics and research, environmental groups, etc.

In the early days of LASS initiatives, the introduction and use of low-cost, self-assembled sensors created huge conflicts between EPA and LASS community. As the interviewee explained, *"at the beginning, EPA … or those people from the field of environmental engineering … very much despise this micro-monitoring thing. They consider these microsensors toys which are inaccurate and useless … In their view, sensors ought to be accurate, and have to be calibrated."* The interviewee further argued that, since the measurement of particulate matters in ambient air are *"inherently unpredictable and uncertain"* and, moreover, *"you cannot explain the causal relation between PM2.5 and health"*, it is impossible to accurately measure particulate matters and its impact on human health. In their perspective, EPA's way of dealing with measuring air quality with the use of low-cost sensors was *"unrealistic"*: *"it's like you're asking a thing … which is impossible to be measured accurately … to be measured accurately, and if the measurement were not accurate, you can do nothing."* These conflicts were gradually resolved through the somewhat implicit dialogue established through the researcher at the Institute, although till date there was no direct collaboration or partnership between EPA and the community of LASS.

2. Collaborating with the government

LASS's way of working with the EPA today is through an implicit collaborating mode. As the interviewee explained, the community were actually hoping that *"the government could do something nice"* and therefore, they were very pleased when the government "copied" their work: *"we don't want the government to create something awful, so we demoed how it's supposed to be done for them."*

3. Challenges, lessons learned and next step

When being asked about the sustainability of the initiatives, the interviewee highlighted the importance of "usefulness" of the relevant projects of AirBox. As the interviewee explained, *"from what we have now, the government is installing sensors in industrial zones, and we're doing this with the citizen science approach … If this mode could continue to work, I think it's nice."* Per the interviewee, *"it would be a pity"* if EPA's Smart U&R project later just discontinued after it were completed since "*it has a lot of positive impacts on the society"* after all.

A.5 Interview with a Researcher at a National Research Institute in Taiwan (AirBox)

Note: We avoid explicitly indicating the name of the national research institute in this study in order to prevent the interviewee from being easily identifiable. A national research institute in Taiwan could be, for instance, Academia Sinica, National Chung-Shan Institute of Science and Technology (NCSIST), Industrial Technology Research Institute (ITRI), etc.

1. The context

The origin of the project of air quality micro-sensing on campus (hereafter referred to as Campus AQ project) can be traced back to the 2016 Taipei Smart City pilot project, which was initiated partly as a response to the emerging trend of environmental sensing with the use of low-cost sensors as well as the Internet of Things (IoT) techniques that arose in around the year of 2013–14. In addition, the issue of air quality was a heated debate in Taiwan in 2014–16. In this context, the pilot was put forward to experiment with the concept of IoT sensing network in the domain of air quality monitoring. The launch of the project was made possible also because of the organizational culture of the then Taipei City Government (TCG), or more specifically, the (shared) beliefs and values established by the head of government and leaders in the organization. At the time, the mayor in office "very much values the use of Internet and new technologies". Moreover, the then head of the Department of Information Technology, TCG *"was able to understand these things"* and was very willing to experiment with the innovative technologies in the city of Taipei. The pilot was a collaboration among the Taipei City Government, the National Research Institute (see note above; hereafter referred to as the Institute), as well as a fabless semiconductor company "Realtek" and (later) a manufacturing company of network communication products "Edimax", based on the sensor prototype (i.e. LASS AirBox) developed by the LASS community. The success of the pilot project in Taipei then attracted the attention of the local governments of the remaining five major cities in Taiwan, which paved the way for the later Campus AQ project — a project under the umbrella program of Civil IoT Taiwan — where air quality sensors were installed in primary and secondary schools throughout the nation.

2. Partners in the Airbox project

The researcher at the Institute has a dual role both from the side of citizens — namely, as a participant or a member of the LASS community, and from the side of science and research when involved in the Taipei Smart City pilot project and co-initiating the Campus AQ project. The Campus AQ project is mainly a collaboration between the Ministry of Education, the Institute and EPA, together with different local governments — more specifically, the Bureau of Education (main contact) and the Bureau of Environmental Protection (supporting role) — of the cities where the sensors were installed.

During the project, the Institute had diverse experiences when working with different local governments. For instance, in the experience with the city of Taichung, the local government was more critical of the idea of AirBox particularly because it was around the time of local elections, and air quality issue was the most debated and sensitive topic at the time; therefore, the government of Taichung City was under great pressure, for which some *"blamed AirBox for being a drag on the government because the information was disclosed."*

3. The link to politics and policies

The link of sensor data to policies is twofold. First, the sensor data generated from the Smart U&R project were analyzed and used to inform "smart auditing" on illegal pollutant emissions, primarily by the industrial plants. Second, the sensor data played an important role on influencing politics through the communications between the environmental groups and the government. This was evidenced by the institutionalization of the "pre-derating policies" — i.e. by launching a derating, the emissions of air pollutants were temporarily reduced, and the quality of air would potentially be improved or kept at an acceptable level. Although the effects of power plants derating on the quality of air were already known to the policymakers, the derating policy was previously only launched based on "mutual understanding" between the government and the power plant, and only after the quality of air indeed worsened. It was after the continuous communications on the needs and concerns of the public to the regulators — partly through the use of sensor data — that the pre-derating policy was finally institutionalized into regulations.

4. Communications with citizens

The communications with citizens were less relevant for the Institute from the point of view of the researcher. As the researcher commented, they would help on communicating the methods and scientific principles of air quality measurement "in passing" but they would not proactively do so as if it were their responsibilities: *"it is not within our scope of research."* When being asked about EPA's communications with the citizens on the limitations of AirBox, the researcher at the Institute suggested that *"LASS is actually a quite nice platform"* for bridging the communication gap between the government and citizens.

5. Challenges, lessons learned and next step

The researcher at the Institute is now aiming at a further scale-up of LASS AirBox to a global level. In this regard, the criticality of open data was underlined by the researcher: *"we were hoping that everyone sees eye-to-eye on the opening of data, instead of working on closed systems that are isolated on their own … I think closed systems are all a splurge of money. Once the financial support stops, the ecosystem would be gone, which would be such a pity."*

A.6 Interview with an Officer at Department of Environmental Monitoring and Information Management, Environmental Protection Administration in Taiwan (AirBox)

1. The context

The project of *Smart Air Quality Micro-sensing in Urban and Rural Areas* (hereafter referred to as the Smart U&R project) is a project under the umbrella program of Civil IoT Taiwan. The Smart U&R project was mainly implemented by two sectors in EPA which are respectively in change of tasks related to hardware and to software, and the latter part fell under the scope of the Department of Environmental Monitoring and Information Management, EPA (abbreviated as Dept. EM&IM). The main tasks on the software side are around the transmission, storage, and analysis of sensor data, including server setups as well as development of application systems. It is worth noting that the Civil IoT Taiwan program — advised by the Board of Science and Technology (BoST), Executive Yuan and sponsored by the Ministry of Science and Technology (MoST), Taiwan — is a part of the construction of digital infrastructure under the Forward-looking Infrastructure Program, or more specifically, an institutional response to the trend of Internet of Things (IoT) technologies. Because of EPA's accountability in air quality and water quality monitoring, they therefore put forward the proposal of installing air quality microsensors, whereby data collected could be used for "smart auditing" — i.e. using the findings from sensor data analysis as "informants" to assist in auditing on illegal pollutant emissions primary by the industrial plants. The proposal was relevant to the development of micro-sensing technologies, as explained by the officer, *"when we were drafting the [Smart U&R] project… because the Forward-Looking Program is a technology-led program, it is about some new development … though there were non-governmental initiatives of low-cost micro-sensing like LASS and AirBox, we thought … this [i.e. micro-sensing] could be an application in the industry."*

In the first phase of the project (2016 — 2020), around 200 sensors were deployed in the industrial parks, including Guanyin Industrial Park in Taoyuan, Yingge Industrial Park in New Taipei, and Dalinpu Linhai Industrial Park in Kaohsiung. In the upcoming second phase of the project, EPA will be working with local Environmental Protection Bureaus (EPBs) in the local governments in the cities and counties to deploy more sensors. The goal is to construct a multi-level air quality monitoring network, with more than 10,000 sensors deployed at the lowest levels of the network.

2. The link to politics and policies

The relevance of the Smart U&R project on politics and policies was mainly the use of sensor data for "smart auditing". In this use, as the officer at EPA describes, the analysis of sensor data assists EPBs in identifying the "crime hotspots" so that EPBs "crackdown on" illegal emissions of air pollutants. It should be note that, however, the sensor data were not legally binding even though they were generated from EPA's sensors, and were therefore not directly used as "evidence" but rather as "informants" in the application.

3. Communications with citizens

The relationship between the Smart U&R project and the Campus AQ project (as well as LASS) was more like two parallel lines, although implicitly EPA and LASS were in a positive competition or, in some sense, LASS acted as an inspiration for EPA on development the plans for air quality micro-sensing.

When being asked about EPA's attitude towards citizens' initiatives on air quality measurement using low-cost sensors, the officer emphasized EPA's "openness" towards the cases. As the officer explained, *"we did not ban or tell people that you cannot do it … So people are developing this thing [i.e. air quality micro-sensing], we are quite open to it. Because you have your own purposes. We were just reminding the people that the measurements from microsensors cannot be used as the only reference of the air quality of your living environment. Of course, they can still install sensors, at different locations … and they will take care of the calibration for sensors with whatever methods they think is necessary. And of course, they can also come to EPA for calibration in reference to our measurement stations … per my understanding this was also the case [of interaction with people]."*

It was also underlined by the officer on the difference between EPA's need and citizens' motivations in their response towards citizens' initiatives. Because of this disparity, the requirements on sensors in terms of their installations, quality control and maintenance also differ. Accordingly, EPA has a stricter requirement on the quality of the sensor data that EPA released on their data portal.

Appendix B. Supplementary Information of the Case of AirBox

B.1 Relation between Relevant Projects of AirBox

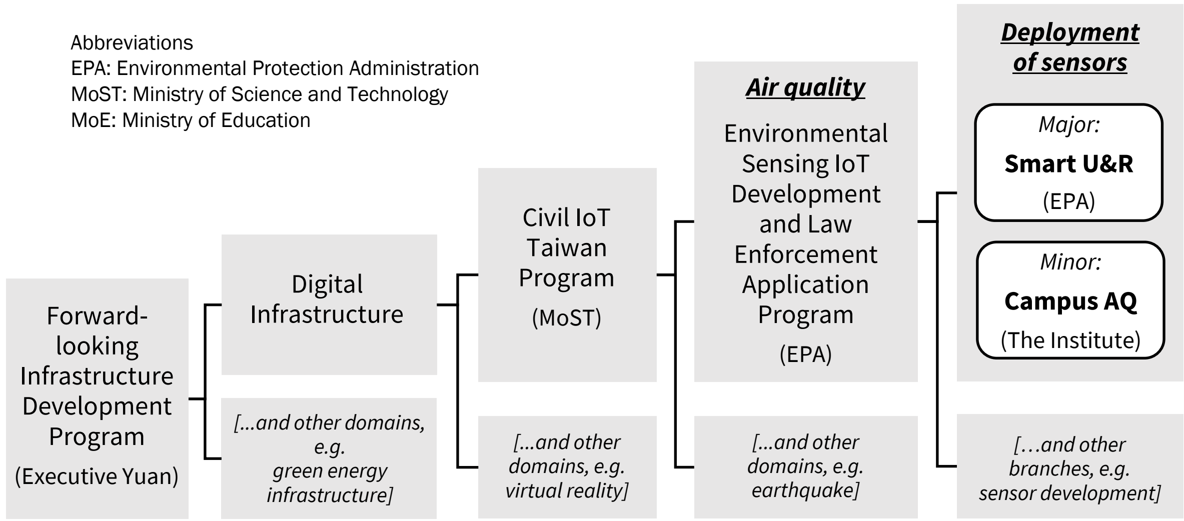

Figure B-1. Relation between relevant projects of the case of AirBox

Note: EPA's *Environmental Sensing IoT Development and Law Enforcement Application Program* (環境品質感測物聯網發展布建及執法應用計畫) encompasses a variety of efforts towards the establishment of an air quality monitoring network and relevant application in environmental protection. The projects of Smart U&R and Campus AQ are responsible for the part of microsensor deployment. Other parts include the development of microsensors, data analytic tools as well as innovative use of the network. For more details, see Most, EPA, MoT, MoIA & MoEA (2017), pp. 15–17 and EPA (2018) pp. 6.

B.2 Original Quotes in Taiwanese Mandarin

The quotes taken from interviews for the case of AirBox were translated from Taiwanese Mandarin to English. Below the original quotes were provided as a reference for the English translations used in the thesis report.

1) Enablers and Drivers

a. “我們當初是在提前瞻計畫的時候我們就是…這個是屬於比較偏科技計畫，那是一個新的發展，因為以前沒有…在民間雖然說像那個 LASS 啊、Airbox 他們已經有在做簡易型的，那我們是認為說…這個是可以做產業程度上面的應用，所以來提這樣子。” — Officer at Dept EM&IM, EPA

b. “我覺得有一個滿典型的，就是台中，台中其實一開始不喜歡我們，我們其實一開始在台中…就是我們會很害怕去，因為那時候剛好選舉…那時候就卡在選舉，我們要在選舉前還是選舉後去布建，然後後來就決定我們在選舉後，我們不要去淌混水。結果那一次其實空品…其實空汙是一個很大的議題，甚至就是…（訪談人: 主戰場。）對啊，甚至從立委那邊壓力都有啊…因為大家都在討論空品，然後都覺得是空氣盒子害了那時候的政府嘛，因為很多數據就被揭發出來嘛。那…那個時代，實際上台中市的教育局、環保局，其實他們通通都…應該都不喜歡啦，應該對我們本身比較排斥的啦。你說不喜歡，他也不會說不喜歡，也是有請我們去演講什麼的，但是實際上是比較難溝通的。” — Researcher at the Institute, Taiwan

2) Development of the Case

c. “它在一開始的時候，環保署或者是很多那個…那我們應該叫做環工界…在很早期的時候，他們非常瞧不起這個微型感測，他們覺得這個東西是玩具，又不準，不能拿來騙人，這是垃圾，差不多是這個概念…他們就是認為說，你感測器就是一定要準，就是一定要校正，這在他們教科書裡面寫的…那我們的認為就是說，你這個東西是可比對的嘛，它是穩定的、它是可比對的嘛，而且就核心上來講就是說，PM2.5…很多東西其實它跟裡面的粒子…它本來就是不保證的，而且…你又講不出 PM2.5 跟健康的關係，你一直要求它很準，然後是以某一種標準的東西，它又不是很全面…有點概念就是，你本來就是一個測不準的東西，然後呢你一直要它測得很準，如果測不是很準，你就什麼事都不能幹。這不現實嘛。” — Founding member of LASS community

d. “我們又沒有收他的標案、又沒有幹嘛，我又不鳥他，對不對…那但是民眾就會去哀他啊，他就覺得我們這個很爛、很煩啊，然後他總是需要發一些公開的新聞啊，他就是要強調說，民眾你不能盡信這些空氣盒子的東西啊。他講的也是事實啊，但是對我們…聽起來就很刺耳啊，他就是很公開地說我們東西有問題啊…所以一開始是很衝突的。” — Founding member of LASS community

e. “我們並沒有特別的…就是說這樣不行啊，怎麼樣的。那所以他發展這些事情的話，這是…應該是還是滿開放的啦。因為你有你自己目的嘛。但是我們只提醒你民眾說，那個不能當作你空氣品質的唯一參考，那他還是可以布啊，他可以在不同地方布，那他有需要什麼樣的校正他自己會自己去處理，那當然他也可以來跟環保署說，那我是不是可以跟你的測站一起…以前我印象中之前有做過。” — Officer at Dept EM&IM, EPA

f. “我們會順便做（註：與民溝通及知識宣傳），但是不會主動去做，因為這畢竟…不是我們研究的範圍。那…環保署他們有在…有系統地在做，可是他們做的效果，我覺得很差。因為他只要一出來講這些東西，就會覺得…他有他的包袱在，所以他怎麼講，他都一定會再搬出一套…就是讓人家聽了不是很舒服的話。那民眾要聽的語言，跟政府的官話，其實又不太一樣。那他需要一個中間人去傳。那 LASS 其實是一個很好的平台。” — Researcher at the Institute, Taiwan

g. “因為我跟他講，你這個機器拆開來之後看到的感測器民眾也買得到，所以如果它吐出來的資料跟民眾自己做出來的資料不一樣，就完蛋了。所以你…你必須要吐出來的資料就是 raw data，然後你再告訴民眾，你是如何校正它的。” — Researcher at the Institute, Taiwan

3) Boundary-bridging or Boundary-policing by Standards

h. “環保署的微型感測器…它的感測器其實跟我們的感測器一開始是一樣的，那唯一的差別是什麼，就是他把環保署的標準測站的那一套拿來用在他的微型感測器。所以…他的微型感測器，出廠前要先放在同一個地方，去放個一個月、還是三個月…去做觀察，然後去做校正，之後才到現地。到現地之後呢，他每一段時間就會派人去檢修，去看一下有沒有狀況，去清潔一下，然後會放另外一台機器在旁邊去做平行比對，啊如果不一樣的話，就把舊的那一台就拿下來，拿回去整理，拿新的一台放上去。所以他是用…非常高的維護成本去 maintain 他的便宜的感測器。” — Researcher at the Institute, Taiwan

4) Project Outcome

i. “對。他有包袱，所以…我覺得他是需要幫忙…所以其實你看環保署跟我們之間這樣糾結很多嘛，常常這樣互相…一開始還不是很客氣，他對我不客氣，我對他也不客氣。可是…後來會發現說我們本質上應該是朋友，因為我們目標是一樣的，然後都是在接觸新科技，所以你知道他的困難點在哪裡的時候，兩邊應該是互相幫忙，互相黑臉、白臉，因為最後是兩邊一起往前推進，這才是最好的狀況。那現在就是有這種默契在啦，我們平常也都不吵對方了啦…然後有問題的時候我們…是可以有溝通管道，然後一起去解決。” — Researcher at the Institute, Taiwan

j. “假設政府能夠做得很好，那我幹嘛做這些東西…我又沒在賺錢，我那麼辛苦做這些幹麼，啊社群的理念、那麼多的人都沒有賺錢，在這邊做、在這邊幹麼，他們就是希望政府做得好嘛。所以當政府把我們的東西抄走了，我們是很開心的事啊，你…不要做爛東西嘛，所以我們 demo 一次給你看什麼才是對的嘛，大概就這樣子。” — Founding member of LASS community

k. “一開始提前降載是…好像施予恩惠，人家求他的，現在變成是強迫…怎樣 condition 下你就要強制降載，或者是即使 condition 沒有到，民眾就會說一定會糟的，你不聽我的話，到時候一定會糟的，他現在都知道一定要降載。什麼樣的條件，就是預報一定會…空氣會變差的時候。” — Researcher at the Institute, Taiwan

5) Sustainability of the Case

l. “我覺得重點是有用就更發揚光大嘛…我覺得以現在來講，就是這種結構，政府做到工業區，然後我們這些民間用公民科學的方式做這些東西，如果他能夠繼續這樣子的維持下去，應該是好事。但是他其實…他的專案是有點像…他四年一期，然後四年後呢，難聽一點，搞不好他停掉也不一定，對不對。然後…我覺得停掉相對就可惜了，因為他畢竟就有很多的社會的影響，或者說這些有效果的東西。所以就評估上來講他應該延續。” — Founding member of LASS community

Appendix C. Reflection on MSc Engineering and Policy Analysis Program

This research was conducted in partial fulfillment of the requirements for the degree of Master of Science in Engineering and Policy Analysis (EPA) at Delft University of Technology. In this appendix, a reflection of the study on its relevance to the master program is presented.

The linkage of this study to the MSc Engineering Policy Analysis program lies in the analytical, social-technical character of the research approach and the conceptual modeling aspect of perceptions. The investigation into how citizen science initiatives could be linked to policymaking was central in this research. Conceptual modelling was employed in this study to attain understanding on the described phenomenon from a system perspective. Case study analysis from a multi-actor perspective was also used to shape the quest for perceptions.

This thesis is a typical EPA thesis because it focuses on the subject that is related to so-called "Grand Challenges". The grand challenges related in this study is the "harness" of emerging technologies, the facilitation in trust building in a post-truth world, and the empowerment towards participatory actions. Policy recommendations were formulated based on the insights gained from the empirical case studies with an aim to inform decision-makers. This thesis has therefore contributed to facing the grand challenges.