Citizen Science and Policy: A European Perspective

by Muki Haklay

CITIZEN SCIENCE AND POLICY: A EUROPEAN PERSPECTIVE

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About the Author

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Acknowledgements

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Foreword

In the past decade we have witnessed a global explosion of citizen science projects covering a compelling range of topics. From reporting crop yields in Tanzania to carbon accounting in Mexico, the Internet and the rise of smartphones enable citizens to become researchers, sensors, advocates, and watchdogs. Budget cuts make citizen science an attractive method to bolster limited, or even declining, organizational and governmental resources. The age of big data supports large-scale data collection and analysis, often augmenting human intelligence with support from computational systems.

Despite these common accelerators, the implementation of citizen science unfolds differently in diverse corners of the world. These differences may be traced to the 1990s, when the phrase "citizen science" simultaneously emerged in the United States (to describe volunteer data collection to support ornithological research) and in the United Kingdom (to reference the integration of science and citizenry to advance policy goals). And while attempts to standardize the field are led by three convening associations—the U.S. Citizen Science Association, the European Citizen Science Association, and the Citizen Science Network Australia—key differences persist.

In particular, the method and degree that citizen science is integrated into local, city, national, and international policy varies between towns, cities, states, countries, and continents. Additionally, citizen science increasingly takes place on an international scale. If citizen science is to support research and action on global phenomena such as climate change, local, regional, and national projects will need to find international partners to maximize their impact. However, keeping volunteers motivated will require striking a balance between what's important locally and what's important globally.

Observing other countries enables the United States to keep pace with international standards for the field and paves the way for future collaborations. Through highlighting these different geographic scales using case studies from the United Kingdom and Europe, this report offers recommendations for designing and executing citizen science initiatives that help inform and create public policy, based on sound science and citizens' needs.

The Commons Lab fosters the burgeoning field of citizen science by analyzing the legal, administrative, and social barriers to incorporating new tools like citizen science in government, as well as demonstrating how these tools succeed. Innovation is most useful when supporting infrastructure can help government and other actors benefit from new paradigms and ideas. By examining demonstrated European successes, governments, NGOs and policy makers may improve their own implementations of citizen science and fast-track the creation of new projects to support public policy in the United States.

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Executive Summary

This report explores the intersection of citizen science and policy at local, regional, and national levels and across policy domains, on the basis of the emerging experience in Europe.

The past decade has witnessed a sustained growth in the scope and scale of participation of people from outside established research organizations, in all aspects of scientific research. This includes forming research questions, recording observations, analyzing data, and using the resulting knowledge. This phenomenon has come to be known as citizen science. While the origins of popular involvement in the scientific enterprise can be traced to the early days of modern science, the scale and scope of the current wave of engagement shifts citizen science from the outer margins of scientific activities to the center—and thus calls for attention from policymakers. This is to ensure that citizen science is supported appropriately by policymakers and officials who understand the paradigm and its potential, as well as the impact that citizen science can have on policy formation and implementation.

This report explains the current phenomenon of citizen science and the underlying societal and technological trends behind it. On the basis of this understanding, unfolding analysis considers the multidimensional aspects of citizen science: geography, policy area, and type of citizen science activity. This report identifies areas where citizen science actively contributes to the formation of policy and also explores areas where we can expect to see further developments. The final portion explores key challenges and potential solutions for policy and decision making within the context of widespread and accessible citizen science.

More specifically, the report charts three dimensions of the intersection of citizen science and policy. First, the **level of geography**: from very local community (e.g., neighborhood scale), where local issues are frequently the motivation for citizen science activities, through city level, where activities are driven by coordination and collaboration between different groups, to regional level, where coordination effort becomes more formalized, then, to state/country level, and finally to continental scale.

Second, there are different **policy application areas** – environmental monitoring and environmental decision making, agriculture and food, urban planning and

smart cities, health and medical research, humanitarian support and development aid, science awareness, and support of scientific efforts. Within this context, we differentiate between citizen science used in support of public policy and policy that facilitates citizen science.

The third and final dimension is the **level of engagement and the type of citizen science activity** – from *passive sensing*, where participants use available sensors (e.g., in smartphones); *volunteer computing*, in which participants donate the unused processing power of their computers and devices; *volunteer thinking*, in which participants engage in cognitive tasks to assist scientists; to full-scale *environmental and ecological observation*s, *participatory sensing,* and *civic/community science*, which include active engagement in building and deploying scientific tools and methods. Examples from various scientific domains – physics, biology, life sciences, ecology, and environmental sciences – ground the analysis in real life activities.

Throughout the report, *dimension* is used in relation to these three major aspects, while *scale* is used to denote either the geographical or temporal scope of the activity, as well as the number of participants. The report concludes with recommendations for improved integration of citizen science into policy making:

- First, because of the need for multiple skills to run successful projects, citizen science activities should receive funding that takes the longevity of start-up time into account, and allocates appropriate long-term funding to support sustainability.

- Second, the interaction with knowledge-based institutions such as universities and private and public research institutions is critical to the success of citizen science. This requires raising awareness and providing incentives to such organizations to be involved in citizen science, as well as targeted efforts in establishing mechanisms such as Science Shops to encourage greater interaction with the public.

- Third, together with practitioners, local and national government can analyze existing regulations and policies, and consider which of them are inhibiting the use of citizen science, and which can be adapted to promote citizen science.

- Finally, while citizen science can yield high quality data, this requires an understanding both at the level of the project, as well as end-users of the inf0ormation. Appropriate guidelines and information should be developed to facilitate the use and interpretation of citizen science data.

Introduction

The past decade has witnessed a rapid change in the way people outside public and private research institutions can participate in scientific research. From 2007 to 2014, over one million people participated in classifying images of galaxies, listening to bat calls, transcribing World War I diaries, and identifying animals in the Serengeti in a Zooniverse project.[1] In Germany, in 2012, scientists collaborated with 5000 people to capture over 17,000 samples of mosquito, resulting in the discovery of an invasive species (Asian bush mosquito)[2] with implications to public health as they can carry certain diseases. And in the early months of 2014, a team of climate researchers at Oxford University, who wanted to suggest the degree to which recent floods could be attributed to climate change, was able to run over 33,000 models using the unused computing resources of over 60,000 volunteers.[3]

This collaboration between scientists and people from all walks of life has received growing recognition by the general media and by researchers. It is now commonly referred to as "citizen science." The term entered the Oxford English Dictionary in June 2014 as "*scientific work undertaken by members of the general public, often in collaboration with or under the direction of professional scientists and scientific institutions.*"[4]

As we shall see in the next chapter, some aspects of citizen science can be traced back to the early days of modern science in the 17th century with weather and nature observations. Yet, the current incarnation is qualitatively and quantitatively different. It is facilitated by societal and technological changes that make the range, scale, and possibilities of citizen science more significant than ever before.

This change in significance is calling for attention by policy makers, as well as policy actors such as government officials, government scientists, and those working in non-governmental organizations. Indeed, UNESCO,[5] the European Commission,[6] the European Environment Agency,[7] and national level policy bodies such as the UK Environmental Observation Framework[8] have recognized the importance of citizen

science for their present activities and future policy directions. There are multiple reasons for this, which include a growing understanding of the importance of citizen science within science, technology, engineering, and math (STEM) education and awareness; the importance of the information gathered through citizen science efforts for policy formation and implementation; the growing evidence for the accuracy and quality of citizen science information; and, as noted, the scope and scale of citizen science in terms of number of participants and the amount of data produced.

Existing reports from the Commons Lab of the Wilson Center have already covered many aspects of citizen science in the United States (US), including the growth in participatory sensing,[9] the range of citizen science activities,[10] and legal considerations.[11] To provide a complementary perspective, the current report focuses on European and international experience. While some references do relate to US case studies, most of the attention is paid to cases elsewhere. In particular, this report explores the intersection of citizen science and policy. Its aims are to:

• Provide an overview of citizen science from a European and international perspective.

• Understand the facets of this phenomenon using the geographical, policy area, and forms of participation dimensions.

• Explore the challenges and opportunities that citizen science offers policy makers and actors.

• Identify and suggest ways that policies can be developed to support citizen science activities, and demonstrate the impact of citizen science on policy.

The report was created with policy makers and their advisers in mind. From the outset, there is no assumption of prior knowledge of citizen science and its potential impact on policy issues. Therefore, the report provides the necessary information to build an understanding of the field. As non-governmental organizations (NGOs) and charities play a critical role in coordinating and running citizen science efforts, this report can be used by people considering citizen science in these realms, to ensure that citizen science will lead to desired impacts. Finally, the report can also be used by researchers who want to integrate citizen science into their practice and want to understand the policy implications of their work, as well as organizations who want to promote citizen science activities to policy makers.

Before turning to the outline of the report, it is important to clarify the general stance that is taken toward citizen science activities here. In general, the report will consider citizen science as a leveling practice, in which the roles of professional and non-professional participants, while not becoming equal, are valued and respected for their contribution

and their knowledge and skills. In most cases, equality in roles is not possible, due to differences in knowledge, resources, and the ability of professional scientists to dedicate significant amounts of their time to research activities on the one hand, and interest by participants to learn more about the science or to deal with a specific issue on the other. Yet, although equality is not assumed to be the end goal of citizen science, it does require closer cooperation between professionals and amateurs; therefore mutual respect is critical for productive relationships.

This stance avoids taking the view that citizen science is mostly about scientists who engage with the public in one-way communication and use members of the public as "subordinated laborers."[12] At the same time, it does not assume that the need for professional scientists or experienced researchers will diminish. On the contrary, because of the growing interest of public volunteers, the vast majority of which recognize that there is value in scientific expertise and knowledge, scientists have a critical role to play within citizen science. Therefore, professional scientists will need support to enable them to continue to excel in their professional activities while also engaging with a wider group of people in new ways.

In the next chapter, we cover the background of citizen science to provide an introduction to the field. The chapter opens with the main definitions and concepts in citizen science in order to set the scene for the rest of the report. Next, we review the trends that explain the current wave of citizen science as well as the main terms that are being used to describe it, followed by current limitations and barriers to increasing the scope of citizen science. The chapter ends with a review of the evidence for current awareness of citizen science within policy bodies.

After these scene-setting chapters, the third chapter explores citizen science, using geographical, policy area, and levels of engagement dimensions. The chapter includes examples and short case studies to demonstrate the various points.

The fourth chapter looks at the areas in which citizen science can support policy formation, as well as policies that are necessary to support citizen science. In particular, we will look at governance aspects, data and information quality, the process of production and consumption of citizen science information, and the relationship of citizen science with open data, open science, and open access.

This lays the foundation for the final chapter, which explores how to develop inclusive and effective citizen science projects. Here we will look at the emerging bottom-up and top-down mechanisms to support citizen science, the interaction of citizen science with policy areas, and, finally, examples of the challenges that are emerging from citizen science. This is followed by conclusions and recommendations.

Summary

- Citizen science, the participation of people from all walks of life in scientific research, is growing as an important form of public participation in the scientific enterprise.

- Citizen science has grown in scale and scope, and is therefore receiving increasing attention from policy makers at local, national, and international levels.

- This report will examine the interaction of citizen science and policy, focusing on European and international developments.

Chapter 1
Citizen science – what is it and why now?

What is citizen science?

The core elements of what came to be recognized as the scientific method have been in use haphazardly by different cultures across the world for many millennia. Recently, the anthropologist and tracking expert Louis Liebenberg argued that the origins of modern science can be linked to practices of hunters-gatherers in the "repeated experiments" of tracking animals, understanding weather conditions, and the hunter's own physiology.[13] While such traditional knowledge is increasingly recognized as important for understanding environmental conditions, and not dismissed out of hand,[14] it is different from the scientific method, which emerged in the 17th century. The hallmarks of the modern scientific method are careful observation of the natural world and experimentation, combined with quantification and testing of hypotheses. The modern industrialized world relies on this form of knowledge in many areas – from ensuring that food can be provided safely, to the development of new medicine to combat emerging diseases.

The first generation of people who dedicated their effort to science were not "professional scientists," and this is not only due to the fact that the term "scientist" was coined only in the 1830s. Much more important was the lack of established frameworks to pursue scientific research. Therefore, the creation of institutions dedicated to scientific research, such as the Royal Society in 1660, provided the framework for the scientific enterprise. While the institutionalized framework of science evolved, many people outside it were involved in the development of science. Well into the 1800s, it was still possible for non-professional scientists to contribute significantly to scientific research, as demonstrated by Mary Anning's many discoveries of fossils in Lyme Regis in Dorset, which advanced Paleontology and Geology. However, due to gender, religion, and social class Anning never held a position in any scientific institution. During the late 19th century, and especially during the latter part of the 20th century, the role of amateurs diminished as established science grew in scale. Despite this, in many areas of science the participation of people outside scientific institutions continued, with volunteer meteorologists collecting weather observations and amateur naturalists sending specimens to university- and museum-led collections.

The final decade of the 20th century marked the beginning of another change in the relationship between professional scientists and the wider public. Due to societal and

technological changes such as increased levels of education and electronic communication, the ability of the public to contribute to scientific projects increased dramatically, ushering in a new era of public involvement in science. As we shall see, this involvement is qualitatively and quantitatively different from that of the past. The new form of engagement in science received the name "*citizen science.*" The first recorded example of the use of the term is from 1989, describing how 225 volunteers across the US collected rain samples to assist the Audubon Society in an acid-rain awareness raising campaign. The volunteers collected samples, checked for acidity, and reported back to the organization. The information was then used to demonstrate the full extent of the phenomenon.[15]

The term continued to slowly gain recognition throughout the 1990s – for example, in 1996, Rick Bonney of the Cornell Lab of Ornithology described the activities of birdwatchers as citizen science in which amateurs collect data, while also learning about bird species, gain skills in systematic observation, and understand the scientific process better.[16] The past decade has seen a rapid increase in the number of citizen science projects and their scale. As a result, citizen science is now the accepted term for a range of practices. The term was first noted in Wikipedia in 2005 and recognized by the Oxford English Dictionary in 2014. Box 1 provides some of the common definitions and related terms.

Box 1 *Definitions of citizen science*

Citizen science has been given various definitions in dictionaries, encyclopedias, and scholarly publications. Chronologically, Wikipedia noticed the topic first, in 2005, defining citizen science as "*a project (or ongoing program of work) which aims to make scientific discoveries, verify scientific hypotheses, or gather data which can be used for scientific purposes, and which involves large numbers of people, many of whom have no specific scientific training*."[17] The Oxford English Dictionary accepted the term in 2014, defining it as "*scientific work undertaken by members of the general public, often in collaboration with or under the direction of professional scientists and scientific institutions.*"[18]

Researchers who review the field also provide useful interpretation, including Jonathan Silvertown who, in 2009, defined: "*A citizen scientist is a volunteer who collects and/or processes data as part of a scientific enquiry*." Bonney et al., in a recent policy paper in *Science*, described it as "*Around the globe, thousands of research projects are engaging millions of individuals—many of whom are not trained as scientists—in collecting, categorizing, transcribing, or analyzing scientific data. These projects, known as citizen science…*"[19] What is common to these definitions is the collaboration beyond institutional boundaries, the activities that are part of the scientific process, and the cooperation between members of the public and professional scientists.

In addition to the term "citizen science," this form of public involvement in scientific research has also been termed Public Participation in Scientific Research (PPSR),[20] participatory science, civic science, and amateur science,[21] as well as crowdsourced science. In specific areas of scientific research, citizen scientists are known with domain-specific terms such as birdwatchers or birders, amateur astronomers, volunteer weather observers, or amateur archaeologists. This variety points to the longevity of the practice and the current convergence under an umbrella term due to the growing importance of these practices.

Trends underlying current citizen science

Many reviews of citizen science draw parallels between the early days of science and current public involvement in scientific research, or highlight the areas of science in which volunteers and amateurs continue to play a part. Yet, considering the current scale and depth of engagement, current forms of citizen science have eclipsed previous forms of public involvement in scientific research. Even in the areas that are considered as continuous engagement (e.g., in astronomy or ecological observations), there have been important shifts in skills, knowledge, and ability of participants.

There are several societal and technological trends that help to explain the emergence of citizen science today. These include the rapid growth in education (especially higher) during the second part of the 20th century, increased leisure time especially in middle and high income countries, and growth in educated and able retirees. On the technical side, we should pay attention to the growth of the Web and mobile communication, and the ubiquitous connectivity that they offer. In particular, the emergence of Web 2.0 systems and the evolution of peer-production systems in the past 10 years, as well as the development and proliferation of cheap sensors that can collect data from the environment, played a significant role. We now turn to look briefly at each of these.

During the second half of the 20th century there has been a major educational transformation across the world, with countries such as the UK moving from 1.6% of the population with tertiary level of education in 1950, to 21.7% in 2010 (or, in other words, from less than one in 50 to over one in 5) and, more generally, across advanced economies, moving from 2.8% in 1950 to 17.9% in 2010.[22] Importantly, this transition happened while the size of the population itself increased almost twofold, and significant improvements occurred at all levels of education, which expressed themselves in the "Flynn effect" of increased results in IQ test scores during the 20th century.[23] Flynn explained the change by suggesting that both culture and education across the developed world became more oriented toward scientific thinking.

In conjunction with the increased levels of scientific education, across advanced economies the time dedicated to work reduced during the late 20th century, culminating in about 40 hours across OECD countries.[24] The reduction in working hours provided people with time to pursue hobbies and interests, including citizen science.

The final societal aspect is increased life expectancy which, combined with slow changes in retirement age, has led to a growth in educated and healthy people in their 60s and 70s who

are active in their community. For some, citizen science provides a way of reengaging with topics of science that they studied earlier in their life, but have not engaged with during their working life.

On the technical side, the main factors are more familiar and have been covered extensively in the media and academic literature.[25] First is the growth of the Web and the ability to access scientific information through platforms from Wikipedia or lecturers recorded on YouTube, to scientific papers that are shared through repositories and Open Access journals. In addition, the proliferation of smartphones with computing and sensing abilities, as well as the ability to stay connected while out and about, increases the ability of volunteers to record and share observations quickly and easily: sometimes as small tasks that last a few seconds (micro-tasks), or even by carrying the device itself passively.

Amateur naturalists or birdwatchers in the early 20th century could not be relied on to identify and report the scientific names of species and were not equipped with scientific understanding, nor were they carrying around powerful scientific instruments in their pockets. In contrast, today there are hundreds of millions of people with such abilities, and therefore the potential for participation is much higher. Yet, it is important to note how the multiple underlying trends (education, access to and use of technology, leisure time, etc.) are also defining the demographics of those who participate in citizen science.

Citizen science today

Because citizen science is gaining ground in different domains and scientific disciplines, there are multiple practices associated with it. When these practices are ordered according to the level of engagement of participants in the scientific process and in terms of the required level of commitment, we can identify major types of activity. They include the following demonstrated in Table 1 on the following page

However, in spite of these significant advances, this new incarnation of citizen science is not without limitations. The societal and technological transitions provide a portrait of ***the average participant in citizen science activities – well educated, working in a job that provides enough income and working conditions for ample leisure, and with access to the internet as well as ownership of smartphones***.

Table 1 *Types and examples of citizen science activities*

Type and definition	Example
Passive Sensing relies on participants providing a resource that they own (e.g., their phone or space in their backyard) for automatic sensing. The information that is collected through these sensors is then used by scientists for analysis.	*Flight Radar 24* is a commercial service that provides information about airplanes, their routes, and whereabouts. The website relies on official information that is enhanced by 4,000 volunteers who install an ADS-B receiver in their home and feed the information to the website. The receiver collects information from airplanes that pass in the area and are equipped with ADS-B transponders.
Volunteer Computing is a method in which participants share their unused computing resources, on their personal computer, tablet, or smartphone, and allow scientists to run complex computer models when the device is not in use.	Researchers at Tsinghua university in China collaborated with IBM World Community Grid to set up *Computing for Clean Water,* in which volunteers donate their unused computing resources to allow researchers to simulate novel ways to design water filters.[26]
Volunteer Thinking uses what Clay Shirky termed "Cognitive Surplus,"[27] which is the cognitive ability of people not used in passive leisure activities such as watching TV. In this type of project, the participants contribute their ability to recognize patterns or analyze information that will then be used in a scientific project. Commonly, the analysis task is fairly standardized, making it easy to aggregate and compare results from different participants.	The *Galaxy Zoo* project is the premier example of **Volunteer Thinking**, in which hundreds of thousands of participants log on from their computers and tablets, and help astronomers with classifying galaxies and mapping the universe.[28]

Environmental and Ecological Observation, while linking participants to the oldest forms of citizen science, is transformed by the societal and technological changes that were noted above. It focuses on monitoring environmental pollution or observations of flora and fauna.	The UK *Big Garden Birdwatch* was started in 1979 by the Royal Society for the Protection of Birds (RSPB). It is marked by engaging very large numbers of people (over 590,000 in 2012) in the observation and identification of birds, with strong attention from national media such as the BBC. The project mainly focuses on raising awareness of conservation and birds.
Participatory Sensing is similar to the previous type of observation, but gives the participant more roles and control over the process. While many environmental and ecological observations follow data collection protocols that were designed by scientists, in participatory sensing the process is more distributed and emphasizes the active involvement of the participants in setting what will be collected and analyzed.[29]	In the European Commission funded project *EveryAware*, participants used their smartphone to monitor noise, utilizing software that was provided by project organizers. The project team worked together with concerned community members that live near Heathrow airport in London to collect information about the level of noise that they are exposed to.[30]
Civic/Community science, also known as bottom-up science, is initiated and driven by a group of participants who identify a problem that is a concern for them and address it using scientific methods and tools. Within this type of activity, the problem formation, data collection, and analysis are often carried out by community members or in collaboration with scientists or established laboratories.	*SafeCast* (http://blog.safecast.org/) emerged in Japan in 2011 after the Fukushima earthquake, to develop a DIY radiation meter that can be used by participants while driving around. The project was proposed at a technology conference and a Tokyo Hackerspace (a club in which people who are interested in tinkering with technology meet and work together), culminating in developing a low-cost radiation monitor now used by volunteers across the world who share their data on the SafeCast website.[31]

Royal Society for the Protection of Birds: Big Garden Birdwatch (Photo Credit: NC Nutmeg's Wildlife Photography)

Not surprisingly, because of imbalances in care responsibilities, biases in science education, and in income, men are overrepresented in citizen science. For example, a study found that 87% of the participants in a volunteer computing project were men,[32] while a similar bias was identified in ecological observations of birds.[33] Moreover, white men aged 20-65 from well-to-do socioeconomic backgrounds are overrepresented in citizen science. At the international level, citizen science is concentrated in advanced economies, especially the US and northern Europe. The need to access the internet still presents an obstacle, with level of access ranging from 87% in the UK, 81% in the US, and only 65% in European countries such as Poland or Portugal.[34] At the more local level, even for those who have access to a smartphone, many of the software applications (apps) that support citizen science assume continuous web connectivity, even though 3G and 4G coverage is partial in highly urbanized environments such as London or New York City, let alone in remote nature reserves. Language can also present a barrier. As the background material and the apps are being developed by

scientists, the amount of discipline-specific jargon and the level of understanding that is needed to get involved in a project can exclude many people. Finally, since English is the main language of scientific papers and of science more generally, many of the tools and technologies that support citizen science activities rely on knowledge of English, and are not available in local languages, especially in areas of high cultural heterogeneity such as Europe.

The result is somewhat ironic. Much of the rhetoric of citizen science discusses its potential for including new social groups, raising awareness and interest in the scientific enterprise, and providing new routes for education and skills. The current demographics demonstrate that, without purposeful effort, this will not happen. Sometimes, there are simple routes to overcoming challenge (e.g., to provide paper forms in areas of low connectivity) but, more generally, special attention should be paid to those that are, mostly unintentionally, excluded from citizen science activities.

Box 2 *Extending participation in citizen science*

Purposeful activities to increase and diversify participation in citizen science can occur in large-scale programs such as the UK Open Air Laboratories (OPAL) project,[35] where one-fifth of those who took part in citizen science activities came from disadvantaged communities – by identifying these communities and creating activities in local schools with community scientists that came from nearby universities (see Box 6).

The Extreme Citizen Science research group, at UCL, is reaching out to non-literate indigenous groups to support them in carrying out citizen science activities. To this end, they have developed software that runs on rugged smartphones and is based on pictorial representations, which allows hunter-gatherer tribes in the Congo Basin to track illegal poaching and record resources that are important to them, in order to communicate with logging companies and other stakeholders in the area.

This new form of citizen science over the past decade has been noted at different levels of policy making. This is not surprising when considering the many aspects that citizen science might touch – from education to environmental protection. Before turning to the analysis of the policy dimensions of citizen science, it is useful to briefly review what current policy documents that relate to citizen science tell us about the field.

National and multinational environmental policy was the first area to demonstrate an awareness of citizen science, especially in Europe and the UK. This became explicit in a talk given by Prof. Jacqueline McGlade, the then Executive Director of the European Environment Agency (EEA), in 2008. In the speech, she announced the creation of a

Global Citizens' Observatory for Environmental Change, starting with integrating citizens' observations with official data about water quality. She noted that: ***"Often the best information comes from those who are closest to it***, and it is important we harness this local knowledge if we are to tackle climate change adequately… people are encouraged to give their own opinion on the quality of the beach and water, to supplement the official information"[36] (emphasis added).

The EEA continues to promote citizen science, and the Eye on Earth Summit (held in Abu Dhabi in 2011) shows another indication of environmental policymakers' interest in citizen science. The summit, which was part of the United Nations Environmental Programme (UNEP) preparations for the Rio+20 conference in 2012, focused on environmental information and the sharing of it and included examples of environmental information collection by the public. Examples of citizen science included educational initiatives in the US as well as indigenous knowledge-sharing in the Amazon. Following this summit, during the first meeting of the Eye on Earth network in Dublin in 2013, the final statement explicitly stated that the parties: "Decided to continue to collaborate through the Eye on Earth network, to promote, support, and improve access to data and information for sustainable development and, where appropriate, by participating in special initiatives, collaborating on related technical developments, **establishing citizen science as an important source of knowledge within the diversity of knowledge communities**, building capacities across the network and convening meetings to achieve this goal"[37] (emphasis added). Further interest is represented in policy documents of the Environment Directorate General of the EU,[38] at the national level in the analysis and guidance within the UK Environmental Observation Framework,[39] in policy documents of the Scottish Environmental Protection Agency (SEPA),[40] and in a briefing for policy makers by the UK Parliamentary Office for Science and Technology.[41]

Linked to environmental policy, the legal and regulatory potential of citizen science was recognized by the International Institute for Sustainable Development (IISD), especially for ensuring environmental compliance.[42]

The educational potential of citizen science within the science, technology, engineering, and math (STEM) area also received attention. For example, the UN Education, Scientific, and Cultural Organization (UNESCO) identified it as an important area within the agenda of Information and Communication Technologies (ICT) use in science (e-science), and dedicated a chapter to it within the preparations for discussion on the World Summit on the Information Society goals beyond 2015 (WSIS+10).[43] In the final WSIS+10 declaration, there is an explicit call on UN members to "encourage the use of ICTs, including the Internet and mobile technologies, **to facilitate greater participation in the entire scientific process including public participation in scientific research (citizen science) activities** and the introduction of e-science activities

in the context of all forms of education"[44] (emphasis added). Similar recognition can be seen in a white paper on citizen science in Europe that was supported by the digital science unit of the European Commission.[45] This is also echoed in the US Open Government National Action Plan which commits to extend the use of citizen science.[46]

We shall see, in the next chapter, the potential of citizen science to go beyond these two policy domains.

Summary

- Citizen science emerged in the past decade due to technological and societal changes. The societal change includes the increase in levels of education and understanding of scientific concepts, increase in leisure time, and growth in healthy retirees. On the technological side, the growth in web-based systems and mobile technologies provided the necessary instruments.

- Citizen science today encompasses activities that people can do at home by installing sensors (passive sensing), software on their computer (volunteer computing), or helping to classify information on websites (volunteer thinking). Outdoor activities include recording environmental or ecological observations, carrying out sensing activities using smartphones or other devices (participatory sensing), or purposeful community activities aimed at addressing a common issue of concern (community or civic science).

- Awareness of citizen science started among environmental policy makers in Europe in 2008, and it is now becoming established in policy documents. Science, technology, engineering, and math (STEM) education is another area in which citizen science has already seen some attention.

Chapter 2
Policy dimensions of citizen science

To understand the policy dimensions of citizen science, we will use the following conceptual framework, based on three organizing axes: geography, policy area, and participation form.

The first dimension is the **level of geography** because it influences policy formation and control, and the actors that operate in a specific geographical area. The geographical scales start at very local community (neighborhood scale) where local issues are frequently the motivation for citizen science activities; toward city scale, in which we explore the coordination and collaboration between different groups; regional scale, where we usually find more established organizations operating; then state/country, and finally continental scale.

The second dimension is the different **policy domains**. As we have seen, environmental monitoring and environmental decision making have already received some attention, but citizen science will also influence areas such as agriculture and food, urban planning and smart cities, humanitarian support and development aid, science awareness, and support of scientific efforts. While covering different geographical scales, we will explore these areas of policy making.

The third dimension that will be explored is the **level of engagement and the type of citizen science activity**. Here we use the types of activities that were introduced in the previous chapter: Passive Sensing, Volunteer Computing, Volunteer Thinking, Environmental and Ecological Observation, Participatory Sensing and Civic/Community science. Table 2 provides examples of citizen science projects and their association with the analysis dimensions.

Table 2 *Examples of the analysis framework: geography, policy, and engagement*

Dimensions mapping	Sample case study
Geographical scale: neighborhood *Policy domain*: environmental monitoring *Engagement*: participatory sensing, civic/community science	Community monitoring of noise from a local scrapyard to provide evidence of the nuisance from car braking and crashing. The study was carried out in collaboration with NGOs and a local university (https://www.youtube.com/watch?v=17hR_YfrK-I).
Geographical scale: city level *Policy domain*: smart cities *Engagement*: passive sensing	*Street Bump*, a smartphone app that was originally developed in Boston. Volunteers use the app while driving around the city, and the application detects when the car passes a pothole and reports it to the city's authorities. Verification can be achieved by multiple observations, although coverage favors affluent areas.[47]
Geographical scale: regional *Policy domain*: ecology/public health *Engagement*: ecological observations	*Mückenatlas* (*Mosquito Atlas*) is a German project, which started in the area of Lower Saxony (West Germany). Scientists collaborated with 5000 people who helped them to capture over 17,000 samples of mosquitoes, resulting in the discovery of an invasive species (Asian bush mosquito) and mapping it out, as it is potentially a carrier of tropical diseases.[48]
Geographical scale: country *Policy domain*: education / environmental awareness / environmental monitoring *Engagement*: environmental and ecological observation, participatory sensing	*My Wild Street* (*Sauvages de ma Rue*) is a French project founded in 2011. This project began in Paris, but has expanded to the whole of France. My Wild Street encourages participants to survey their street, identify wildflowers that grow in pavement or on walls, and upload images of these flowers to a website. As of 2014, over 45,000 observations from 12,000 locations have been submitted. This information supports research on biodiversity gradients in urban areas.[49]
Geographical scale: continental *Policy domain*: support of scientific effort *Engagement*: ecological observation	The *Evolution MegaLab* project engaged thousands of participants in 15 countries across Europe to report the changes in color and patterns of snail shells, exploring climate-change-induced evolutionary change.[50]
Geographical scale: country *Policy domain*: support of scientific effort, climate change policy *Engagement*: volunteer computing	Following UK floods in the early months of 2014, a team of climate researchers at Oxford University, which has already established a network of volunteer computing in their *weather@home* initiative, recruited participants to run regional climate models to suggest the degree to which the recent floods could be attributed to climate change. The researchers ran over 33,000 models using the unused computing resources of over 60,000 volunteers.[51]
Geographical scale: country *Policy domain*: humanitarian aid *Engagement*: volunteer thinking	The project *Missing Maps* was set by medical charities (Doctors Without Borders with British; American Red Cross) and the Humanitarian *OpenStreetMap* team. The project involves volunteers in the process of mapping areas that require medical support, but for which there are no maps. The mapping is done in collaboration with remote volunteers who use aerial images to identify roads and other major features, and more detailed work on the ground to capture place names and other information that can help humanitarian efforts.[52]

Local and city-scale citizen science

The most localized geographical scale is the most familiar to people – namely, the streets, squares, and backyard of their homes. These places are the location of daily activities, and therefore suitable for short observations and activities that can be integrated with other routines. Moreover, local issues are a source of community action and a way for people to come together with the aim of addressing collective concerns. Such concerns can be about local industrial activities and their potential pollution or interest in local food growing and urban agriculture. Citizen science is used in such contexts to provide evidence about the issues that are discussed, or to address a specific concern. For example, a measurement of noise level with handheld devices can confirm or refute perceptions about the noise nuisance from a local industrial activity.[53]

At the individual level, citizen science can a leisure activity carried out in one's backyard, such as the Big Garden Birdwatch, in which participants spend one hour observing birds. Individual volunteers may also contribute to a network that monitors earthquakes by installing software on their laptops that utilizes the internal accelerometer for seismographic observations.[54] While the activities of an individual are highly localized, such participation is carried out as part of a wider network or a project that is a wider scale (see later sections of this chapter). In other words, to understand the role of each individual participant, it is important to look at the purpose of the citizen science project as a whole in terms of geography, level of engagement, and research area.

The most distinctive activity that occurs at a local level happens when a topic of concern brings people together.[55] This may be an ad hoc gathering of people with common interest, or an extension of an existing localized organization; for example, when people who are familiar with each other through neighborhood watch activities expand their attention to issues that require systematic evidence gathering.

Local citizen science is sometimes linked to social and environmental activism, especially in issues such as environmental justice or community response to a planned development. In some cases, the local community is able to ask for help from other organizations, especially when the issue at hand matches the advocacy mission or research interest of the external organization. Another example of scientific support addressing local issues is the network of Science Shops, which originated in the Netherlands and now exist throughout Europe. A Science Shop provides scientific expertise, resource, and support to community organizations and is often linked to a local university.[56] Box 3 provides a specific example of a local study motivated by environmental justice concerns.

Box 3 *Local level – air quality study at the Pepys Estate, London*

The Pepys Estate in Deptford, South London, is a predominately 1960s housing estate on the banks of the Thames, characterized by high-rise tower blocks and social housing. Situated near a busy thoroughfare and surrounding an industrial site, the estate is exposed to a variety of urban environmental issues. In late 2009, the community carried out an air quality study of the pollution caused by a local scrapyard, situated in the heart of the community. In particular, concern focused on the mechanical break-up of vehicles, trucks servicing the scrapyard, and local traffic, which were seen as potential sources of pollution. The possible impact of a planned housing development further heightened their desire to assess local air quality. The study was initiated by Pepys Community Forum and Mapping for Change, a social enterprise owned by University College London, and commissioned by London Sustainability Exchange (LSx), a charity geared to creating a more sustainable London. Some further support for the study was provided through the OPAL project (see Box 6).

Following a meeting in the local community center, residents were provided with instructions and equipment to carry out their investigations. The area was divided up into 100m grids to obtain a good distribution of samples taken. Key activities included setting out a series of diffusion tubes on lampposts around the area. Diffusion tubes are routinely used by local authorities and scientists to measure nitrogen dioxide (NO_2), yet they are now both affordable and easy to install. Wipe samples, another established method which involves using a tissue to sample dust from hard surfaces, were taken from around the area to assess the quantity and types of metal being deposited. Ozone levels were measured using Eco-badge™ ozone detection kits, and leaf samples were collected and analyzed by Lancaster University. Leaves are a natural pollutant collection surface for heavy metals. Using magnetic bio-monitoring techniques the leaves can be magnetized due to the iron present in the pollution particles.

All of the data collected was analyzed and compiled into a series of maps. A public meeting was held to provide feedback on the findings. The community activity led the local authority to install diffusion tubes at the main junctions identified by the survey as having higher levels of NO_2. They also installed Particulate Matter (PM10 – dust) monitoring stations to get a more accurate picture of PM10 levels in the area. Previously, the closest fixed monitoring station was just over a kilometer away. With the installation of the new air quality monitoring devices, the community will be able to obtain data relative to conditions on the estate over a longer period of time.

The case of the Pepys Estate demonstrates a high level of engagement by the local community, as it participated in shaping the topic that would be explored and the locations in which samples would be collected and, while the analysis was carried out in the laboratory and visualization was done by external organizations, the information was used by a community organization to raise issues with the local authority.

Participant samples dust from a bus stop at Pepys Estate, London (Photo Credit: Mapping for Change)

At the next level of analysis, we look at city-wide activities. At this level, there are more resources available to fund coordination and management of citizen science activities, while at the same time the geographic concentration, as well as aspects of the infrastructure, such as transport or education, makes projects possible at relatively low costs.

City-scale projects can be organized by a municipal body with a remit of dealing within the city area, as demonstrated in the development of the Street Bump app by the City of Boston.[57] Museums, local universities, and science education organizations are also important in initiating or maintaining activities. Finally, city-specific NGOs can initiate a citizen science activity to promote their objectives.

The advantage of city-scale infrastructure is especially important in terms of policy. For example, in many cities public transport reduces the costs of bringing participants to training sessions. Moreover, less tangible infrastructure is important, such as higher education institutions and experts with detailed scientific knowledge that can assist projects in training and technical expertise, or local media that can promote the project. Finally, cities harbor knowledge networks which enable an organization to connect to other people with the necessary experience to start an activity. Thus, cities can provide the backdrop for a patchwork of localized monitoring, each done as a result of different concerns, yet with the possibility of using the accumulated data to see a wider picture.

In terms of policy areas, environmental quality and ecological monitoring issues are significant at this level. There is also city-specific promotion of science or pro-environmental behavior through educational programs. Building on the previous example, we see how localized air quality monitoring can grow to city-scale practice.

Box 4 *City-scale air quality studies*

Of the methods that were used on the Pepys Estate, the use of NO_2 diffusion tubes proved to be both easy to deploy and effective in providing useful results. The reduction in cost of diffusion tubes (down to £7, or $11, including processing costs) meant that the costs of a dense network in which tubes are installed in every 100m or 50m grid cell are not prohibitive. The results are easily understandable by local authorities and can be compared to guidance in regulations which rely on diffusion tubes as the basic measurement tool. Further, the installation of the tubes is straightforward and requires little expertise. The use of the tubes also give the participants a sense of control in selecting the sites for monitoring, installing and collecting the tubes, as well as entering the results on web maps so they can shared with others.

Both London Sustainability Exchange (LSx) and Mapping for Change developed further case studies with communities across London. Over the past four years, communities have used the diffusion tube surveys to identify cycle routes that are less polluted, to understand the pollution that impacts schools and the routes that children take to reach them, to demonstrate to Transport for London that buses need upgrading to less polluting ones, and to gather information about the level of pollution in areas of proposed development. LSx developed a special toolkit for schools to allow schoolchildren to participate in air quality studies.[58] The methodology of work, including setting up and using the results, was explained in different documents and presentations by the two organizations, including in targeted dissemination events (e.g., Mapping for Change hosted a one-day conference on urban air quality issues in April 2013). The most interesting result of this work is that other organizations, such as one that is focused on residents' concern over a proposed development of a tunnel under the Thames in east London, run their own independent studies, demonstrating the replicability and clarity of the methodology. This also demonstrates the knowledge transfer that can happen in a city.

In the cases that were managed by Mapping for Change, all the data was collated on one system – an in-house community mapping system, which allowed the participants to enter the values of their observations and see the results on a map. As a result, instead of isolated air quality studies, all the studies are shared on a single map, which now provides a snapshot of these highly detailed air quality studies across the city.

Despite the scaling up of the air quality monitoring activities, the level of engagement in this activity is within the spectrum of participatory sensing and civic/community science: the configuration of the activities in such a way that each group decides on the sites in which monitoring will happen and carries out the installation and data entry, and the use of the information that emerged from the monitoring by the local authorities.

Community based air quality monitoring in Highbury, London (Photo Credit: Mapping for Change)

Regional, country, and continental-scale citizen science

Beyond the city, the regional scale is frequently limited in political and financial power. At the regional scale, there are also issues with a lack of NGOs that are set to operate at this scale. At the same time, many ecological and environmental issues require regional monitoring and management, such as water quality, wildlife, or invasive species. Therefore, local research institutions and universities are important for accessing the capacity and interest to carry out studies that involve people from a region, as well as national NGOs with regional offices or sub-organizations. Similar to the way local organizations can come together to address city-scale issues through a distributed model of collaboration, at the regional scale a coordinated effort of the city, town, and village authorities can lead to a similar outcome. However, the coordination overheads, for example in terms of distance of travel, or ensuring cooperation across the participating authorities, are higher.

At the regional scale, carrying out high level participatory process, in which the participants set the research questions and carry out the research, is more challenging, mostly because such bottom-up practices are done with limited budgets and the coordination overheads of such activities at a regional scale are beyond the abilities of small organizations. From this scale onward, most projects are contributory in nature – participants are asked to share observations, or carry out simple analysis, while centralized bodies collate the information, analyze it, and use it in their activities. In terms of policy areas, regional issues are typically environmental issues, transport, and public health that require collaboration between local government organizations.

Mapping for change provides mapping, geographical analysis and community engagement services for all types of projects and entities (Photo Credit: Mapping for Change)

Box 5 *Mückenatlas and Atrapa el Tigre – mosquito monitoring in Germany and Spain*

The German Mückenatlas ("Mosquito atlas") provides an example of a highly successful citizen science project which started as a regional project. It was launched in April 2012 and participants are asked to collect culicid mosquitoes in their homes and gardens, kill them by freezing, and send them to the participating research institutions. There, the mosquitoes are identified to species by experts in entomology who inform the "mosquito hunters" of the identification of the species they have sent and provide them with some biological facts on the collected species. The specific data associated with the collected mosquito, such as collection date, locality, description of the collection site, and weather, are stored in the German national mosquito database CULBASE. In the long run, the aim is that this database will be opened to the scientific community and political stakeholders to support mosquito research in Germany. This will facilitate risk assessments and modeling as to where to expect mosquito-borne diseases in the future and how to manage them. Thus, the submissions to the Mückenatlas directly contribute to mosquito research and public health in Germany. The upgrading of the Mückenatlas to an international European level is under consideration (see the Spanish example below).

The citizen science project has proved an excellent instrument of passive mosquito surveillance and led to significant scientific findings. These include the detection of the Asian bush mosquito *Aedes japonicus*, an invasive mosquito species, in the German federal states of North Rhine-Westphalia, Rhineland-Palatinate, and Lower Saxony in 2012. Scientists were able to confirm these detections as established populations. As for 2014, the first two specimens of the Asian tiger mosquito (*Aedes albopictus*), an invasive mosquito species considered not as yet established in Germany, have been submitted to the Mückenatlas from southwestern Germany. Moreover, several rare mosquito species, not found in Germany for decades, have been rediscovered.

Almost 5,000 citizens sent more than 17,000 mosquitoes from 6 different genera and 39 species in 2012 and 2013. Information about the Mückenatlas project is distributed using traditional media, such as press releases (5 since April 2012), media appearances (approximately 500), and ongoing intensive societal communication through website, social media, journal articles, lectures, and presentations to the non-scientific society.[59]

A related project is AtrapaelTigre.com ("Hunting the tiger"), started in 2013 in Catalonia, Spain, which is exploring new methods to monitor the spread of the invasive Asian tiger mosquito in Spain. Since it is a potential carrier of disease (e.g., vector of Chikungunya), discoveries of it in new regions demand regional changes in public health protocols and regulations.

The project is led by the research group ICREA-Movement Ecology Laboratory (CEAB-

CSIC), and envisages the development of citizen-driven alert systems for invasive species, while promoting good practices in households and raising awareness. The project includes training and raising awareness workshops, online communication through the project website (www.atrapaeltigre.com), and a smartphone application. Through the app, participants collect and share data on adult tiger mosquito sightings and potential breeding sites in public spaces.

Similarly to the German project, it was promoted on social media (Twitter and Facebook), general media (with over 70 appearances in online media, blogs, TV, magazines, etc.), and workshops at different regions in Spain (around 25 workshops engaging over 1,600 people), as well as through governmental bodies and NGOs. Around 6,000 people all around Spain downloaded the app and more than 1800 geolocations were sent by over 1,300 contributors. About half of the reports were accompanied by a picture that could be used for further data validation.

As noted, the project started at a regional scale, but developed into a country-scale project. The mosquito invasion is mostly established in the region of Catalonia, and this led to much more presence in this region. However, this summer a new region was invaded by the mosquito and this was discovered thanks to the project: now there are at least five regions in Spain with confirmed presence.

Both projects mostly focused on ecological monitoring in which the participants contribute the observations (and, in these cases, an actual specimen) but the analysis of the information and the use of it to alert authorities about public health risks is done by scientists in the regional institutions. In both cases, while the project started at a regional level, it was scaled further to a national program.

Asian bush mosquito, target species for the Atrapa el tigre project (Photo Credit: Medialab Prado)

The country level is another governance level that can benefit from good organizational infrastructure in the form of government departments or national NGOs which coordinate and manage the data that emerge from citizen science projects. Citizen science activities can be linked directly to specific policy objectives and processes, although there are only a handful of examples of this.

National organizations that are dedicated to monitoring and advocacy of wildlife or science education are currently important actors at this level, as they can use the information that emerges from citizen science efforts to promote their goals, as was demonstrated in Audubon when coordinating volunteers' monitoring of acid rain in the late 1980s.[60] However, the challenge at this level is the geographical coverage and reach. In organizations that are structured with regional and local branches, the coordination and promotion of citizen science is carried out through country-wide structures. In other cases, national organizations have direct contact with their members and supporters, and recruit them to be involved in activities. A strong national organization can reach out to other organizations at regional and local levels and find ways in which they can cooperate and work together on a joint project.

The country level benefits from the potential of promotion through national media; for example, the RSPB Big Garden Watch is mentioned by the BBC in various programs and thus receives high exposure. At the same time, the competition for attention with national media is fierce, and therefore the exposure can be limited (e.g., a single report in the evening news). Yet, the geographical scale raises issues of completeness of coverage, which is the problem of ensuring that all the locations that require coverage receive it in a consistent way. It also requires considerable resource in collecting the information and ensuring its quality.

From the point of view of participants' engagement, participation is likely to be in a contributory form, reporting information in a highly structured way to ensure quality and consistency. To ensure that information is consistently structured, websites or apps can be used to enforce how the data are entered. Therefore, we can find ecological observations, participatory sensing, and passive sensing at this scale. In addition, because of the very high attrition rate between people who hear about a project and follow all the steps to participate in it, this level is suitable for volunteer computing and volunteer thinking. Yet, the involvement of national organizations means that a form of civic science can happen at this level, when such an organization uses citizen science to promote its objectives – for example, protection of a specific habitat. National organizations can also focus their activities in areas that are held by the public – such as national parks or nature reserves – and link them to visitors' activities in the area.

Box 6 *The Open Air Laboratories project in the UK*

The Open Air Laboratories (OPAL) example was noted previously. The project was originally carried out across England (and very recently has been extended to the rest of the UK), with significant funding from the national lottery program (£17m) which uses the proceeds from the UK national lottery to support projects across the UK in the areas of education, health, and the environment.

OPAL started in 2007, under the coordination of Imperial College London, with a network of nine universities including the Open University (which has an outreach mission and in-depth knowledge on distance learning), national bodies (Met Office, Field Studies Council, Royal Parks, and the National Biodiversity Network), and the Natural History Museum. The project's objectives were structured around wellbeing (encouraging people to spend more time outdoors), educational, and research goals. To deliver the program, OPAL worked with over 1,000 organizations in the voluntary, community, and statutory sectors.

The main method that OPAL uses is based on field surveys, which are sets of instructions, simple tools, and educational information that allow a group or individual to carry out an environmental monitoring activity of about an hour. Over 270,000 toolkits were sent to the public and to schools, or downloaded from the project website. While 30,000 sites have been surveyed and results submitted, OPAL estimates that at least five times this number were completed by participants but without the final stage of entering the information online. OPAL included seven surveys covering tree health, bug count (monitoring invertebrates), biodiversity evaluation of hedges, air quality through studying lichens, weather observations by observing clouds and plane contrails, soil quality survey through monitoring earthworms, water quality survey in local lakes and ponds, and evaluation of metals in lakes. In all these cases, OPAL relies on "biomonitoring," which is a method of using living things to assess the state of the environment.

Many of OPAL's surveys were paper-based to allow simple use in school settings. In addition, OPAL supported the development of an online biodiversity monitoring website and app that runs on smartphones, such as iSpot, which allows participants to capture an image of a specimen and get an accurate identification of it by a team of virtual volunteers, many times in less than an hour.

OPAL is remarkable in its success to balance multiple objectives – the science surveys revealed new scientific information that was not known before while, at the same time, the activities showed that they encouraged people to spend more time outdoors, and to increase participation of marginalized groups in society. The project engaged over 850,000 people of which one-fifth were from disadvantaged groups in society. At an average cost of £20 (about $30) per participant, the project also represented excellent return on investment. Significantly, many of the activities that started with the project have continued to evolve since, demonstrating a culture shift in the understanding of citizen science in environmental monitoring in the UK.[61]

OPAL was structured as a contributory activity with an emphasis on education and awareness, as can be seen in its objectives. However, some of the activities, especially online apps such as iSpot, provided opportunities for participants to be involved in the analysis and to become experts in the classification of species.

OPAL employee demonstrates identification methods to a participant (Photo Credit: Open Air Laboratories)

The final level, which is the continental scale, again usually presents challenging governance structures. In cases where there is a single country that spans a significant area of a continent (or all of it, in the case of Australia), the geographical distances and variability of population densities create management challenges in terms of recruiting participants or communicating with them. Even more challenging are situations when the topic of interest is one that requires collaboration between multiple countries. For example, patterns of bird migration can only be answered by looking at the full span of their journeys, which do not stop at borders. In Europe, issues of pollution or biodiversity monitoring are also cross-border issues.

In such situations, there is a need to create coordination mechanisms that enable the coverage of the area by multiple actors – often national organizations in each country. In the case of Europe and Australia, there are also emerging network organizations dedicated to facilitation of continental-scale activities: the European Citizen Science Association and the Citizen Science Network Australia. As in the city scale and country scale, it is also possible for a group of research organizations to coordinate local activities in a specific project.

European Environment Agency NoiseWatch website (Photo Credit: Muki Haklay)

The European Environment Agency (EEA) projects in the area of citizen science provide an example of continental-scale activities. The NoiseWatch app, launched in 2011, allows participants to provide a simple sound level measurement using their smartphone. Within three years, the EEA collected over 195,000 measurements taken all over the world (see image above). The app itself did not receive significant international promotion, and yet it became used beyond the area to which it was designed. A similar experience was seen in the EveryAware project, in which an app for noise monitoring was released as part of it (WideNoise). The project included targeted activities in London, Rome, and Antwerp, yet the app has been widely used in China, the US, Australia, and many other parts of the world.[62] The scaling that is enabled by ICT is discussed further in the next section.

Box 7 *Evolution MegaLab – continental-scale citizen science*

The Evolution MegaLab project provides a valuable demonstration of the use of biological indicators to climate change, as well as evidence for evolutionary theory – both are significant contributions to scientific knowledge provided through the effort of thousands of participants over a large area. The project was coordinated by the Open University in the UK to celebrate the Charles Darwin 200th anniversary in 2009. The experiment evaluated if there was a change in the coloring and patterns of shells of snails due to both reduction of evolutionary pressure from birds (which are less common) and to climate change. It was expected that climatic changes will allow light-colored snails to be active further north than they used to be – the light color absorbs less warmth from the sun, and it was assumed that only dark-colored snails survived further north.

The project provided easy-to-use information sheets and a multilingual website (http://www.evolutionmegalab.org/), with scientific support in each country. The geographical coverage of the project required versions in Catalan, Dutch, English, Estonian, French, German, Hungarian, Italian, Portuguese, Polish, Spanish, Latvian, and Welsh, as well as additional country-specific versions for Austria and Switzerland. By 2011, nearly 2,500 participants in 15 countries across Europe had provided over 7,600 reports, while a further 4,000 registered volunteers who submitted no records. The reports provided the necessary evidence for climate-change-induced evolutionary change.[63] Of course, such a project required careful design and coordination between the participating institutions, and significant effort in providing consistent and clear information in multiple languages. The project was designed for nearly two years before its public launch and used the wide publicity of Darwin's anniversary to reach out to the public.[64] Similar to OPAL, the project was designed so the activities were suitable for schools, university students, and the general public, and in each country the local coordinators carried out a publicity campaign.

In terms of engagement level, the project was mainly contributory – the participants had to learn the basic procedure of identifying snails and reporting their patterns, and then submit information through a website. While they received an automatic response with information about other observations in their area, their role was limited to making the observations and submitting the results. Thus, although participants could also use the project's website to view multiple data points, there was no expectation that they would carry out activities beyond the contribution of the observations.

Interestingly, the study concluded that the assumption about the color change was wrong, but other unexpected evolutionary changes in the patterns of snail shells were discovered.

Snails used to determine water quality (Photo Credit: Robert Cameron)

Technology-mediated engagement at various scales

In addition to the examples provided so far in this chapter, it is worth noting the way in which the technological changes identified in the first chapter have opened up the opportunities to create citizen science activities that operate through the web and use the abilities of mobile devices. As a result, a range of citizen science projects became possible, and some of them are changing the patterns of engagement and observation. In this section we look at the impact of this transition.

As the noise monitoring cases demonstrate, the reach of current ICT led to rapid change in scale and geographic reach. Both NoiseWatch and WideNoise were picked up by people from outside the geographic area for which it was originally conceived. The Cornell Lab of Ornithology eBird system, which has been running for over a decade, now records observations across the globe – with extensive coverage across Europe, Australia, Central America, and many other places.

Interestingly, despite the ability of technology-based projects to transgress national boundaries, the importance of place and location do not diminish. An example is provided by volunteer computing which is not place specific – in principle, anyone with a computer linked to the internet can download the software and join a project as they wish. Yet, there is still an advantage for country-specific organizations to promote such activities. The German non-profit organization Rechenkraft.net e.V. started from discussions among German-speaking volunteers in 2001, and evolved into an established organization in 2004. Eventually, it started to carry out local projects that were created by participants, based on their own interests.

This project utilizes technical additions to the basic volunteer computing platform BOINC, which was developed in the US. The organization itself is small (about 80 members) but provides a forum for volunteers who are looking for a higher level of engagement, which goes beyond the fairly limited installation of software or selection of projects. The need for organization and the interest in face-to-face meetings demonstrate the importance of providing participants with localized contacts and meeting opportunities. Similar patterns have been observed in volunteer thinking activities, such as participation in mapping local places in OpenStreetMap, where ad hoc local meetings happen regularly and are important in keeping the motivation of highly engaged volunteers.

Another impact of the use of ICT is the ability to engage volunteers at different stages of the research process, and to provide them with the tools to enhance their understanding beyond basic data collection. The work of the Zoological Society of London and the Bat Conservation Trust demonstrates this. The Indicator Bats (iBats) project was established in 2006, and included monitoring activities in Romania, Bulgaria, Hungary, Croatia, Ukraine, and western Russia. Over 700 volunteers in the project drove along a predefined transect of 40km at a speed of 25km/h after sunset, using equipment that could record ultrasonic bat calls (see facing page).[65] Later on, in 2011, the recording and location data collection was integrated into a mobile phone app, thus simplifying the monitoring process. As in the example of the Evolution MegaLab, the collaboration across countries was facilitated through British organizations, by collaborating with local conservation and research organizations in each country. The engagement of volunteers at the data collection stage is significant – it requires investment of time and resources to ensure that the data are collected correctly.

An iBat volunteer preparing for a bat-recording journey (Photo Credit: Indicator Bats Programme)

iBats is also utilizing the volunteer thinking mode of engagement, through the project "Bat Detective" http://www.batdetective.org/. The need for this project emerged from the amount of recording that the iBats volunteers created, and the opportunity to engage many more volunteers who can listen to bat calls on their computers and help the scientists in classifying them. This allowed a further 2,400 participants to join the project and analyze the data. The mode of engagement in the Bat Detective program is lighter and supports micro-volunteering in which participants use a small portion of their free time to carry out a classification task online.

Moreover, examples of more sophisticated analysis are provided in the Scratchpads project (http://scratchpads.eu/about), which allows volunteers and professionals to create their own biological recording website and share information at a higher level. The project hosts over 630 sub-sites, with over 6500 people using the system. The discussions in each sub-area are highly specialized, and the citizen scientists who participate in the discussions are the more committed ones.

ICT has a growing role in the process of engaging and recruiting participants to different projects, especially with the Web's ability to provide, at very low costs, support to niche

interests — as Scratchpads demonstrates. For over 20 years, electronic mailing lists have assisted in sharing environmental information between activists, NGOs, and authorities, even in places with very low connectivity (e.g., the area of the Soviet Union in the 1990s[66]). The proliferation of social media has increased the ability of projects to encourage people to move from passive to active participants. For example, a short video of the OPAL Tree Health survey (see Box 8) provides a link to the website where further information can be found. However, since the social media audience is segmented between the different platforms (e.g., Facebook, Twitter, or Google+), the challenge for project organizers is to be able to operate on these multiple platforms. Another important role of ICT is in maintaining engagement and interest in a project. By providing volunteers with near immediate feedback on their observations and contribution (e.g., in Evolution MegaLab), the evidence shows that participants increase their engagement and motivation to contribute further.

Multidimensional understanding of citizen science

In this chapter, we have looked at different jurisdictions and types of engagement in citizen science. We have seen that the local and city level are more amenable to community-led citizen science activities, while larger scale and longer temporal scales require standardization that limits the tasks of individual participants, although a few of the participants will be interested in becoming more involved and the use of ICT can enable them to do so.

In terms of policy areas, the examples are representative of the general literature. Ecological monitoring and dealing with environmental issues, such as air quality, are the most widespread and well-established areas in which citizen science is used regularly and is increasingly recognized as an effective and necessary method.[67] Education, and especially efforts to promote science, technology, engineering, and math (STEM) interest, is another area that recognized the potential of citizen science.[68] Some examples of citizen participation in management of their cities are also emerging, although much of the discourse around "smart cities" is focused on the utilization of information that has been collected passively, and this is an area that has been recognized as having potential growth.[69] The transport system and collecting evidence on its performance is another area where there is a potential for citizen science to augment passive and sensor-based monitoring, which are currently at the center of attention. As shown, citizen science can contribute to public health and increasingly also be involved in medical research — such as 500,000 volunteers who are part of Cancer Research UK's citizen science effort.[70]

Another area that can benefit from extending citizen science activities is addressing issues of food production and agriculture. For example, under the guidance of France National Museum of Natural History, a specific project was developed for the agricultural sector. The Agricultural Biodiversity Observatory (http://observatoire-agricole-biodiversite.fr/) was commissioned by the Ministry of Agriculture and is contributing to the National Biodiversity Strategy by providing observations of pollinators, earthworms, molluscs and beetles. The project started in 2009 and by 2013 engaged over 400 farmers in recording biodiversity indicators in 530 plots. The farmers have control over their data, which remains confidential, because of its commercial value. However, farmers can also see aggregate information and use it to improve their practices.

In the next chapter, we turn to look at the influence of policies on citizen science and its practice.

Summary

- From policy perspective, it is valuable to analyze citizen science projects according to their geographical scale – local, city, regional, country, and continent/global. Different levels lend themselves to different modes of participation and, as the geographical scope increases, the role of individual participants in the whole scientific process diminishes.

- Citizen science is especially effective at the local, city, and national level, due to the availability of suitable organizational structures that can support it.

- Recent technological changes provide new forms of activities that participants in citizen science can carry out, and also support the scaling up of existing activities.

Chapter 3
Policy support for citizen science, and citizen science support in policy formation and operation

Chapter 2 explored the dimensions of citizen science along geographical, policy, and engagement axes. We will now use this framework to understand the ways in which citizen science can be supported by policy actions, and the ways in which citizen science can help policy makers in developing and implementing policies. We start with the implications of citizen science governance on public policy.

Legal and organizational frameworks of citizen science activities

In Chapter 2, we encountered the different organizational structures that support citizen science activities at different levels. The organizational structure influences the way in which people can participate, the longevity of the activity, and its scope and scale.[71] The most basic organizational structure is an ad hoc one, which is especially common when local concerns are at the focus of the activities. An ad hoc structure can come to life as a result of people coming together to address an issue that galvanized them into action – for example, a planned development in their area.[72] Ad hoc organizations can easily support their activities using electronic communication to coordinate their work (e.g., create an email address on Gmail, and a Twitter handle for the group) and to promote and disseminate information (e.g., a Facebook page).

Ad hoc settings are usually headed by a small group of committed individuals who carry out many of the aspects of the activity – from setting the tasks to collecting and sharing the resulting information. Such a structure can work well over a short period of time and at very local scale, where the communication with policy actors (e.g., municipality environmental services) can be done directly by one of the members as concerned citizens. However, this can also lead to failure if the issue being dealt with is not localized, such as an airport that is used by a whole region, or if the issue that the community addresses is a long-running one. In such cases, it is critical to maintain knowledge about the issue, the actions that have been carried out, and the evidence that has already been collected.

Often, ad hoc citizen science activities are linked to an existing neighborhood-scale organization, such as residents' association or a parent and teacher association, where people are already familiar with one another. When the citizen science activity is linked to such an organization, even if it is operating at a small scale and with limited means, it can provide the ability to maintain interest and activities over time.

As the geographical and temporal scales of the project increase, a formal organizational framework is required. The rationale is that such projects need, at the least, a coordinator who will recruit participants, keep them informed, and manage the data collected through the project. Small to medium sized NGOs (such as charity, foundation, or not-for-profit) are suitable to manage such activities and provide the necessary support and, in many cases, can do that with their existing personnel, especially in cases where the activity fits within the organizational objectives. In other cases, the structure can include a few researchers at a university or public research establishment. In both cases, funding a coordinator is necessary, in addition to the other costs of equipment, meetings, and promotion of the project.

These fairly light organizational structures have the benefit of dedicated effort for coordination and management, as well as ensuring that training for participants is similar across different sites. To some extent, NGOs have the advantage of longevity over research institutions, as the former do not operate within a mindset of time-limited projects which is more common in universities and research institutes. Indeed, when examining the longer-running citizen science projects, they are frequently managed by NGOs. Notice that in the case studies in Chapter 2, at both neighborhood and city scale, we've seen the role of NGOs (Mapping for Change and London Sustainability Exchange) in developing the lessons from one study to the next, as well as managing and harmonizing the information. The role of research institutions was demonstrated at the regional and continental scales (Open Air Laboratories). The longevity issue is best demonstrated with Evolution MegaLab, which had a very specific time frame of funding and, while the website continues to operate, there is no clear indication if submitting further records will be of any use or how the information that was submitted can be used for other purposes.

As noted, cooperation between organizations is a common characteristic of citizen science activities, especially at the larger geographical scales. Cooperation can be established between NGOs, as well as by close contact with governmental bodies. For example, the OPAL Tree Health survey (see Box 8) was developed in close contact with the UK government's Department for Environment, Food and Rural Affairs (Defra) and its related body (Forestry Commission). Close cooperation between community groups, NGOs, and universities is also common in many cases; however it's vital to identify a specific person or entity at the university as a liaison and facilitator.

The model of Science Shops provides a clear location and time when advice can be sought, while in online citizen science activities, such as those that are run by Zooniverse, a community manager is appointed to respond to queries that are submitted to the bulletin board. There are only rare examples of public-private partnerships or attempts at for-profit citizen science activities. In 23andMe, participants purchase a personalized DNA sample kit and send it to a company that may use the information for research in the area of genetics and healtcare. Google Earth Outreach has been involved in a range of citizen science projects, although mostly as philanthropic activity. In the UK the energy company EDF sponsored a study of the distribution of bees, as part of their corporate social responsibility to encourage education in STEM. However, the most successful integration of citizen science activities into the private sector is the organization EarthWatch Institute, which is covered in Box 8.

Box 8 *EarthWatch Institute collaboration with the private sector*

The EarthWatch Institute, which was established in 1971, have been running many citizen science projects using a model that is somewhat similar to 'crowdfunding' in which the institute matches scientists with interested participants, who then join a scientific expedition. Over the past 25 years, EarthWatch Institute developed a corporate engagement program in which employees join expeditions and carry out scientific research. For example, together with Starbucks a project was designed to assist coffee growers in Costa-Rica[73]. In the project, volunteers collected information on yield, quality and environmental conditions. The information was used to improve crop growing practices. In another project, HSBC employees were involved in forest monitoring that contributed to climate change assessment in India. The monitoring also assisted the corporate aim of improving its own sustainable practices by giving employees an opportunity to see how scientific analysis is carried out. EarthWatch lists over 20 companies on its website that participate in this exchange.

The organizational settings can also influence citizen science activities in terms of inclusion, outreach, and the purpose of the activity. Different organizations, especially at the city level and above, will have specific aims and objectives in their mission, and these will set the topics that they will cover and the way in which they will operate. Therefore, governance and policy changes in the organization can impact the level in which it is interested in citizen science. Funders can also set terms that will influence the characteristics of citizen science activities – for example, OPAL funding from the national lottery in the UK led to an emphasis on outreach and inclusion, while the EU funding stream for the participatory sensing project EveryAware (see Table 2) emphasized the scientific outcome without attention to who was involved.

Moreover, the resources that are available to an organization will influence the scale of support that it can provide to participants in citizen science activities, and therefore the likelihood of success. While only a few organizations running such activities will employ

different people to perform each specific role, an analysis of the range of skills helps in appreciating the complexity of large-scale citizen science activities. Notice that, in some cases (e.g., development of apps for different smartphones' operating systems), there is a need for more than one person. As a result, Table 3 lists nine distinct roles that are needed in a large-scale project. In smaller projects, these roles will be merged: sometimes into a single person who will be supported by existing systems and external contractors.

Table 3 *Roles in citizen science project(s)*

Role	Description
Project Manager	Coordinates between scientists, developers, community members, and other organizations that are involved in the project, ensuring that the project progresses as expected.
Scientist	Provides the scientific support to the project and help in designing the methodology, ensuring that information is of good quality.
Community Manager	Manages the communication with participants, promotes the project on various social media, and provides updates through such channels.
Science Communicator	Prepares the scientific information that will be shared to participants and answers questions in a language that is accessible to a wider public audience.
Community Scientist	Provides training to participants to ensure that the methodology is well understood and that the information in data sheets, apps, and website is understood by participants. The community scientist can also help in framing the local problem as a research question that will be integrated into the project.
Software Developer	Supports the development of apps and web-based data collection systems. Develops the main project website, linking it with various social media, email lists, etc.
Data Manager	Maintains the information that is provided by participants. Uses appropriate procedures to ensure the quality of the information. Ensures that the data is protected and shared appropriately.
User Interaction and Experience Specialist	Ensures that apps, websites, and data collection forms are easy and enjoyable to use and assists in evaluating the levels of engagement in various media and the usability of digital tools.
Graphics and Information Designer	Ensures that the project information is presented in a consistent way across printed and digital media, and provides advice on information visualization.

The variations in organizational structure and practices have direct implications for policy makers. Each of these structures requires a different level of support and funding – especially if the aim is to integrate citizen science information into a long-term monitoring effort that requires longevity in coordination and information management. The role of NGOs is recognized in law (for example, with respect to environmental decision making), however they are only in a few areas of policy and are not recognized as producers of information by themselves. ***It is therefore expected that, in the coming years, there will be a need to amend legislation to allow for integration of public generated information.*** A good example is the strong legislation in Europe following the Arhus Convention of 1998 on public access to environmental information, participation in decision making, and access to justice.[74] The legislation that followed the convention ensured strong provision of environmental information to the public, yet it doesn't consider the situation when the public creates its own information during a decision making process.

Another aspect that requires the attention of policy makers is raising the awareness of public officials to citizen science. For example, environmental protection officers at the city level need to be able to communicate with NGOs, and even ad hoc community groups, to provide them with guidance about the procedures and potentially loan them high-quality equipment. At the higher level of government, those who are in charge of policy implementation need to be aware of the potential of citizen science to be part of the approach used for achieving policy goals, as well as providing appropriate support and resources to organizations that are running the citizen science program itself.

Information management and data quality

The level of geography, topic, and form of engagement, as well as the reliance on ICT, has an influence on information management and data quality. In ad hoc formation, and in very small NGOs, valuable information can be lost if the organization folds or if a single individual is responsible for data management and decides to leave the activity. At a very local scale, paper forms and non-computerized data collection is feasible; however, this information cannot be shared easily. Therefore there is an advantage in ICT provision which is designed in such a way that it will encourage even ad hoc groups to use it, for example, by providing them communication tools.

In larger organizations, it is more likely that a technical team will be in place and therefore longevity in data management is possible. For smaller organizations, the use of existing infrastructure provided by larger organizations can provide the necessary continuity. An example of a best practice is provided by the UK Biological Records Centre which, with a small team, provides services to country-scale monitoring. This is done through the support of over 80 ecological recording schemes and societies, thereby assisting with information management for many thousands of volunteers.[75]

From a policy making perspective, the quality of the information used for decision making is vital. Citizen science information is produced by a different process from highly structured and controlled information production which the state or commercial organizations are used to. When information is standardized, detailed specifications can be drawn, against which the general quality elements (e.g., is everything recorded correctly?) are tested and quality assurance procedures are developed to ensure that the surveyor collected the necessary information on the ground. The practices of centralized, scientific, and industrialized information production lend themselves to quality assurance procedures that are deployed through organizational or professional structures, and explain the perceived challenges with citizen science data. For example, procedures for appropriate calibration of air quality monitoring equipment can be drawn up and then applied at predefined intervals. Centralized practices also support employing people with the focus on quality assurance.

In contrast, most of the collection of citizen science takes place outside organizational frameworks. Some misguided perceptions of citizen science assume that, because the people who contribute the data are not employees, they cannot be put into training programs, be asked to follow quality assurance procedures, or be expected to use standardized equipment that can be calibrated from time to time. The lack of coordination and top-down forms of production raise questions about ensuring the quality of the information that emerges from citizen science.

Over the years, several approaches have emerged for quality assurance in citizen science projects. These approaches take into account the specific characteristics of these projects and can be termed as ***crowdsourcing, social, geographic, domain, instrumental observation***, and ***process oriented.***

The ***crowdsourcing*** approach builds on the principle of abundance of observers. Since there are a large number of contributors, quality assurance can emerge from repeated verification by multiple participants. Thus, if several participants deliver a Global Positioning System (GPS) tagged image of a rare flower, taken independently from different devices but at the same location, we can be certain that the information is accurate. In volunteer computing and volunteer thinking, the same task can be carried out by multiple volunteers, to allow for statistical analysis to verify the level of agreement among them. Even in projects where the participants actively collect data in an uncoordinated way, such as the OpenStreetMap project, it has been shown that, with enough participants actively collecting data in a given area, the quality of the data can be as good as authoritative sources[76]. The limitation of this approach is when local knowledge or verification on the ground ("ground truth") is required. In such situations, the crowdsourcing approach works well in central, highly populated or popular sites where there are many visitors and therefore the probability that several of them will be involved in data collection rises. Even so, it is possible to encourage participants to record less popular places through a range of suitable incentives.[77]

The **social** approach also builds on the principle of abundance in terms of the number of participants, but with a more detailed understanding of their knowledge, skills, and experience. In this approach, some participants are asked to monitor and verify the information collected by less-experienced participants. The social method is well established in ecological monitoring such as birdwatching, where some participants who are more experienced in identifying bird species help to verify observations by other participants. To deploy the social approach, there is a need for a structured organization in which some members are recognized as more experienced and are given the appropriate tools to check and approve information. The downside of this approach is the potential of delays due to a shortage of moderators, or their ability to check and verify observations. In some cases, the backlog that is created can mean that many months pass between submission of an observation until it is shared in an accessible form.

The **geographic** approach uses known geographical knowledge to evaluate the validity of the information that is received by volunteers.[78] For example, by using existing knowledge about the distribution of streams from a river, it is possible to assess if water quality samples are comprehensive or not. A variation of this approach is the use of recorded information, even if it is out of date, to verify the information. For example, through comparing known information in a location to citizen science input. This geographic knowledge can be potentially encoded in software algorithms that evaluate new information in light of existing knowledge.

The **domain** approach is an extension of the geographic one and, in addition to geographical knowledge, uses specific knowledge that is relevant to the domain in which information is collected. For example, in many citizen science projects that involve collecting meteorological or astronomical observations, there will be a body of information about expected observations both spatially and temporally. Therefore, a new observation can be tested against this knowledge, again algorithmically, which helps to ensure that new observations are accurate or if further checks are needed such as asking another volunteer to verify the information.

The **instrumental observation** approach removes some of the subjective aspects of data collection by a human who might make an error and relies instead on the availability of the equipment that the person is using. As noted, accurate-enough equipment is now widely available with the various sensors that are integrated in smartphones. For example, image files that are captured in smartphones include the GPS coordinates and time-stamp which, for a vast majority of people, are beyond their ability to manipulate. Thus, the automatic instrumental recording of information provides evidence of the quality and accuracy of the information. This can provide verification to citizens' reporting in many urban applications.

Finally, there is a **process oriented** approach, which brings citizen science closer to traditional industrial processes. Under this approach, the participants go through some

training before collecting information, and the process of data collection or analysis is highly structured to ensure that the resulting information is of suitable quality. This can include provision of standardized equipment, online training, or instruction sheets, and a structured data recording or classification process. For example, in volunteer computing, the whole analysis and modeling process has been automated, leaving no action on the side of the participant apart from software installation. Volunteer thinking projects, such as Zooniverse, are based on a highly structured process that guides the participant through training before allowing them to carry out analysis. The software also constrains the participant to analyze the aspects that were built into it. As noted in Chapter 3, there are also growing opportunities for members of the public to learn the basics of the scientific approach and its methodologies using ICT. The UK Open University OpenScience Laboratory[79] demonstrates this by providing the necessary resources to learn these concepts and principles.

Box 9 *The use of quality assurance methods in practice*

In practice, quality assurance approaches are not used in isolation and any given project is likely to see a combination of them in operation.[80] Thus, an element of training and guidance for users can appear in a downloadable app that is distributed widely. This can done by guiding the participant through several information screens the first time the application is used. In such a case the method will be a combination of the process oriented and the crowdsourcing approaches. Alternatively, the observations from a structured app that guide the participant to collect data in a certain way are verified by experts before committing them to the main database is a combination between process oriented and social approaches.

The OpenStreetMap project provides another example. In general, OpenStreetMap gives limited guidance to volunteers in terms of information that they collect or the location in which they collect it and therefore they are free to record whatever they like. As a result, the crowdsourcing and the instrumental approaches are used[81]. Yet, a subset of the information collected in the OpenStreetMap database about wheelchair access is completed through the highly structured process of the WheelMap application in which the participant is required to select one of four possible settings that indicate accessibility for wheelchair users. Another subset of the information recorded for humanitarian efforts follows the social model in which the tasks are divided between volunteers using the Humanitarian OpenStreetMap Team (H.O.T) task manager, and the data that is collected is verified by more experienced participants.

The final, and critical, point for evaluating the relevance of citizen science information for decision making is ***fitness for purpose***. One of the core aspects of citizen science information is its heterogeneity over space and time. Therefore, before using such information for a specific application, there is a need to check for its fitness for

this specific use. While this is true for all environmental information, and even so-called "authoritative" data sources can suffer from hidden biases (e.g., lack of updated information in rural areas), the situation with citizen science is that variability can change dramatically over short distances. There are also limitations that are caused by the instruments in use – for example, the GPS positional accuracy of the smartphones. Therefore, analysts working to provide information to decision makers need to be aware of the source of the data and how to use it appropriately. In addition, adequate policies on information that accompany the citizen science information (metadata) should be in place to assist intermediaries in providing suitable metadata that can be used to assess the relevance of information for a given analysis.

Citizen science information: production, use, and the open science movement

As the previous sections made clear, while information from citizen science can be valuable for decision making and monitoring, the creation of a successful and sustainable project is a challenging task. In this section, we focus on the impact of who produces the information and how.

As noted in Chapter 2, in many projects there is unequal participation in terms of gender, ethnicity, age, and socioeconomic backgrounds. In some cases, this is the result of the multiple prerequisites that are needed from participants – access to advanced smartphones and the Web, technical knowledge, and domain knowledge, as well as leisure time and the self-motivation to learn about the project and participate in it. Because citizen science can serve multiple goals (STEM education, awareness of scientific or environmental issues, provision of new information to scientists, monitoring, etc.), there is a need to carefully consider the trade-offs and to decide which of those will be addressed in a given activity. Local and city projects can be more inclusive, since the barrier to participation is usually low. As the project grows in scale, there is a need to carefully consider the target audience and the reach. A common misconception is that social media and the Web are enough to ensure wide participation, since there is no obstacle for anyone to be able to participate in the project. There is, therefore, a need to differentiate between *potential participation*, which any website can be for any person with web connection (assumed to be over 3 billon people), and *actual participation* which is limited by skills, time, connectivity costs, and coverage, along with other aspects discussed above*. If the aims of the funder are to increase participation of disadvantaged groups, or to achieve improvement in STEM education to a specific group, then a purposeful activity must be designed to reach the target group and engage them in an effective way.*

In projects that require coverage of observations in places people do not visit often, or require observations throughout the year, there is also a need to consider the incentives

and motivation of various participants. In some cases, the commitment in time is quite significant, as in a request to examine bird population along a predefined transect of a kilometer, several times during the spring and summer, as the British Trust of Ornithology (BTO) asks from its volunteers. While some volunteers will be willing to accept challenges in terms of the effort that they need to put into observations, in other cases, providing some incentives – such as covering fuel costs – can be used. Recruitment can be targeted at a specific area that lacks coverage or even in combination with paid observers who complement the areas not covered by volunteers.

Gamification (providing a competitive or playful framework for data collection) is another successful strategy to cover remote areas, as demonstrated in the Geograph.org.uk website, in which the aim is to provide an image of each square kilometer of the UK. Over the years, volunteers have provided images for 293,000 square kilometers, which is over 80% of the total area. Participants compete with each other the load to most images. Outreach to unlikely participants can also be a useful approach; for example, the Citizens' Network for the Observation of Marine BiodivERsity (COMBER) project in Greece engages with local diving clubs to monitor biodiversity in a marine environment. By capitalizing on existing infrastructure this approach reduces any recruitment and equipment costs.

Once the information is produced by citizen scientists and validated by a suitable organization, there is a need to consider the form and procedures in which it will be shared. Importantly, the project team who set up the project and communicated with the observers will be in the best position to evaluate the quality of the information. As noted in the previous section, the provision of documentation in the form of useful metadata is necessary to allow analysts who use the data to understand its origin and fitness for purpose. However, most of the existing metadata standards assume that the information was produced in an industrial process that is standardized and easy to evaluate and therefore do not fit the paradigm of citizen science. For example, in 2007 the European Union member states started a process to provide standardized access to environmental information following the "Infrastructure for Spatial Information in the European Community (INSPIRE)" directive. However, the provisions of the directive do not include citizen science data, and further amendments and guidance will be needed to integrate such data into the overall framework.

Beyond metadata, there is the issue of accessing the information itself. Here we encounter issues not only in the organizational structure and practices but also with its business model. As noted, the ability of an organization to manage and share its data depends on its size and the available personnel, or the level in which it works with other organizations who can manage the data for it. However, the ability of an organization to share the data further depends on its funding model – which sometimes is based on access to the data. Because of the complexities of running and sustaining a citizen science project, especially when considering the roles and responsibilities of different

people within the organization, sustainability of funding to run the activity is highly important. Sometimes, charging for data can provide additional income. For example, the British Trust of Ornithology (BTO) is securing nearly £100,000 (over $155,000) from royalties that are partially based on access to their data. As a result, access to the data is paid for – although at a symbolic rate for personal and research use.

In other cases, while the data is available, the process of accessing the data for download and further analysis requires approval from the organizations who are the custodians of that data, and who also control the level of access to information. This is appropriate, as different contributors will set their conditions on who should be able to see their information – for example, information about rare species needs to be protected, as well as records that provide detailed personal information such as name and address. But, the moderation of access requests does slow down the speed with which information can be used. ***Furthermore, there are also technical challenges in setting up an operational data portal and, unless a data portal is funded and supported at the national or international level, it is likely to be beyond the capacity of an organization to do so.*** For example, current and emerging requirements mean that the data will be formatted in a machine readable way and comply with standards, such as those of the Open Geospatial Consortium (OGC), which are not trivial to implement. In contrast, some local ecological recording volunteers use spreadsheets and even paper forms to record the information that they collect – thus there is a need to fund the effort of converting such data into a form such that it can be shared and consumed widely.

The issue of information sharing brings up the final aspect that needs to be considered within the analysis – open science, open data, and open access. While all use the word "open" in them, it is important to note the differences. Open science is an umbrella term for a range of activities that call for the opening up of the scientific process to society. It includes activities such as making the process itself transparent – so a researcher will declare their research aim from the start and will carry out all the activities in such a way that it is possible to check the underlying data or the methods that are used. The open science movement also calls for making all the data sets produced by science open for anyone to use in any form they wish to (open data) as well as ensuring that the outcomes of the research, in the form of research publications, are free to access and reuse (open access). In practice, different organizations and researchers support part of these elements. However, the general movement of open science is very relevant to citizen science activities, and policy discussions on open science should also consider these impacts.

Because citizen science information is produced on a voluntary basis, there are growing calls for the information to be shared first with those who provided it, as well as with other researchers, once it is aggregated[82]. For example, data portals such as the Global Biodiversity Information Facility (GBIF) provide access to free and open-to-use biological records, of which about a third originate from citizen science records. In terms of access to records, the Swedish/Norwegian uArtsobservasjoner system

(http://www.artsobservasjoner.no/), to which over 9000 volunteers contribute, provides access to all the information and by doing so enables volunteers to see how their observations contribute to a wider whole. While the information is free to use, they established that the observer is the owner of the information – for example, if a commercial user wants to use an image in a publication, they will need to approach the participant to obtain permission.

Open data can be important to volunteers who want to carry out analysis on the records that they collected, and see how well they match the overall pattern of observations. The availability of free software for the analysis of information (such as the sophisticated statistical package R, or the mapping package QGIS, or Google Earth) means that the more dedicated or research focused volunteers can carry out scientific analysis at the level of professional scientists.

Open access is also critical to citizen science from two perspectives: recognition and learning. As citizen scientists gain recognition within the scientific community, it becomes more common to recognize their contribution in scientific publications or in published datasets. If the publication is made available in scientific publications that are charging for access, the people who have contributed to it cannot see it. Such feedback has been shown to be part of the motivation for citizen scientists to continue their engagement, and therefore it is important to ensure that publications based on such data are provided under open access terms.

The other contribution of open access publications is to allow citizen scientists to learn more about the topics they are investigating. For example, in the case of local concerns over pollution, open access publications can provide the means for community members to interpret the data they have collected and to assess the health implications, if any. This is similar to the transition in the medical profession, when patients have both access to understanding the research on their condition and the ability to understand the finding and use them to work together with their physicians to treat it.

Yet, it should not be assumed that all citizen science data will be provided under open data and free reuse terms. First, as noted above, access to data can represent a valuable source of income to maintain the necessary infrastructure, and opening the data without provision of alternative funding can undermine the basic data collection support. Second, data can be sensitive in its content, as in the case of endangered species or in information about the participant,[83] especially in cases where information was collected by a local group and there are issues of collaborative decision making regarding which data should be released, to whom and under which conditions. In large-scale projects, agreements with participants are more standardized, but the data aggregators and analysts need to be aware of sensitive issues such as privacy. For example, they need to be aware of the existence of algorithms that allow for meaningful analysis without compromising location details of participants[84].

The current structure of academic publications, and hence promotion, job security, and the likelihood of further research funding, is impacting the process of data sharing. For example, the UK Natural Environment Research Council (NERC) has recognized in its data policy that researchers are allowed to keep the data without sharing it for two years, or even more (embargo period). Since the common measurement of scientists' and research centers' productivity is the number of publications in highly regarded peer-reviewed publications, the wish to provide open data needs to be balanced with the wish of project coordinators to ensure that they have published the most significant results themselves. In cases where significant financial value can result from the research (e.g., discovery of a new drug) and intellectual property rights (IPR) are to the fore, we can expect significant challenges to the integration of citizen science. The same is true when there are commercial concerns such as those of the farmers in the French Agricultural Biodiversity Observatory. Different biological recording schemes have also reported on volunteers who have been collecting observations for many years, but share them only judiciously, for a whole host of reasons.

Therefore, in terms of policy, there is a need to develop suitable incentives that will encourage scientists and volunteers to share their data. In terms of the impact of citizen science on policy, a rapid sharing of verified data can help the analysts who support decision makers to have near real time and accurate information. This is demonstrated in the Asian tiger mosquito which can be valuable for preparedness of public health and medical professionals because they need to be aware of the potential encounters with diseases that the mosquito may be carrying.
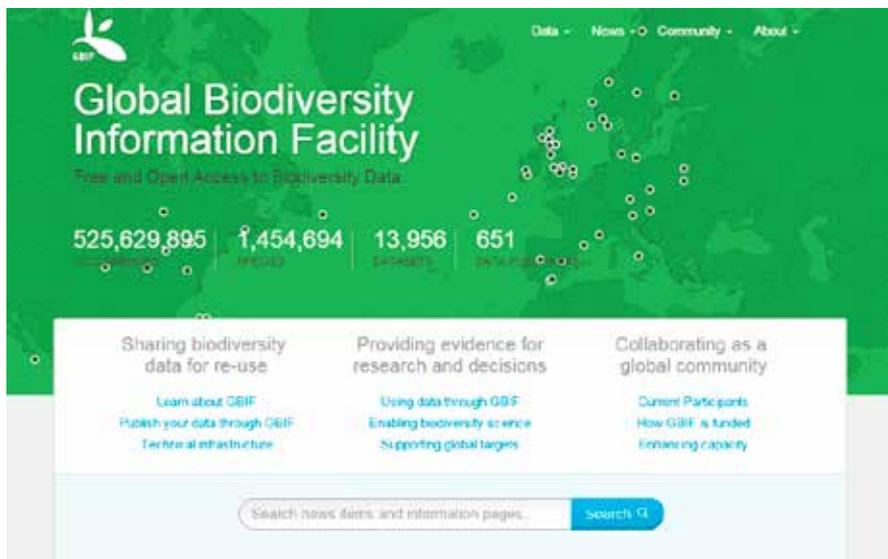
Global Biodiversity Information Facility is a free and open access database to biodiversity data. About a third of the observations originate from citizen science records. (Photo Credit: www.gbif.org)

Summary

- Citizen science activities vary in their organizational settings: from ad hoc community groups to national NGOs or leading research institutes. Policies should be in place to support citizen science at different levels and organizations.

- Creating a successful citizen science project requires multiple skills – from good understanding of the scientific issue, to science community and ICT development. This requires ensuring the suitable investment is provided before starting a given project, and that the multidisciplinary nature of the field should be taken into account.

- Government officials and policy actors at different levels should be made aware of citizen science, so they can use it as part of policy implementation, as well as supporting existing activities.

- Citizen science can yield high quality, policy relevant information. Analysts who work with policy makers should be aware of the specific characteristics of such data, and use it appropriately.

- Support for information management and data quality procedures is needed for citizen science activities, especially when the activities are run by small organizations.

- The costs of information sharing and technical infrastructure need to be taken into account in citizen science projects, and be funded accordingly.

- Open access to academic publication is important for citizen science for two reasons: to allow participants to see the end result of their contribution and to support the learning process of citizen scientists.

- Open data policies need to be sensitive to citizen science data and allow control and judgment over what should be released. Specific incentives are needed to encourage scientists and volunteers to share their data.

Chapter 4
Toward inclusive and effective citizen science

In Chapter 3 we looked at different aspects of citizen science and policy at different scales. In this final chapter we look at policy aspects that can help and hinder the development of citizen science in general, as well as policy challenges that can emerge from it. We will look at emerging organizations dedicated to citizen science itself, as well as targeted activities of government agencies to develop the area. In the second section, we will look in more detail at the influence of existing policies on citizen science practices, as some of these policies are significant to the acceptance of citizen science information. Finally, we will look at the emerging challenges that citizen science creates.

The professionalization of citizen science

Within the past five years, scientists, project coordinators, and practitioners of citizen science activities have realized that there is a need to share best practice in multiple aspects of citizen science – from recruitment to data handling – to ensure that citizen science evolves in a way that will increase the likelihood of successful projects. As the previous chapters of this report demonstrate, there is also a need to ensure that policy makers and funding bodies understand how citizen science can be used, and sustain support for citizen science activities. Furthermore, as lessons from a range of citizen science projects continue to evolve, there is a growing need to provide continuing professional development (CPD) to practitioners and, potentially, accreditation. As a result, three organizations have emerged across the world. The organizations have started to operate in the past two years, and are currently setting up internal structures and practices.

The first organization is the Citizen Science Association (CSA), based in the US, but with the aim of supporting the global community of citizen scientists and practitioners. The association focuses on advancing citizen science through communication, coordination, and education. The European Citizen Science Association (ECSA) was launched in 2013 and is coordinated from the Natural History Museum in Berlin, Germany. ECSA has members from across Europe and beyond. The association focuses on coordinating citizen science activities across the European Union (EU) and its research area (which

also includes the Mediterranean), and has a focus on ensuring that policy makers in the European Commission (EC) and its related bodies, such as the European Environment Agency, are supporting citizen science. The aim of ECSA is to see the growth of citizen science, especially in environmental monitoring, across the EU. The last organization is Citizen Science Network Australia (CSNA), which had its inaugural meeting in May 2014, focusing on creating a community of citizen science practice in Australia.

All these organizations are currently exploring the most appropriate funding structure – for example CSA allowed anyone to become a member without charge, a call to which 2900 individuals from 65 countries have responded. In contrast, ECSA chose a paid membership model and already has over 40 paying members, which include various organizations and individuals. Its annual meeting was attended by 60 participants. ECSA also set itself a clearer policy advocacy goal, while CSA and CSNA are focusing on the practitioners' community as their first steps. The three organizations maintain a dialogue with each other to ensure a level of coordination.

While the associations present a "bottom-up" approach, since they have been set up and are developed by practitioners, there is also effort from governmental bodies to support and promote citizen science. The European Environment Agency carried out several workshops on citizen science and continues to provide information about citizen science in its newsletter, as well as support to ECSA. Other parts of the European Commission are also supportive of citizen science activities, as indicated in several calls in the EU research and innovation program of the EC for 2014-2020 (named Horizon 2020), which are targeted at developing citizen science activities and establishing them on a sustainable footing. In fact, the EU recognized the need for targeted investment in citizen science in 2012, and funded projects that are creating "citizens' observatories" (http://www.citizen-obs.eu/), covering areas from environmental monitoring for air quality and noise in cities, to odor from chemical and agricultural facilities, to monitoring marine water quality. In addition, the integration of a specific stream within the funding scheme, which is about "science with and for society," ensures that there will be ongoing opportunities to fund the development of novel citizen science activities.

At a national level, the Scottish Environmental Protection Agency (SEPA) followed its strategic commitment to citizen science with funding for guidelines for best practice in the use of citizen science[85] as well as financial support to ECSA. The UK government is also showing growing awareness of citizen science. The UK Department of Environment, Food and Rural Affairs (Defra) recognized the importance of citizen scientists' observations during a recent outbreak of a tree disease (Chalara, also known as Ash Dieback) when reports provided by citizen scientists confirmed the scale of the spread of the disease. The current plans for addressing this disease and, more generally, Defra's Tree Health Management plan integrate citizen science into the operation of the policy.[86] In Germany, The German Ministry for Education and Research (BMBF) supports a programme dedicated to capacity building as well as to

develop a citizen science strategy in an open consultation process, with resources and information on German Citizen Science Projects are available on a dedicated website (www.buergerschaffenwissen.de)[87]. We are starting to see across Europe the explicit integration of citizen science into national policies.

Policy "side effects" and citizen science

While citizen-science-specific policies are starting to emerge, there is a need to note how other policies can impact this area: often inadvertently (side effects). This is especially relevant for existing policies that are in place; however, others might seem, at first sight, unrelated.

In Chapter 3, we encountered examples of policies in the areas in which citizen science is active and which need to be adapted to the characteristics and practices of citizen science. The examples included regulations that focus on public access to environmental information and participation in decision making (Arhus Convention) but, at the time they were set, the potential for public participation in the production of environmental information was not envisaged. Therefore, public-produced information is not yet recognized as part of the framework that the Convention set, and it will likely require amendment to address it. A similar issue was demonstrated with more recent regulation on sharing environmental information across the EU (INSPIRE directive). The INSPIRE directive instructs all the bodies that create and maintain environmental information make the metadata about the information easily available, as well as a sharing arrangement for the data itself. While the directive was set in 2007, it does not include appropriate provisions to handle and share citizen science data. However, since the implementation of INSPIRE continues to 2019, there is scope to adjust the guidelines and standards so they can accommodate these data. Fortunately, INSPIRE is coordinated by the EEA, a body that endorses citizen science.

Another policy area that directly impacts the potential of citizen science is educational policy. A common issue reported regarding using citizen science in schools refers to policies that emphasize specific learning outcomes and educational curricula (e.g., in UK and France). Contributory activities can and are organized to match current school programs, as was successfully implemented by the OPAL project.[88] Arguably, the more inquiry-based citizen science activities have greater potential in increasing interest in STEM subjects, as demonstrated in the Blackawton Bees study in which children aged 8-10 designed and carried out a neurological experiment with bees that led to a scientific publication.[89] However, these more exploratory activities sit less comfortably within current curricula.

As can be expected, scientific policy is another area that can impact citizen science, beyond direct investment in the development of citizen science, as provided by the

EU Horizon 2020 program. Yet, the budgets that will be allocated to citizen science will be, by necessity, miniscule compared to the rest of the investment in research and development by government or the private sector. Therefore, citizen science needs to be considered beyond the narrow framing of public engagement in scientific research as a way to educate the public and raise awareness. Here, the example is set by the concept of "Responsible Research and Innovation" (RRI), another element of the EU Horizon 2020 program. RRI calls for researchers, companies, NGOs, and members of the public to "work together during the whole research and innovation process in order to better align both the process and its outcomes, with the values, needs, and expectations of European society."[90] Because the RRI calls for an inclusive and participatory research process, it opens up opportunities for the integration of citizen science across the research landscape.

As Chapter 3 demonstrated, ICT is highly important for the reemergence of citizen science, and therefore policies in this area will also have an impact on the participation potential in citizen science. A good example of this is the EU policy on roaming charges for mobile phone use and data access. Since 2007, the EC has been intervening in the mobile phone market to ensure reasonable pricing for mobile phone use across the EU. One of the side effects of this policy is that people are more likely to use their smartphone for data services while travelling, as a result tourists can use their phone during holidays, at times when they have more leisure time, and some will use this to add observations to their collection. Another example occurs in the UK where current policy is to achieve 95% coverage of superfast broadband (over 24Mbps) across the country by 2017. This policy will impact the reach of volunteer computing and volunteer thinking, since both forms of participation assume that the participant is connected by broadband link to the Web.

A final example of an area that can have implications on citizen science is within the area of culture and museums. For example, the provision of access to museums (such as science, natural history, or archaeological) can be linked to citizen science activities that allow the participants to enhance their visits with opportunities for informal learning. Investment in public broadcasting can also spark interest in participation. For example, the ongoing collaboration between the BBC and the Open University led to an announcement, during the long-running radio series *Saving Species* (2010-2013), to encourage the audience to join the iSpot community. While the commissioning of science programs or investment in museums is not aimed at citizen science, the existence of these cultural institutions provides opportunities to promote citizen science and increase participation.

In summary, because of the multifaceted nature of citizen science, it is impacted by many policy areas. While it is not expected that citizen science will be considered in each policy formation process, there is a need for awareness by policy makers and practitioners of these potential side effects.

Emerging challenges from citizen science

To complete the analysis, some of the challenges that can emerge from citizen science activities in policy areas and decision making processes need to be considered. Here we will look at three challenges – the potential of conflict due to citizen science, the use of indigenous knowledge, and the potential risks from DIY Science activities.

Citizen science in its civic/community science form might seem inherently confrontational, especially at the local and city level, where the community collects information to oppose or challenge local industrial facilities or future plans by local authorities, or even a case of "Not In My Back Yard" (NIMBY). However, citizen science can be seen as a potential tool to calm discussions, mainly because of the social perception of science as objective, disinterested, and based on rigorous observations. Participatory science practices to ascertain the exact state of affairs are part of making environmental decision making more transparent, and can increase the trust of the community in the conclusions of experts. Instead of opinions and perceptions about impacts of traffic or industrial activities, citizen science can move the discussion to the realm of factual information which can be tested. Of course, there is a risk of misinterpretation of results or misunderstanding what the scientific literature is saying about the issue – but, if handled correctly, citizen science can lead to positive outcomes.

Another challenging area is the opening up of local and indigenous knowledge across the world, through its integration in citizen science. The increase in recording of information can lead, inadvertently, to the release of sensitive information such as the location of an endangered species. At the personal level, there are privacy considerations and reduction of risk to the participant in cases where they have recorded information at their home.[91] With the growth in citizen science and the engagement of indigenous groups (see Table 2), there is a need to ensure that mechanisms for consent to participate, protection of information, ensuring intellectual property rights, and other aspects are in place, in accordance with international best practices, such as the International Labour Organization (ILO) Indigenous and Tribal Peoples Convention from 1989,[92] or the ethics guidelines of the International Society of Ethnobiology.[93] Importantly, many of the guidelines and the need to ensure ownership and control over local knowledge are also relevant for other situations of community-based participatory research.

Finally, although most of the report did not explore the highly specialized movement of Do-It-Yourself Science (DIY Science), in which participants are repurposing a range of materials and tools to build laboratories, there are risks associated with them. For example, the analysis of the diffusion tubes that are discussed in Chapter 3 case studies are carried out in commercial laboratories for now, however there is a potential for the analysis to be carried out also at the community level, as it is not especially complex. Yet, it involves the handling of corrosive and poisonous materials, and therefore needs to be

carried out with an understanding of the risks, as well as appropriate safety procedures. Similar issues are emerging in the area of "biohacking," which involves carrying out biological experiments in public laboratories by amateurs. Current research shows that the participants in such activities are usually aware of the complexity and are seeking out professional support. This was demonstrated in 2011 when members of a global DIYbio community convened to draft a Code of Ethics to govern the informal community of "biohackers."[94] The model of Science Shops that will allow interested members of the public to learn about safety procedures can be effective in addressing these issues.

Summary

- Citizen science is becoming more professional, with communities of practice emerging in the US, Europe, and Australia.

- Government bodies, at EU level as well as national levels, are integrating citizen science as part of their policy actions, as well as provision of funding to promote research and sharing of best practice.

- There are aspects that can influence citizen science within policies that have both direct connection to citizen science, such as STEM education, and indirect connection, such as ICT or culture.

- Some of the emerging challenges for citizen science and policy include the integration of citizen science in environmental decision making in a way that it improves the process, handling community information appropriately and considering the risks and opportunities from emerging practices such as DIY Science.

Summary and Recommendations

In this report, we have looked at citizen science from a multidimensional analysis approach. We have noted how geography, policy area, scientific domain, and mode of participation influence the interaction of citizen science with policy making. At the local level, community concerns will motivate people to deal with them, and citizen science can be seen as part of the toolkit for evidence-based and democratic decision making. At the regional level, citizen science can help in monitoring the implementation of policies. The growth in web-based citizen science and the use of mobile phones has opened up many new opportunities for instrumental observations which can enhance the abilities of analysts to use the information for decision making processes.

Overall, we have seen that policy makers and government officials need to be aware that citizen science, in its new incarnation, is a phenomenon that will continue to grow, and impact all levels of government. Each citizen science activity will always represent trade-offs between inclusion of people, education, awareness of science, and contribution to scientific research. The emerging examples from the European cases show that, with appropriate multidisciplinary teams, it is possible to achieve several of these goals in any given activity.

Although each chapter's summary, in effect, provided recommendations, it is worth revisiting them and noting the most significant lessons that emerge:

- First, because of the need for multiple skills to run successful projects, citizen science activities should receive funding that takes the longevity of start-up time into account, and allocates appropriate long-term funding to support sustainability.

- Second, the interaction with knowledge-based institutions such as universities and private and public research institutions is critical to the success of citizen science. This requires raising awareness and providing incentives to such organizations to be involved in citizen science, as well as targeted efforts in establishing mechanisms such as Science Shops to encourage greater interaction with the public.

- Third, together with practitioners, local and national government can analyze existing regulations and policies, and consider which of them are inhibiting the use of citizen science, and which can be adapted to promote citizen science.

- Finally, while citizen science can yield high quality data, this requires an understanding both at the level of the project, as well as end-users of the information. Appropriate guidelines and information should be developed to facilitate the use and interpretation of citizen science data.

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