CITIZEN SCIENCE:
THEORY AND PRACTICE

Turbé, A, et al. 2019. Understanding the Citizen Science Landscape for European Environmental Policy: An Assessment and Recommendations. *Citizen Science: Theory and Practice*, 4(1): 34, pp. 1–16. DOI: https://doi.org/10.5334/cstp.239

RESEARCH PAPER

Understanding the Citizen Science Landscape for European Environmental Policy: An Assessment and Recommendations

Anne Turbé[*], Jorge Barba[†], Maite Pelacho[†,‡], Shailendra Mugdal[§], Lucy D. Robinson[‖], Fermin Serrano-Sanz[†], Francisco Sanz[†], Chrysa Tsinaraki[¶], Jose-Miguel Rubio[**] and Sven Schade[¶]

Citizen science is increasingly upheld with the potential to underpin all aspects of the environmental policy process. However, to date, contributions of citizen science to environmental decision-making remain sparse and not well understood. Evidence points to a gap between the potential relevance of citizen science for policy and its actual implementation. We lack a comprehensive assessment of the current impacts of citizen science projects on environmental policy, and an identification of the scientific, engagement, and governance characteristics of projects that facilitate successful contributions to policy. This paper addresses that knowledge gap through identifying the characteristics of citizen science projects that support policy. We present an inventory of 503 citizen science projects with environmental policy relevance, and an in-depth analysis of 45 case examples with quantitative assessment of characteristics of the citizen scientist, scientific, socio-economic, and policy dimensions. Our results demonstrate that citizen science can underpin all steps of the environmental policy process, and that a diversity of approaches can be used to achieve this. However, governmental support, scientific excellence, and NGO-leadership facilitate policy linkages. We discuss the main challenges and opportunities identified by project leaders in linking citizen science and policy and present a set of recommendations for promoting the better integration of citizen science in the different phases of the policy cycle. Central among these are clarifying policy needs, facilitating access to citizen science data, and improving their evaluation and recognition by decision-makers.

Keywords: environment; policy impact; inventory; citizen science; monitoring; reporting

Introduction

Decision makers in the 21st century are faced with the responsibility of addressing new and increasingly complex environmental challenges to protect ecological and public health. Environmental problems occur at different spatial extents, typically unfold over long temporal scales, and have possible global implications. They require holistic, trans-disciplinary approaches, because efforts to solve one aspect may reveal or create other problems (Burke et al. 2017). More integrative assessments encompassing the socio-political dimensions of resource management, along with new forms of knowledge production, are necessary to meet the growing array of collective and international environmental obligations (Danielsen et al. 2014; Hyder et al. 2015). To be effective, decision making must address the goals and values of stakeholders and incorporate public input in crafting the solutions (Weichselgartner and Kasperson 2010; McKinley et al. 2017). Moreover, the pace of environmental change makes it imperative to identify emerging environmental issues rapidly to avoid or minimize damage. Decision makers thus need new ways to extend the scientific knowledge base, engage citizens, and support the different steps of the policy process.

Citizen science is emerging as a practice that can be a powerful addition to the policy toolbox because it can effectively contribute to all aspects of the policy process. Citizen science has been tremendously useful for identifying new environmental problems, such as farmland birds declines, and promoting issues such as pesticide use and intensive farming practices on the policy agenda (Donald, Green, and Heath 2001). There is widespread evidence that citizen science can expand the scientific knowledge base

[*] Ecoscope, Haifa, IL
[†] Ibercivis Foundation, ES
[‡] University of the Basque Country (UPV/EHU), ES
[§] BIO Innovation Service, Paris, FR
[‖] Natural History Museum, Cromwell Road, London, UK
[¶] European Commission – Joint Research Centre (JRC), Ispra, IT
[**] European Environment Agency (EEA), Copenhagen, DK
Corresponding author: Anne Turbé (aturbe@gmail.com)

by mobilising lay, local, and expert knowledge, or by carrying out research in places and at scales that would not have been possible otherwise (Newman et al. 2017), and citizen science has been instrumental in the early detection of a range of environmental issues (BIO Intelligence Service 2010). Citizen science also can be used to signal new or ongoing issues to decision makers and to support policy formulation by providing the necessary background data to establish restrictions or targets. Examples include the use of beach litter data to inform all plastic levies introduced in the UK (Beachwatch; for links to the project see Table S2, supplementary files).

Citizen science initiatives also have been used frequently in later stages of the policy process, notably to support policy implementation. Several citizen science monitoring programmes have been instrumental in informing the designation of protected areas (e.g., eBird, Seasearch; Table S2, supplementary files), while other programs contribute to better understanding of environmental issues and the means that can facilitate changes in practices (e.g., Propage; Table S2, supplementary files). Citizen science data also can be a means to address the large-scale data limitations of traditional monitoring programmes and to allow evaluation of the impacts of a policy decision. The Common Farmland Bird Index is one of the recognised citizen science indicators for biodiversity monitoring in Europe (Eurostat 2019) which is being used to assess the impacts of the Rural Development Plans. Perhaps more remarkably, volunteer participation can support the enforcement of laws and regulations, for example by reporting environmental breaches to relevant environmental authorities (Owen and Parker 2018). Together, these examples underscore the idea that citizen science can help to strengthen public input into policymaking as well as to expand the scientific evidence base needed for better informed policy decisions.

However, to date, the contribution of citizen science to environmental decision making remains sparse and poorly understood (Conrad and Hilchey 2011; Newman et al. 2017; Roy et al. 2012). Evidence points to a gap between the potential relevance of citizen science for policy and its actual implementation. On the one hand, there is growing recognition of the value of citizen science by environmental organisations in Europe and the United States (Owen and Parker 2018). Recently, the potential of citizen science for developing a cost-effective evidence base and for engaging the wider public has been officially recognized in Europe for supporting the Nature Directives and the EU pollinators initiative, as well as environmental reporting and environmental compliance (EU-Communication 2017; EU-Communication 2018a; EU-Communication 2018b). Despite this progress, some governmental organisations can be reluctant to use citizen science data owing to concerns about data quality, interoperability, and continuity (Blaney, Pocock, and Jones 2016; Roy et al. 2012).

Further evidence for the unfulfilled potential of citizen science to contribute to environmental policy has been found when considering its use for monitoring of global environmental agreements. Danielsen et al. (2014) showed that 63% of the indicators used for monitoring the progress of 12 international environmental agreements can be collected through some form of citizen science. Yet, evidence suggests that current citizen science may not be targeting the essential policy questions (Chandler et al. 2017). For instance, in biodiversity, citizen science programs focus mostly on species distribution data at the expense of other measures of biodiversity and are seldom used for global analyses of biodiversity (Chandler et al. 2017). This may be, in part, because many citizen science projects do not provide easy, open access to their data, despite an apparent willingness to do so (Schade et al. 2017). It is also possible that some contributions of citizen science to policy remain unnoticed, because of the complex connections between scientific evidence and policy decisions. When the connections are clearly made, the citizen science projects stand to gain more impact, and policy-makers also can prove that they have considered public contributions in a participatory process (Schade et al. 2017). Despite some emerging efforts to improve the support infrastructure for citizen science activities (Pocock et al. 2014), there is little guidance on good practices to improve policy linkages, relevance, and impact.

As the value of citizen science to support environmental policy is increasingly recognised by national and international bodies (Bonn 2016; Crowdsourcing and Citizen Science Act 2016; UNEA 2017), there is a pressing need to better understand the key factors that promote the policy impact of citizen science projects. Central to furthering this agenda is understanding whether citizen science projects that support science also can co-benefit environmental policy and provide meaningful citizen engagement. The objectives of these three agendas may in fact trade off against each other, because the scientific needs for rigorous, comprehensive data collection may conflict with the needs for simple, not too time-consuming data collection to retain participation (Pocock et al. 2014). In an age where demand for civic participation in both research and policy is growing, citizen science is often viewed by decision-makers as a way to engage people with science and to help raise awareness about environmental issues and governance (Blaney, Pocock, and Jones 2016). However, retaining the interest of participants can prove challenging. Gathering long-term data series or achieving the spatial coverage necessary for the data to be of policy relevance takes time, and decision-making processes are also typically long and complex. Citizen contributions may thus occur long before political decisions are made, risking eroding or losing the trust of citizens in the policy process (Schade et al. 2017). Moreover, the scientific and policy agendas may not always align, and the capacity of citizen scientists to deliver high-quality, reliable data that are consistent with official and mandatory statistics standards to support evidence-based policy making remains a hotly debated issue (Nascimento et al. 2018).

To date, no study has attempted to comprehensively assess the impacts of citizen science projects on environmental policy, or to identify the scientific and engagement characteristics of projects that successfully contribute to policy. The aim of this paper is to address that knowledge gap through an inventory of 503 European citizen science projects of policy relevance and an in-depth analysis of 45 case examples. We quantitatively assess how citizen science can support environmental policy, examining a broad range of characteristics related to citizen scientist, scientific, socio-economic (in terms of governance and resources), and policy dimensions. We identify some key challenges and opportunities and present a set of recommendations for promoting the better integration of citizen science in the different phases of the policy cycle (**Figure 1**).

Methods

We compiled an inventory of European citizen science projects having environmental policy relevance, from which we selected a set of case studies for in-depth analysis of the integration of citizen science into environmental policy. The approach taken to generate these is detailed below.

Inventory of policy-relevant environmental citizen science projects

We used a three-step approach to identify 503 environmental citizen science projects of policy relevance in a repeatable way (**Figure 2**). We launched an EU-wide Internet survey, reviewed the databases of EU-funded projects (FP7, Horizon 2020, COST, LIFE) and performed a desk study using the results from recent systematic reviews of citizen science projects (Chandler et al. 2017; Fritz, Fonte, and See 2017; Pocock et al. 2017) and surveying relevant citizen science directories. Only those projects with activities in Europe were retained. This survey does not claim to be exhaustive, but rather to present an ample and representative sample of the diversity of environmental citizen science initiatives ongoing in Europe at the time of this study. Nevertheless, the search method may have led to some biases towards larger-scale citizen science projects, in particular EU-funded ones and those with an Internet presence. Given the time constraints of the project, not all identified directories could be surveyed to the same extent, and the survey may also over-represent English, French, and Spanish-speaking initiatives (for full details see BIO Innovation Service 2018). Each project in the inventory was characterised by its main environmental field, lead organisation category, geographic extent, and type of citizen science initiative by adapting Haklay's et al. (2015) scheme to seven categories: Passive sensing, volunteer computing, crowdsourcing, occasional reporting, monitoring, civic science, and DIY engineering projects (Table S1, supplementary files).

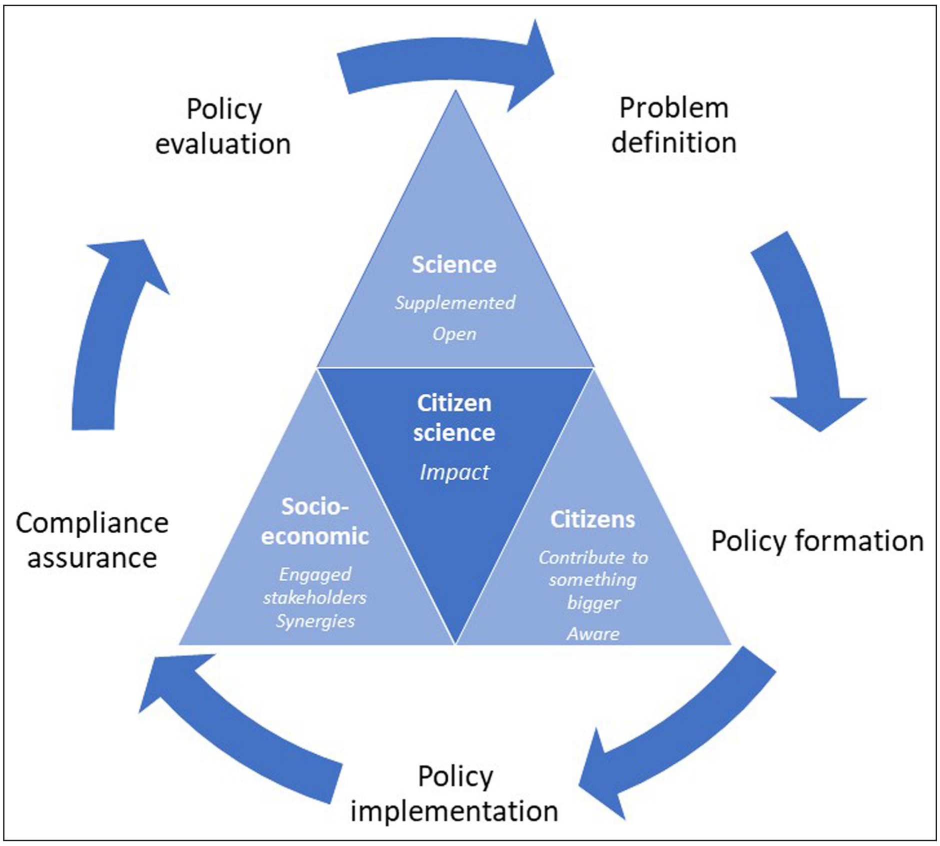

Figure 1: The three key dimensions of citizen science (citizen scientist, scientific, socio-economic) interact with the policy process to generate impact and improve policy relevance. Citizen science can contribute to each step of the policy process: Problem definition (identification of new environmental issue or formulation of new hypothesis about known issues); Policy formation (definition of the structure of the policy); Policy implementation and monitoring (putting into effect policies or describing their implementation); Compliance assurance (measures to promote, monitor, and enforce compliance with existing environmental regulation, such as through awareness raising, inspections, fines, and warnings); Policy evaluation (assessing the outcomes of policy interventions).

Case studies of environmental citizen science projects of high policy relevance

A second, more detailed survey (documenting up to 94 project characteristics, Table S1, supplementary files) was sent to 108 citizen science projects included in the inventory. The projects were selected for their demonstrated or high potential for policy uptake, representing a diversity of environmental fields and forms of policy support. Out of the 108 projects, 45 projects responded (i.e., a response rate of 42%) and documented most attributes (not all questions were mandatory).

To understand the factors that influence the policy relevance of citizen science projects, we analysed the case studies along the three main dimensions of citizen science: The citizen-scientist dimension, the scientific dimension, and the socio-economic dimension, as well as along the policy dimension (**Figure 1**). Following Kieslinger et al. (2017), a process-based evaluation was used to describe some of the operational strengths and weaknesses of the projects. Some of the key process-based criteria considered include, for instance, the levels of citizen engagement, support measures and training, the scientific grounding of the project, its data quality control and validation processes, and its endorsement by key stakeholders. The socio-economic dimension was assessed at this level in terms of the project's governance and funding structure. An outcome-based evaluation along the citizen-scientist, scientific, and policy dimensions was then performed by running four stepwise general linear regressions using the package MASS in R version 3.5.1 (R Core Team 2018). The response variables were chosen as follows:

- Citizen scientist participation level was assessed by using the total number of participants in the project since its inception, as reported by the survey respondents.
- Scientific impact was assessed through the number of peer-reviewed publications from each citizen science project. Selected keywords were used to uniquely identify the projects, and all results from a Google Scholar search were then screened to identify relevant peer-reviewed, scientific publications (excluding book and thesis chapters) that either used project data or cited the project research.
- Policy impact was assessed through two distinct response variables: The likelihood that the data from the citizen science project were effectively used for policy, as justified by adequate evidence from the respondents, and the number of phases in the policy process that the project contributed to (e.g., contribution to policy formulation or data for policy evaluation).

The explanatory variables included intrinsic characteristics of the projects, such as the age of the project (in years), its spatial extent (number of countries in which data were collected), the total number of data records (since the inception of the project), the number of staff members, and the main category of the project. We also explored characteristics related to the socio-economic dimension of the project, in terms of governance (main funding body and lead organisation type) and to stakeholder endorsement (governmental, academic). Finally, we calculated an index of "ease of engagement" for the citizen-scientist dimension, and an index of scientific quality for the scientific dimension (Table S1, supplemental files).

Count variables were log-transformed such that all models assumed a normal error distribution, except for the likelihood of policy uptake, which used a binomial distribution. We tested for the absence of auto-correlation among the explanatory variables and for the normality of the residuals. As respondents could leave out non-mandatory questions, the sample size for individual questions varied.

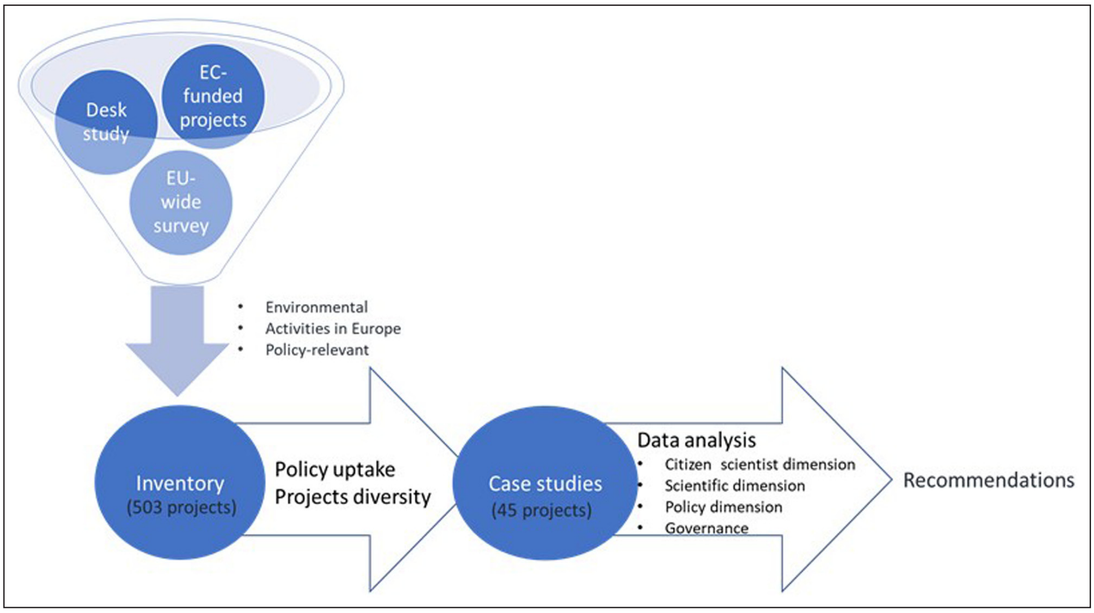

Figure 2: Workflow used to identify citizen science initiatives for the inventory and to select environmental citizen science case studies that have high policy relevance and represent a diversity of environmental areas to be used for in-depth analysis.

Results

Inventory of policy-relevant environmental citizen science projects

There was substantial variation in the use of policy-relevant citizen science across environmental domains. The majority of projects focused on nature and biodiversity (**Figure 3**), mostly through monitoring or occasional reporting of species occurrences. Other natural resources (air, water, land) were the second most frequent source of citizen science projects in the inventory, representing 7%, 6%, and 3% of all projects, respectively. Most air and water-related projects were based on top-down monitoring activities (63% and 69%, respectively), whereas the majority of projects related to land use and soil used more bottom-up forms of citizen science (**Figures 3** and **4**). Few projects focused on resource issues. Overall, passive sensing/participation and bottom-up forms of citizen science involving co-design with the participants remained scarce. Together passive sensing, volunteer computing, civic science, and DIY engineering represented fewer than 8% of all projects in the inventory (**Figure 4**). Most of the environmental citizen science projects in the inventory were focused on the national and sub-national levels (41% and 29%, respectively), and were led by non-governmental organisations (41%) or academic institutions (29%).

Case studies of environmental citizen science projects of high policy relevance

Citizen scientist dimension

The case studies demonstrate that citizen science projects carefully designed their engagement and communication strategies to promote successful participation of citizen scientists. Most projects were easy to engage with, by targeting all audiences (80% of projects), requiring limited to no specific skills (91% of projects; **Figure 5a**) and a low level of effort (75% of projects requiring less than 24 hours per year; **Figure 5c**). Projects also provided support measures, with the majority of projects offering in-person training (56%), and 36% of projects also providing supporting material (**Figure 5b**). Finally, all projects offered options to communicate the data back to citizen scien-

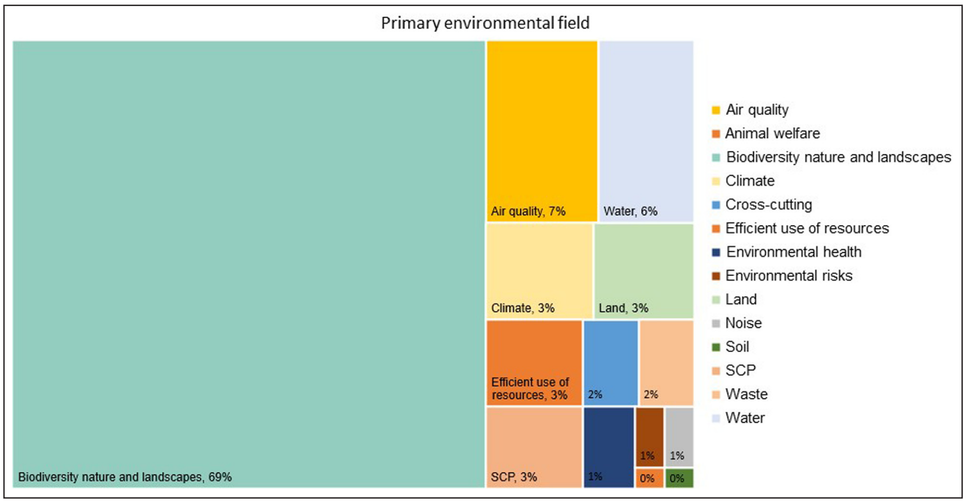

Figure 3: Coverage of environmental domains by the citizen science initiatives in the inventory. The size of the squares represents the share of citizen science initiatives in each environmental domain.

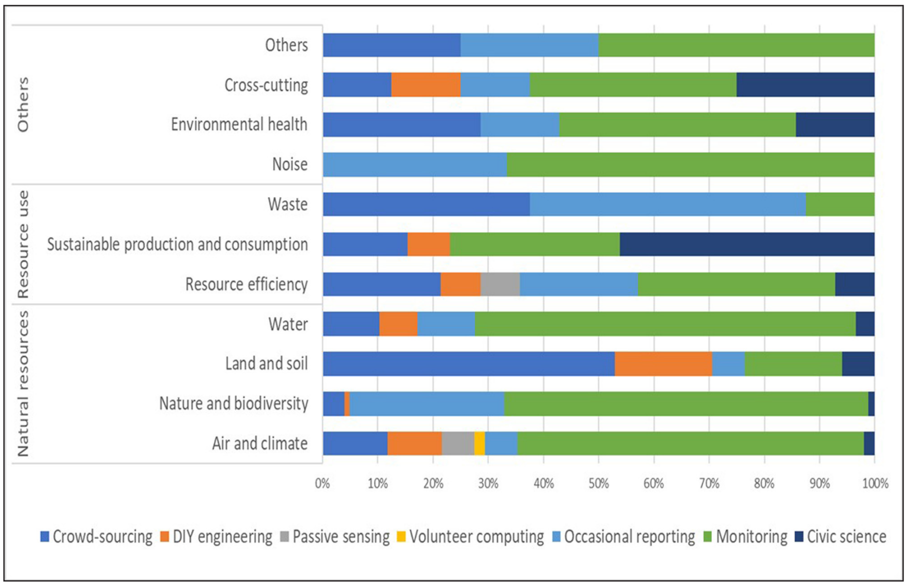

Figure 4: Share of the different types of citizen science projects in the inventory by main environmental domain.

tists, mostly by giving them access to aggregated or processed data (67% and 64% respectively).

The case studies differed widely in their number of participants, with nine projects having fewer than 50 participants, and highly successful projects like Artportalen, the Swedish Species Observation System, which muster a million participants. Monitoring projects attracted significantly more participants than other categories of projects (**Table 1**). Government-led projects had significantly fewer participants than projects led by scientists, consortiums, or NGOs (**Table 1**). The ease of engagement did not appear to significantly affect the number of participants in a project, nor did obtaining scientific endorsement. The age of the project, its spatial extent, and the number of staff resources also did not significantly affect volunteer participation (**Table 1**).

Scientific dimension

All case studies adhered to fairly good scientific standards (**Figure 5d**, **5e**, **5f**). Almost all projects provided metadata (91% of projects), had a fully disclosed and reproducible methodology (**Figure 5d**), and involved some form of quality assurance (**Figure 5e**). But we found that while 55% of projects were willing to share their data with the public, more than 35% of projects included some restrictions, and 9% did not provide any public access at all (**Figure 5f**). The data produced by the case studies were widely used by scientists. According to the survey respondents, these data were used by the scientific community in 87% of projects (BIO Innovation 2018). The independent survey of peer-reviewed publications showed that the data from 82% of projects were used by scientists or were referred to as examples of citizen science good practice.

Large data quantity and accessibility were the primary drivers of the likelihood of a project to feature in scientific research. The number of scientific publications from a project was best explained by the number of data records available, as well as to a lesser degree by the broad spatial extent of the project (**Table 1**). The number of scientific publications was also strongly affected by the data accessibility, with projects providing unrestricted access to their data significantly more likely to deliver a scientific output (**Table 1**). Endorsement by scientists significantly improved the likelihood that the projects yielded scientific output (**Table 1**). Other indicators of scientific quality, such as whether the projects were led by scientists or whether they had better scientific quality procedures, did not have any significant effect (**Table 1**).

Socio-economic and policy dimensions

Looking at the wider socio-economic conditions for successful citizen science projects, we found that most case studies were led by non-governmental and academic organisations, but seldom were any led by government agencies or the private sector (**Figure 5g**). Projects differed in their funding structure, with the majority of projects receiving their main financial support from EU or governmental institutions, but funding from the private sector

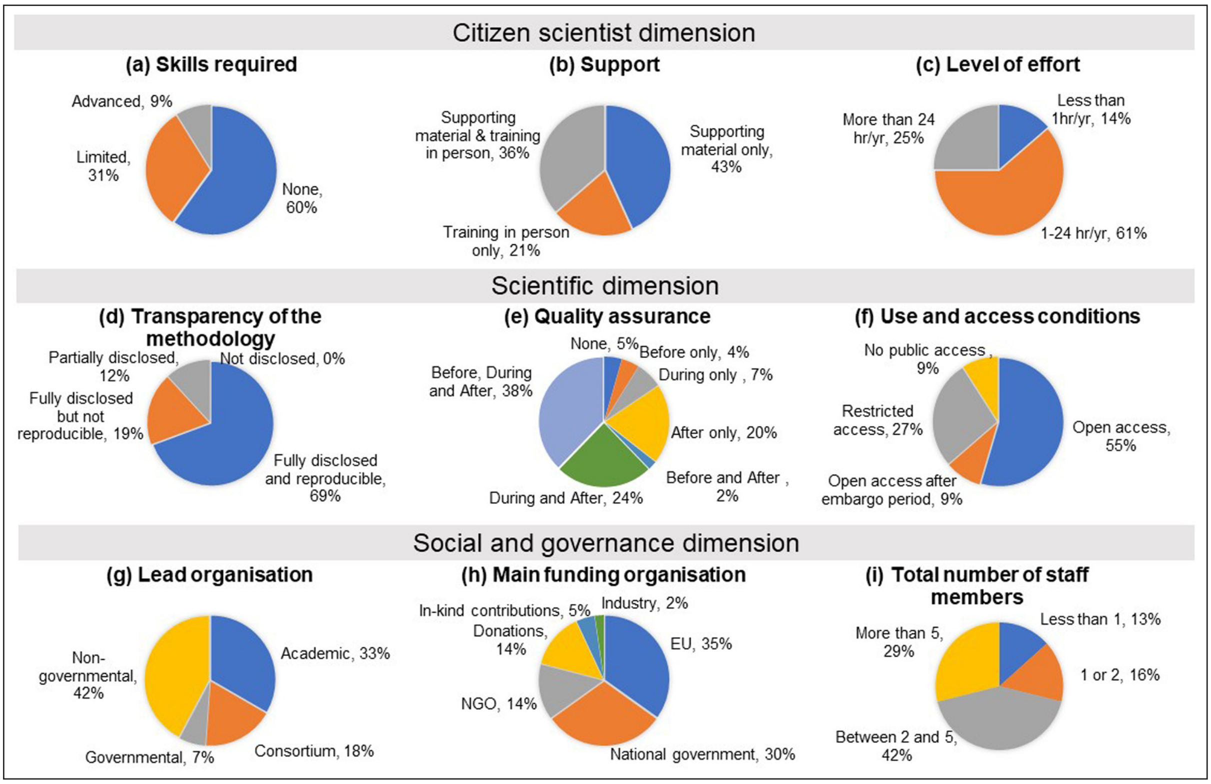

Figure 5: Characterisation of the policy-relevant citizen science case studies along the three dimensions of citizen science. Citizen scientist dimension: levels of **(a)** skills, **(b)** training, and **(c)** effort required; Scientific dimension: levels of **(d)** transparency, **(e)** quality assurance, and **(f)** use and access conditions; Socio-economic dimension: including **(g)** lead organisation type, **(h)** main funding organisation, and **(i)** total number of staff members (FTE).

was negligible (**Figure 5h**). Academia-led projects were mostly funded by the European Commission or national governments (47%). In contrast, NGO-led projects were more likely to get a large part of their funding from NGOs or alternative private funding sources (e.g., donations, private companies). They tended to be medium-sized initiatives, employing two to five staff members and with broad stakeholder endorsement.

Table 1: Effect sizes and standard errors of minimum adequate models explaining the impact on the citizen scientist dimension (1 – Number of participants), scientific dimension (2 – Number of peer-reviewed publications) and policy dimension (3 – Policy uptake), and 4 – (Diversity of policy phases used) for the case studies.*

Attributes			**1 – Number of participants (Log+1)**	**2 – Number of peer-reviewed publications (Log + 1)**	**3 – Policy uptake**	**4 – Diversity of policy phases used**
			Linear model, n = 39 (R^2 = 38%)	***Linear model, n = 33 (R^2 = 75%)***	***Binomial model, n = 39 (R^2 = 12%)***	***Linear model, n = 39 (R^2 = 27%)***
	Intercept		2.35 ± 0.61***	–0.77 ± 0.26	4.91 ± 2.59.	–0.48 ± 0.83
General characteristics	Project category	Crowd-sourcing (reference)	–	NS	NS	NS
		Monitoring	1.34 ± 0.57*	–	–	–
		Occasional reporting	0.31 ± 0.64	–	–	–
		Other	–0.60 ± 0.76	–	–	–
	Age of the project		NS	0.00 ± 0.00.	0.08 ± 0.07*	NS
	Spatial extent (n countries)		0.01 ± 0.01.	0.00 ± 0.00*	NS	0.02 ± 0.01*
Citizen scientist dimension	Number of records (Log + 1)		Not in model	0.28 ± 0.04***	Not in model	Not in model
	Index Ease of engagement		NS	Not in model	–2.43 ± 1.46*	NS
	Social media page	No	NS	Not in model	Not in model	Not in model
		Yes	–	–	–	–
Scientific dimension	Index of scientific quality		Not in model	NS	NS	0.16 ± 0.11
	Access conditions	None	Not in model	NS	Not in model	Not in model
		Restricted	–	0.18 ± 0.22	–	–
		Open	–	0.35 ± 0.21*	–	–
Governance aspects	Lead organisation	Academic (reference)	–	NS	NS	NS
		Consortium	–0.05 ± 0.51	–	–	–
		Governmental	–2.65 ± 0.80**	–	–	–
		Non-governmental	–0.11 ± 0.40	–	–	–
	Personnel	2 or less	NS	Not in model	Not in model	Not in model
		More than 2	–	–	–	–
	Academic endorsement	No	NS	–	NS	–
		Yes	–	0.26 ± 0.17*	–	1.26 ± 0.54*
	Governmental endorsement	No	Not in model	Not in model	NS	NS
		Yes	–	–	–	–

* Significance levels are shown: . p < 0.1, * p < 0.05, ** p < 0.01, *** p < 0.001, NS p > 0.1. Not in model signals variables that were omitted during the model selection process.

We found a gap between the potential or intended contributions of projects to policy and the realised one. Respondents estimated that the data from their citizen science project could contribute to virtually all phases of the policy cycle, including compliance (**Figure 6**, reported potential usefulness >80% for all categories, except for compliance 73%). Evidence for policy use of the citizen science data was less widespread. Respondents were aware of some evidence of use of their project data for problem definition in 58% of cases, but this share dropped to 40%–45% for early-warning or policy implementation and even further for policy evaluation or compliance (**Figure 6**). Respondents were unsure of the actual policy contributions of their projects in up to 30% of cases.

The likelihood that a citizen science project was used for policy significantly increased with the index of ease of engagement (**Figure 7a**) and with project's age (**Table 1**). Other variables related to the project's internal characteristics, its scientific credentials, or official endorsement from governmental or academic institutions did not significantly affect policy uptake. Among the projects for which the policy contribution was known, many embraced the cyclic nature of the policy process and contributed to at least two different phases (Mean ± SD = 1.95 ± 1.53; **Table 1**). Projects that benefited from academic endorsement and projects with high scientific quality standards contributed to significantly more policy phases (**Figure 7b**, **7c**; **Table 1**). Projects covering a greater spatial extent were also more likely to contribute to a greater diversity of policy phases (**Table 1**).

Challenges and opportunities from connecting to policy

Aspects related to the scientific dimension ranked among the most important challenges in connecting citizen science to policy (**Figure 8a**). In particular, achieving the right balance between the requirements for data quality and the needs for engagement was a key concern, as well as achieving appropriate data scalability in the case of initiatives that spanned different cultures or multiple landscape grains. Governance aspects related to lack of sufficient human and financial resources were also frequently mentioned as a barrier. Other common identified barriers related to the policy aspects, such as resistance from decision-makers and difficulty in identifying the relevant policy linkages. In contrast, aspects related to engagement or policy time scales were less often identified as barriers.

Respondents identified some opportunities from connecting citizen science to environmental policy in all three dimensions of citizen science (**Figure 8b**). Aspects related to the citizen scientist dimension ranked the highest, by allowing for improved public awareness and improved involvement of citizens in the decision-making process. Policy aspects, such as improved environmental protection and more relevant and improved policy frameworks, were also frequently highlighted as benefits from linking citizen science to policy, on par with scientific aspects such as an extended knowledge base and more open and responsible research. In contrast, governance aspects, such as improved legitimacy or networking, ranked low.

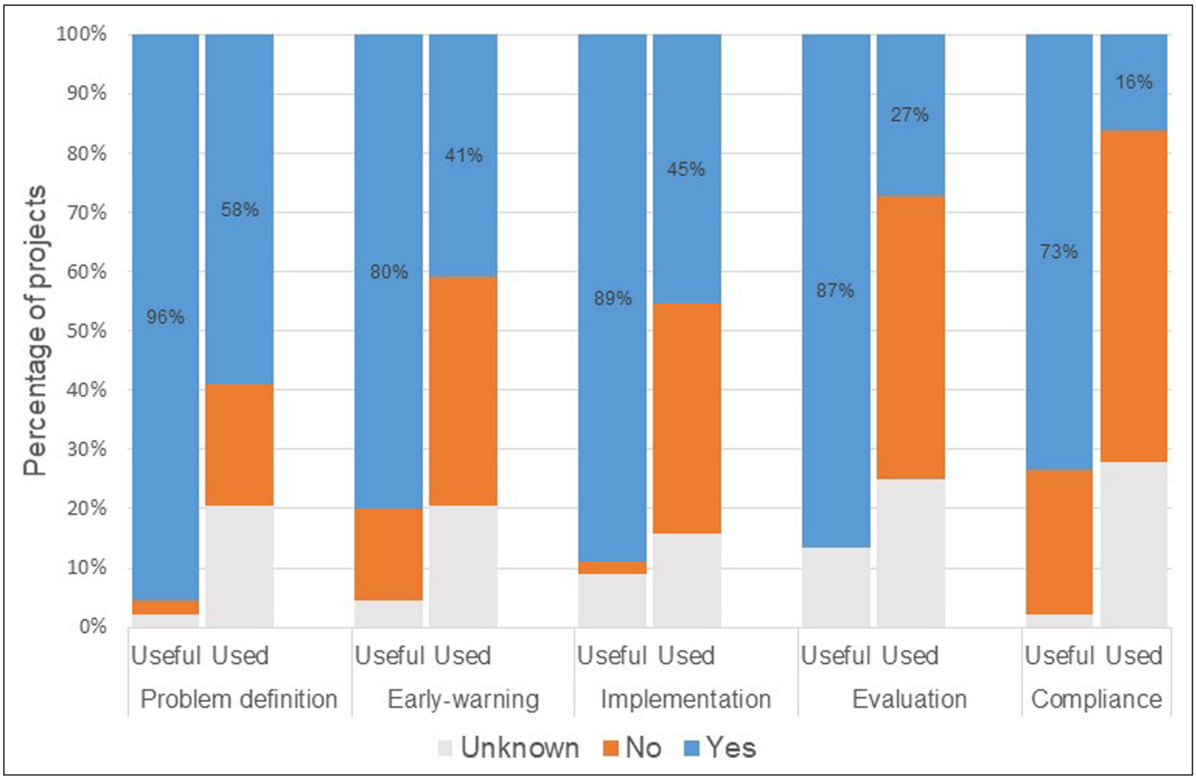

Figure 6: Comparison of potential and realised contributions to policy. Distribution of answers (Yes, No, Unknown) to the question of whether a given citizen science project had the potential to be useful for policy or was effectively used for policy. For instance, whereas 96% of respondents thought their project could contribute to problem definition, only 58% of projects actually did so.

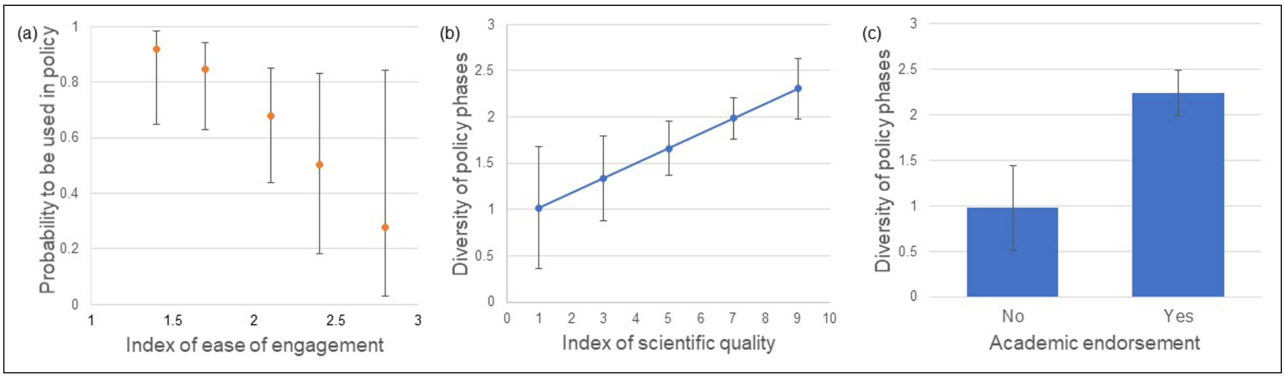

Figure 7: Factors affecting the impact of citizen science initiatives on the policy dimension, based on the 45 case studies. **(a)** Policy uptake (mean ± SE) significantly increases with ease of engagement. Projects contribute to significantly more policy phases when **(b)** they have high scientific standards and **(c)** receive academic endorsement. Predicted means and standard errors are from the linear models.

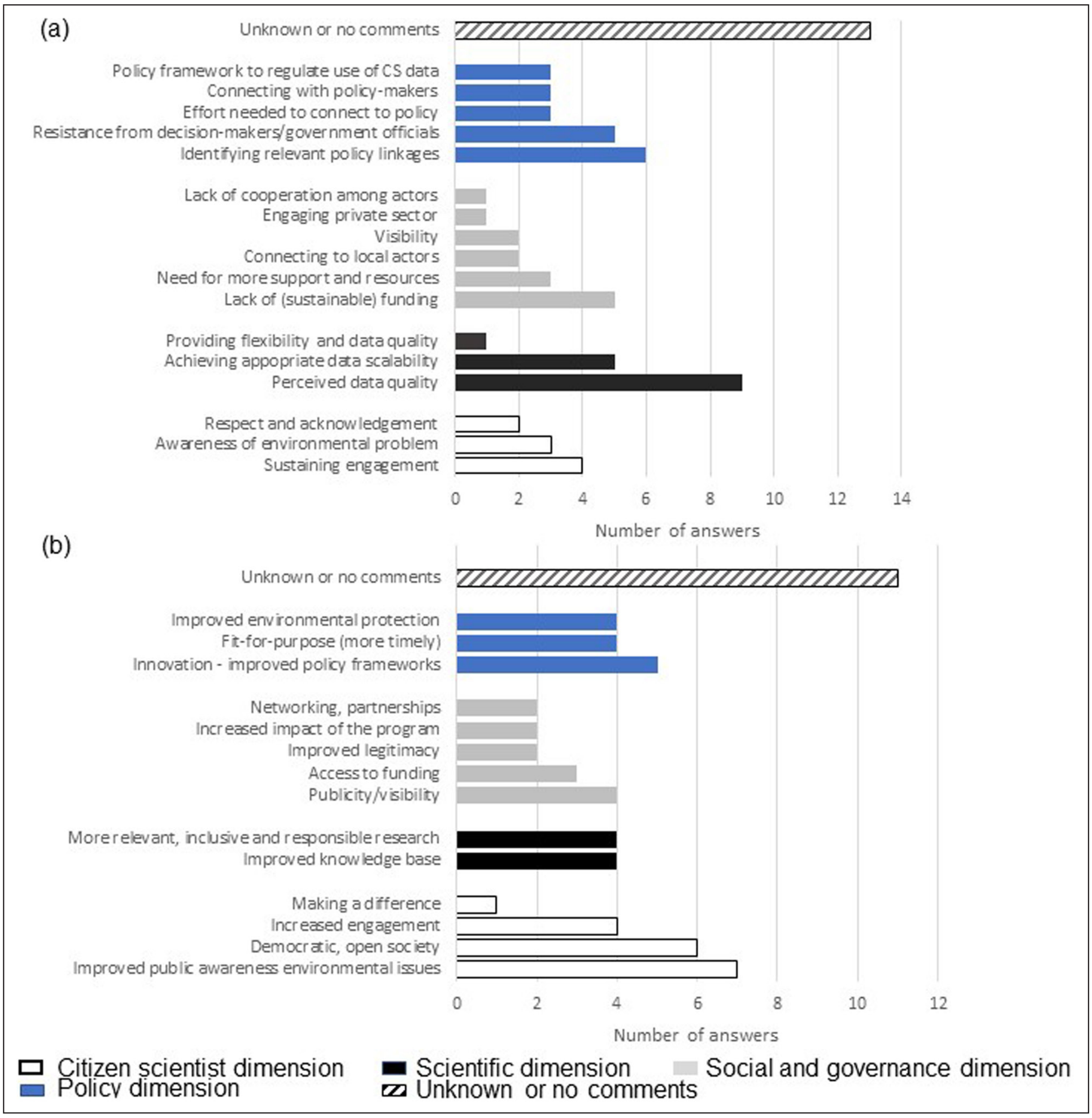

Figure 8: Importance attributed by survey respondents of the case studies to **(a)** different challenges potentially preventing linking citizen science projects to policy and **(b)** opportunities to be gained from successfully linking to policy. Bars represent different barriers/opportunities, and shading differentiates the four dimensions (citizen-scientist, scientific, socio-economic, and policy).

Discussion

Characteristics of citizen science projects of environmental policy relevance

As environmental legislation is becoming ever wider ranging and comprehensive (EU-Communication 2017), citizen science is emerging as pivotal to support more inclusive, evidence-based policy-making (Turrini et al. 2018). Our study shows that while policy-relevant citizen science projects have been developed in all environmental fields and include all types of citizen science actions, the landscape of projects may not adequately cover all the most pressing policy issues. Congruent with previous reviews of citizen science projects (Hecker et al. 2018; Pocock et al. 2017; Schade et al. 2016), the inventory shows that the monitoring of nature and biodiversity dominates the environmental citizen science landscape. This is while the EU environmental policy agenda until 2020 focuses on issues such as green growth, the preservation of natural resources, and safeguarding citizens from environment-related pressure (EU-Ares 2016). Citizen science projects related to natural resources (air, water, land), and even more the efficient use of these resources remain a minority, and projects related to risks to health and wellbeing were barely represented in the inventory.

The case studies showcase three pathways through which citizen science projects can achieve policy relevance. Projects that collect large amounts of data over broad spatio-temporal scales, such as Artportalen, the Pan-European Common Bird Monitoring Scheme, and Phenowatch, provide policy-makers with an evidence base that can be repurposed to address a range of questions. This is a cost-effective alternative to support policy, because the same data can be used to serve multiple objectives (Cooper et al. 2014), and the data might be used to meet current as well as future policy objectives. On the flip side, the data may not be customized to most adequately answer the policy question at hand, and some policy questions cannot be addressed in this way.

In contrast, several projects were specifically designed to address policy data gaps. For example, the rapid evolution of the EU marine legislation over the past ten years has created a demand for data on marine species distribution to inform the designation of marine protected areas. SeaSearch was designed specifically to fulfill this need by working directly with local inshore regulators in England (Inshore Fisheries and Conservation Authorities) to provide data about the marine environment which underpin bylaws. Similarly, the implementation of the Water Framework Directive in France has created a legal requirement to develop catchment-specific action plans to reduce pollution from agriculture, but quick and insufficient solutions are often applied (Chantre et al. 2016). Co-click'eau was developed to address this gap, by providing farmers with a decision-support tool drawing on stakeholder participation to forecast the consequences of different scenarios of crop management at the river catchment scale.

Finally, a less appreciated value of citizen science for policy lies in the communication of government aims and messages. Although improving the awareness of policy issues is not a recognised part of the policy cycle, it can be critical to gain public support and understanding. The OPAL Tree Health Survey data have been used to meet the strategic objectives of UK governments to engage people with trees and to raise their awareness of trees. In a different way, the Observatoire Agricole de la Biodiversite in France (Agricultural Biodiversity Observatory) relays governmental priorities related to reductions in pesticide use to farmers by providing them with tools to assess the impacts of these practices on biodiversity.

Policy impact remains hard to determine

Nevertheless, the policy landscape is dynamic and can make it challenging for project leaders to identify the relevant policy priorities for their projects. The survey suggests that most citizen science projects do not fulfil their full potential for policy. There seems to be a paradox whereby some governmental organisations have prescriptive needs for (citizen science) data, but rely entirely on these data being developed by others (Roy et al. 2012). Conversely, many citizen science programmes are unaware of some policy issues that their data could help to answer, with no or minor adjustments. Establishing policy linkages is typically a lengthy process, which can be complex. A project's relevance to policy is often indirect, and linkages may need to be made at multiple scales (Socientize 2014). Project leaders reported difficulties in identifying relevant policy needs, connecting with decision makers, and convincing them of the value of citizen science data. In particular, some respondents stressed the difficulty in adapting international aims and targets to the local context. Improved contribution of citizen science to policy would thus benefit from clarifying policy needs and sharing best practices, tools, and methods to achieve the data reliability needed for citizen science data to be trusted and to align with environmental regulation and monitoring requirements from governments.

Additionally, evidence from this study and others emphasise the difficulty in tracing back the uses of citizen science data, both in science and for policy or decision making (Cooper, Shirk, and Zuckerberg 2014; Hyder et al. 2015). There is no clear feedback loop between end users and project leaders, nor any simple way to track the use of citizen science data. This highlights the difficulty to identify actual policy contribution and to attribute it to a specific policy area.

Balancing citizen engagement, scientific quality, and policy use

A key challenge for citizen science projects is to balance the needs for sufficient data quality to enable research and policy use with the necessity to sustain volunteer engagement (Williams et al. 2018). However, our survey demonstrates that most policy-relevant projects had high scientific standards, notably in terms of training and data validation, and provided easy engagement conditions for participants by requiring limited efforts and either no or limited a priori skills. The fact that ease of engagement was a strong predictor of policy use, over scientific credentials and stakeholder endorsement, emphasises the importance of mass participation citizen science for providing policy evidence. Indeed, our sample of projects suggests that citizen engagement is mostly valued for its contribution to data collection, in particular for monitoring changes over large spatio-temporal scales. Monitoring projects enlisted significantly more volunteers than all other categories of citizen science projects except for crowdsourcing. While crowdsourcing projects are built to attract mass participation, monitoring programmes typically require a durably engaged set of volunteers, and they may thus expend more efforts on sustaining citizen engagement – an aspect that would need further study. In light of these large-scale monitoring programs, an outstanding question is how to encourage more local scale, community-based initiatives to support not only science, but also policy and community actions. We found no evidence of truly co-designed projects or bottom-up projects in the inventory. This may be due to the difficulty in identifying such projects, because they do not always have an Internet presence. It does suggest, however, that much still needs to be done to embrace citizen participation in all steps of the scientific process (Albert and Haklay 2018) and to realise the full social potential of citizen science in terms of citizen empowerment and transformative capacity (Bela et al. 2016).

We found that opportunities to sustain citizen engagement were not maximised across the board. A number of important recent policy documents exhibit a desire to increase the awareness, engagement, and participation of volunteers in environmental management (EU-Water Framework Directive 2000/60/EC; CBD 2013; EU-Communication 2017; EU-Communication 2018a; EU-Communication 2018b). Such engagement can typically be achieved by ensuring communication and feedback to participants, as well as sufficient staff and financial resources (Turrini et al. 2018). Although the case studies exhibited some support and feedback mechanisms to participants, most restricted the type of data available to the citizen scientist. While this may be justified to provide data in a form that is more understandable to a layperson, it may impede the way that the citizen scientist sees how his/her data contribute to the whole, and more importantly, affect the re-usability of the data. Moreover, it appears that most initiatives are short in personnel and of uncertain lifetime: More than two-thirds of projects employed fewer than five full-time equivalents over their entire lifetime, and only about a quarter of case studies reported sustainable funding (BIO Innovation 2018). This makes it difficult for projects to dedicate the efforts to generate the necessary level of citizen engagement for policy.

Scientific quality and impact

Although scientific aspects did not affect the policy uptake of the citizen science projects studied, the level of scientific excellence was a strong determinant of how well the project could serve environmental policy. Projects with high scientific standards and endorsed by scientists contributed to more phases of the policy cycle. Nevertheless, lack of trust about the quality of the data was the most commonly reported barrier preventing the integration of citizen science in policy. This echoes findings from other studies and suggests that end users still have a negative bias towards non-traditional data sources (Burgess et al. 2017; McKinley et al. 2017), despite accumulating evidence that these can complement or improve traditional scientific data (Cooper, Shirk, and Zuckerberg 2014; Hadj-Hammou et al. 2017). These concerns have lessened as the statistical methods to deal with large, imperfect datasets have improved. Yet, resistance from decision makers and government officials was still the third most frequently cited barrier to policy integration.

The good scientific quality of the case examples usually led to scientific impact, with most projects fewer than ten years old cited by more than twenty other researchers. Two salient elements characterized the use of citizen science in peer-reviewed publications. First, coordination of the project by academic institutions did not appear to be a necessary condition to ensure scientific impact; academic support in the project appears to be sufficient. This suggests that projects managed by NGOs may produce data as reliable as those produced by projects managed by governments or academic institutions, as long as they receive academic support. Second, the scientific impact of projects was more influenced by data accessibility than by data quality, possibly because good overall quality assurance was evident in all selected practices. Similar findings were found by Theobald et al. (2015) for biodiversity-related citizen science data. These findings support the idea that open data and open standards promote interoperability and re-use (Williams et al. 2018) and emphasize the key role that citizen science can play in the open science movement (Hecker et al. 2018).

Nevertheless, there is still much room for improvement in terms of data accessibility and data-sharing standards. Almost half of the case studies restricted access to their data, either by allowing only participants to access the data or by not granting any access at all. Although the majority of projects claimed open access, most projects provided only data summaries or maps on their websites, and few provided a clear interface for data download. The data were often available on request only, and the contacts and options for data access often not clearly identified. This confirms the findings from Schade et al. (2017) that identified a gap between the apparent willingness to provide free, open data by many citizen science projects and the actual reality of how these projects operate. This gap may result partly from insufficient awareness of best practices for the promotion of open access, in particular regarding licensing conditions (Schade et al. 2016), but also to lack of foresight or means to set up the adequate data infrastructure.

Governance and business model

Overall, most if not all case studies included multiple actors, bringing together stakeholders and communities that would never collaborate otherwise. Our analysis suggests that there is a range of business models behind citizen science initiatives relevant for environmental policy, underlined by the diversity of partnerships and funding models. Although most of the case studies were medium-sized, NGO-led initiatives with a mix of non-governmental funding sources, there were also many EU or government-funded academia-led projects. Government support, not only in funding but also through active participation in the design and implementation of the project, appears to be a key factor for the successful uptake of citizen science in environmental policy. In several case studies, the staff from national government departments helped to develop the surveys (e.g., OPAL Tree Health) or invited the development of the surveys and/or indicators used (e.g., Propage, Observatoire Agricole de la Biodiversite, Co-click'Eau).

However, government-led initiatives tended to attract fewer participants than projects led by NGOs, academics, or consortiums. This suggests that government-led projects in our survey may not have very effective communication and engagement strategies. In contrast, NGOs appear to be the most capable of running long-term, successful projects (Albert and Haklay 2018). There is a long tradition of NGO leadership of environmental citizen science activities, and more than half of the projects in the inventory older than ten years were NGO-led, in contrast to only around 10% for projects led by other combinations of institutions. The case studies also revealed that NGO-led projects were good at attracting broad stakeholder support, including from the private sector, although survey respondents admitted struggling to obtain sufficient organizational, academic, and financial support.

The business models also may need to be adapted to the policy question, and in particular the spatio-temporal extent that it covers. While dedicated, one-off initiatives may be very impactful for policy, especially if scheduled along elections or at well-selected points in the decision-making process, establishing policy linkages is typically a lengthy process. Decision makers will commit to using the data for policy only if they can rely on a predictable data influx. Accordingly, the vast majority of case studies reported having a sustainable data infrastructure (BIO Innovation 2018). In contrast, only 24% of case studies considered that they had a guaranteed funding structure, and survey respondents often raised the need for funding mechanisms to ensure the mid- to long-term maintenance of citizen science initiatives. A noteworthy missed opportunity highlighted by the case studies is the absence or small role played by the private sector in environmental citizen science. Businesses present high opportunities not only for financing citizen science activities, but also as sites where research can be conducted (Snep et al. 2011) and as a source of volunteers, by providing opportunities for meaningful employee engagement in research.

Recommendations to improve policy linkages and conclusions

The study led to six key recommendations, which interconnect and reinforce each other, to enhance the environmental policy relevance of citizen science initiatives.

1. **Improve coverage of environmental policy areas**. Currently, several environmental policy areas are poorly covered by citizen science, despite high potential. Chief sectors are resource efficiency (including sustainable production and consumption, energy efficiency, and waste), food, and land use. Citizen science projects targeting these issues have a high impact potential, with clear policy relevance and many technology and engagement-based opportunities for contributions. More generally, globally recognized policy frameworks, such as the Sustainable Development Goals (SDGs), should be systematically analyzed in order to identify and promote the many opportunities that citizen science can bring to policy implementation and monitoring. Provision of financial and policy incentives would then help trigger the development of innovative citizen science projects in these areas.
2. **Increase the awareness of decision makers, in particular local authorities, about the relevance of citizen science data.** Resistance to change and skepticism from decision makers and government officials, in particular at the local level, needs to be addressed to improve policy uptake. This could be achieved through capacity building, showcasing of best practices, and guidelines. In particular, guidance to clarify the legal aspects related to the use of government data vs. non-governmental data for policy would be useful. Indeed, in some countries, citizen science data that are controlled by the citizen scientists themselves, instead of being controlled by independent academic or governmental staff, cannot be used for policy (Schade et al. 2017). Moreover, because many national and supra-national policies are implemented locally, it is important to facilitate the access and use of citizen science for local authorities and to provide them communication channels with macro-regional and global institutions. Matchmaker events could be organized to foster exchange and networking between decision makers and project leaders across governance levels.
3. **Public institutions should be proactive in linking with citizen science activities.** Clarifying policy needs would help to overcome the difficulty that project leaders face in identifying relevant policy linkages. One way for public institutions to become more proactive would be to sponsor a yearly horizon scanning exercise to identify key data gaps for environmental policy progress and then to prioritize these. Alternatively, public authorities could promote a central interface where decision makers could advertise their data or citizen participation needs, and where citizen scientists could also get feedback on how their data contributed to policy decisions.
4. **Centralise the access to citizen-science resources.** Current citizen science initiatives are often disparate, which hinders engagement and policy uses, and can lead to duplication of efforts. Creation of knowledge hubs would improve access to citizen science data and allow projects to pool resources for training and support, and to share and reuse tools and best practices at larger geographical scales. Such platforms could additionally ensure the sustainability of the data infrastructure and of-

fer opportunity for ensuring data standards and interoperability by requesting appropriate metadata, encouraging open data, and providing incentives to make the data fully accessible. Together, these components could provide a one-stop shop for different policy domains, at which all relevant actors could find the knowledge and resources needed. An excellent example of such a platform is the Swedish Artportalen portal that centralizes most biodiversity data in one place, including but not exclusively citizen science. Such a one-stop shop also could help project leaders to achieve the adequate scale for their project by transferring already existing solutions and adapting them to fit the needs of a particular community or local context.

5. **Promote multi-actor partnerships and cooperation.** Our survey shows that NGOs seem to be the most prevalent leaders of citizen science activities in the environmental domain, but often lack organisational, academic, and financial support. Research funding or other dedicated funding mechanisms (e.g., LIFE, Structural Development Funds) could promote NGO participation and NGO-academic partnerships in citizen science. Moreover, the potential of the private sector to contribute to environmental citizen science, both in terms of person-time and financing, is largely unexploited. We recommend increasing the awareness of private actors about the potential impacts of environmental citizen science by demonstrating the multiple benefits to be gained and by providing different incentives, or by developing innovative ways to grant companies sustainability credentials for financing such activities if they credibly commit to contribute to environmental sustainability. Finally, place-based networks of interests, drawing on people's knowledge and affinity for their home environment to detect, collect, and engage with environmental issues, could help to increase meaningful citizen participation in local decision-making processes (Newman et al. 2017).
6. **Seek evaluation and traceability of citizen science impacts.** Demonstrating the success of citizen science initiatives in advancing scientific research, social engagement, and policy uses is important to increase the attractiveness of developing such projects and to provide a strong business case for their financing. Evaluation requirements should be embedded in any citizen science funding scheme, with supporting guidance and criteria for how this should be done. Funding could encourage the continuation of the most policy-relevant initiatives by being tied to impact indicators such as outcomes or numbers of participants. Moreover, persistently and uniquely identifying citizen science contributions should be encouraged, at the very least through simple labels stating that a research or policy was supported by citizen science data.

In conclusion, this work shows that despite a number of challenges, citizen science brings key opportunities if its links to policy are improved. First, the timeliness and spatial granularity of fit-for-purpose citizen science data can greatly improve our knowledge base and, thereby, help to shape better policies and contribute to a healthier environment. Second, when publicly visible and legitimized by public administrations, citizen science can deliver value not only to science but also to policy, social innovation, and individual wellbeing. Third, by bringing multiple stakeholders together and helping them collaborate on a common interest, citizen science provides opportunities to develop new and innovative business models that can help to address pressing challenges with the resources that are needed. Finally, citizen science provides the means for more inclusive and responsible research – contributing to a more open and democratic society. This work is forming a key input for the integration of citizen science in the EU environmental policy cycle, in particular for the guidelines on how to promote the wider use of citizen science in environmental monitoring and reporting, as a response to Action 8 of the EU Action Plan to Streamline Environmental Reporting (EU-Communication 2018a).

Supplementary Files

The supplementary files for this article can be found as follows:

- **Table S1.** Attributes used in the inventory (light grey) and in the case studies of policy-relevant environmental citizen science initiatives. DOI: https://doi.org/10.5334/cstp.239.s1
- **Table S2.** The 45 environmental citizen science initiatives of high policy relevance. Initiatives that are cited in the manuscript are in bold. DOI: https://doi.org/10.5334/cstp.239.s2

Acknowledgements

We would like to sincerely thank all citizen science projects that invested time in answering our surveys; this study would not have been possible without their support. We also thank Elena Montani (DG ENV) for overall guidance; Assaf Shwartz, Margaret Gold, and colleagues at the European Commission; and Marjan Van Merloo (DG RTD), Izabela Freytag (EASME), and Liam Cashman (DG ENV) for their support and comments.

Funding Information

This work results from a study funded by the European Commission, DG Environment under the contract 070203/2017/768879/ETU/ENV.A.3, finalized in October 2018.

Competing Interests

The authors have no competing interests to declare.

Author Contributions

A.T., S.S., and J-M.R. conceived the ideas; A.T, M.P., J.B., and C.T. collected and prepared the data; A.T. analysed the data; A.T and S.S. led the writing and policy recommendations; and all coauthors contributed ideas.

References

Albert, A and **Haklay, M.** 2018. Innovation Management Plan: 'Making citizen science work'. *Deliverable 6.6, Doing It Together Science Horizon 2020 project.*

Bela, G, Peltola, T, Young, JC, Balázs, B, Arpin, I, Pataki, G, Hauck, J, Kelemen, E, Kopperoinen, L, Van Herzele, A, Keune, H, Hecker, S, Suškevičs, M, Roy, HE, Itkonen, P, Külvik, M, László, M, Basnou, C, Pino, J and **Bonn, A.** 2016. Learning and the transformative potential of citizen science: Lessons from the Study of Nature. *Conservation Biology*, 30(5): 990–999. DOI: https://doi.org/10.1111/cobi.12762

Bio Intelligence Service. 2010. Scoping report on Lay, local and traditional knowledge, Service contract 3403/B2009/EEA53737 for the for European Environment Agency on technical support for the Late Lessons project. Paris, France.

Blaney, RJP, Pocock, M and **Jones, GD.** 2016. Citizen science and environmental monitoring: towards a methodology for evaluating opportunities, costs and benefits. Final report. London, UK: UK Environmental Observation Framework.

Burgess, HK, DeBey, LB, Froehlich, HE, Schmidt, N, Theobald, EJ, Ettinger, AK, HilleRisLambers, J, Tewksbury, J and **Parrish, JK.** 2017. The science of citizen science: Exploring barriers to use as a primary research tool. *Biological Conservation*, 208: 113–120. DOI: https://doi.org/10.1016/j.biocon.2016.05.014

Burke, TA, Cascio, WE, Costa, DL, Deener, K, Fontaine, TD, Fulk, FA, Jackson, LE, Munns, WR, Orme-Zavaleta, J, Slimak, MW and **Zartarian, VG.** 2017. Rethinking Environmental Protection: Meeting the Challenges of a Changing World. *Environmental Health Perspectives*, 125(3): A43–A49. DOI: https://doi.org/10.1289/EHP1465

Chandler, M, See, L, Copas, K, Bonde, AMZ, López, BC, Danielsen, F, Legind, JK, Masinde, S, Miller-Rushing, AJ, Newman, G, Rosemartin, A and **Turak, E.** 2017. Contribution of citizen science towards international biodiversity monitoring. *Biological Conservation*, 213: 280–294. DOI: https://doi.org/10.1016/j.biocon.2016.09.004

Chantre, E, Guichard, L, Ballot, R, Jacquet, F, Jeuffroy, M-H, Prigent, C and **Barzman, M.** 2016. Co-click'eau, a participatory method for land-use scenarios in water catchments. *Land Use Policy*, 59: 260–271. DOI: https://doi.org/10.1016/j.landusepol.2016.09.001

Conrad, CC and **Hilchey, KG.** 2011. A review of citizen science and community-based environmental monitoring: issues and opportunities. *Environmental Monitoring and Assessment*, 176(1–4): 273–291. DOI: https://doi.org/10.1007/s10661-010-1582-5

Convention of the Biological Diversity. 2013. Quick guides to the Aichi Biodiversity Targets. Version 2.

Cooper, CB, Shirk, J and **Zuckerberg, B.** 2014. The Invisible Prevalence of Citizen Science in Global Research: Migratory Birds and Climate Change. *PLOS ONE*, 9(9): e106508. DOI: https://doi.org/10.1371/journal.pone.0106508

Crowdsourcing and Citizen Science Act. 2016 (15 USC 3724). Available at: https://www.citizenscience.gov/about [Last accessed 9 September 2018].

Danielsen, F, Pirhofer-Walzl, K, Adrian, TP, Kapijimpanga, DR, Burgess, ND, Jensen, PM, Bonney, R, Funder, M, Landa, A, Levermann, N and **Madsen, J.** 2014. Linking Public Participation in Scientific Research to the Indicators and Needs of International Environmental Agreements: Monitoring environmental agreements. *Conservation Letters*, 7(1): 12–24. DOI: https://doi.org/10.1111/conl.12024

Donald, PF, Green, RE and **Heath, MF.** 2001. Agricultural intensification and the collapse of Europe's farmland bird populations. *Proceedings of the Royal Society B-Biological Sciences*, 268(1462): 25–29. DOI: https://doi.org/10.1098/rspb.2000.1325

EU-Ares. 2016 1443186. Strategic plan 2016–2020, DG Environment; 7th Environment action programme to 2020 Decision No 1386/2013/EU of the European Parliament and of the Council of 20 November 2013 on a General Union Environment Action Programme to 2020 'Living well, within the limits of our planet'. Brussels, Belgium: European Commission.

EU-Communication. 2017. COM (2017) 312 final. Report from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions: Actions to Streamline Environmental Reporting. Brussels, 9 June 2017. Brussels, Belgium: European Commission.

EU-Communication. 2017. SWD (2017) 139 final: An Action Plan for nature, people and the economy. Brussels, Belgium: European Commission.

EU-Communication. 2018a. COM (2018) 10 final: EU actions to improve environmental compliance and governance. Brussels, Belgium: European Commission.

EU-Communication. 2018b. COM (2018) 395 final: EU Pollinators Initiative. Brussels, Belgium: European Commission.

Eurostat. 2019. Common bird index (EU aggregate), 1990–2016. Available at https://ec.europa.eu/eurostat/web/products-datasets/-/t2020_rn130 [last accessed 18 February 2019].

EU-Water Framework Directive. 2000/60/EC. Directive 2000/60/EC, of the European Parliament and of the Council. Establishing a framework for Community action in the field of water policy (in particular: Art. 14 "Public Information and consultation"), 23 October 2000. ELI: http://data.europa.eu/eli/dir/2000/60/oj. Brussels, Belgium: European Commission.

Fritz, S, Fonte, C and **See, L.** 2017. The Role of Citizen Science in Earth Observation. *Remote Sensing*, 9(4): 357. DOI: https://doi.org/10.3390/rs9040357

Hadj-Hammou, J, Loiselle, S, Ophof, D and **Thornhill, I.** 2017. Getting the full picture: Assessing the complementarity of citizen science and agency monitoring data. *PLOS ONE*, 12(12): e0188507. DOI: https://doi.org/10.1371/journal.pone.0188507

Haklay, M. 2015. *Citizen science and policy: a European perspective*. Washington, DC: Woodrow Wilson International Center for Scholars.

Hecker, S, Bonney, R, Haklay, M, Hölker, F, Hofer, H, Goebel, C, Gold, M, Makuch, Z, Ponti, M, Richter, A, Robinson, L, Iglesias, JR, Owen, R, Peltola, T, Sforzi, A, Shirk, J, Vogel, J, Vohland, K, Witt, T and **Bonn, A.** 2018. Innovation in Citizen Science – Perspectives on Science-Policy Advances. *Citizen Science: Theory and Practice*, 3(1): 1–14. DOI: https://doi.org/10.5334/cstp.114

Hyder, K, Townhill, B, Anderson, LG, Delany, J and **Pinnegar, JK.** 2015. Can citizen science contribute to the evidence-base that underpins marine policy? *Marine Policy*, 59: 112–120. DOI: https://doi.org/10.1016/j.marpol.2015.04.022

McKinley, DC, Miller-Rushing, AJ, Ballard, HL, Bonney, R, Brown, H, Cook-Patton, SC, Evans, DM, French, RA, Parrish, JK, Phillips, TB, Ryan, SF, Shanley, LA, Shirk, JL, Stepenuck, KF, Weltzin, JF, Wiggins, A, Boyle, OD, Briggs, RD, Chapin, SF, Hewitt, DA, Preuss, PW and **Soukup, MA.** 2017. Citizen science can improve conservation science, natural resource management, and environmental protection. *Biological Conservation*, 208: 15–28. DOI: https://doi.org/10.1016/j.biocon.2016.05.015

Nascimento, S, Rubio Iglesias, JM, Owen, RP, Schade, S and **Shanley, L.** 2018. Citizen science for policy formulation and implementation. In: Hecker, S, Haklay, M, Bowser, A, Makuch, Z, Vogel, J and Bonn, A (eds.), *Citizen Science: Innovation in Open Science, Society and Policy*, 219–240. London: UCL Press. DOI: https://doi.org/10.14324/111.9781787352339

Newman, G, Chandler, M, Clyde, M, McGreavy, B, Haklay, M, Ballard, H, Gray, S, Scarpino, R, Hauptfeld, R, Mellor, D and **Gallo, J.** 2017. Leveraging the power of place in citizen science for effective conservation decision making. *Biological Conservation*, 208: 55–64. DOI: https://doi.org/10.1016/j.biocon.2016.07.019

Owen, RP and **Parker, AJ.** 2018. Citizen science in environmental protection agencies. In: Hecker, S, Haklay, M, Bowser, A, Makuch, Z, Vogel, J and Bonn, A (eds.), *Citizen Science: Innovation in Open Science, Society and Policy*, 284–300. London: UCL Press. DOI: https://doi.org/10.14324/111.9781787352339

Pocock, MJO, Chapman, DS, Sheppard, LJ and **Roy, HE.** 2014. *Choosing and using citizen science: a guide to when and how to use citizen science to monitor biodiversity and the environment*. Wallingford, Oxfordshire: Centre for Ecology & Hydrology.

Pocock, MJO, Tweddle, JC, Savage, J, Robinson, LD and **Roy, HE.** 2017. The diversity and evolution of ecological and environmental citizen science. *PLOS ONE*, 12(4): e0172579. DOI: https://doi.org/10.1371/journal.pone.0172579

Roy, HE, Pocock, MJO, Preston, CD, Roy, DB, Savage, J, Tweddle, JC and **Robinson, LD.** 2012. Understanding citizen science and environmental monitoring. Final report. London, UK: UK Environmental Observation Framework. Available at http://www.ukeof.org.uk/documents/understanding-citizen-science.pdf [Last accessed 6 September 2018].

Schade, S, Manzoni, M, Tsinaraki, C, Kotsev, A, Fullerton, KT, Sgnaolin, R, Spinelli, F and **Mitton, I.** 2017. *Using new data sources for policymaking*. EUR 28940 EN, Luxembourg: Publications Office of the European Union, ISBN 978-92-79-77078-4, JRC109472.

Schade, S, Tsinaraki, C and **European Commission and Joint Research Centre.** 2016. Survey report: data management in citizen science projects; EUR 27920 EN; Luxembourg: Publications Office of the European Union; 2016.

Snep, RPH, Wallis DeVries, M and **Opdam, P.** 2011. Conservation where people work: A role for business districts and industrial areas in enhancing endangered butterfly populations? *Landscape and Urban Planning*, 103(1): 94–101. DOI: https://doi.org/10.1016/j.landurbplan.2011.07.002

Socientize. 2014. Citizen science for Europe: towards a better society of empowered citizens and enhanced research. *Green paper on citizen science for Europe*. Zaragoza, Spain: European Commission.

Theobald, EJ, Ettinger, AK, Burgess, HK, DeBey, LB, Schmidt, NR, Froehlich, HE, Wagner, C, Hille Ris Lambers, J, Tewksbury, J, Harsch, MA and **Parrish, JK.** 2015. Global change and local solutions: Tapping the unrealized potential of citizen science for biodiversity research. *Biological Conservation*, 181: 236–244. DOI: https://doi.org/10.1016/j.biocon.2014.10.021

Turrini, T, Dörler, D, Richter, A, Heigl, F and **Bonn, A.** 2018. The threefold potential of environmental citizen science – Generating knowledge, creating learning opportunities and enabling civic participation. *Biological Conservation*, 225: 176–186. DOI: https://doi.org/10.1016/j.biocon.2018.03.024

UNEA. 2017. *Global vision statement*. Nairobi, Kenya: Science-Policy Business Forum, 3rd UN Environmental Assembly.

Weichselgartner, J and **Kasperson, R.** 2010. Barriers in the science-policy-practice interface: Toward a knowledge-action-system in global environmental change research. *Global Environmental Change*, 20(2): 266–277. DOI: https://doi.org/10.1016/j.gloenvcha.2009.11.006

Williams, J, Chapman, C, Leibovici, DG, Loïs, G, Matheus, A, Oggioni, A, Schade, S, See, L and **Lodewijk van Genuchten, PP.** 2018. Maximising the impact and reuse of citizen science data. In: Hecker, S, Haklay, M, Bowser, A, Makuch, Z, Vogel, J and Bonn, A (eds.), *Citizen Science: Innovation in Open Science, Society and Policy*, 219–240. London: UCL Press. DOI: https://doi.org/10.14324/111.9781787352339

How to cite this article: Turbé, A, Barba, J, Pelacho, M, Mugdal, S, Robinson, LD, Serrano-Sanz, F, Sanz, F, Tsinaraki, C, Rubio, J-M and Schade, S. 2019. Understanding the Citizen Science Landscape for European Environmental Policy: An Assessment and Recommendations. *Citizen Science: Theory and Practice*, 4(1): 34, pp. 1–16. DOI: https://doi.org/10.5334/cstp.239

Submitted: 27 February 2019 **Accepted:** 28 May 2019 **Published:** 02 December 2019

]u[*Citizen Science: Theory and Practice* is a peer-reviewed open access journal published by Ubiquity Press. OPEN ACCESS