European Commission

Citizen science for environmental policy: Development of an EU-wide inventory and analysis of selected practices

Bio Innovation Service, in collaboration with Fundación Ibercivis and The Natural History Museum

Disclaimer

The information and views set out in this report are those of the authors and do not necessarily reflect the official opinion of the Commission. The Commission does not guarantee the accuracy of the data included in this

study. Neither the Commission nor any person acting on the Commission's behalf may be held responsible for the use which may be made of the information contained therein.

Project team

Shailendra Mugdal (BIO Innovation Service)

Anne Turbe (BIO Innovation Service)

Francisco Sanz (Ibercivis)

Jorge Barba (Ibercivis)

Maite Pelacho (Ibercivis)

Fermin Serrano-Sanz (Ibercivis)

Lucy Robinson (Natural History Museum)

Margaret Gold (Natural History Museum)

Acknowledgments

We would like to express our sincere thanks to all citizen science projects that invested their precious time in answering our questions, this study would not have been possible without their support. We also thank the colleagues at the European Commission: Sven Schade and Chrysi Tsinarki (JRC), José Miguel Rubio Iglesias (EEA); Marjan Van Merloo (DG RTD); Izabela Freytag (EASME); Liam Cashman (DG ENV); for their support and comments and Elena Montani (DG ENV) for overall guidance.

Citation

Bio Innovation Service (2018) Citizen science for environmental policy: development of an EU-wide inventory and analysis of selected practices. Final report for the European Commission, DG Environment under the contract 070203/2017/768879/ETU/ENV.A.3, in collaboration with Fundacion Ibercivis and The Natural History Museum, November 2018.

LEGAL NOTICE

This document has been prepared for the European Commission however it reflects the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

More information on the European Union is available on the Internet (http://www.europa.eu).

Luxembourg: Publications Office of the European Union, 2018

PDF - ISBN:978-92-79-98104-3- doi:10.2779/961304 - KH-03-18-528-EN-N

Table of Contents

List of Figures

List of acronyms

DITOs	Doing It Together Science
DIY	Do-it-yourself
EKC	Environmental Knowledge Community
EPAs	Environmental Protection Agencies
EU	European Union
IPCC	Intergovernmental Panel on Climate Change
JRC	Joint Research Centre
KIP	Knowledge and Innovation Project
MS	Member States of the European Union
NGO	Non-Governmental Organisation
SDGs	Sustainable Development Goals
SEPA	Scottish Environment Protection Agency
UKEOF	Environmental Observation Framework of the United Kingdom
UN	United Nations

Executive summary

Citizen science is the non-professional involvement of volunteers in the scientific process, whether in the data collection phase or in other phases of the research. Citizen science is a powerful tool for environmental management that has the potential to inform an increasingly complex environmental policy landscape and to meet the growing demands from society for more participatory decision-making. While there is growing interest from international bodies and national governments in citizen science, however the evidence that it can successfully contribute to environmental policy development, implementation, evaluation or compliance remains scant. Central to elucidating this question is a better understanding of the benefits delivered by citizen science, that is to determine to what extent these benefits can contribute to environmental policy, and to establish whether projects that provide policy support also co-benefit science and encourage meaningful citizen engagement.

The aim of this study was to provide the European Commission with an evidence base of citizen science activities that can support environmental policies in the European Union (EU). The first objective was to develop an inventory of citizen science projects relevant for environmental policy and assess how these projects contribute to the Sustainable Development Goals (SDGs) set by the United Nations (UN) General Assembly. To this end, a desk-research and an EU-wide survey were used to identify 503 citizen science projects of relevance to environmental policy. The second objective was to assess the conditions under which citizen science can best support environmental policy, through the selection and analysis of a sample of citizen science projects. This was followed by an in-depth analysis of 45 projects along 94 project attributes. Subsequently, this analysis provided the foundation for making a series of recommendations to leverage the contribution of citizen science to environmental policy.

The study demonstrates the breadth of citizen science that can be of relevance to environmental policy. Citizen science projects have been developed in all environmental fields and include all types of citizen science actions, from monitoring and occasional reporting to crowd-sourcing and passive sensing. However, citizen science activities focused on the monitoring the state of natural resources, nature and biodiversity in particular, dominate the environmental citizen science landscape. In contrast, citizen science projects related to the efficient use of resources only represent 7% of the projects in the inventory.

Environmental citizen science projects already contribute to a diversity of SDGs, in particular goals related to Health and well-being (SDG 3), climate mitigation and adaptation (SDG 13), terrestrial nature conservation (SDG 15) and global partnership for sustainable development (SDG 17). However, projects in the inventory provided limited direct contributions to five environmentally-related SDGs, with regard to food, water, sustainable energy, sustainable cities, as well as sustainable consumption and production (SDGs 2, 6, 7, 11 and 12).

The in-depth analysis of selected projects shows that a diverse continuum of approaches can be used to achieve policy-relevance. While most of the analysed projects converge on the scientific dimension holding high standards to training and data validation, there are limitations in terms of data accessibility and interoperability. In contrast, projects differ more widely on their approaches to citizen engagement , and notably on the importance of social media. Policy linkages seem mostly to be considered either in the project design, or to be a spinoff resulting from the large amounts of data compiled by citizen science projects that cover broad spatio-temporal scales.

Three salient features were found: (a) Government support, not only in the 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. (b) When there is easy engagement process for the citizens, that is, with projects requiring limited efforts and a priori skills, this facilitates their policy uptake. (c) Scientific aspects on the other hand did not appear to affect the policy uptake of the analysed projects, but they were a strong determinant of how well the project could serve policy: projects with high scientific standards and endorsed by scientists served more phases of the environmental policy cycle.

Establishing policy linkages is typically a lengthy process, and project leaders often reported difficulties in identifying relevant policy needs, connecting with decision-makers and convincing them of the value of citizen science data. Succeeding in making those links can help to develop more inclusive, relevant and timely research as well as policies, and offer citizens an opportunity to make a difference, however, project leaders often find it challenging to ensure sustained volunteer engagement. The analysis illustrates that there is a range of business models behind citizen science initiatives relevant for environmental policy, underlined by the diversity of partnerships and of approaches to ensure the long-term sustainability of data infrastructure, community and funding. Although most of the surveyed citizen science projects were Non-Governmental Organisation (NGO) -led, medium-sized projects, there were also several EU or national government-funded academia-led projects. Only 25% of the projects had a guaranteed funding structure, and survey respondents raised the need to identify funding opportunities to ensure the mid- to long-term maintenance of citizen science initiatives. Interestingly there is very little support from the private sector, whereas this could in fact be mutually beneficial.

We, therefore, recommend actions to bridge the gap between policy, scientists and the public by encouraging active government support in all stages of a citizen science project, to grant credibility to the project and promote policy linkages. In particular, it is important to increase the awareness of local authorities about the potential benefits they can gain by using citizen science. There is also a need to facilitate the connection and communication between decision-makers and project leaders. In addition, centralising citizen science information and resources, and improving the national coordination of citizen science activities would help projects gain visibility, share and reuse tools and best-practices, while avoiding redundancies among activities. This would foster better returns on investment in citizen science activities. Such centralization could be achieved in different ways through — national platforms on environmental protection, as already exists in some Member states (MS), or by creating more focused topic-based and/or citizen science-based platforms. The platforms should aim to go beyond a simple catalogue of projects and provide guidance, tools and methods to help project leaders and end-users make the most of the data, while enabling citizens to easily identify communities of interest. Additionally, the centralisation of end-users' needs via a portal or interface that publicises the data needs and invites citizen science projects to respond with appropriate data would channel citizen science efforts towards direct policy applicability.

Improved traceability of citizen science data uses, both in science and for policy, is important to appreciate its impact and optimise its uses. This can be achieved by including persistent identifiers to uniquely identify citizen science datasets or through the development of a tool to track policy development. This tool should clearly reference the data and/or forms of participation used to monitor each environmental indicator of a policy. Moreover, requirements to evaluate citizen science impacts can be embedded in the financing conditions, so as to facilitate the demonstration of successful citizen science initiatives.

Finally, to gain maximum potential of environmental citizen science for policy, we recommend: providing tools and methods to promote the scalability of citizen science projects across cultures and spatial extents; ensuring or developing financing options for the continuation of citizen science initiatives; improving NGO support (financial, organisational, and academic); incentivising the participation of the private sector for financing and contributing to citizen science; and promoting citizen science in other environmental fields than those related to natural resource management, such as resource efficiency, food, and sustainable consumption and production.

In conclusion, this study demonstrates that citizen science has the potential to be a cost-effective way to contribute to policy and highlights the importance of fostering a diversity of citizen science activities and their innovativeness. It is important, however, not to erode the support and trust of citizens in the environmental policy process, which can be long and complex.

All the data used in preparing this report is publicly available at the website of the European Commission[1].

[1] European Commission, Directorate-General for Environment; European Commission, Joint Research Centre; Bio Innovation Service (2018): An inventory of citizen science activities for environmental policies. European Commission, Joint Research Centre (JRC) [Dataset] PID: http://data.europa.eu/89h/jrc-citsci-10004

This page is left intentionally blank.

Résumé

Les sciences participatives sont définies comme des programmes impliquant une participation citoyenne volontaire dans le cadre d'une démarche scientifique, aussi bien pour la collecte de données, que pour les autres étapes du processus scientifique. Les sciences participatives constituent un outil puissant pour la gestion de l'environnement, offrant le double potentiel de documenter le paysage, de plus en plus complexe, des politiques environnementales et de soutenir la demande croissante de la société civile pour une participation plus active aux décisions publiques. Malgré un intérêt croissant pour les sciences participatives de la part des organismes internationaux et des gouvernements, on dispose encore de trop peu de données concluantes pour affirmer que celles-ci peuvent contribuer à la mise en place, l'évaluation ou l'application des politiques environnementales. La solution à ce problème passe par une compréhension fine des bénéfices apportés par les sciences participatives, afin notamment de déterminer dans quelle mesure les projets de sciences participatives contribuent aux politiques environnementales, et le cas échéant s'ils sont également capables de contribuer utilement à la recherche scientifique et de permettre un engagement pertinent des citoyens.

Le but ce cette étude était de fournir à la Commission Européenne une base de données étoffée des projets de sciences participatives susceptibles de contribuer aux politiques environnementales en Europe. Le premier objectif était d'établir un inventaire des projets de sciences participatives pertinents pour les politiques environnementales et d'évaluer leur contribution aux objectifs de développement durable établis par l'assemblée générale de l'Organisation des Nations Unies. A cet égard, une recherche documentaire combinée à une enquête européenne auprès de la communauté de sciences participatives a permis d'identifier 503 projets de sciences participatives pertinents pour les politiques environnementales. Le deuxième objectif était d'évaluer les conditions selon lesquelles les sciences participatives peuvent le mieux soutenir les politiques environnementales, par le biais de la sélection et de l'analyse d'un échantillon de projets de sciences participatives. Pour cela, 45 projets ont été analysés selon 94 critères. Cette analyse a servi de base à une série de recommandations visant à améliorer la contribution des sciences participatives aux politiques environnementales.

L'étude montre qu'un large éventail de sciences participatives peut contribuer aux politiques environnementales. Les programmes de sciences participatives couvrent l'ensemble des domaines environnementaux et tous les types de sciences participatives, des observatoires aux signalements occasionnels, en passant par le crowdsourcing (approvisionnement par la foule). Les projets de sciences participatives centrés sur le suivi des ressources naturelles, en particulier de la nature et de la biodiversité, dominent le paysage des sciences participatives environnementales. En revanche, les projets de sciences participatives liés à l'utilisation efficace des ressources ne représentent que 7% des projets de l'inventaire.

Les programmes environnementaux de sciences participatives couvrent une large diversité d'objectifs de développement durable, en particulier ceux qui touchent à la santé et au bien-être (Objectif 3), à l'adaptation au changement climatique (Objectif 13), à la conservation de la nature sur terre (Objectif 15) et au partenariat global pour le développement (Objectif 17). En revanche, les projets de l'inventaire contribuent peu à cinq objectifs liés à l'environnement, les objectifs concernant l'eau, l'alimentation, les énergies, les villes et la consommation et la production durables (Objectifs 6, 2, 7, 11 et 12).

L'analyse approfondie de l'échantillon de programmes montre qu'un continuum d'approches est utilisé pour servir les politiques publiques. La majorité des

programmes converge sur la dimension scientifique, faisant preuve d'un niveau d'exigence élevé en ce qui concerne la formation des volontaires et la validation des données, mais exhibant des limites en termes d'accessibilité et d'interopérabilité des données. En revanche, les programmes diffèrent davantage pour ce qui est des méthodes d'engagement et de fidélisation des volontaires, notamment quant au rôle des réseaux sociaux. Les liens avec les politiques publiques semblent généralement être considérés dès la conception du projet, soit une retombée liée à la quantité de données collectées par les programmes de sciences participatives à grande échelle, spatiale et temporelle.

Il y a trois observations importantes : (a) Le soutien du gouvernement, non seulement pour le financement des projets, mais également à travers une participation active lors de leur conception et de leur mise en œuvre, semble un facteur clé de l'application des sciences participatives à la gestion de l'environnement. (b) Quand il y a un processus d'engagement simple pour les citoyens, c'est-à-dire des projets nécessitant peu d'efforts et peu de compétences spécifiques, cela facilite également l'application de ces projets dans les politiques environnementales. (c) Les aspects liés à la dimension scientifique des projets échantillonnés ne semblent pas affecter leur utilisation dans les politiques environnementales, mais ils sont en revanche un facteur déterminant de la manière dont un projet peut être utilisé par les politiques : les projets aux exigences scientifiques élevées et soutenus par les chercheurs sont utiles dans un plus grand nombre d'étapes du cycle de l'élaboration des politiques environnementales.

L'établissement de liens avec les politiques est typiquement un long processus, et les responsables de projets éprouvent souvent des difficultés à identifier les besoins politiques, à établir des liens avec les décideurs et à les convaincre de l'utilité des sciences participatives. L'établissement de tels liens devrait permettre de développer à la fois des projets de recherche et des politiques plus pertinents, opportuns et inclusifs, tout en offrant aux citoyens l'occasion de changer les choses. Mais malgré ces multiples bénéfices, les responsables de projet affirment rencontrer des difficultés à maintenir l'engagement des citoyens dans le temps. L'analyse suggère qu'il y a différents modèles économiques derrière les projets qui parviennent à servir les politiques environnementales. En effet, les projets diffèrent quant au niveau de soutien reçu par différentes parties-prenantes et quant à leur approche pour assurer la viabilité à long terme du financement, ainsi que de l'infrastructure nécessaire au maintien des données et de la communauté de volontaires. Si la majorité des projets de sciences participatives échantillonnés était de taille moyenne, dirigés par des organisations non-gouvernementales, un nombre important de projets étaient également dirigés par des scientifiques et financés par la Commission Européenne ou des organismes gouvernementaux. Seulement un quart des projets échantillonnés avaient un financement garanti, et les responsables de projets ont signalé la nécessite d'identifier des opportunités de financement pour permettre le maintien à moyen ou long terme des programmes. Quasiment aucun des projets échantillonnés n'a reçu le soutien du secteur privé, ce qui représente une importante occasion manquée.

Nous recommandons donc de combler le fossé entre politique environnementale, scientifiques et citoyens en encourageant le soutien des organismes gouvernementaux aux différents stades des projets de sciences participatives, afin d'aider les programmes à gagner en crédibilité et de favoriser la création de liens avec les politiques environnementales. En particulier, il semble important d'augmenter la prise de conscience des autorités locales au sujet quant aux bénéfices qu'elles peuvent tirer du recours aux sciences participatives. Il convient de faciliter la mise en contact et la communication entre les responsables de projet et les décideurs. En outre, la centralisation des projets et ressources dédiés aux sciences participatives, ainsi que l'amélioration de la coordination des programmes de sciences participatives au niveau national, permettraient aux projets de gagner en visibilité, de mutualiser et de réutiliser outils et bonnes pratiques, tout en évitant les redondances entre programmes. Un meilleur retour sur investissement des activités de sciences participatives pourrait ainsi être assuré. Il existe plusieurs options pour réaliser cette centralisation, que ce soit au travers de portails nationaux sur la protection de l'environnement, comme cela existe déjà dans certains Etats Membres de l'Union Européenne, ou bien en ciblant un thème spécifique ou un ensemble de sciences participatives. Ces portails devraient viser à être plus que de simples catalogues de programmes, afin de fournir du soutien, des outils et des méthodes pour aider les responsables de projet et les utilisateurs à tirer le meilleur parti des données, tout en permettant aux volontaires d'identifier facilement des communautés d'intérêt. En outre, la centralisation des besoins des utilisateurs finaux, toujours par le biais d'un portail internet ou bien d'une interface publiant les besoins en données/participation et invitant les projets de sciences participatives à répondre avec les données pertinentes, permettrait de canaliser les efforts des sciences participatives en vue d’une application directe par les politiques.

Une meilleure traçabilité de l'utilisation des sciences participatives, à la fois par la science et par les politiques environnementales, permettrait de mieux apprécier leur impact et d'optimiser leurs usages. Une option pourrait consister à associer un identifiant permanent à chaque jeu de données, ou encore à créer un outil pour suivre le développement des politiques environnementales. Cet outil ferait clairement référence aux données et/ou modes de participation utilisés pour suivre chaque indicateur environnemental d'une politique. En outre, la nécessité d'évaluer les impacts des projets de sciences participatives pourrait être une condition associée au financement des projets, ce qui permettrait d’appréhender plus facilement les bénéfices fournis par les sciences participatives.

Enfin, afin d'atteindre le plein potentiel des sciences participatives pour les politiques, nous recommandons: de fournir des outils et des méthodes permettant l'évolutivité des projets à travers différents contextes culturels et échelles spatiales; d'assurer ou de développer des options de financement pour la continuation des programmes de sciences participatives; d'encourager la participation des entreprises privées dans les sciences participatives, en tant que financeurs et contributeurs; de promouvoir les sciences participatives dans d'autres domaines environnementaux que ceux liés à la gestion des ressources naturelles, comme l'utilisation efficace des ressources, l'alimentation, la consommation et la production durable.

Pour conclure, cette étude montre que les sciences participatives peuvent contribuer utilement aux politiques environnementales, et souligne l'importance d'encourager la diversité des activités de sciences participatives et leur innovation. Il convient toutefois de prendre garde à ne pas éroder le soutien et la confiance des citoyens, tant le processus d'élaboration des politiques environnementales peut être long et complexe.

Toutes les données utilisées pour préparer ce rapport sont disponibles en accès libre sur le site de la Commission Européenne[2].

[2] European Commission, Directorate-General for Environment; European Commission, Joint Research Centre; Bio Innovation Service (2018): An inventory of citizen science activities for environmental policies. European Commission, Joint Research Centre (JRC) [Dataset] PID: http://data.europa.eu/89h/jrc-citsci-10004

This page is left intentionally blank.

1. Introduction

The enormous scale and complexity of current environmental problems poses serious challenges for science, policy and society at large. Environmental legislation is becoming ever more complex, with increasingly large datasets required to support evidence-based policy-making (Danielsen et al., 2014; Hyder et al., 2015). In addition, there is a growing demand from society for a more participatory approach to decision-making that engages with more stakeholders and involves citizens. Citizen science offers a powerful tool for tackling these challenges, by building scientific knowledge, informing policy and inspiring public action. Citizen science is a growing worldwide phenomenon, born out of a long history of public participation in scientific research enacted through many approaches. Citizen scientists are non-professional volunteers involved in the scientific process, commonly in data collection, but also in other phases of the scientific process, such as data interpretation, problem definition, or dissemination of results (Bonney et al., 2009; Haklay, 2015). Citizen science is particularly developed in the environmental domain (Kullenberg & Kasperowski, 2016), where it offers a unique opportunity to expand the knowledge base, by mobilising lay and local knowledge or carrying out research in places and at scales that would not have been possible otherwise (Newman et al., 2017). But, one of its defining aspects is that beyond data, it focuses on engaging people with science, and can help to raise the awareness of citizens about environmental issues and governance, develop a common understanding of issues and possible solutions (Turrini et al., 2018). In an age where demand for civic participation in both research and policy is growing, citizen science is increasingly seen by policy-makers as well as scientists as a cost-effective method to inform policy (Blaney et al., 2016). Nevertheless, its contribution to decision-making remains sparse and poorly understood (Conrad & Hilchey, 2011; Roy et al., 2012; Davies et al., 2013; Newman et al., 2017)

1.1. Aims of this study

Citizen science can contribute to realising three important goals: generating new knowledge for science and society, increasing science literacy, and democratizing decision-making and scientific processes (Figure 1) (Kieslinger et al., 2017; Turrini et al., 2018). However, significant gaps remain in our understanding of the actual impacts of citizen science on each of these dimensions, and more specifically on the potential tradeoffs between them. Harnessing the three-fold potential of citizen science also requires an in-depth understanding of the best-practices in environmental citizen science in order to identify which conditions are the most conducive.

The aim of the present study is to provide the European Commission with an evidence base of citizen science activities that can support environmental policies in the European Union (EU). It forms part of the work of the Environment Knowledge Community (EKC) on citizen science. Specifically, it will provide inputs for guidelines to promote a wider use of citizen science to complement environmental reporting, as well as for recommendations on the integration of citizen science in the EU environmental policy cycle.

The five-fold objectives of this study were to:

i. develop a comprehensive inventory of environmental citizen science projects, spanning the range of environmental fields and geographical contexts in the EU;

ii. develop criteria and assess how the projects in the inventory contribute to the UN Sustainable Development Goals (SDGs);

iii. assess the conditions under which citizen science can best support environmental policy, through the selection and analysis of selected-practices in environmental citizen science that support policy;

iv. provide a brief assessment of main opportunities and challenges for increased citizen science contribution in environmental policy; and

v. develop policy recommendations on better integration of citizen science in the different phases of the environmental policy cycle, in particular for monitoring, reporting and regulatory compliance.

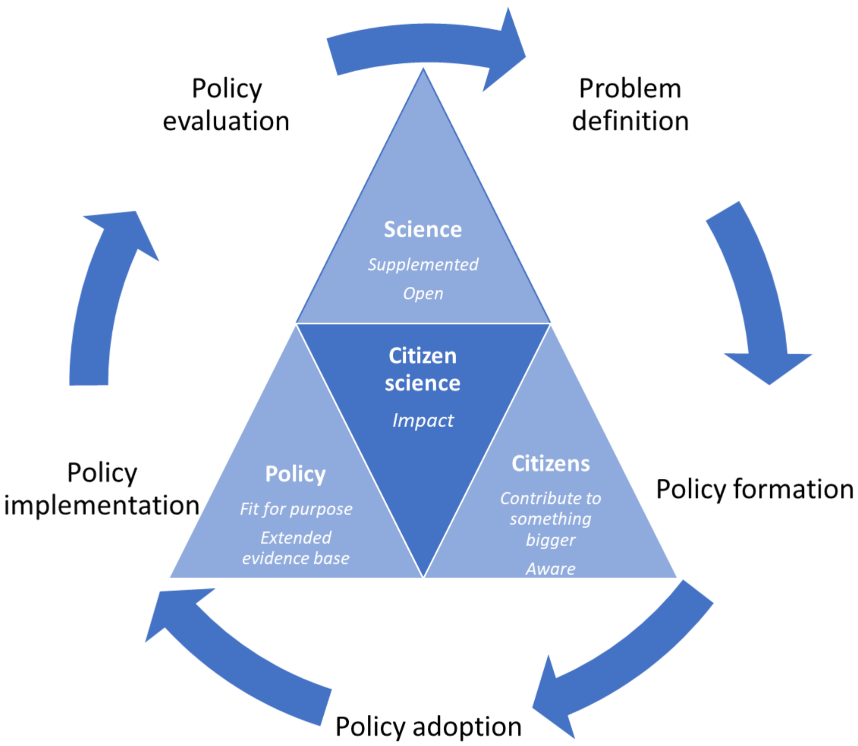

Figure 1 – Three main pillars of citizen science in the policy cycle: scientific excellence, citizen engagement, and policy-relevance

2. Background

2.1 Citizen science for the environment

There are many different types of citizen science projects in the environmental area. The majority are 'contributory' projects, designed by scientists, but enlisting the help of volunteers to collect monitoring data (e.g. on invasive species or litter sightings). Volunteer involvement in ecological monitoring, and bird surveys in particular, have a long history. In the past, amateur scientists have contributed a great deal to science, particularly with networks of weather collectors and ocean monitoring, or all kinds of programmes aimed at monitoring the location and abundance of species through time, or the timing of nature's events (phenology, migration) (Cooper et al., 2014; Chandler et al., 2017a). Initiatives such as Austria's Phenowatch network, have been recording phenological observations at fixed locations in Austria since the mid-1800s. But the most successful examples of environmental citizen science programmes may still be the volunteer bird surveys. National bird monitoring schemes have been developed in every European country, some of them dating back as early as in the beginning of the century (e.g., the volunteer bird ringing programme led by the British Trust for Ornithology in the UK). These national observation networks are now coordinated and compiled at European level through the Pan-European Bird Monitoring Scheme, to provide long-term data that has been used to reveal many important impacts on biodiversity at continental level, including effects of pollution, land uses and practices, and climate change (Hames et al., 2002; Hurlbert & Liang, 2012; Jiguet et al., 2012). Citizen scientists can also engage in process studies and assess the impacts of factors on ecosystem components and functions.

The development and democratisation of new technologies, such as smartphone apps and social networks, has broadened the scope of citizens contributions, enabling scientists to process far higher volumes of data than would previously have been possible. For example, Malaria Spot enlists volunteers to count the number of parasites in blood samples through a gaming application to help with Malaria diagnosis. Volunteers involved in Geo-Wiki help in clarifying discrepancies between different land cover maps from their observations of Google Earth images. Some programs, such as Tela-botanica, are engaging citizens to assist in interpreting and digitizing their museum collections, making historic records accessible to wider audiences. Specific engineering solutions are developed to respond to pressing societal needs. For example, FoodSmartphone develops diagnostic tools for simplified on-site pre-screening of food quality and safety parameters and transfers these data to relevant stakeholders. iSpex allows citizens to use their smartphones to measure aerosols, while FreshwaterWatch provides citizen scientists across the world with a simple a test kit to monitor nitrate and phosphate freshwater quality.

Recently, more shared forms of citizen involvement in the scientific process have been on the rise, with the development of collaborative projects (designed by scientists with volunteers contributing data, refining project design, analysing data or disseminating findings), or co-created projects (scientists and volunteers collaborate throughout all stages of the scientific process). For example, following the Fukushima nuclear plant disaster, the internationally crowdfunded and crowdsourced project Safecast distributed handheld sensors to volunteers, resulting in over 27 million observations on radiation measurements in Japan and worldwide. These data are publicly available and have been shown to be reliable and useful for public safety (Coletti et al., 2017). Some citizen science programs equip volunteers with the tools or expertise with which to lobby for local or national policy change, or simply with the goal of engaging the public in the environment (Shirk et al., 2012). Community-based citizen science can help answer questions of concern that are important for local management and policy, but go unaddressed by professional science (Arlettaz et al., 2010). For example, the "See it? Say it!" application developed by Ireland's Environmental Protection Agency allows citizens to collect and direct their environmental concerns to relevant local authority, so that it can take action. The Doing It Together Science (DITOs) programme is organising many innovative events across Europe to promote the active involvement of citizens in science. Initiatives where the public leads the process are also on the rise, in what is called 'Do-it-yourself (DIY) science' projects. For example, the Aircasting project developed an open source device to measure fine particulate matter and support air quality monitoring.

By achieving hitherto unrealised levels of large-scale monitoring, for features which would remain inaccessible if it was not for people's local contributions, citizen science is rapidly becoming a mainstream approach for collecting environmental data. But the extent to which these data are used to answer societal and policy issues remains unclear. Adoption of citizen science results in policy is still slow (Hyder et al., 2015; Blaney et al., 2016; Thornhill et al., 2016). While not all citizen science programmes are designed or fit to inform policy, it is essential to understand and maximise the conditions for the uptake of citizen science by decision-makers to contribute to the locally-relevant and globally-scaled evidence base needed to understand progress in environmental initiatives and agreements.

2.2 Citizen science for environmental policy

The value of citizen science has been widely recognised by international bodies and national governments alike, e.g. European Environment Agency (EEA 2011), EU Green paper on citizen science (Socientize 2014), Scottish government, German citizen science strategy to 2020 (Bonn 2016)). It is clear that the growing number of collective and international environmental obligations, requiring regular and timely assessments, on whole ecosystems and over long periods of time (e.g. under the Convention on Biological Diversity, the UN Framework Convention on Climate Change, or for OECD environmental reporting), will only be met if all sources of data are leveraged. Citizen science may serve a unique role in fostering the knowledge and governance needed to advance and track progress towards these international goals (Danielsen et al., 2014; Chandler et al., 2017b). The co-production of knowledge by technical experts and members of the public is likely to be very important in the future of decision-making (Weichselgartner & Kasperson, 2010). Accordingly, the United Nations Environment Programme has identified citizen science as essential to achieve sustainability (UNEA, 2017). The US Department of State, with the Earth Day Network and the Wilson Centre, has set the ambitious goal of engaging one billion people in citizen science by 2020. This is backed up by a growing commitment to citizen science in the USA and in the EU (Socientize consortium, 2014; Science Europe, 2018). Since September 2015, the USA has been officially advocating the use of crowd-sourcing and citizen science across federal government agencies (Crowdsourcing and Citizen Science Act, 2016). To promote the use of citizen science across the US government, the government developed a community gateway for citizen science practitioners as well as a catalogue of federally supported citizen science projects and a toolkit to assist federal practitioners with designing and maintaining their projects[3]. Although Europe does not provide a single gateway like the US, the European Commission has been strongly promoting citizen science since 2015.

[3] https://www.citizenscience.gov/about [accessed 09/09/2018]

2.2.1 Citizen science in the EU

In 2013, the European Commission published an in-depth report on environmental citizen science, highlighting several issues: the role of new and developing technologies in citizen science projects feeding into environmental policy; accuracy of environmental data produced by citizen scientists compared to those produced by the scientists; and ways in which citizen science benefits environmental monitoring and policymaking (Science Communication Unit, University of the West of England, Bristol 2013). It showcased several case studies, identified key challenges and opportunities, and highlighted the difficulty to provide evidence for the influence of citizen science on environmental policymaking as many initiatives that emphasise participatory forms of democracy are in their early stages. The Environmental Knowledge Community (EKC), an informal partnership between DG Environment, DG Joint Research Centre (JRC), DG Eurostat, DG Research and Innovation, DG Climate Action and the European Environment Agency is spearheading the way by investigating the role of citizen science in environmental policy-making. Under the lead of the JRC (Digital Economy Unit), it is leveraging synergies among the different EKC partners on citizen science experience and the role of stakeholder engagement on policy (Schade et al., 2017a). The EKC operates a Knowledge and Innovation Project (KIP) on citizen science, running from 2015 to 2020, to consider, inter alia, how citizen science data could best be used to complement environmental monitoring and reporting process in a cost-effective manner. It is also reviewing the potential of lay, local and traditional knowledge to fill knowledge gaps, and examining how citizen engagement can foster behavioural change. Some of the achievements of this citizen science KIP so far include a citizen science platform to extend the evidence base of European policies[4], an EU community of practice on the use of citizen science for EU policy, and demonstrative citizen science apps to support EU policies on invasive alien species and nature protection (MyNatura2000), both in collaboration with JRC.

The work carried out so far underlines that Citizen Science can be a strategic tool for environmental policies, and contributed to the integration of actions on citizen science in four Commission's documents:

- The Action Plan on nature, people and the economy[5] promotes the development and use of an extended, publicly accessible, evidence base on species and habitats protected under the Nature Directives, notably through dedicated support for citizen science projects in the funding period 2017-2019 (Action 3).
- The action plan to streamline environmental reporting[6] foresees the stepwise promotion of citizen science data for environmental monitoring and reporting (Action 8). This will lead to the development of guidelines in 2019.
- A 9-point action plan on environmental compliance has been adopted by the European Commission on 18/01/2018 to increase compliance with and improve governance on EU environmental activities[7]. Action 7, which focuses on improving how Member States deal with public complaints, identifies citizen

---

[4] http://digitalearthlab.jrc.ec.europa.eu/activities/citizen-science-platform-%E2%80%93-tool-extend-evidence-base-policy/57787 [accessed 06/09/2018]

[5] COM(2017) 198 final

[6] COM(2017) 312 final

[7] European Commission, COM(2018) 10 final. EU actions to improve environmental compliance and governance.

science as a powerful tool to engage the wider public and ensure this information is reliably recorded and assimilated by the authorities. A guidance document on best practices is planned by mid-2019.

- The EU pollinators initiative[8] to stop the decline of insect pollinators, foresees a key role for citizen science in two of its three priority areas of action. Citizen science can be one of the potential approaches to devise cost-effective, standardised monitoring and contribute to improve knowledge on pollinators decline and its causes (Priority 1). It also plans for the development and dissemination of a guidance on citizen science on pollinators, as part of its actions to raise awareness and engage society in the conservation of pollinators (Priority 3).

Moreover, citizen science is emerging as a useful method to contribute to (Digital) Social Innovation, which is gaining momentum on the EU agenda for growth and inclusion. This is in particular the case for the more bottom-up, co-created initiatives that address public issues where institutional actors and resources are not enough to tackle the issue with the necessary relevance, quality, or granularity (Schade et al. 2017a).

In addition, the European Commission recognises the role that citizen science can play in opening research and improving the societal impacts of science:

- The European Open Science agenda[9] adopted in 2016 recognises the transformation and opening up of science, with increasing demand from the society to address societal challenges, the availability of increasingly powerful digital technologies, and the globalization of the scientific communities. It sees citizen science as both an aim and enabler of open science, notably to make science more accessible and better understandable by society, as well as more responsive to societal challenges.
- The EU is a prominent funder of citizen science initiatives through its Research and Innovation programmes. Within Horizon 2020, the "Science with and for Society" programme aims to build effective cooperation between science and society, and will support research to explore and support citizen science (strategic orientation 4). The "Responsible Research and Innovation" programme supports the design and implementation of research and innovation policy that will engage society more broadly and increase access to scientific results. Some recent citizen science initiatives funded under Horizon 2020-ICT programme also include the Collective Awareness Platforms for Sustainability and Social Innovation (CAPS)[10] which intend to create awareness on the role that each of us can play to ease sustainability problems. The CAPs offer collaborative solutions based on networks, enabling new forms of data innovation (e.g. Capsella, Captor, MakingSense, SavingFood 2.0). The European Commission has also supported the development of a number of citizen science observatories. For instance, under the Environment Theme of the 7th Research and Innovation Framework Programme five citizen science observatories were funded, covering a diverse range of environmental issues, including biosphere monitoring (COBWEB), air pollution monitoring (CITI-

[8] European Commission, COM(2018) 395 final. EU Pollinators Initiative.

[9] http://ec.europa.eu/research/openscience/index.cfm [accessed 06/09/2018]

[10] https://ec.europa.eu/programmes/horizon2020/en/h2020-section/collective-awareness-platforms-sustainability-and-social-innovation-caps

SENSE), flood and drought monitoring (WeSenseIt) and coastal and water quality monitoring (Citclops). Under the Societal Challenge section of Horizon 2020 for Climate Action, Environment, Resource Efficiency and Raw Materials, an additional four observatories were funded, Landsense, SCENT, Ground Truth 2.0 and GROW Observatory. These citizen science observatories share in common the fact that they exploit the capabilities offered by citizens' own devices (e.g. smartphones, laptops or other social media) to strengthen environmental monitoring capabilities and citizens environmental stewardship. The Horizon 2020 project WeObserve was set-up to improve the coordination between the growing number of citizen science observatories in Europe and help in improving their connection to European policy (Gold, 2018).

2.2.2 Citizen science at national level

Several governments in Member states and public organisations are also starting to support citizen science. Environmental Protection Agencies (EPAs) in particular, are promoting citizen science, as demonstrated by the Interest Group on Citizen Science of the European Network of Environmental Protection Agencies. The work programme of this interest group i.e. includes actions on how to contribute to streamline environmental reporting as well as how to share information on best practice and lessons learned among its members. The Scottish Environment Protection Agency (SEPA) has developed a large support infrastructure for citizen science activities, including best-practice guidance on appropriate design of citizen science projects to support public authorities (Pocock et al., 2014), advice on funding models and access to citizen science design tools[11]. In Germany, a Green Paper Citizen science strategy for 2020 (Bonn et al., 2016) presents the understanding, requirements and potentials for citizen science in Germany. Germany has developed a central citizen science platform[12] since 2014 which was instrumental in building the citizen science community in Germany, in collaboration with the capacity-building programme for citizen science GEWISS. It comprises 95 projects, includes various support tools, such as guidance and training for citizen science practitioners and development of quality procedures for citizen science projects (Ziegler and Mascarenhas, 2017). In the UK, the Environmental Observation Framework (UKEOF) has formed a citizen science working group to share good practice and improve environmental observation data quality[13]. It has produced a step-by-step guide to citizen science providing evidence-based advice on how to set up and run a successful citizen science project (Tweddle et al., 2012), as well as a tool to assess the costs and benefits of citizen science (Blaney et al., 2016). Interest and support for citizen science is growing in other Member States as well, with a recent review of citizen science initiatives and best-practice guide produced in France for the Ministry of Education and research for instance (INRA, 2016).

2.2.3 Remaining challenges for making citizen science policy-relevant

Despite this growing support, evidence that citizen science can successfully contribute to policy development, implementation or evaluation remains scant. Some key challenges include understanding the key factors that promote the policy impact of citizen science projects. Central to this question is understanding whether citizen

---

[11] https://www.environment.gov.scot/get-involved [accessed 09/09/2018]

[12] www.buergerschaffenwissen.de

[13] http://www.ukeof.org.uk/our-work/citizen-science [accessed 09/09/2018]

science projects that support policy also co-benefit science, by demonstrating scientific excellence, and encouraging meaningful citizen engagement (Figure 1). The objectives of these three agendas may in fact trade-off against each other, since the scientific needs for rigorous, comprehensive data collection may typically conflict with the needs for simple, not too time-consuming data collection to retain participation (Pocock et al., 2014). The key challenges for integration of these three dimensions are discussed in the next section.

2.3 Scientific excellence

In today's world, policy decisions increasingly rely on the best available scientific evidence (Holmes & Clark, 2008). But the best scientific evidence does not necessarily come from the best peer-reviewed scientific publications, with the most robust designs; rather, it is the best scientific information to answer a specific question (McKinley et al., 2017). Key aspects for policy relevance of scientific data are fit-for-purpose, data quality and access/re-usability.

2.3.1 Fit-for-purpose

Citizen science can provide advantages over conventional science in multiple ways, but its primary benefit is probably the collecting of data that would otherwise be unavailable. Citizen science can gather data by operating at greater geographic scales and longer time periods than conventional science, sometimes at greater resolutions. Benefits accrue particularly when data cannot be collected otherwise. For instance, only volunteers can cost-effectively collect observations of breeding birds in sufficiently large areas and over long-enough periods of time to be scientifically relevant and meaningful (Devictor et al., 2010). Science also greatly benefits from volunteers collecting data when observations are rare, and rapid detection might be critical, such as for invasive species, pests, or diseases. Additionally, citizen science may leverage the experience from a given community to pinpoint key locations/issues of concern or to monitor the effectiveness of management practices (Conrad & Hilchey, 2011). Beyond data collection, citizen science may also help refine research questions and involve citizens in the data validation process. This can be done by taking advantage of the workforce that mass participation can provide, allowing for large amounts of data to be validated with appropriate statistical methods. For instance, volunteers are able to recognise patterns and interpret images better than any machine processing solution. Projects may also build on the specific expertise of a community, e.g. naturalist networks, to identify or validate records. A less studied contribution of citizen science to the scientific process is related to the "power of place", embodying the many experiential, cultural and material connections that people have for the place in which they live (Newman et al., 2017). For instance, projects may leverage citizens' ability to cross-check facts in a local area (Schade et al., 2017a). Projects may also include the lay, local and traditional knowledge people have regarding their place, and/or allow participants to discover and collect such local knowledge (McKinley et al., 2012). Such place-based information would be wholly inaccessible to scientists otherwise, and is an essential attribute to the scalability of these projects. Not all scientific research is amenable to citizen science, depending on topic, skills and risks. However, when it is, citizen science data may often better fit policy-makers needs for accessible, timely and applicable evidence, compared to much academic evidence often more focused on credibility (Dunn & Laing, 2017).

2.3.2 Data quality

Ensuring scientific data quality is important both to ensure a reliable evidence base for decision-making and to attract more scientists to use and engage with citizen science programs. Despite the powerful potential of citizens to contribute to science, citizen science has yet to be fully embraced by the scientific community. Citizen science projects in the environmental domain usually report only modest publication rates (Burgess et al., 2017) and have rarely generated highly cited data. Yet, mounting evidence suggests that volunteers can collect data of a quality similar to professionals (Lin et al., 2015; Forrester et al., 2015).

One widely recognised obstacle to the scientific use of citizen science is related to scientists concerns about quality, consistency and reliability of citizen science data. Specific critiques regard inconsistent study design, which may lead to biases. These may be related to uneven recording intensity over time, uneven spatial coverage, uneven sampling effort per visit, uneven species detectability and variations in the type of data collected (Boakes et al., 2016; Chandler et al., 2017a). For instance, people may not voluntarily access difficult terrain or birders may be keener to identify rare species than common species (Dickinson et al., 2010). Maintaining data quality for initiatives that run across different countries and cultures can become challenging. Maximising data quality from citizen science thus requires adhering to scientific standards in research design, data standardisation and database management (Hochachka et al., 2012).

Quality control processes relate to before, during or after data collection. Training is the essential first step to ensure good quality data and may be performed through a range of standard to more innovative online solutions (typically instructions, videos or mobile phone apps). Face-to-face trainings however, such as workshops, or field sessions have been shown to be more effective (Newman et al. 2003, 2010, McShea 2015 in Chandler et al. 2017a book chapter). Quality control procedures are commonly used in the process of submitting the data, to highlight suspect identifications for instance, or against a checklist of species for a certain area, and time period. Alternatively, records can be verified by expert review, or through consensus by multiple crowd-sourced volunteers. The quality of ancillary data also needs to be considered – some of these data may be checked automatically, or apps can be used to help volunteers verify this information.

2.3.3 Data access and re-usability

The (re-)usability of citizen science data is highly dependent on the adoption of data standards, that allow data sharing across projects and networks, nationally and globally (Chandler et al., 2017a). For instance, the Global Biodiversity Information Facility (GBIF) provides links to a number of tools that can be adopted by citizen science projects to facilitate the publishing of biodiversity data for scientific use. Data management guidelines and templates may improve the inter-operability of heterogeneous citizen science data. The recent Citizen Science Global Partnership[14], launched in December 2017, will formalise citizen science data standards and build an open data portal to support inter-operability and re-usability of citizen science data. A recent survey of data management covering over one hundred citizen science projects across the world shows that most projects explicitly consider data re-usability issues (Schade et al., 2016). About three-quarters of the surveyed projects provided access to raw and aggregated data and followed a dedicated data management plan. However, there was a great variation in the conditions for re-use, in terms of restrictions, licensing conditions, and acknowledgement. Most projects surveyed did not provide details about the reuse conditions or metadata, did not have licenses that

[14] https://www.wilsoncenter.org/article/concept-note-citizen-science-global-partnership [accessed 09/09/2018]

matched the intended re-use conditions, and did not store the data on public repositories (Schade et al., 2016). This suggests that much improvement is still needed to facilitate the dissemination of citizen science data.

2.4 Citizen engagement

Citizen science projects can engage people in decision-making processes by increasing first-hand understanding of environmental issues and fostering environmental stewardship. On one hand, increasing citizen engagement in the scientific process may improve citizen science literacy, trust in the underlying data, and understanding of environmental decision-making process (Schade et al., 2017a). On the other hand, the participatory nature of citizen science can facilitate the inclusion of diverse perspectives in decision-making, in a timely manner (McKinley et al., 2017). Indeed, near real-time information can be made available to the decision-makers. Past lessons suggest that the use of 'lay" knowledge can help governments and civil society address environmental problems at early stages (Bio Intelligence Service 2010). Collecting environmental data may also prompt volunteers to care more about the environment, and change their behaviour (Schuttler et al., 2018), especially when engaging in research around local issues (for example, changing their own management practices (Cooper et al., 2007), such as planting pollinators gardens in their backyard by learning how butterfly habitat is vanishing). Citizen scientists may also act as vectors of change, by spreading knowledge among their personal or professional network. They can be an influential vector since examples set by friends typically have more leverage than those promoted by media (Bikhchandani et al., 1992). However, not all science projects are easily amenable to citizen science, and much depends on the topic, the potential risks and whether simple data collection protocols can be devised (Pocock et al., 2014). Succeeding in meaningfully and sustainably engaging participants is key to maximise the scientific and policy benefits.

2.4.1 Engaging citizens

The creation of a meaningful experience for the citizen scientist thus starts with setting clear and achievable project goals. Careful planning about which data will be collected, for what purpose, and by whom and how is essential. Indeed, the motivations of citizen scientists are diverse, requiring a tailored portfolio of interfaces and options to cater for the needs of the different groups. Furthermore, projects typically need to strike a balance between the scientific needs for rigorous, comprehensive data collection, and the ease of data collection, which should neither be too complex nor too time-consuming to retain participation (Pocock, 2015). As a result, citizen science projects often involve collaborations among different organisations, with complementary skills in data management and citizen engagement, such as academic institutions and NGOs. Citizen science thus also proves to be a means to promote collaboration and create synergies between different stakeholder groups. Community-based citizen science projects in particular typically involve many stakeholders, tend to improve citizen engagement with local issues, and promote more sustainable communities (Conrad & Hilchey, 2011).

2.4.2 Retaining citizen engagement

The second challenge relates to sustaining the engagement of citizen scientists over time, so as to leverage the full potential of scalability of citizen science projects. Long-term motivation is thought to be linked to the feedback and acknowledgement that citizen scientists get along the process (Geoghegan et al., 2016). Citizen scientists want to feel that their time is well spent and that their initial motivations for volunteering are fulfilled and they are making an impact (West & Pateman, 2016). The simplest way to communicate back their impact to the participants is through a well-documented website that provides visualisation tools, as well as easy access to outputs from the project data. In this way, citizen scientists can see how their individual data contributes to the whole. A growing number of programs develop a reward system, or gamification strategies, where individuals can gain status, quiz themselves or compete to reach the leader board. They may also get more informed feedback from experts on their data entries. Together, these methods offer participants the possibility to build experience and learn over time, which may ease the technical feasibility of the project over the long-term. Other powerful ways for building and maintaining communities are through communication campaigns, presence in events, and mostly social media. Projects may have a dedicated Facebook or Twitter page, and some of them may even be integrated with Facebook (e.g. iSpot). A key motivation behind citizen science engagement is also social, and long-term involvement is linked to networking and feeling part of a community of interest and (Gheoghegan et al., 2016). This links back to making participation an enjoyable experience, that helps citizen scientists meet new people. It is also about empowering and building capacity in participants to make change at a local level, potentially improving their livelihoods (Danielsen et al., 2014), and instilling a sense of responsibility and stewardship for the environment. A key outcome of citizen science is thus about providing the tools for people to engage with.

2.5 Informing environmental policy

We have shown how citizen science can improve and inform environmental policy by building scientific knowledge and by encouraging public action. It notably has the potential to extend the evidence base for policy-making, by complementing the scientific evidence (Thornhill et al., 2016). But how much potential is there really for citizen science to support, augment, or replace environmental monitoring undertaken through governmental agencies?

2.5.1 Citizen science uptake in environmental policy

Whilst some citizen science projects have been massively successful at supporting environmental action (e.g., eBird for conservation planning, management and policy - Sullivan et al., 2017), a review of mostly UK biodiversity citizen science initiatives shows that only about a third of the projects where deemed to be used for policy (11 out of 30 projects, Roy et al., 2012). Evidence points to a gap between the potential relevance of citizen science for policy and its actual use. A recent survey of UK government agencies suggests that although government agencies show growing interest in citizen science, there is still a large unfulfilled potential for them to consider and use citizen science (Blaney et al., 2016). Danielsen and colleagues (2014) assessed 12 international environmental agreements and showed that 63% of the indicators used for monitoring the progress can be collected through some form of citizen science. However, other evidence suggests that current citizen science may not be targeting the essential policy questions. A recent study from Chandler and colleagues (Chandler et al. 2017b) analysed the contribution of citizen science to biodiversity monitoring, by assessing its coverage of the Essential Biodiversity Variables (EBV) (Pereira et al., 2013). They found that citizen science programs mostly focus on one EBV, namely species distribution data, while a number of EBVs are not well covered at all by citizen science programs. Potentially more concerning, Chandler et al. (2017b) found that only less than 10% of citizen science programs contributed to global analyses of biodiversity. This points to a need to improve the visibility, access and inter-operability of citizen science data in order to increase its policy relevance and impact, for instance through the development of toolkits, data standards, and the bundling of tools and services for different projects. Facilitating platforms regrouping several citizen science initiatives under a similar theme in one place are one step in this direction. Additional issues may be related to lack of trust in the quality of the data, or legal issues regarding the use of these data by governmental institutions (Roy et al., 2012; Blaney et al., 2016). In some cases, legal requirements do not allow for quality control of data to be used for policy by citizen scientists only (Schade et al., 2017a). There may also be a temporal or priority mismatch between what citizen science offers and policy requirements. It takes time to build up temporal data series or spatial coverage necessary for the data to be of policy relevance. Alternatively, in cases where the citizen science contributions occur long before political decisions are made, citizen engagement and trust in the decision-making process may in fact erode or be lost (Schade et al., 2017a).

2.5.2 Contributions of citizen science to environmental policy

Another grey area concerns the timing and use of citizen science data in the policy process. Citizen science data can contribute at each of the phases of the policy cycle:

- Identify problems or issues, by making valuable, systematic observations: For instance, the results of atlas bird surveys have identified important declines in species frequencies in farmland, pushing issues such as pesticide use and intensive farming practices on the policy agenda (Donald et al., 2001).
- Help formulate public policy: Citizen science can often be used to signal new or ongoing issues to decision-makers, and provide the necessary background data to establish restrictions or targets (e.g. the data from the Beachwatch project have been used to inform all plastic levies introduced in the UK).
- Strengthen public input into policy-making: Typical examples include reporting of environmental issues or of the arrival of new species. Inclusion of lay and traditional knowledge can help design better policy (EEA, 2011).
- Help government agencies and other organisations implement policies: For example, the collection of butterfly monitoring data by green space managers in the PROPAGE project contribute to their better understanding of the impacts of pesticides on wildlife and can facilitate change in practices. Several citizen science monitoring programmes have been instrumental in informing the designation of protected areas (e.g. eBird, Seasearch).
- Help evaluate the impacts of a policy decision: The Common Farmland Bird Index is produced by citizen science data and one of the recognised indicators for biodiversity monitoring in Europe. It is notably being used to assess the impacts of the Rural Development Plans.
- Help in enforcing laws and regulations (for some examples, see Box 1)

The cyclic nature of the policy process and complex connections between scientific evidence and policy decisions can make it difficult to trace back the actual contributions of citizen science to policy. As a result, citizen scientists may not always receive the credit they deserve for their contributions, again risking eroding trust in the entire decision-making process. On the other hand, when the connections are clearly made, the citizen science projects and respective policies stand to gain more impact. Policy-makers can also prove that they have considered public contributions in a participatory process (Schade et al., 2017a).

Box 1 - Monitoring policy impacts with citizen science

Once a policy is already in place, the cycle can be closed by including Citizen Science approaches in the monitoring of policy impacts. The potential use of Citizen Science in monitoring and reporting has been recently highlighted in the European Commission's Actions to Streamline Environmental Reporting (SWDCOM(2017) 230312 final) as well as in the Action Plan onenvironmentalon environmental compliance assurance [ADD REFERENCE].(COM(2018) 10 final). Action 7 of the action plan on environmental compliance adopted in 2018 focuses on improving how Member States deal with public complaints and identifies citizen science as a powerful tool to engage the wider public and ensure this information is reliably recorded and assimilated by the authorities.

SENTINELLES DE LA NATURE

The "nature sentinelNature sentinels" programme developed by France Nature Environnement, (FNE), one of the key non-governmental environmental organisations in France, allows citizens to flag an environmental complaint or positive environmental initiative on their smartphone. These reports are then handled by the regional coordinator to decide whether they can be made public or whether further information or verification is needed. Depending on the seriousness of the issue, the FNE may then contact the liable party to identify a solution, transmit the information to the relevant authorities, or take the matter to court. The programme currently covers about half of the French territory (10 regions), and an interactive map allows to visualise all published reports. Citizens can follow in real-time how the warnings are taken up by decision-makers. Supporting material on the steps to be taken to prevent or mitigate environmental issues, information meetings and workshops are also provided.

2.6 Investment needs of citizen science

An aspect often overlooked, but essential to citizen science and policy impact, relates to the sustainability of the projects. It takes time to develop databases of scientific and policy relevance, and to build the trust among stakeholders, e.g. about the quality of these data. Accordingly, it can be hypothesised that projects that are set up to be long-running, and that have planned for the sustainability of their data and of the citizen science community are more likely to deliver policy impacts. Additionally, in order to make the case for using citizen science over other sources of data, the benefits of using citizen science need to be assessed in light of the full range of financial costs of doing so. There is a lack of tools to evaluate the impacts of citizen science, including its cost-effectiveness (see Blaney et al. 2016 for a first example). Achieving goals for public engagement and input requires planning, expertise, and sufficient resources to achieve these goals. Although citizen science relies on volunteers, it is far from being free. Investment in personnel, tools or equipment for data collection, storage and management, and for all the resources that volunteers need to successfully carry out the project are needed. In addition to these start-up costs, the running costs typically account for the project coordinators, data quality control and evaluation, but also all the communication costs for recruiting, training and retaining volunteers, as well as for communicating the project's results. Citizen science is not always cheaper than conventional science (McKinley et al., 2017; Chandler et al., 2017b), and careful thought should be given as to whether it is the most cost-effective way of collecting the data needed. Adequate planning, accounting for investments in data quality is essential. Too often, citizen science data is open to the public, but does not come with adequate metadata (documentation of data collection and analysis methods, information on important caveats, and instructions for appropriate use and citation) to allow for its relevant use (McKinley et al., 2017). The scale of the investment depends on the goals, scale and scope of the project. Small-scale projects require little to no organisational investment and can be led by a single investigator, with a small team of volunteers. Larger projects, and projects with multiple goals require more thoughtful investment by organisations, but partnerships may help organisations take advantage of economies of scale, e.g. if they can use or modify existing tools or resources.

2.7 In summary

- Environmental citizen science offers a great potential to further scientific research, connect citizens to policy and support the design more relevant, inclusive policy. However, the evidence base demonstrating the use and effectiveness of citizen science for environmental policy still needs to be developed.
- The context is ripe for furthering the use of citizen science in policy, with four documents from the European Commission explicitly calling for the use of citizen science in policy, and a growing number of international and national public institutions, such as Environmental Protection Agencies, supporting the further use of citizen science for environmental reporting, policy development, implementation, evaluation, and/or compliance.
- Improving the policy relevance and policy use of citizen science projects requires balancing the needs for sustained citizen engagement, with those of scientific excellence and different types of policy uses.
- Full consideration of whether citizen science can replace, augment or complement existing monitoring schemes requires an understanding of the resources and investments needed to run such projects and ensure sustained data availability.

All the data used in preparing this report is publicly available at the website of the European Commission[15].

[15] European Commission, Directorate-General for Environment; European Commission, Joint Research Centre; Bio Innovation Service (2018): An inventory of citizen science activities for environmental policies. European Commission, Joint Research Centre (JRC) [Dataset] PID: http://data.europa.eu/89h/jrc-citsci-10004

3 Approach and methodology

3.1 Study scope

A full systematic review of citizen science activities was beyond the scope of this project. Instead, this inventory aims to be a first representative list of the citizen science efforts going on in the EU which could be relevant for environmental policy. Best practices from the rest of the world have also been included where relevant.

3.2 Approach

The strategy for data collection followed a sequential approach as shown in Figure 2.

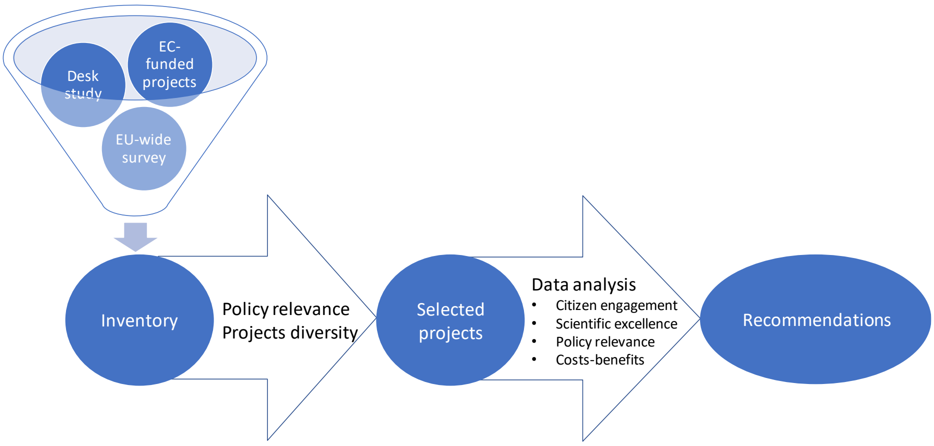

Figure 2 – Overview of the methodology

In the first step, we identified a long-list of environmental citizen science projects. The long-list aimed to capture generic information about the projects, as well as to provide a first idea of their societal and policy relevance.

In the second step, we short-listed a smaller number of projects for in-depth analysis. They were selected to represent a breadth of environmental domains and relevance for policy, as well as projects that were popular in their own scale and that represented different forms of citizen science engagement. The projects in the short-list were then characterised along three dimensions, the citizen-scientist, scientific and societal or policy dimensions. For each of these dimensions, a process-based evaluation and an impact-based evaluation were carried out (Kieslinger et al., 2017). Finally, a qualitative analysis of the costs and benefits of the short-listed projects was performed. Main conclusions and recommendations were then drawn from the results of the survey and its analysis.

3.3 Data collection

3.3.1 Data collection process

The data collection followed a three-step approach. First, we built upon existing evidence as much as possible. We thus conducted a desk study, using results from recent scientific (systematic) reviews of citizen science projects, namely three reviews: Chandler et al. (2016), Pocock et al. (2017) and Fritz et al. (2017). In Chandler (2016), projects were filtered according to their geographic extent (Europe, global), and only global projects with activities in Europe were retained. We also identified and surveyed relevant citizen science directories. We selected those projects related to environmental issues by using the keywords 'biodiversity' or 'environment' in the relevant language[i], as well as projects for which it was possible to obtain information on the web.

Second, since the European Commission is an important funder of citizen science activities, we surveyed the databases of EU-funded research projects (Cordis FP7, Horizon 2020, COST) as well as LIFE projects related to citizen science activities. We also leveraged the EKC network for citizen science and the Interest Group on Citizen Science of the EPA network. The projects were searched using the keywords "citizen science", "public engagement", "citizen scientist", "participatory science", "citizen observatory", "crowdsourcing", or "volunteer".

Finally, in order to benefit from information available in existing citizen science networks or through our professional networks, we launched an EU-wide survey to identify further citizen science projects in the environmental domain. The approach for the survey is provided in Annex 1.

3.3.2 Data collection results

Collectively, the desk-study, the survey of EC-funded projects and the EU-wide survey yielded a total of 814 projects by the end of the data collection phase, before removing duplicates and irrelevant projects. Under the time constraints of the project, the data collection phase was limited until February 6th, 2018. This meant that only the Ciencia-ciudadana directory was thoroughly surveyed in the desk study. Other directories (i.e., national citizen science platforms, Living knowledge, ENOLL, Citizen cyberlab) were used as necessary in the pre-processing phase, in order to improve the coverage from projects in Western and Central Europe in the long-list.

3.4 Inventory development

3.4.1 Attributes for the inventory

A structure for the inventory of citizen science projects was created: 18 attributes were identified as well as the approach to assess project contribution to the 17 SDGs was developed. The attributes and criteria used are detailed in Table 1 and 2 below. A first coarse assessment of the societal and policy impact of each project was carried out by scoring each project with regards to its social and policy uptake. At this stage, policy uptake was based on whether any evidence of policy support or implementation was reported on the project website. We then identified the phase of the policy cycle that this project was most likely to contribute to. Social uptake is reportedly difficult to assess reliably, and we simply tried to differentiate projects with a high number of users, whether because of tradition or popularity, from smaller projects, with lower uptake. This proxy does not intend to measure social impact, and may under-estimate the social value of projects, since local, community-based projects may typically score low but have high social impact.

The contribution of each project to each of the 17 SDGs was assessed, by distinguishing criteria for direct contribution (the stated project aim fits an SDG), indirect contribution (project may contribute to fulfilling an SDG, as a by-product of its activities), and no contribution (Table 2). All fields were filled based on information available from the project's website, except fields in italics, that required expert assessment.

Table 1 - Attributes for the long-list of projects

Attribute id	Attribute	Attribute type	Attribute values	Description
1	**Name**	(text)		Name of the project/activity
2	**Website**	(text)	Hyperlink	Link to the project's website
3	**Contact**	(text)		Contact for the project, ideally an e-mail address (alias or personal)
4	**Brief description**	(text)		Short description of the project (1 or 2 sentences)
5	**Geographical extent**	Category (7)	Global, Macro-regional, National, Sub-national, Regional, City, Neighborhood	The spatial scale at which the project is implemented. Sub-national is used as generic category for projects for which the sub-national scale is not known (i.e. regional, or city, or neighborhood). All regional, city and neighborhood projects are also sub-national projects.
6	**Geographical coverage**	List	Name of country(ies), lead country first	The countries involved in the project team/consortium (comma separated list; lead country first).
7	**Lead organisation name**	(text)		Name of the lead partner. Local name, in native language
8	**Lead organisation category**	Category (5)	Governmental, Non-governmental, Academic, Private sector, Community-led, Consortium	Type of organisation represented by the lead partner. 'Tbc' in cases where the lead is not clear (see confidence)
9	**Start year**	(Year)		
10	**Still active**	Category (2)	Yes/No	
11	***End year***	*(Year)*		
12	**Primary environmental domain**	Category (4)	Terrestrial, Freshwater, Marine, Atmospheric Cross-cutting	The dominant domain of research. Cross-cutting' has been added for the facilitating platforms. See short-list attributes for other potential environmental domains affected.
13	**Primary environmental field**	Category (13)	Air quality, Biodiversity, nature and landscapes, Climate, Land, Noise, Sustainable consumption and production, Waste, Water, Efficient use of resources, Transport and energy use, Animal welfare, Environmental risks, Environmental health, Cross-cutting.	The dominant environmental field tackled by the project activities. List adapted based on the environmental fields in the environmental impact assessment under the Better Regulation Agenda. 'Cross-cutting' has been added for the facilitating platforms. See short-list attributes for other potential environmental fields impacted.
14	**Primary category of project**	Category (8)	Passive sensing, Crowd-sourcing, Volunteer computing,	Adapted from on Haklay et al. (2013). *See short-list attributes for other potential categories of projects impacted.*

Attribute id	Attribute	Attribute type	Attribute values	Description
			Monitoring, Occasional reporting, DIY engineering, Civic science, Facilitating platform.	
15	***Social uptake***	*Category (3)*	*- Very large* *- Large:* *- Considerable*	*Index of number of participants or followers.* *- Very large: large number of users, tradition, excellent EC-funded projects with high numbers of users (above 1,000). So: zooniverse, opal, ebird, ornitho and other big names, because of number of users. Old UK societies (from XVII century to late XX century), because of tradition; EC-funded projects that we would say excellent in review and with high number of users (above 1000)* *- Large: EC-funded projects that we would say good in review and with medium number of users (below 1000)* *- Considerable: all others* *Based on expert knowledge*
16	**Policy uptake**	Category (2)	Yes/No	Stated policy uptake (on the website)
17	***Policy uptake description***	*Text*	*Brief explanation of which policies are impacted and how.*	*Only if "Yes" in the "Policy uptake"*
18	***Policy relevance***	*Category*	*- Problem definition:* *- Early-warning* *- Policy implementation or monitoring,* *- Policy evaluation* *- Compliance assurance* *- NA: no clear policy link*	*Main phase of the policy cycle potentially impacted by the project actions. See short-list attributes for other potential policy areas affected.*

Table 2 – Criteria used for the assessment of a project's contribution to SDGs

Sustainable Development Goal	Value
SDG 1 - Poverty	**Direct impact**: projects whose objectives are explicitly related to poverty eradication or mitigation **Indirect impact:** projects whose objectives are potentially related to poverty eradication or mitigation
SDG 2 - Food, sustainable agriculture	**Direct impact**: projects looking at land, soil or water impacts of either pollution or climate change that have an impact on food sources, even when not agriculture (such as hunting, fishing and foraging), for projects dealing with forestry (forest biotic agents) or fisheries, projects dealing with food waste potential. Also, projects like agriculture 4.0 projects, community-based approaches (e.g. recovering local seeds), DIY hydroponic technologies, etc. **Indirect impact**: projects dealing with soils, climate adaptation, land use, pollinators, biological pest-control, as well as with bird monitoring projects that include species important to seed dispersal, or climate change monitoring projects that consider impacts on food production
SDG 3 - Health and well-being	**Direct impact**: projects improving recreation or tourism experience (human health), air quality, water quality (sanitation), noise reduction **Indirect impact**: projects dealing with biodiversity conservation that have clear links to health or well-being, or for projects investigating changes in factors influencing health (e.g. atmospheric allergens)
SDG 4 - Education	**Direct impact**: projects specifically stating an education goal (regardless of target audience) and beyond simple awareness-raising. **Indirect impact**: all citizen science projects, because any citizen scientist is both learning under formal or informal training and being educated by others (professional scientists, peers, etc), but education is rarely the direct project goal.
SDG 5 - Gender equality	**Direct impact**: stated goal is gender equality **Indirect impact**: projects with explicit mention of gender equality concerns
SDG 6 - Water availability and sustainable management	**Direct impact**: projects dealing with water quality, water monitoring **Indirect impact**: projects dealing with climate adaptation measures (flood management, soil water retention), sustainable agriculture (reduced water pollution, improved soil water retention), or reporting of environmental damage, including water pollution or wetland destruction.
SDG 7 - Energy affordable, reliable, sustainable	**Direct impact**: projects dealing with transport and energy use. Projects that could fit are: DIY energy management systems and communities. **Indirect impact**: projects dealing with efficient use of resources, sustainable consumption and production with links to the energy sector.

Sustainable Development Goal	Value
SDG 8 - Sustainable economic growth and employment	**Direct impact**: in cases where social employment, business development, social integration or Sustainable consumption and production are stated project goals. **Indirect impact**: projects that have the potential to transfer technical skills or DIY skills
SDG 9 - Resilient infrastructure, innovation	**Direct impact**: projects addressed to empower communities through co-creation of technologies, all DIY projects, maker spaces, fablabs. Any project with urban or industrial development dimension, as well as projects creating research infrastructures (e.g. mapping or network of national databases) **Indirect impact**: all other projects, because one of the key elements of citizen science projects is the re-use of existing volunteer-based equipment such as smartphones or desktop computers that compose a distributed infrastructure for research.
SDG 10 - Reduce inequality	**Direct impact**: projects specifically targeting economic, fiscal or social inclusion/skills development in the professional sector **Indirect impact**: all other citizen science projects with a stated economic or social dimension
SDG 11 - Sustainable, resilient Cities / settlements	**Direct impact**: projects focused on improving urban environmental sustainability, e.g. projects focused on nature-based solutions **Indirect impact**: projects that also include urban areas (e.g. large-scale monitoring projects), and improve environmental status or social inclusiveness, e.g. projects focused on drinking water access and management
SDG 12 - Sustainable consumption and production	**Direct impact**: projects dealing with sustainable food chains or industry (including addressing pollution impacts), waste management (food, household), green labelling, consumption patterns, eco-efficiency **Indirect impact**: projects related to co-creation of technologies, all DIY projects, maker spaces, fablabs
SDG 13 - Action to combat climate change and its impacts	**Direct impact**: projects with stated goal to combat climate change, help with climate change adaptation or mitigation (monitoring air quality, climatic conditions, coastlines). **Indirect impact**: all air, marine, biodiversity, and natural disasters projects that state a link to climate change
SDG 14 - Marine conservation and sustainable development	**Direct impact**: for marine related projects (incl. marine litter) **Indirect impact**: freshwater projects, waste projects that relate to effluents in the sea; (sea)food consumption patterns
SDG 15 - Terrestrial biodiversity conservation, sustainable forest management and land use management	**Direct impact**: projects with stated goal to contribute to biodiversity, nature and landscapes, land projects **Indirect impact**: all other terrestrial (and freshwater) projects, and for projects promoting changes in land use patterns (e.g. in agricultural practices).

Sustainable Development Goal	Value
SDG 16 - Peace, justice for all	**Direct impact**: projects with stated goal related to environmental justice **Indirect impact**: all projects, because they promote a participatory approach and support public access to information
SDG 17 - Strengthen Global Partnership for Sustainable Development	**Direct impact**: projects with multi-national AND cross-sectoral partnerships (promote public-private-civil society partnerships) AND direct impact on at least one of the other SDGs **Indirect impact**: projects that share data AND the data can be globally aggregated (contribute to data monitoring and accountability)

3.4.2 Data pre-processing

The database of citizen science projects was screened to assess the relevance of each project and characterise it according to the 18 attributes and 17 SDGs. This phase involved a dynamic process of addition and removal of projects to create a relevant and representative inventory on citizen science activities in the environmental field. On the one hand, the pre-processing involved a first filtering of projects, to discard projects that were not citizen science, obviously not related to environmental issues, that could not be related to environmental policy, or for which the available information was scarce or non-existent. On the other hand, all projects that were received after February 6th, whether through the EU survey or stakeholders, were considered for addition to the database. Furthermore, to ensure a good representation of projects from different MS, more projects from the citizen science directories were included at this stage. Figure 3 shows the distribution of projects in the inventory across EU. All retained projects were characterised by the 18 attributes presented in Table 1. A quality check was performed to ensure harmonisation of the form and content of the attributes, and to remove duplicate entries. Facilitating platforms (n=17) were not included in further analysis, since they cannot be characterised in the same way as individual projects.

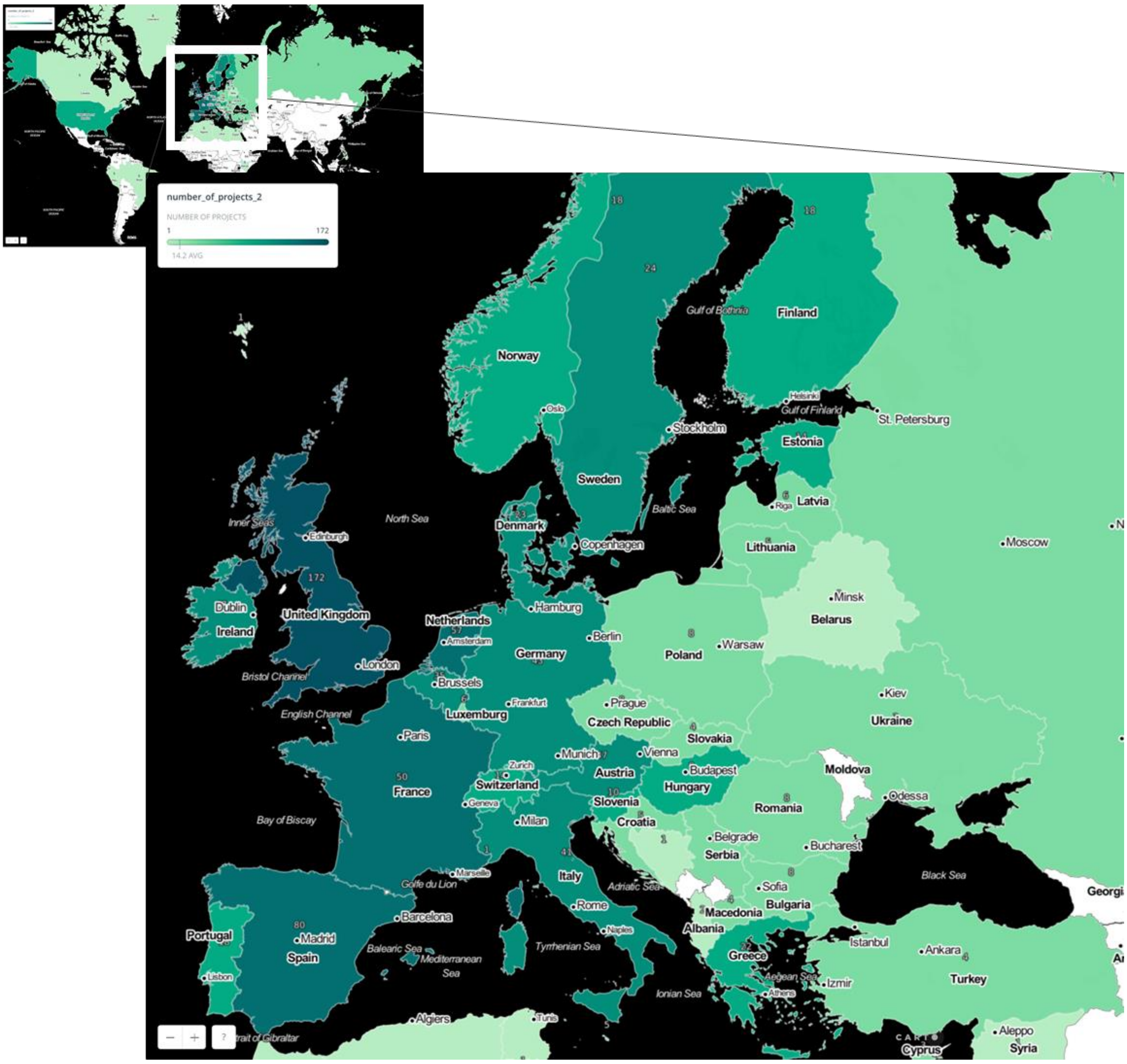

Figure 3 – Geographical distribution of the projects in the inventory

Dark green countries are those with a high number of citizen science projects represented in the inventory

3.4.3 Inventory of citizen science projects in the environmental domain

The resulting consolidated inventory comprises 503 projects (see Table 3 for the classification based on the source). The full inventory, including the 18 attributes and 17 SDGs is available at: http://data.europa.eu/89h/jrc-citsci-10004

Table 3 – Sources for identifying the projects included in the inventory

Data source	Data source	Number of projects
EC-funded projects	Horizon 2020 or FP7	57
	Life+	13
	DG ENV, EEA, JRC, EPA Network	32
	JRC survey	11
EU survey	Questionnaire responses	100
Directories	Citizen science directories	78
Literature review	National directories	61
	Chandler et al. 2016	105
	Fritz et al. 2017	19
	Pocock et al. 2017	123

The total number of projects in the table exceeds 503, since some projects were identified from more than one data source.

3.5 Selection of citizen-science practices for in-depth analysis

A total of 100 projects were initially selected for in-depth analysis. An additional eight projects were subsequently added to this list following the recommendations of key environmental policy stakeholders.

3.5.1 Selection criteria and data collection

The projects were selected to represent a diversity of environmental fields and forms of policy support, large social uptake, and for their demonstrated or high potential for policy uptake.

The following criteria were used to select the projects:

- Selection of known interesting projects by the project team, including projects with global coverage or local, bottom-up initiatives (n = 35 projects).
- Additional selection of projects relevant for EU policy (n = 65): Policy uptake = "Yes" AND Still active = "Yes" AND Social uptake = "Large" or "Very large". Within these, only 50% of projects on "Nature and biodiversity" were retained: 50% of monitoring and occasional reporting projects, and all "Nature and biodiversity" projects in the other policy categories. Attention was paid to ensure a good geographical spread.

For the in-depth analysis 94 project attributes were defined. To collect information on those attributes, a survey questionnaire was sent to the project leaders of the 108 short-listed projects (see http://data.europa.eu/89h/jrc-citsci-10004 for the table). A further 7 attributes were then documented by the project team for those projects that answered the survey. The response rate to the survey was 42%, such that in the end a short-list comprising 45 projects was documented for most attributes (not all questions were mandatory) of which an in-depth analysis was conducted.

3.6 Data analysis

3.6.1 Assessment of the policy relevance of the projects in the inventory

We used the diversity of SDGs that a project directly contributed to as an indicator of the policy impact of the projects in the inventory of environmental citizen science. A simple stepwise linear regression was used considering the project age and tested the effects of the main environmental field of the project, type of citizen science activity, and lead organisation category.

3.6.2 Assessment of project characteristics for selected projects

Despite widespread recommendations of the need for evaluating citizen science projects (Socientize 2014, ECSA, 2015), comprehensive evaluation frameworks that would allow comparability across citizen science projects and programmes are missing (Bonney et al., 2009, 2014). This makes it difficult to show the direct and indirect impacts of citizen science on society and the environment. To remedy this issue, and after intensive stakeholder consultation, Kieslinger et al. (2017) developed an open framework for evaluating citizen science activities. The framework proposes evaluation criteria focusing on both the process and outcome level of citizen science projects. Outcome-based evaluation deals with assessing the overall goals of the projects and the benefits to the participants of the results (i.e. the impacts). Process-based evaluation, in contrast, identifies the operational strengths and weaknesses of the projects (i.e. the descriptors of the projects). The evaluation can then be structured along the three main dimensions of citizen science:

- The scientific dimension (including aspects such as scientific knowledge, data quality and data validation processes)
- The citizen-scientist dimension (including aspects such as engagement, communication, motivations and attitudes)
- The social and policy dimension (including aspects such as societal impact, policy uptake, stakeholder collaborations and synergies)

The evaluation of the selected projects follows this framework, and structured along these three main dimensions, with an investigation of the characteristics, where possible the processes, and the impacts in each dimension (Table 4). Within the scientific dimension, particular emphasis was given to data validation issues.

To understand the factors that affect each of the impact measures, simple stepwise linear regression was used. The explanatory variables included intrinsic characteristics of the project, such as the age of the project (in years), its spatial extent (number of countries in which data was collected, the number of records, the number of staff, and the main category of project (see Table A2).

Table 4 – Evaluation matrix for the selected projects

Citizen science dimension	Characteristics/Process	Impact
Scientific dimension	▪ Spatial extent and granularity ▪ Data duration ▪ Quality assurance ▪ Transparency of the methodology ▪ Training/Support ▪ Use and access conditions	▪ Number of peer-reviewed publications
Citizen engagement dimension	▪ Target audience and skills ▪ Level of effort and contribution frequency ▪ Training/Support	▪ Number of participants ▪ Communication outlets ▪ Number of followers
Policy dimension	▪ Relevance to the different phases of the policy cycle ▪ Characteristics of projects used for policy	▪ Richness of SDGs ▪ Likelihood of policy uptake ▪ Diversity of policy phases

The explanatory variables also comprised characteristics related to the governance of the project (type of main funding body, lead organisation type) and to its endorsement (governmental, academic), as well as indexes related to the specific dimension under consideration:

- Citizen dimension: an index of "ease of engagement", with values ranging from 1 to 3, where 3 represents the projects where it was more difficult to engage with citizens. The index was calculated by scoring each of the six variables characterising citizen engagement (level of effort, frequency of effort, training method, location of involvement, skills needed, target audience) on a scale of 1 to 3, and then doing an arithmetic average of these scores to obtain the index value. The scores were averaged and not summed, since not all projects had data for all six variables.
- Scientific dimension: index of scientific quality, with values ranging from 1 to 9, where 9 represents the projects with the highest scientific data standards. The index was calculated by scoring each of the three attributes, Support, Quality assurance and Transparency on a scale of 1 to 3, and then summing the individual scores to get the index of scientific quality.

Count variables were log-transformed and 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. All analyses were carried out in R version 3.5.1. The full datasets and R scripts that were used for the analyses are available at http://data.europa.eu/89h/jrc-citsci-10004.

3.6.3 Assessment of the costs and benefits

The investments required to establish policy-relevant citizen science projects were assessed qualitatively in terms of the governance characteristics and presence of sustainable funding, and quantitatively in terms of personnel required and yearly budgets.

3.7 Limitations of the study

The inventory is not exhaustive and it is possible that the data collection process led to some biases in the types of projects that were retained. Our data collection methodology was well-suited to identify larger scale citizen science projects, in particular EU-funded ones, and projects that have a website and internet presence. Given the time constraints of the survey, not all national directories identified were subsequently analysed to retrieve projects. As a result, our survey may have been biased towards Spanish projects (Socientize directory) and projects from English-speaking communities (through the reviews). It may have under-sampled small-scale projects, in particular local or community ones that may not have online presence.

This is the first EU-wide survey of policy relevant environmental citizen science projects. The survey respondents were typically the person in charge of the project or the main contact point for the project. However, they may not always have information on every aspect of the project with same degree of certainty. Some were not connected to the project's policy work and policy impacts. Nevertheless, they were typically the best-informed person, so their views are representative of what is known about a project impact. In some cases, they consulted other members of their organisation to answer all questions and improve the reliability of the answers.

3.8 In summary

- An inventory of 503 environmental citizen science projects of policy relevance, covering all the EU, was created using desk-research and a survey. The general characteristics of the projects and their contribution to each of the 17 SDGs was assessed.
- An in-depth analysis of 45 selected projects was performed to assess how different aspects of the citizen, scientific, and policy dimensions contribute to the impact of citizen science projects and explain their policy use.

4 Analysis of the citizen science inventory

4.1 Geographical scope

Projects varied widely in the scale of citizen science activities, from neighbourhood-based projects to international ones with a global scope. However, most of the citizen science projects in the inventory were focused on the national or sub-national levels (Figure 4a): 42% of the projects focused on the national scale, and 29% on the sub-national scale. The vast majority of sub-national projects for which the scale could be identified had a regional scope (80%). Local initiatives, however, may have been under-represented in the inventory since they usually have less online presence. Multi-national initiatives may also have been under-represented, since the inventory focused exclusively on those global/multi-national projects implementing citizen science activities at least in parts of the EU, but did not consider others. Additionally, although the search aimed for a European coverage, projects in English, French, Spanish and German-speaking countries may have been better represented in the inventory than those using other EU languages.

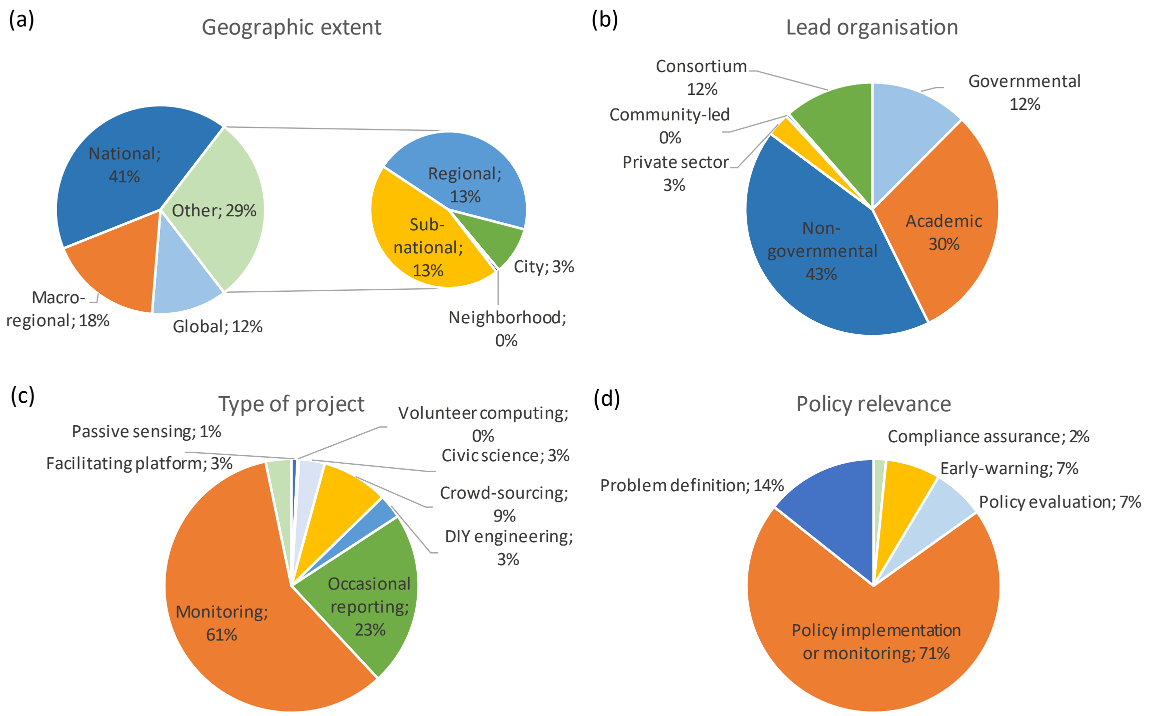

Figure 4 – Characterisation of the citizen science projects in the inventory: (a) geographic extent, (b) lead organisation, (c) project category, (d) policy relevance for policy

4.2 Project lead

Most of the projects in the inventory were led by non-governmental organisations (41%) or by academics (29%; Figure 4b). Few governmental organisations led such activities (12%) and only a very small proportion of the projects in the inventory were led by private companies (3%). Even less projects in the inventory were bottom-up community-led projects (<1%). Mix-leadership consortiums led 11% of projects. Overall, these findings are consistent with those of other surveys (Roy et al. 2012), but it is likely that community-led projects were under-represented in the inventory, since they may not always have a web presence or feature on citizen science facilitating platforms or networks.

4.3 Main project category

The projects were categorised according to their depth of engagement with volunteers, by adapting Haklay's et al. (2015) scheme. We distinguished eight categories, ranging from passive sensing, volunteer computing and crowd sourcing to occasional reporting and monitoring, and including civic science and DIY engineering projects (see http://data.europa.eu/89h/jrc-citsci-10004). Some projects may span different categories, but only the main project category was considered for this analysis. The large majority of environmental citizen science projects were monitoring programs (61%) or occasional reporting programs (23%, Figure 4c). Crowd-sourcing programs appear to be emerging, with 9% of projects, they have been exponentially increasing since the 1990s. More bottom-up forms of citizen science involving use of participants resources or co-design with the participants remain scarce (passive sensing and volunteer computing <1% each; civic science and DIY engineering 3% each).

4.4 Policy relevance

The main phase of the policy cycle potentially impacted by the project actions was assessed based on information available on project websites. A vast majority of projects in the inventory were mostly relevant for policy implementation or monitoring (71%, Figure 4d). A smaller share of projects appeared relevant for problem definition (14%), early-warning (7%) and policy evaluation (7%). Seldom any projects in the inventory appeared to be geared towards compliance assurance (2%). These results should however be treated with caution, since they are not based on an in-depth analysis of the projects' contribution to policy.

4.5 Main environmental domains

There is substantial variation in the use of citizen science across environmental domains. The majority of projects focused on nature and biodiversity (69%), mostly through monitoring or occasional reporting of species occurrences (Figure 5). This prevalence corresponds to what has been found in previous studies: according to a recent review of 509 citizen science projects in the environmental and ecological domain, 84% of projects focused on biodiversity rather than on the abiotic environment (Pocock et al., 2017); similarly, a survey of 102 citizen science projects in the environmental sciences found that 68% covered the field of biodiversity (Schade et al., 2016).

Other natural resources (air, water, land) were the second most important source of citizen science projects in the inventory, representing 3 to 7% of all projects respectively (Figure 5). Whilst most air, climate and water-related projects were based on monitoring activities (62% and 69%, respectively), the majority of projects related to land use and soil were crowd-sourcing (53%, 9 out of 17 projects) or DIY engineering projects (17%, 3 out of 17 projects) (Figure 6).

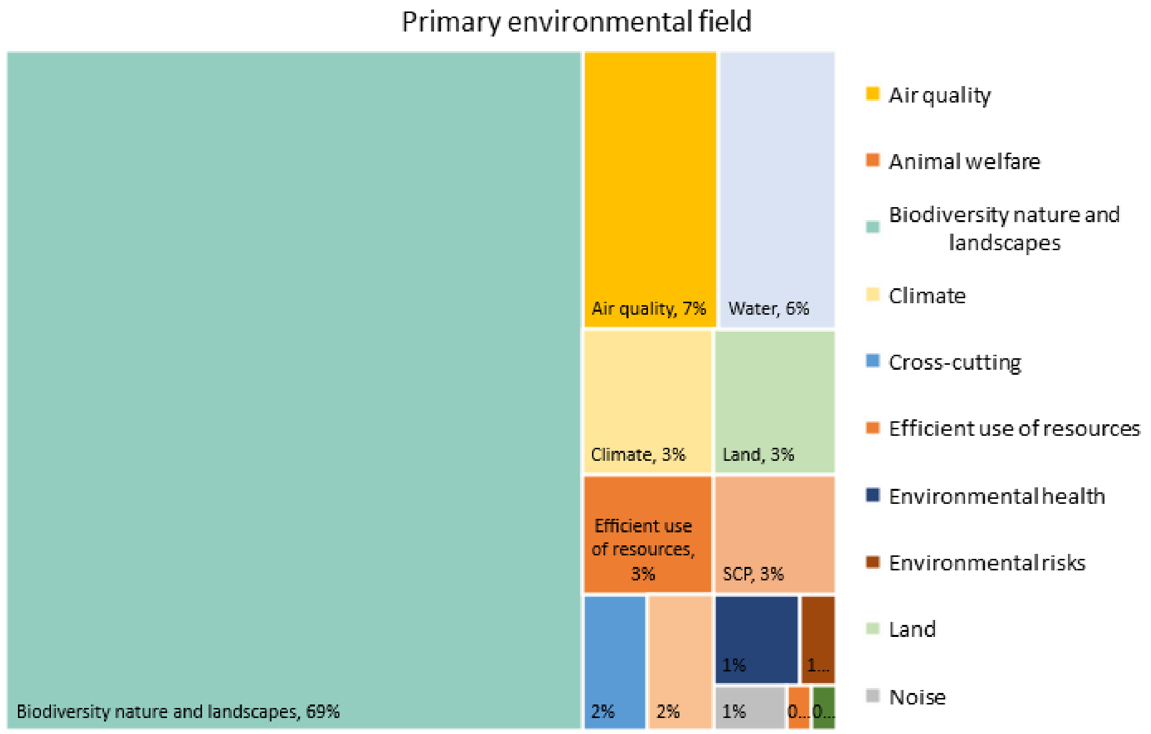

Figure 5 – Coverage of environmental domains by the projects in the inventory

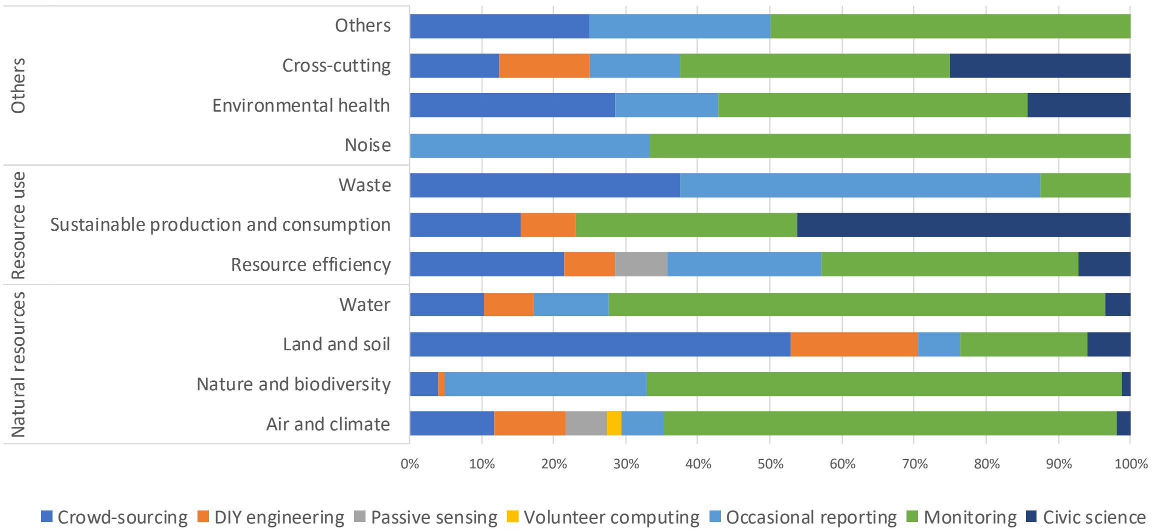

Figure 6 – Share of the different types of citizen science projects in the inventory by main environmental domain

Fewer projects focused on resource issues, whether resource efficiency, sustainable production and consumption, or waste (<3% of all projects each). Notably, these projects were less focused on monitoring and tended to rely substantially on crowd-sourcing (>15% of projects) and civic sciences (46.2% of Sustainable consumption and production projects), or occasional reporting (50% of projects on waste, 21% of projects on resource efficiency). Environmental risks, environmental health, noise and animal welfare are the least well covered fields by citizen science activities (<1% of projects).

Passive sensing and volunteer computing were seldom used across environmental fields (Figure 6). DIY computing projects were found in almost all environmental fields, but always remained fairly minor (<10% of projects, except for land and soil), probably due to the fact that such projects are fairly recent in the landscape of citizen science. With one exception in 1998, all DIY engineering projects in the inventory started after 2011.

Overall, the inventory appeared representative of the landscape of environmental citizen science, with similar relative importance across fields to what has been found elsewhere (Schade et al., 2016).

4.6 Contribution to Sustainable Development Goals

The citizen science projects in the inventory covered all SDGs, but to different levels (Figure 7).

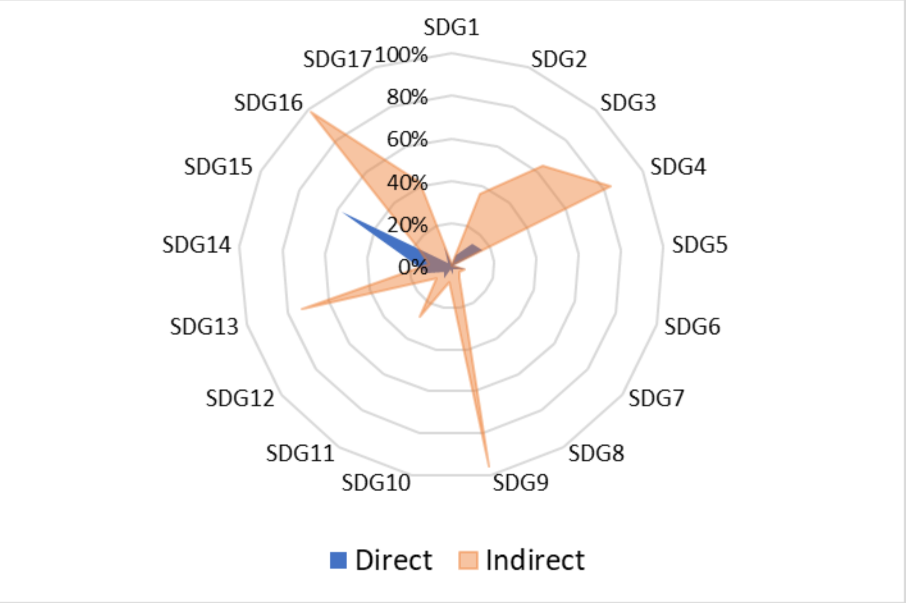

Figure 7 – Contribution to the different SDGs by the projects in the inventory
Direct contributions are represented in blue and indirect contributions in orange. Each SDG is represented on one axis, and each axis shows the share of projects that contribute to a specific SDG.

The SDGs 4 (Quality education), 9 (Industry, innovation and infrastructure), and 16 (Peace, justice and strong institutions) were by definition considered to be covered by all citizen science projects, at least indirectly. The SDGs 3 (good health and well-being), 13 (climate action), 15 (life on land), and 17 (partnerships for the goals) were covered by the majority of projects (78%, 86%, 75%, and 52% respectively, when considering both direct and indirect contributions). Interestingly, the two SDGs on nature conservation 14 (life below water) and 15 (life on land) received the highest direct contributions, with 18% and 58% of projects in the inventory directly contributing to them. In contrast, five SDGs focused on socio-economic aspects received little contribution from the citizen science projects in the inventory, with less than 10% of projects contributing to them: these were 1 (No poverty), 5 (Gender Equality), 8 (Decent work and economic growth), 10 (Reduced inequalities), and 16 (Peace, justice and strong institutions). An additional five SDGs of environmental focus received a reduced direct contribution from the projects in the inventory, with 2% to 7% of the projects in the inventory directly contributing to those goals. These were 2 (Zero hunger, 6%), 6 (Clean water and sanitation, 7%), 7 (Affordable and clean energy, 2%), 11 (Sustainable cities and communities, 7%), and 12 (Responsible consumption and production, 5%).

A given citizen science project covered 7.5 ± 2 different SDGs on average, but there was substantial variation according to the project category, the environmental field and the nature of the contribution (Figure 8, Figure 10). On average, citizen science projects only directly contributed to a little less than two SDGs (mean ± Standard Deviation (SD) = 1.7 ± 1.5), but this depended on the environmental field. Projects focused on environmental health and on sustainable production and consumption directly contributed to over 3 SDGs on average, whereas nature and biodiversity projects directly contributed in one SDG on average, SDG15 (mean ± SD = 1.3 ± 0.9, Figure 8 and Figure 9).

The citizen science projects in the inventory indirectly contributed to a higher diversity of SDGs (mean ± SD = 5.8 ± 1.6), with no significant differences across environmental fields (all post-hoc tests are non-significant). Overall, civic science and DIY engineering projects directly contributed to more SDGs than the other types of projects (Figure 10), an aspect that warrants further exploration.

4.7 In summary

- The environmental citizen science projects in the inventory were representative of the landscape of citizen science projects.
- The inventory is dominated by monitoring and occasional reporting nature and biodiversity projects. Projects monitoring other natural resources (e.g. air, water, soil) come second, but few projects were related to resource issues (i.e. resource efficiency, sustainable production and consumption, waste).
- Most projects in the inventory were contributory (monitoring or occasional reporting), and DIY projects, passive sensing projects and volunteer computing projects remain rarely used.
- Four SDGs were covered by the majority of projects in the inventory (SDG3, 13, 15, 17), but projects in the inventory provided limited direct contributions to five environmentally-related SDGs (SDG2, 6, 7, 11, 12 were covered by less than 7% of all projects).
- Citizen science projects in the inventory contributed to 7.5 SDGs on average, but to only 2 SDGs directly. Nature and biodiversity projects tended to be more focused than environmental health and sustainable consumption and production. Civic science and DIY engineering projects directly contributed to more SDGs than the other types of projects, an aspect that warrants further exploration

Figure 8 – Contribution of the projects in the inventory to SDGs according to the main environmental field

Direct contributions are represented in blue, and indirect contributions in orange. Projects are categorised according to their main environmental fields. The radar charts then provide a visual comparison of the number of projects in each environmental field contributing to a given SDG. Each axis shows a specific SDG, where higher scores indicate a higher number of projects meeting that goal.

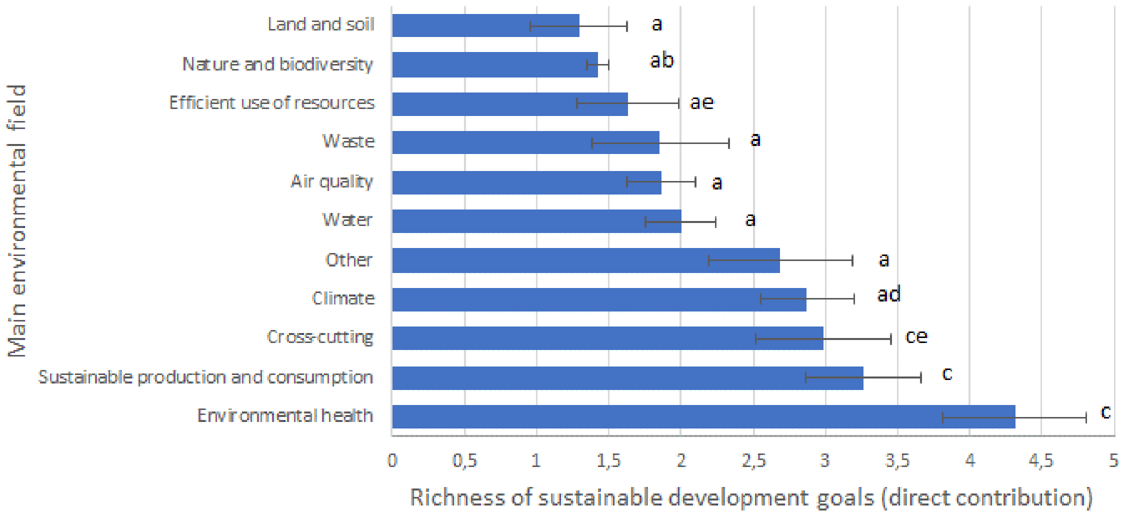

Figure 9 – Differences in the diversity of SDGs contributed by the projects from the inventory according to their main environmental field

Adjusted means and standard errors are from the linear models. Significant differences from the general linear models and post-hoc tests are shown with different letters; if there is one letter in common, then there are no significant differences between the two variables.

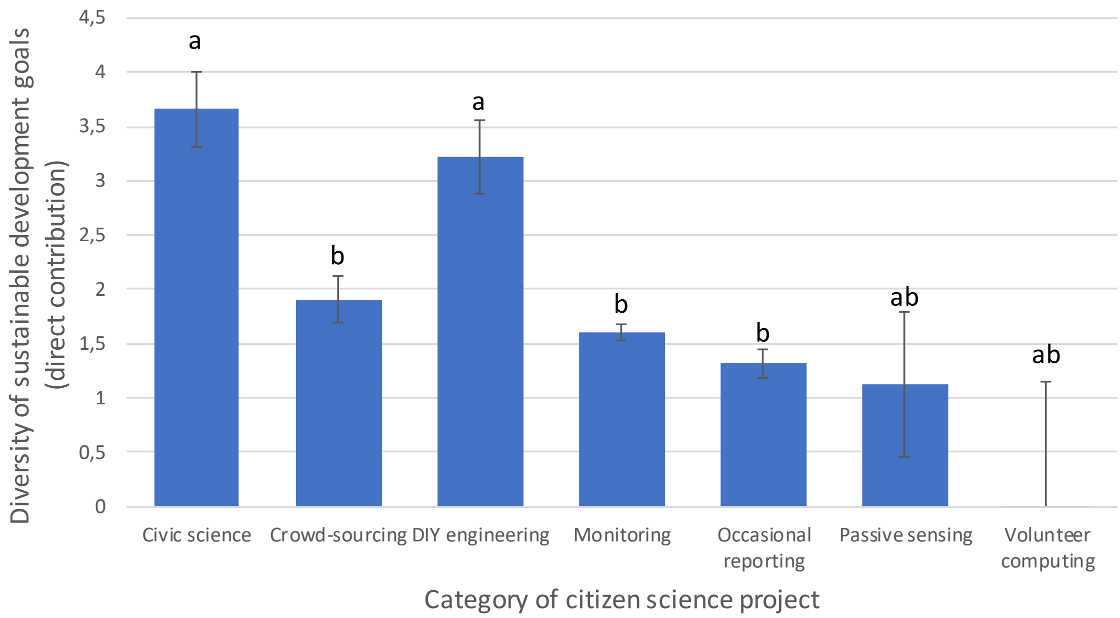

Figure 10 - Differences in the diversity of the contribution to SDGs by the projects in the inventory according to the type of citizen science project

Adjusted means and standard errors are from the linear models. Significant differences from the GLMs and post-hoc tests are shown with different letters: a is significantly different from b.

This page is left intentionally blank.

5 Analysis of a sample of selected citizen science initiatives of relevance to environmental policy

5.1 Characteristics of the selected projects

In total, 45 citizen science projects of high policy relevance responded to the in-depth survey, as well as two facilitating platforms. The latter were not further considered in the analysis since not comparable to single project initiatives: they group different types of citizen science projects and follow different business models. The case studies covered a good breadth of environmental fields (9 in total) and all types of citizen science activities (Table 5). This short-list was representative of the current environmental citizen science landscape, with 28 case studies focused on nature and biodiversity (61%, compared to 69% in the inventory) and a dominance of monitoring (22 projects, 49%) and occasional reporting (12 projects, 27%) activities (compared to 61% and 23% respectively in the inventory). The majority of projects occurred at national or sub-national level (23 projects, 51%, compared to 42% in the inventory), with 16% of projects activities taking place at EU level (compared to 18% at macro-regional level in the inventory). The proportion of large scale or global scope projects being implemented in 10 countries or more was slightly higher than in the inventory, with 31% of projects (compared to 12% in the inventory).

Table 5 – Overview of the 45 citizen science initiatives of high policy relevance for in-depth analysis, based on the survey responses

Project name	Start date	Category	Environment field	Spatial extent	Number of participants	Number of records
AEMET miniMET	2017	Monitoring	Climate	National or below	20	20
AGIIR	2013	Occasional reporting	Biodiversity nature and landscapes	National or below	1,000	3,000
Aqua	2016	Monitoring	Water	National or below	4,000	4,000
Artportalen	2013	Monitoring	Biodiversity nature and landscapes	National or below	1,000,000	65,000,000
Datenbank der Pilze Österreichs	2003	Monitoring	Biodiversity nature and landscapes	National or below	1,000	475,000
Beachwatch	2014	Monitoring	Environmental health	National or below	300,000	9,000,000
BioBlitz UK	2018	Monitoring	Biodiversity nature and landscapes	National or below	110,000	195,000
Biodiversidad Virtual	2008	Crowd-sourcing	Biodiversity nature and landscapes	More than 10 countries	4,357	2,000,000

Project name	Start date	Category	Environment field	Spatial extent	Number of participants	Number of records
BioLit	2012	Occasional reporting	Biodiversity nature and landscapes	National or below	6,300	8,300
BirdTrack	2002	Monitoring	Biodiversity nature and landscapes	More than 10 countries	30,000	57,650,606
CAPSELLA	2016	DIY engineering	Biodiversity nature and landscapes	NA	250	N/A
CAPTOR	2016	Civic science	Air quality	European	90	200
Citclops / EyeOnWater	2014	Monitoring	Water	More than 10 countries	3,000	5,000
COBWEB	2012	Crowd-sourcing	Efficient use of resources	European	300	N/A
Co-Click'Eau	2011	Crowd-sourcing	Sustainable consumption and production	National or below	15	N/A
CSMON-LIFE	2014	Monitoring	Biodiversity nature and landscapes	National or below	20,000	25,000
D-NOSES	2018	Passive sensing	Air quality	More than 10 countries	N/A	N/A
EuroBirdPortal	2016	Monitoring	Biodiversity nature and landscapes	More than 10 countries	100,000	200,000,000
European Breeding Bird Atlas II	2014	Monitoring	Biodiversity nature and landscapes	More than 10 countries	50,000	5,000,000
FreshWater Watch	2013	Monitoring	Water	More than 10 countries	9,000	20,000
Haltwhistle Burn Citizen Science	2013	Occasional reporting	Biodiversity nature and landscapes	National or below	153	4,900
I-REACT	2016	Crowd-sourcing	Cross-cutting	More than 10 countries	N/A	N/A
Irish Butterfly Monitoring Scheme	2007	Monitoring	Biodiversity nature and landscapes	National or below	310	105,737
iSCAPE	2016	Crowd-sourcing	Air quality	European	250	N/A

Project name	Start date	Category	Environment field	Spatial extent	Number of participants	Number of records
Monitoring birds (Sacre, Sacin, Noctua)	2008	Monitoring	Biodiversity nature and landscapes	National or below	1,100	2,500,000
Monitoring of butterflies and surveying Apharitis cilissa	2006	Occasional reporting	Biodiversity nature and landscapes	National or below	50	300
Mosquito Alert	2013	Monitoring	Biodiversity nature and landscapes	More than 10 countries	44,000	12,600
MyNatura2000	2016	Monitoring	Biodiversity nature and landscapes	More than 10 countries	10	150
Observatoire Agricole de la Biodiversite	2009	Monitoring	Biodiversity nature and landscapes	National or below	900	280,000
Observatoire des Saisons	2006	Monitoring	Biodiversity nature and landscapes	National or below	4,129	14,500
OPAL Tree Health Survey	2007	Occasional reporting	Biodiversity nature and landscapes	National or below	4,000	2,000
Pan-European Common Bird Monitoring Scheme (PECBMS)	1980	Monitoring	Biodiversity nature and landscapes	More than 10 countries	12,000	30,000,000
Phenowatch, Naturkalender	1868	Monitoring	Biodiversity nature and landscapes	National or below	500	450,000
Phytophthora diseases of forest trees	2017	Occasional reporting	Biodiversity nature and landscapes	National or below	30	300
Propage (Vigie-Nature)	2008	Monitoring	Biodiversity nature and landscapes	National or below	116	58,682
RISC (Recording Invasive Species Counts)	2010	Occasional reporting	Biodiversity nature and landscapes	National or below	N/A	N/A
Safecast	2011	Monitoring	Air quality	More than 10 countries	10,000	100,000,000
Save Fens - Protect Biodiversity	2014	Occasional reporting	Efficient use of resources	European	N/A	N/A

Project name	Start date	Category	Environment field	Spatial extent	Number of participants	Number of records
Schone Rivieren (Clean Rivers)	2017	Occasional reporting	Waste	European	250	200
SEA CHANGE	2015	Occasional reporting	Biodiversity nature and landscapes	More than 10 countries	500	1,500
Seasearch	2011	Occasional reporting	Biodiversity nature and landscapes	European	5,000	650,000
Sensing the Air	2016	Passive sensing	Air quality	National or below	250	N/A
Smart Citizen	2011	Passive sensing	Efficient use of resources	More than 10 countries	3,012	N/A
Near Eastern Fire Salamander monitoring	2016	Occasional reporting	Biodiversity nature and landscapes	National or below	50	130
Waste4Think	2016	Crowd-sourcing	Waste	European	40	N/A

5.2 Citizen dimension

5.2.1 Characteristics of the citizen engagement

Most citizen science projects of high environmental policy relevance provide an easy access for citizen scientists (Figure 11a). The large majority of projects are targeted to all audiences (37 projects, representing 80% of projects), with a smaller share of projects dedicated to skilled experts or professionals only (6 projects, representing 13% of projects). For example, Propage is dedicated to green space managers, and the *Observatoire Agricole de la biodiversite* to farmers.

The majority of projects requires limited to no specific skills from the citizen scientist (63% of projects require no skills, and 28% only limited skills; Figure 11b). The projects also provide a fair amount of freedom to the citizen-scientist about where the data collection should take place, since in 50% of cases, the citizen scientist can choose the site himself.

Regarding the degree of involvement, most projects require a moderate level of commitment: only 13% of projects involved one-off data collection, while 51% of projects requested data collection at irregular intervals (Figure 11d). However, for 36% of projects, data collection at regular time intervals was required. Similarly, the level of effort on a yearly basis is moderate for 60% of projects, representing between 1-24 hours, but 27% of projects requested a fairly high effort from participants, with more than 24 hours per year (Figure 11c). This is comparable to rates reported in the literature, for biodiversity citizen science projects and others (Theobald et al. 2015).

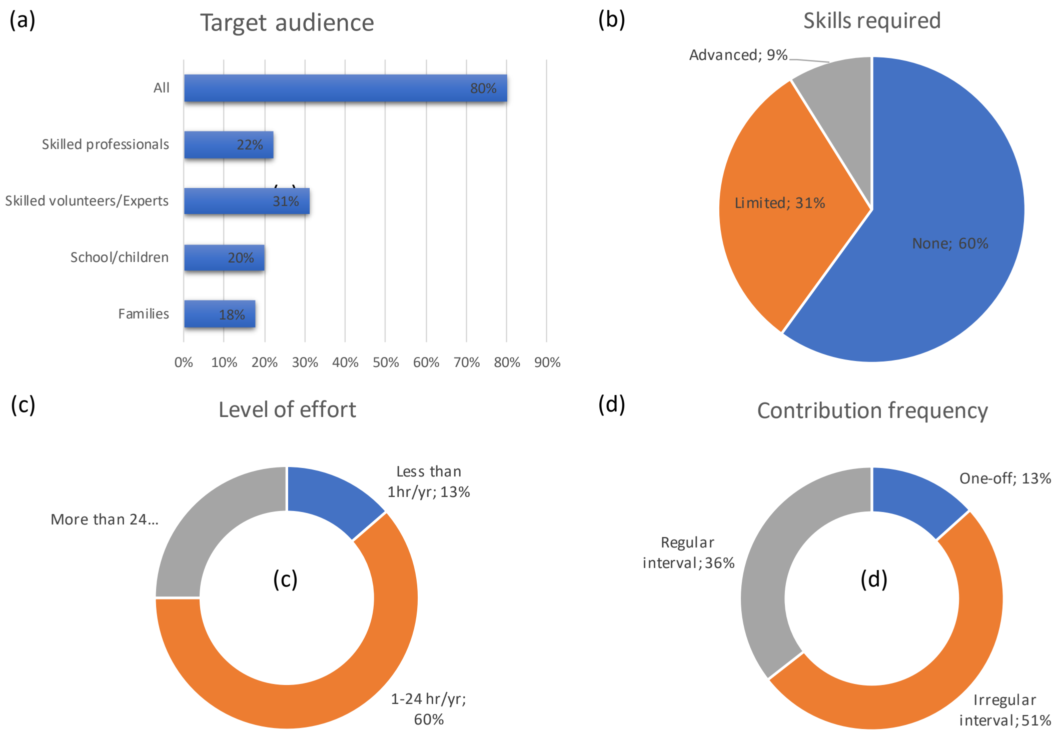

Figure 11 – Characteristics of the selected projects for citizen engagement

5.2.2 Process of citizen engagement

Good communication and support, as well as empowerment and capacity-building are seen as critical to sustaining the involvement of volunteers (Geoghean et al. 2016). There was no evidence of truly co-designed projects in our in-depth survey. The best evidence was the project CAPTOR, that aims to engage the communities in a collaborative learning process about air pollution, supporting a bottom-up process of defining and designing measures for actions. It hopes to empower citizens in this way and promote behavioural change and active participation in the decision-making process. Nevertheless, CAPTOR is a Horizon 2020 project, and the overall project questions have been designed by scientists. Although CAPTOR has developed some collaborative learning processes, it has relied on fairly traditional methods for citizen empowerment, such as calls for volunteers or school workshops (Battistelli et al., 2017). Several projects achieved large scale monitoring through a cascading model of volunteer leaders. The Beachwatch project provides training to some volunteer organisers who can then coordinate a local beach clean. The volunteer leaders have to register online to provide contact details and they are provided a training manual, including some tips about how to promote the event and recruit helpers. Similarly, the FreshWater Watch programmes offers different tiers of engagement for certain groups/communities.

Training is the most common way used to support the citizen scientists, and the different forms of trainings used are detailed in the scientific characteristics section. The importance of feedback to volunteers is widely recognised, and all projects offered at least a means of disseminating the data to the volunteers. Only 51% of projects gave citizen scientists access to the raw data, and 58% to raw data after validation, whilst the majority of projects gave them access to aggregated or processed data (67% and 64%, respectively). A similar proportion of projects allowed the general public to visualise all of the project data (62%), typically with the help of interactive maps. But 30% of projects surveyed displayed only a partial amount of the data collected. There were three projects that did not provide the opportunity to view the citizen science data (7%): OAB, PECBMS, Phytophtora. Altogether, opportunities to sustain citizen engagement were not maximised across the citizen science projects of environmental policy relevance surveyed. While restricting the type of data available to the citizen-scientist may be justified to provide data in a form that is more understandable to a lay person, it may impede the way that the citizen scientist sees how his data contributes to the whole. These issues also affect the re-usability of the data, discussed in the scientific dimension (§ 5.3.2).

5.2.3 Factors affecting the citizen engagement

The knowledge generated within citizen science projects of high environmental policy relevance was primarily published on the website of the projects (71%). But projects were also publicised through more traditional means: for those projects for which this information could be identified, 92% of projects got media exposure on TV or radio (n=22 projects), 79% in international press (n=23 projects), 97% in the national press (n=38 projects) and 87% in the regional or local press (n=34 projects). Social media, such as Twitter or Facebook, are increasingly popular to promote activities to a wide audience. Most projects had a dedicated social media page (82%). Projects differed in the way these social media pages were used for citizen engagement, with a large share of projects having a limited number of followers (47% of projects had less than 500 followers on Twitter and 39% less than 500 followers on Facebook, n=36), but handful of projects using these to their full potential, with as many as 72,200 followers on Twitter and 129,338 followers on Facebook (e.g. Beachwatch, Birdtrack). Biodiversidad virtual, a crowd-sourcing project has collected almost 1.5 million geo-localised pictures of species, some of them being the first sightings of species by relying mostly on its Twitter and Facebook pages for volunteer engagement.

The selected projects differed widely in their number of participants, with a handful of recently started projects having almost no participants, and highly successful projects like Artportalen, the Swedish Species Observation System, that musters a million participants. Artportalen is financed by the Swedish Environmental Protection Agency and represents the most comprehensive database on Swedish biodiversity, with over 60 million observations, from citizen science, environmental monitoring programmes and research projects. It is a unique kind of citizen science project, that exemplifies what open citizen science is all about. It is essentially a freely accessible reporting system and data repository, to which anyone can report the species they have seen. Data validation is ensured through a combination of in-built algorithms that signal outliers to the reporter and external validators. In addition, the openness of the system guarantees that reporting errors are quickly identified by peers. With over 90% of the records with unrestricted access, a customisable analysis portal, an easy interface and minimum data requirements for reports (taxon, reporter, date, and location), Artportalen has quickly become the one-stop destination for all environmental stakeholders in Sweden[16]. It is routinely used by national and local authorities to support their reporting and decision-making (see Table 6), but it is also used by a number of naturalists to compare and share local species information, as well as for research purposes (Leidenberger et al., 2016).

Recognised factors promoting citizen engagement are communication and feedback to participants, the involvement of scientific experts in the project team, and sufficient staff and financial resources (Turrini et al., 2018). Here, we did not find that the

[16] https://artportalen.desk.com/customer/en [accessed 10/09/2018]

number of participants was related to the endorsement by academics, nor related to the index of ease of engagement or the number of employees involved in the project. Differences in number of participants among projects were not related to the age of the project, but projects with a wider spatial extent did tend to have more participants, as has been found elsewhere (Theobald et al., 2015).

Instead, the number of participants in the sample of policy-relevant projects surveyed was related to the kind of citizen science activities. Monitoring projects enlisted significantly more volunteers than all other categories of citizen science projects, except the crowd-sourcing ones (Figure 12b). While crowd-sourcing projects are built to attract mass participation, the reasons for the high participation in monitoring projects may have other explanations. Monitoring programmes typically require a durably engaged set of volunteers, and they may thus expand more efforts on sustaining citizen engagement. Moreover, projects led by a governmental organisation were significantly less likely to recruit volunteers than projects led by NGOs, academics, or a consortium (Figure 12a). This suggests that government-led projects in our survey did not have a very effective communication and engagement strategy.

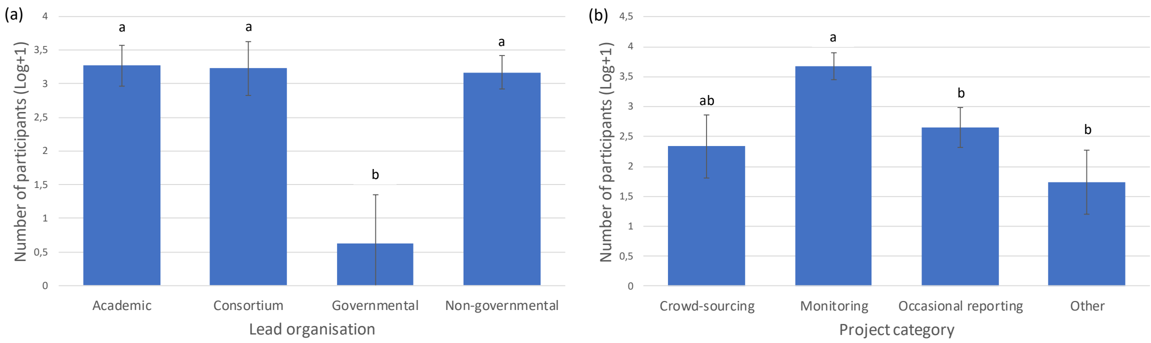

Figure 12 – Variation in the number of participants depending on the category of (a) the lead organisation, and (b) the citizen science project

Significant differences are indicated with a different letter code; variables with the same letter code do not significantly differ. For example, projects led by governmental organisations attract significantly lower number of participants than projects led by other types of organisations. Crowd-sourcing projects do not attract significantly less participants than other categories of projects.

5.3 Scientific dimension

5.3.1 Data characteristics

Selected citizen science projects covered all spatial and temporal scales (Figure 13). Whilst the majority of projects were national initiatives (53% of projects), 26% of projects were macro-regional, involving several EU countries, and another 21% could be considered of global scope (Figure 13a) The spatial resolution of projects was fairly evenly distributed between fine-scale sampling (31% of projects had sampling grids <10 m^2, 28% of projects had sampling grids between 10-100 m^2) and broader-level surveys (25% had grids between 100 m^2 and 10 km^2, 17% had grids larger than 10 km^2; Figure 13b). Short temporal data series did not seem to be an obstacle to the policy relevance of projects. One-fourth of projects spanned less than 2 years of data, and 44% of projects had between 2-10 years of data (Figure 13c). Long-term projects, with data series spanning more than 10 years, represented 30% of the selected projects.

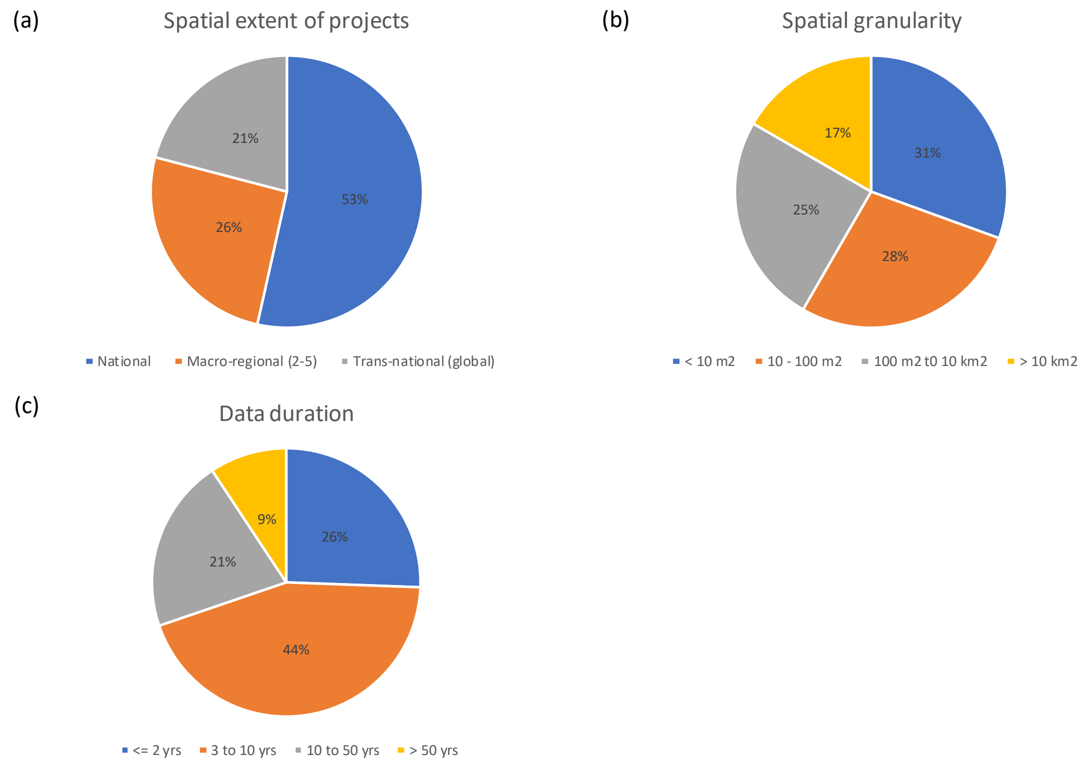

Figure 13 – Characteristics of the scientific data collected by the environmental citizen science projects in the depth-survey

5.3.2 Scientific method

The appropriateness of scientific methods and of the training required for citizen science programs have significant impact on data quality (e.g. Tregidgo et al. 2013). All projects of policy relevance appeared to adhere to fairly good scientific standards (Figure 14). Almost all projects provided metadata (91% of projects), had a fully disclosed and reproducible methodology (86%), and involved some form of quality assurance (96% of projects). Furthermore, all projects offered some kind of training, with the majority of projects offering training in-person (56% of projects). The SeaSearch initiative provides in-person training for every participant, with different levels of training for different tiers of participation, as a way to enhance the scientific robustness of the data. This has led to increased confidence in the SeaSearch data by end users. About 36% of the projects provided both supporting material and training in person. There was substantial variation in the timing and form of data quality assurance among projects. Whilst the majority of projects provided some form of quality assurance procedure after the data collection (84% of projects), several projects combined this with methods to ensure data quality before or during the data collection as well (38% of projects before and during, 24% of projects during, 2% of projects before). The post-control usually involved experts (from the citizen scientist community or scientists) to validate the data, but peer control or algorithms to identify outliers or rule-breakers were also used. In several cases, the monitoring methods and data submission tools were designed to minimise data quality problems before any data was collected. For example, monitoring methods are standardised and kept simple (e.g. simple protocols, supporting manuals, pre-defined locations, calibration of equipment, pre-defined lists).

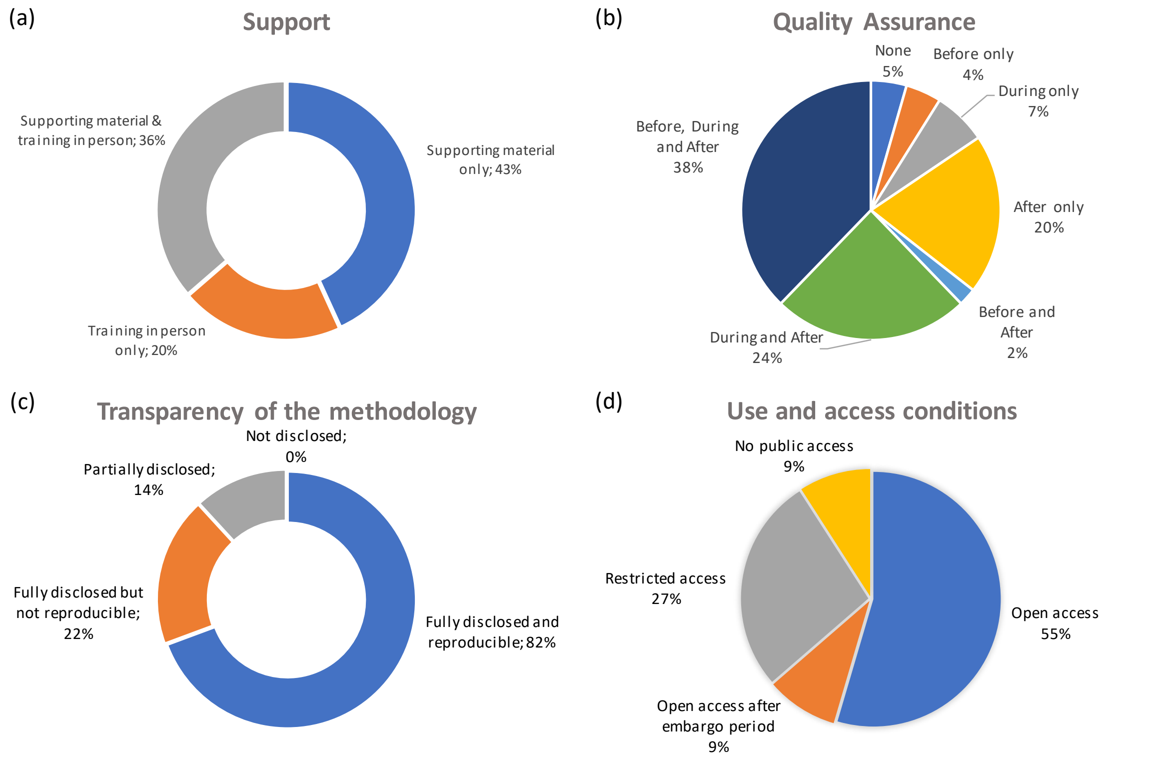

Figure 14 – Coverage of different measures of scientific data quality by the environmental citizen science projects in the in-depth survey.

Quality assurance during data collection mostly consisted in making the data collection not anonymous and in fostering the participant's own verification of the data (e.g. AEMET). Less frequent alternatives included, the generation of tailored options for data entry based on location, or warnings to highlight suspicious observations.

The public accessibility of data is considered a main limitation to the uptake of citizen science data, both by scientists and decision-makers. We found that while the majority of sampled projects was willing to share their data, over 35% of projects included some restrictions and 9% did not provide any public access at all (Figure 14d). In some cases, access was restricted to sensitive data only (e.g. endangered species) or to participants (e.g. Observatoire des saisons). Although 55% of projects claim open access, most projects provide data summaries or maps on their websites, or even data consultation options, but few provide a clear interface for data download. The data are often available on request only, and the contacts and options for data access are often not clearly identified. This confirms the findings from Schade et al. (2017b), which identified a gap between the apparent willingness to provide free, open data by many citizen science projects and the actual reality. This may result partly from insufficient awareness of best-practices for the promotion of open access, in particular regarding licensing conditions (Schade & Tsinaraki, 2016), but also due to lack of foresight or means to set up the adequate data infrastructure. Many projects now appear to use gateways or facilitating platforms as a way to increase the accessibility of their data holdings. For example, the data from the BioLit programme has recently been incorporated in the national data inventory. Exceptions to these trends are projects that have a clear commitment to openness, such as Artportalen or SeaSearch. The latter has won a national award for its open data policy, relying on fully open data, transparent methods and open access publications. Artportalen allows users to customise the analysis portal and allows to query and download over 90% of its data. Together, these findings suggest some improvements compared to the survey of data management conditions carried out by Schade & Tsinaraki (2016), where most projects exhibited restricted access conditions, usually after an embargo period. However, since this survey did not explore in detail the licensing and standardisation procedures, nor the data storage and management options, it cannot conclude on whether improvements have been made in these directions.

Good metadata, rigorous scientific protocols and quality assurance form a preliminary for the uptake of scientific data, but an effective data-sharing strategy is essential to making the data more discoverable and usable by others. In turn, this will also facilitate the use of these data by stakeholders and decision-makers to complement other traditional sources in use in decision-making. Ensuring that the project data are interoperable and can be integrated with, or added to, other data layers, raises both the scientific and policy impact of a project. Most of the projects considered the inter-operability of their citizen science data, but to varying extents. 42% of projects could be fully integrated into data repositories or other institutional datasets, but 47% of projects could only be partly integrated. Sometimes, this is due to differences in objectives between different datasets. For instance, the OPAL tree health data contains information about new pests/diseases, but these cannot be easily integrated into a national survey system, such as those to warn about quarantine pests or pathogens, since each survey contains records about the health of a range of species. In other cases, there is a potential for integration that may require considerable efforts for matching the data formats (e.g. Propage, OPAL Tree Health Survey). The potential for integration was not known in four projects (9%). Better consideration of data interoperability thus seems to be an area in need of improvement.

5.3.3 Scientific impact

The data produced by the selected citizen science projects were widely used by scientists. According to the project respondents, these data led to scientific publications in 65% of projects and were used by the scientific community in 87% of projects. 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 (Figure 15), as well as to a lesser degree by the broad spatial extent of the project. The number of scientific publications was also strongly affected by the data accessibility, with projects providing unrestricted access to their data more likely to deliver a scientific output (Figure 16). These findings are largely consistent with the citizen science literature. Theobald et al. (2014) also found that biodiversity-related citizen science project data was more likely to be published in a peer-reviewed scientific journal if the project had a large spatial extent and publicly accessible data. A number of other studies corroborate the finding that the larger the spatial coverage of the citizen data, the more likely it is to get used in research (Tulloch et al., 2013; Burgess et al., 2017; Hadj-Hammou et al., 2017).

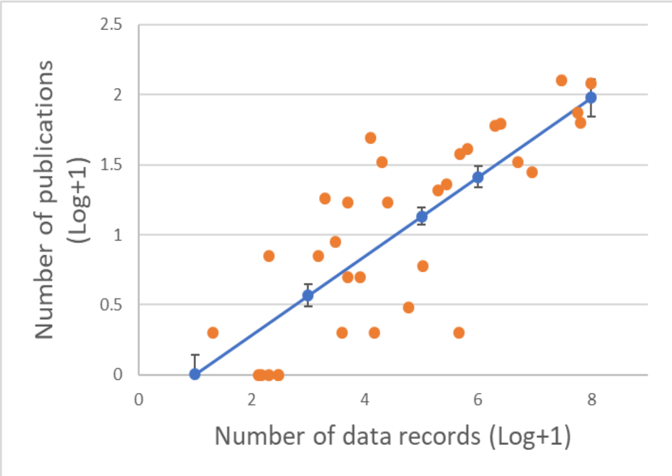

Figure 15 – Number of scientific publications according to the number of data records available in each of the selected projects

The dots represent the observed data and the line the predicted mean ± standard errors obtained from the general linear model.

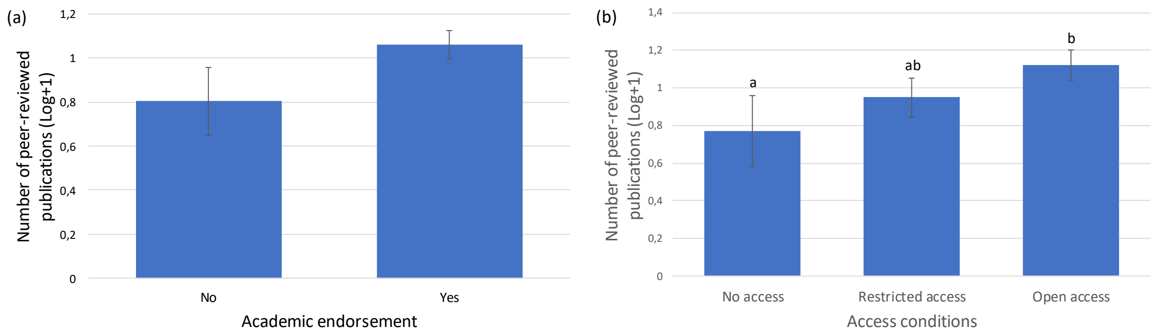

Figure 16 – Significant variation in the number of peer-reviewed publications from the sample of selected projects, depending on (a) the provision of academic support, and (b) the access conditions of the data

Significant differences are indicated with a different letter code; variables with the same letter code do not significantly differ. For example, open access projects lead to a significantly higher number of publications than projects that do not provide data access.

The likelihood of data from the selection of projects to feature in scientific publications was related to only one indicator of scientific quality, i.e. endorsement by scientists. This is in line with findings from a recent study on the scientific uptake of citizen science data, which also found that projects who partnered with academic institutions were more likely to be published in peer-reviewed scientific literature (Burgess et al., 2017). However, in contrast with the latter, long-running projects in the present study tended to lead to fewer peer-reviewed publications than more recent projects. This might be due to a threshold effect, since some of the sampled projects were very long running time period (>100 years). Projects led by scientists were also not more likely to lead to scientific output than other projects. Moreover, the results from the sampled projects do not indicate any significant effect of the scientific quality procedures on scientific output, possibly because good overall quality assurance was evident in all selected practices. A mixed impact of quality assurance on the likelihood of scientific publication was also found by Theobald et al. (2014). They found a positive effect of only one quality assurance measure on the probability of publication (related to species identification training), but not of other quality assurance measures related to data standardisation and verification.

5.4 Policy dimension

5.4.1 Utility of citizen science for policy

The short-listed projects were selected for their policy relevance, but differed in the breadth of policy issues they covered. On average, the projects contributed directly to about two to three SDGs (Mean ± SD = 1.8 ± 1.75, with some EU-funded projects contributing to more than five SDGs (MyNatura2000, CAPSELLA, CAPTOR)). The requirements of the main funding body appeared to be important, with EU-funded projects contributing to a greater diversity of SDGs than projects funded through other sources (Figure 17a). Similarly, government-led projects contributed to two more SDGs on average than projects led by other types of organisations (Figure 17b).

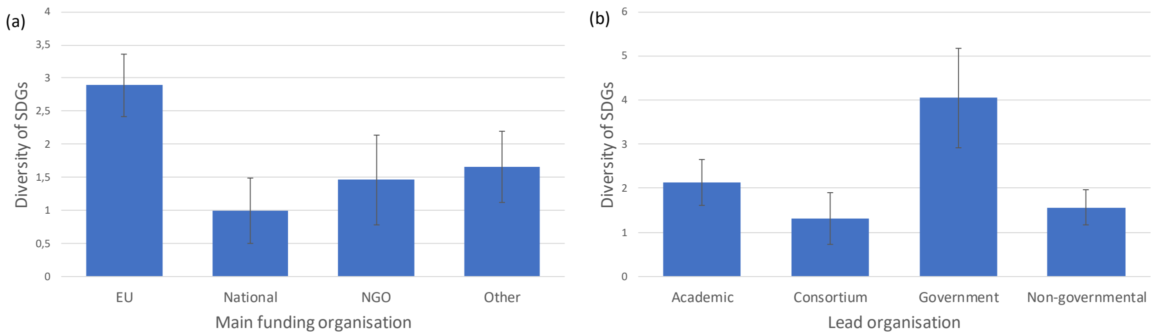

Figure 17 – Differences in the diversity of SDGs that selected projects directly contribute to, according to the project's (a) main funding organisation category, and (b) the lead organisation category

Adjusted means and standard errors predicted by the linear model are displayed.

There were no significant differences among the different types of citizen science projects, or according to the maturity of the project (age), its spatial extent, or whether it received governmental and scientific endorsement (Table A2).

Projects varied in their intended and realised contributions to policy. According to the survey respondents, the data from their citizen science project could contribute to virtually all phases of the policy cycle, including compliance, though to a lower extent in the latter (Figure 18, reported potential usefulness > 80% for all categories, except for compliance 73%). Most projects that could contribute to compliance would focus on compliance monitoring (64% of projects), followed by promotion (33% of projects). Seldom any projects claimed relevance for follow-up or policy enforcement (3% of projects).

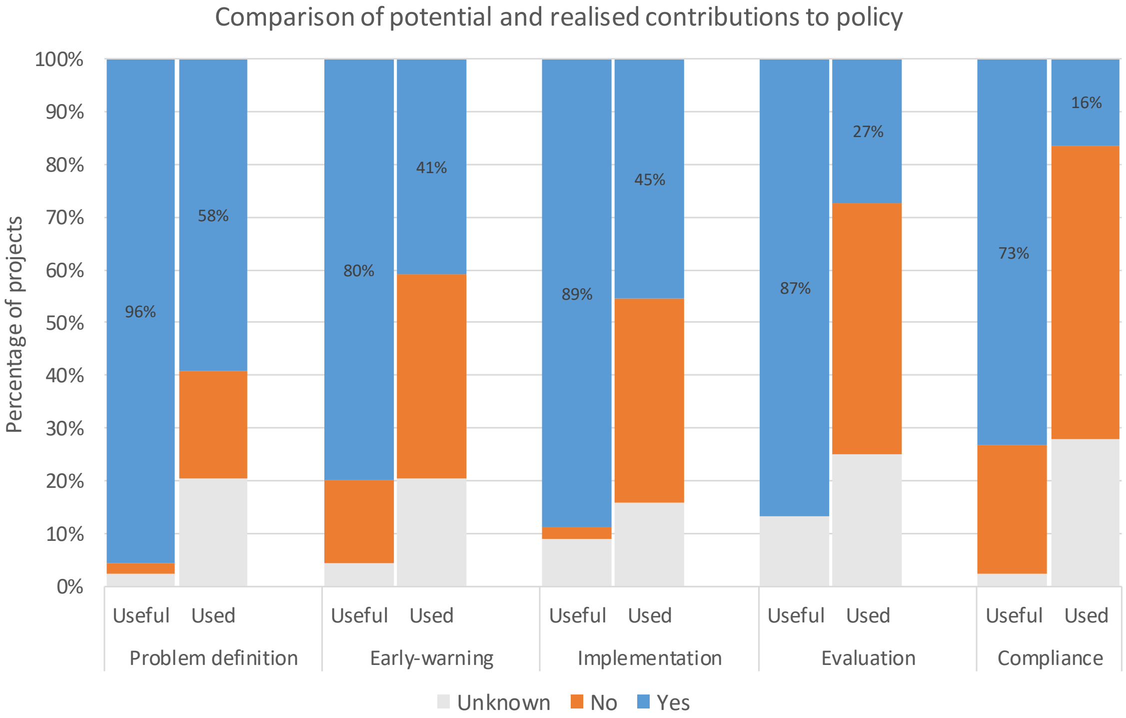

Figure 18 –Distribution of answers (Yes, No, Unknown) to the question of whether a given citizen science project had the potential to be useful for policy, or was effectively used for policy

For instance, whereas 96% of respondents thought their project could contribute to problem definition, only 58% of projects actually did so.

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. Citizen science input allows local issues to come to light and bring them on the policy agenda, such as with the Schoene rivieren project in the Netherlands, which provides evidence of the local and structural problems related to river waste and demonstrate the significance of the issue. This is the starting point for changing waste treatment policy targets. Citizen science is also a remarkably efficient approach to detect rare and infrequent events, in addition to longer or broader trends. This is well exemplified by the OPAL Tree Health Survey, that offers a dual pathway, with a rapid response data submission path for certain quarantine pests or pathogens that is connected to the "Tree Alert" government data portal. This connectivity efficiently alleviates the lack of interoperability of the regular Tree Health Survey data collection with these national databases while enabling early-warning. Citizen science can also be useful in contributing to monitoring requirements set by EU directives, such as in the case of the Water Framework Directive (Box 2).

Respondents only knew about the use of their project data for policy evaluation in 27% of projects, compared to 87% claiming relevance for this policy area. The gap between intended and realised potential was even greater for compliance, with only 16% of projects effectively contributing to policy compliance. Respondents were unsure of the actual policy contributions of their projects in 2-30% of cases, depending on the phase of the policy cycle (Figure 18). This highlights the difficulty to identify actual policy contribution, and attribute it to a specific policy area.

Box 2 – Regulatory support to the Water Framework Directive

The Water Framework Directive (WFD) (2000/60/EC) adopted in 2000 aims for a coordinated approach to freshwater management by achieving good ecological and chemical status for all waters, surface and groundwater bodies. Central to the directive is the development of river basin management plans, that set out how coordination and water status will be improved within these hydrological management units. The WFD also explicitly calls for the extension of public participation to ensure balancing the interests of different stakeholders and to ensure compliance.

FreshWaterWatch

FreshWater Watch is a global community monitoring project led by the Earthwatch Institute that has engaged over 9,000 volunteers in collecting 20,000 water samples since 2013 (Table 5). FreshWater Watch aims to influence policy and allows citizen scientists across the world to collect data on water quality, and it also operates 30 local projects in more than 20 countries to collect data on freshwater dynamics (Thornhill et al., 2018). These local programmes typically involve partnerships with corporate partners or schools to address specific local water challenges (e.g. benefits of restoration activities, sources of water pollution), as well as contribute data for the global FreshWater Watch research.

The project builds on the long experience of Earthwatch in promoting citizen engagement by offering a complete methodology for engaging the public, with specific attention to providing different forms of feedback to the volunteers. Citizen scientists are provided with in person-training and have to complete and pass a research test before they are able to upload records. During the monitoring, they have access to a smartphone application that provides them support on the go, in addition to other training materials. In case the volunteers enter extreme values, feedback is provided and updates are requested to validate the data. Afterwards, participants are informed about potential issues and can participate in monthly QAs sessions organised by trained staff, so that they can complete the learning process and avoid future mistakes.

The data collected is particularly useful in that the citizen scientists record not only water turbidity, nitrate and phosphate pollution, but they are also asked to take pictures of the nearby area and record a number of additional variables (e.g. the vegetation, land use and water levels). Over 40 stewardship programs have been developed with local river trusts and environmental organisations that aim to monitor and comply with WFD requirements for local water bodies. Local authorities can also use this microscale information to improve their management of streams and rivers ecosystems.

A comparison of citizen science data and agency monitoring of water quality in the UK shows that FreshWater Watch data can complement environmental agency monitoring efforts by filling in gaps in the spatial and temporal coverage, as well as water body types (Hadj-Hammou et al., 2017). In particular, FreshWater Watch data identified nutrient excess in low-order stream and ponds, which do not receive sufficient attention by policy-makers. The data have also been used by the UK Environmental Agency to provide early-warning of a pollution event in Lincolnshire. This has allowed the agency to quickly target and visit certain businesses to identify and remedy to some sources of pollution and offer pollution prevention advice (Earthwatch Institute, 2017).

Agriculture is one of the main sources of water pollution in Europe, and the WFD requires the development of agricultural action plans to improve water quality.). Co-click'eau has been developed to provide farmers with a decision-support tool to help them make the most impactful and relevant changes to comply with the WFD legal requirements. It aims to elicit locally-relevant catchment action plans by drawing on stakeholder participation and providing a tool to model different scenarios of crop management and assess their consequences for the whole catchment. To date, 150 people received training and there is steady demand.

The Co-click'eau approach has been tested in three river basins in France in 2011 and 2012, where it successfully engaged catchment stakeholders in the exploration and design of locally adapted solutions to restore water quality in the catchments. It led to the formulation of an action plan in one river basin in the Nord-pas-de-Calais region. Thanks to its iterative process and participative approach, whereby stakeholders contribute to define the objectives and constraints of the scenarios, Co-click'eau facilitates collective consensus decision-making, built upon stakeholders goals and values. For example, relinquishing vegetable production in the Nord-pas-de-Calais region was clearly not an economically feasible option for the farmers. Accordingly, state agents, local authorities and the water agency agreed to consider more consensual solutions to reduce the agricultural burden on water quality while maintaining vegetable production. An example of measure stakeholders agreed to commit to was converting 6% of the catchment area to organic agriculture within the most vulnerable section. Results show that even in the areas where action plans were not built on the basis of the co-designed scenarios, collaborative learning occurred, allowing stakeholders to promote territorial dialogue between farmers and water policy makers, build a common perception of the impacts of agricultural practices on water quality and to discover new technical options and possibilities for river basin water management (Emilia et al., 2014). So far, the participatory process of Co-click'eau has been used to support the implementation of legal requirements of the WFD, but the scenarios developed can also be used to explore the environmental and economic effects of changes in agricultural management or subsidies in a river basin.

There is no clear feedback loop between end-users and project leaders, nor any simple way to track the use of citizen science data. For example, the Haltwhistle Burn citizen science initiative is partly funded and officially endorsed by government departments (Defra, Environment Agency). It features in a number of targeted guidance documents published by the Environment Agency and Defra and is included in a government briefing document. Yet, the survey respondents did not know whether their project and/or any of its data had influenced policy at all.

5.4.2 Characteristics of policy relevant projects

Overall, 32 citizen science projects in the in-depth survey (71%) reported a contribution to one or more policy areas (see Table 6 for some examples). Some excellent examples of the utility of citizen science data come from the development of atlases, which compile species occurrence records to provide distribution maps that can be put to multiple uses. The first European atlas of breeding birds was published in 1990s and represented a real milestone. Its data were used for setting conservation strategies at European and national levels, to study the impacts of climate change, and for scientific studies in a wide range of topics (Vorisek et al., 2015). With the distribution data now outdated, the European Bird Census Council, besides its main role in the PECBMS project, is working on the second European Breeding Bird Atlas (EBBA2), to be delivered by 2020. The project would not be possible without the involvement of citizen scientists: it involves 5 years of fieldwork over 50 countries to cover 5,000 50x50km squares, requiring an estimated 50,000 bird watchers. Similarly, phenological data, which have been collected for decades by many citizen science programs, are proving uniquely useful to answer global change questions (Cooper et al., 2014). For example, the phenological observations collected through the century old Phenowatch program in Austria have been used by the Intergovernmental Panel on Climate Change (IPCC) and in some of its assessment reports. The observations could also be re-purposed to assess the effect of climate protection measures.

Table 6 – Examples of environmental citizen science projects that provide evidence underpinning the different stages of policy-making

Project	Stages of policy-making	Policy impact
Seasearch	Problem definition Policy implementation Compliance	Seasearch data are used by many government bodies and have been fundamental to support the designation of Marine Protected Areas, identify priority species for conservation. The programme continues to identify new areas and monitor existing MPAs (in partnership with regulators to monitor compliance with byelaws etc.). Seasearch also promotes "ocean literacy".
PECBMS	Problem definition Policy evaluation	The Common Farmland bird index and the EU common bird index produced by PECBMS are the recognised indicator for biodiversity monitoring in Europe (env_bio2 and env_bio3, EUROSTAT). The bird indices are used to assess the EU Rural Development Plans and for monitoring the EU biodiversity strategy to 2020. The indexes have also been used to identify a biodiversity problem in modern agricultural landscapes.

Project	Stages of policy-making	Policy impact
EBBA	Problem definition	Data from the first atlas (Hagemeijer and Blair 1997) were used for setting conservation strategies at European and national levels and to study the impacts of climate change. The data from the second atlas will be useful to collect robust evidence on the distribution of priority species or habitats.
OPAL Tree Health Survey	Problem definition Early-warning Compliance (promotion, monitoring)	The data have been used to provide evidence of early-warning and distribution of relatively recently arrived pathogens. The survey includes surveillance for six tree pests/pathogens of official quarantine concern. The project has also been used to meet strategic objectives of governments to engage people with trees and raise awareness of tree health issues.
Mosquito Alert	Problem definition Early-warning Policy implementation Compliance	Mosquito Alert data contribute to identify breeding sites in neighborhoods and near schools to propose further remediation action. It has also been used to discover vectors of diseases in new areas or regions. It is used by public health agencies in some cities to support control and remediation actions. As a continuous monitoring program, it could be used by public control agencies to test the outcome of their interventions. It is an awareness-raising tool, and the maps showing where there are public health problems that need remediation or action have been used by citizens to ask for actions to their city councils.
Artportalen	Problem definition Policy implementation Policy evaluation	Artportalen data are the primary biodiversity data used to support planning and management decisions in Sweden, such as for nature reserves. The data are used routinely by all government authorities, agencies and many environmental consultancies (they have developed their own interfaces to enable rapid searching of the data in Artportalen). The data are used to monitor biodiversity, invasive species, changes in species distributions and form the key tool in the creation of the Swedish Red List.
Beachwatch	Problem definition Policy implementation	The data have been used to inform all plastic levies introduced in the UK, now leading to a 28% reduction in bags found on the beaches. The data are used as a baseline for the MSFD and features in Defra reports, such as Charting Progress 1 and 2. The project data is used to carry out the official UK Beach litter monitoring for MSFD reporting purposes.

Project	**Stages of policy-making**	**Policy impact**
Propage	Policy evaluation Compliance	The Propage data allow the evaluation of changes in management practices on butterfly populations. This supports the evaluation of several local policies developed to promote biodiversity in the management of urban green spaces (e.g. the banning of pesticides and phytosanitary products in 2014). It is also a tool for awareness-raising of the links between management practices and biodiversity.
BioLit	Problem definition Policy implementation	The data are used in the national inventory of natural resources in France, to inform the distribution of 17 mollusc species. They are also used to define an indicator of habitat quality for algae. It is used to support the implementation of the Marine Framework Directive and the Habitats Directive (Article 17 reporting). They have been used to warn of the arrival of new invasive species and to signal mammal landings for remediation.

Some citizen science projects are useful for policy because they cover areas where there are clear data gaps and policy needs. For example, the marine legislation has been evolving rapidly over the past 10 years, with increased requirements from the EU legislation including the Marine Strategy Framework Directive, the Common Fisheries Policy, but also clarifications on designation of marine protected areas in Natura 2000, that have led to increased data and management requirements. So far, much of the uptake of citizen science has been on terrestrial environments, with only 14% of UK citizen science projects of policy relevance based on marine systems (Roy et al., 2012). Projects like SeaSearch fill this gap by focusing on marine species distributions, providing timely data to inform the designation and compliance monitoring in Marine Protected Areas in UK waters, especially the designation of new marine conservation zones. The successful uptake of these data by policy is fostered through direct liaison with policymakers. SeaSearch works with local inshore regulators in England (Inshore Fisheries and Conservation Authorities) to provide data about the marine environment that underpin byelaws, and continue to visit the Marine Protected Areas to record condition and extent of features on an ongoing basis. In a different way, Artportalen has enabled the centralisation of most Swedish biodiversity data in one place, thus facilitating uptake by end-users. Data from Artportalen is used daily by national agencies, such as the Swedish Forest Agency or the Swedish Transport Administration, both to add records and to search the database[17]. Moreover, local authorities routinely use Artportalen for environmental monitoring, or for deciding on protection measures and action plans for threatened species. All stakeholders can see the data underpinning decisions by authorities and agencies. Sometimes, the citizen science project is taking the leadership in new policy areas. Biodiversidad Virtual is involved in the Forum of Networks and Entities of Custody of the Territory in Spain, which sets the

[17] https://artportalen.desk.com/customer/en/portal/articles/2874151-who-uses-data-from-artportalen [accessed 10/09/2018]

strategies and instruments for the conservation and proper use of natural resources among the owners and users of a territory.

A less appreciated value of citizen science for policy lies in the communication of government aims and messages. Although this 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 governments to engage people with trees and raise their awareness of trees. In a different way, Co-click'Eau and the Observatoire Agricole de la Biodiversite (Agricultural Biodiversity Observatory) both enable to relay governmental priorities regarding targets for reductions in pesticide use to the key stakeholders, by providing them first-hand tools to assess the impacts of these practices on biodiversity or water quality.

The likelihood that one of the selected citizen science projects was being used for policy was related to the ease of engagement. Specifically, citizen science project data were more likely to be used if they scored high on the index of ease of engagement, covering aspects related to effort, skills and training (Figure 19).

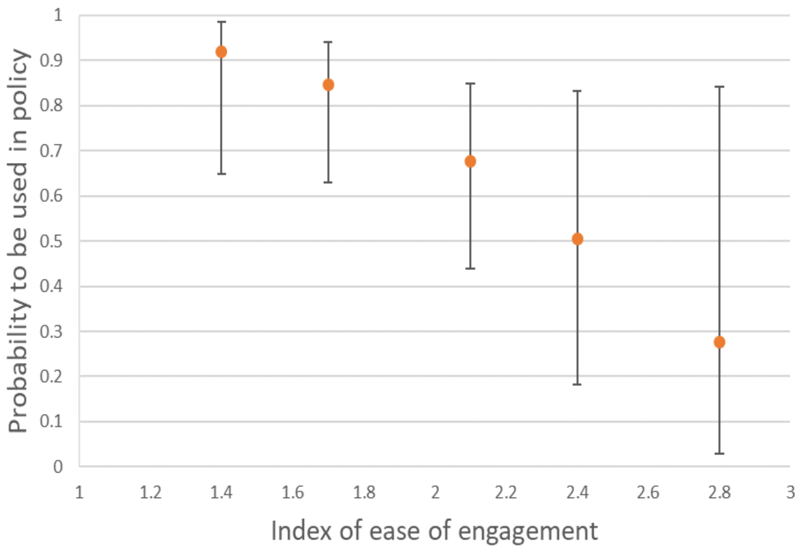

Figure 19 – Mean probability and standard error of a projects being used in policy according to the ease of citizen engagement

An index of 1 signifies a project that is easy for citizens to engage in, and an index of 3 a project that requires a higher level of efforts and/or skills from the citizens.

For instance, the collection of phenological records for the *Observatoire des Saisons* allows volunteers to freely determine their study location and only requires them to record very simple information, such as the date and species observed at a certain stage of its development (e.g. flowering, adult). The only commitment is repeated visits (3 to 4 times in a year) for the monitoring of tree phenology. The BioLit programme also offers a range of simple engagement options for the volunteers to monitor coastal biodiversity, including different options of species monitoring, an alert network for new species arrivals and phenological observations. Most of these only require the volunteer to record the date, location, the starting and end time of the session, and some pictures of the site. The sites are freely chosen, with no obligation to return to them. The user interface providing the details of how to perform the survey is also very straightforward. Aside from the ease of engagement, older projects also showed a tendency for higher policy uptake (Table A2). No significant differences in uptake were detected according to the project's internal characteristics (type of citizen science project or spatial extent), nor according to its scientific credentials (index of scientific quality, or number of publications). Official endorsement from governmental or academic institutions did not significantly affect policy uptake either.

Many projects that contributed to policy embraced the cyclic nature of the policy process and contributed to different phases (Mean ± SD = 1.95 ± 1.53; Table 6). Projects that benefited from academic endorsement, as well as those projects with high scientific quality standards (as scored through the Index of scientific quality) contributed to more policy phases (Figure 20). Projects covering a greater spatial extent were also more likely to contribute to a greater diversity of policy phases (Table A2).

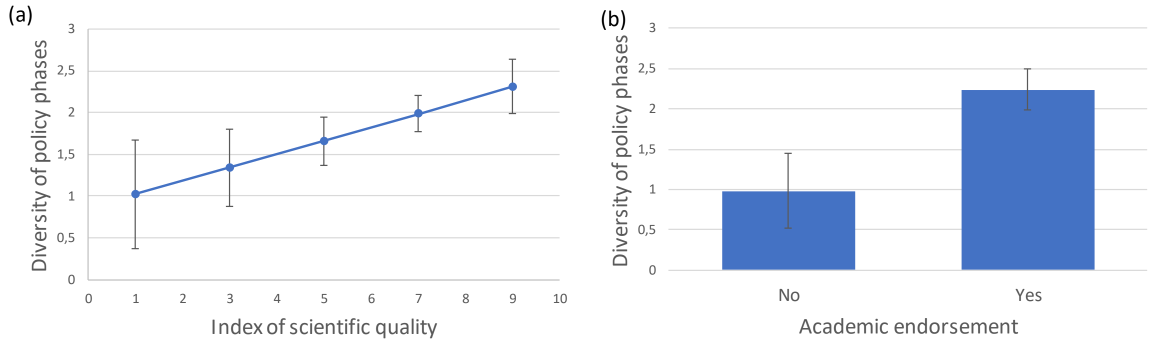

Figure 20 – Impact of scientific aspects on the number of policy phases contributed by the selected projects (a) index of scientific quality, with higher values signifying higher scientific quality in terms of transparency, support and quality assurance (b) whether the project received official endorsement from an academic institution

Adjusted means and standard errors predicted by the linear models are displayed.

5.5 Investment needs

5.5.1 Project governance

Most projects were led by non-governmental organisations (42%), closely followed by academic organisations (33%, Figure 21a). Consortiums, with a mixed leadership structure, led 18% of projects. Few projects were led by government agencies (7%) and none by the private sector. Projects differed in their funding structure, with the majority of projects receiving their main financial support from EU or governmental institutions (62%, Figure 21b). Funding of policy relevant citizen science from the private sector was negligible, with only 2% of projects receiving their main funding from commercial companies, and seven projects (15%) receiving any kind of financial support by private companies. 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 2 to 5 staff members (53%) and with broad stakeholder endorsement. Twelve NGO-led projects (63%) are endorsed by governmental institutions, academic institutions and NGOs, compared to only five projects led by academic institutions (33% of academia-led projects; Figure 21c). Only about half of the projects had civic support, and 36% of projects were endorsed by the private sector. The importance of governmental involvement through funding and participation to ensure policy relevance is evident. In several projects, the staff from national government departments helped develop the surveys (e.g. OPAL Tree Health) or invited the development of the surveys / indicators (e.g. Propage, Observatoire Agricole de la Biodiversite, Co-click'Eau).

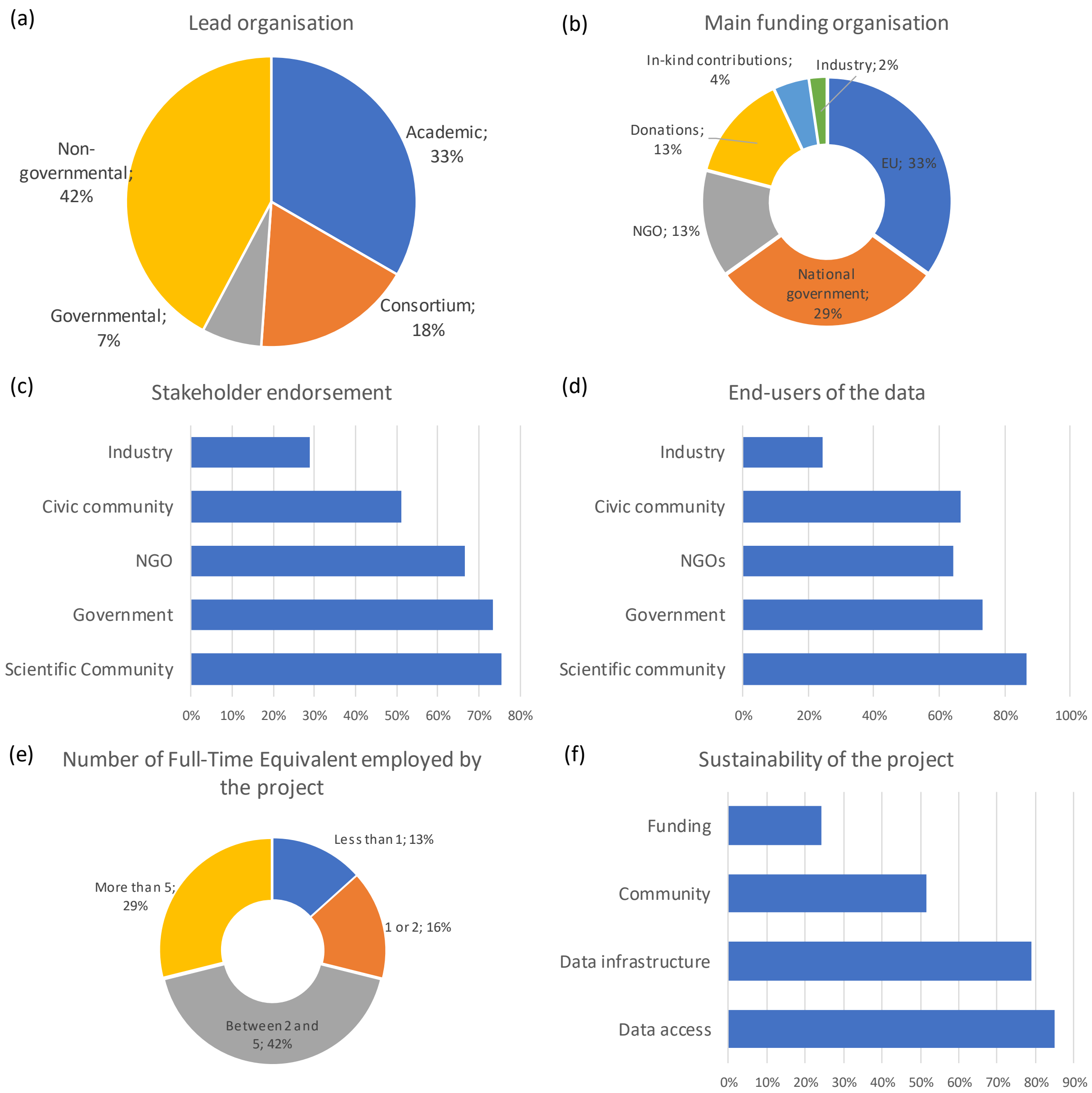

Figure 21 – Characteristics of the governance and resources of the selected projects

The main users of the citizen science data were by far the scientific community and governmental agencies, with the data in over 73% of projects being used by them (Figure 21d). But NGOs and civic communities were also large users of the citizen science data, with over 60% of projects reporting use by them. The private sector was the smallest user of citizen science data (24%).

The sustainability of projects, i.e. their ability to continue their activities far into the future, is essential to ensure a reliable data inflow for end-users. The sustainability of projects was not known for 13 projects. The projects for which it was known usually focused on guaranteeing data access (28 projects, 85%) and the data infrastructure (79% of cases, 26 projects; Figure 21f). Ensuring sufficient funds for data analyses and data sharing is critical to ensure the onward use of data. For instance, the Irish

Butterfly Monitoring Scheme has not been able to pursue the analyses needed to validate whether and how their data can be used as a National Biodiversity Indicator, due to limited resources. A smaller number of projects also considered the maintenance of an active community of citizen scientists (17 projects, 52%). In some cases, the projects have led to the creation of sustainable networks. For instance, the OPAL Tree Health Survey led to the creation of a UK Tree Health Citizen Science network, that has been formed largely out of the original multi-institutional advisory board set up to guide the development of the OPAL Tree health survey. Only eight projects had a guaranteed funding structure. These projects are typically mainly funded (e.g. Artportalen, Propage) or at least partly funded by the government (e.g. Beachwatch, AEMET-minimet, FreshWater Watch). In many other cases, the project funding was linked to a specific, fixed-term, research grant or PhD, which can compromise the long-term continuation of the project. Successful continuation can be ensured when longer term funding is secured afterwards, as in the case of the Haltwhistle Burn citizen science projects, which was initially only funded through a 3-year PhD but managed to attract funding from the River Trust and for nearby communities to replicate.

5.5.2 Resources

A number of questions remain regarding the balance of costs and benefits of including volunteer-based data collection approaches in ongoing research or monitoring programmes (Thornhill et al., 2016). From a programme-development point of view, the costs of training and long-term engagement can be a central hurdle for agencies and researchers, yet they are key to the success and usefulness of citizen science programmes (Thornhill et al., 2016).

Most of the selected projects are medium-sized citizen science projects, employing 2-5 full time equivalent (FTE) (Figure 21c). About one-third of projects are larger size projects, that employ more than 5 FTE (13 project, 29%). Eight projects only employ 1 to 2 FTE, usually divided between different persons, sometimes across different organisations. Five projects employ less than one FTE, (e.g, RISC, Bioblitz UK, Waste 4 think, Irish butterfly monitoring scheme, Sea change)

Based on the responses to the survey, the average yearly investment of best practice projects was a little over 350,000 EUR, but there was considerable variation across projects (Mean ± SD = 362,000 ± 659,690 EUR, n=30 projects). EU-funded projects had significantly higher yearly budgets than when private organisations, governmental or non-governmental organisations were the main funders (Figure 22b). Moreover, the yearly budget decreased with the number of participants, suggesting that economies of scales could be realised for larger-scale projects (Figure 22a). Projects with higher yearly budgets tended to have more employees (Table A2), but no differences in yearly investment were found according to the intrinsic characteristics of the project (e.g. longevity, number of records, spatial extent), nor between different categories of citizen science projects. However, government-led projects tended to have lower average yearly investment than NGO and academic-led projects (Table A2).

These costs are considerable when compared to the reported average costs of policy-relevant citizen science monitoring project in the UK (between EUR 85,000 and 170,000 (Roy et al., 2012)), with large-scale projects at the upper end of this range. A potential explanation for the higher costs of policy-relevant citizen science projects in this study is the share of EU-funded projects. Without these, the mean yearly investment is 112,930 ± 158,674 EUR/year (Figure 22). In addition, the yearly costs considered here include all activities, from coordination to data management, volunteer support and communication. Moreover, these costs have been averaged over the lifetime of the project and thus include start-up costs and running-costs. It is likely that the current running costs of many of these projects are in fact much lower.

Although the respondents were asked to estimate the total projects costs, they may not have been able to assess these with the same accuracy for each project, and these estimates should thus be considered with caution.

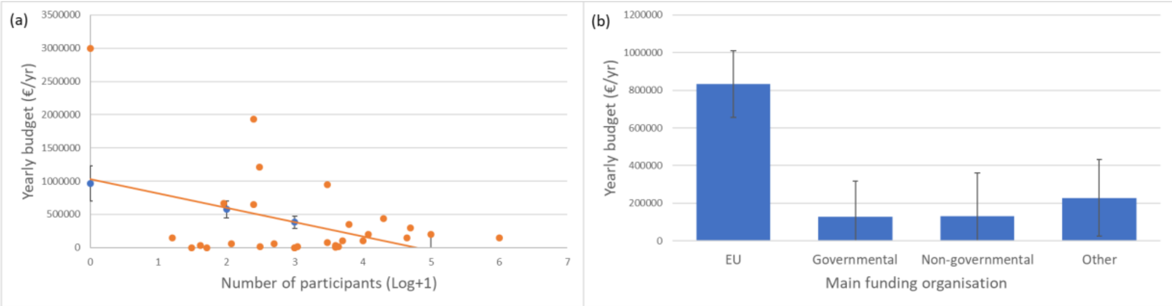

Figure 22 – Variation in the yearly budget of selected projects according to (a) the number of participants in the project, and (b) the main funding organisation

Adjusted means and standard errors predicted by the linear models are displayed.

These yearly costs are nevertheless much less than what it would cost the administration to carry out similar level of biodiversity monitoring. In France, the costs of monitoring trends in species abundance and distribution at national level were estimated to range between 678,523 EUR/year and 4,415,251 EUR/year, depending on assumptions about who would carry out this monitoring instead of volunteers (Levrel et al., 2010). A growing number of studies demonstrate the cost-effectiveness of citizen science, enabling monitoring over larger spatial scales and at reduced costs compared to traditional monitoring schemes (e.g. FreshWater Watch, 6-9hours of sampling time for each hour of training invested (Thornhill et al., 2016), 65% reduced costs for ladybird monitoring over larger spatial extent (Gardiner et al., 2012)). Evidence about the cost-effectiveness of citizen science for other types of contributions than monitoring is still lacking.

5.6 Opportunities and barriers for policy uptake

The examples from this analysis demonstrate that citizen science can contribute to the provision of the evidence base that underpins policy. But whereas in some cases the linkages are intended and planned from the outset, in many instances they appear more of an afterthought, or simply correspond to an unintended use. Whereas it is evident that not all citizen science projects can or should produce policy relevant evidence, since there are many other motivations for citizen science programmes, the challenges and key benefits for linking environmental citizen science to policy issues are discussed. The following discussion reflects opinions of the survey participants. The survey was extended to include free text options for participants to let us know in their own words what the main opportunities and challenges for ensuring policy relevance of citizen science projects. Whilst these opinions were diverse, we grouped them according to the key dimensions of citizen science impact.

5.6.1 Citizen dimension

Opportunities

The three key benefits of citizen science for volunteers identified by respondents can be summarised as follows:

- **Making a difference:** policy-relevant citizen science is rewarding to volunteers primarily by enabling them to contribute to something bigger and meaningful. Citizens can be empowered through their involvement in local problems and their solutions, and sometimes be the force behind changes in the regulatory framework. They can influence decision-making, since citizen science offers ways for citizens to have a say in decisions or to co-produce them.
- **More democratic, open society**: citizen science leads to more informed citizens and generates more transparent data. Citizens can see how the data they contributed to is used for decision-making and science, or in the best cases be involved in the decision-making process.
- **Improved public awareness of environmental issues**, through improved science literacy, and shared information in networks and communities of interest. It can improve or modify the negative perception of citizens about some environmental issues, e.g. weeds, insects.
- **Creation of networks**, citizen science may create new communities of interest (e.g., UK Tree Health Citizen Science network) and improve social connections and sense of place.

Challenges

With the exception of the last one, the key challenges identified by respondents are generic challenges of citizen science and not particularly related to its policy relevance. They include:

- **Sustaining engagement**: once the thrill of discovery is over, it can be difficult to keep citizen scientists motivated over the long-term, or to renew the pool of citizen scientists. A key obstacle is the risk of monitoring fatigue, which can be mediated with the help of professional facilitators. Another obstacle to sustaining engagement can be linked to the spatial disconnection between the source of the problem and its impact. This can make it difficult for citizens to relate with the issue, and thus to engage in the citizen science process.
- **Respect and acknowledgement:** the importance of appropriately valuing and acknowledging citizens' contributions was echoed by many respondents, as well as the need to regulate the use of crowd-sourcing data (e.g., I-react). The voluntary nature of the work may need legal clarification (e.g. in Austria).
- **Overly technical:** the linkages to policy are often complex, sometimes fraught with inefficiencies (e.g. EU agricultural and nature policies) and make a high use of technical jargon. This can make it difficult to communicate to citizens, and thus to use as a leverage for engagement. Similarly, with regard to the scientific dimension, high data standards may tradeoff against the usability/attractiveness of the activity.

5.6.2 Scientific dimension

Opportunities

Citizen science inputs can further science in three main ways:

- **Improved knowledge base:** citizen science can help provide new data, uncover new issues, and add scalability to existing data (potential to scale-up but to also to narrow-down). In particular, citizen science data can complement existing (government-led) monitoring schemes, with a potential for gap-filling (Hadj-Hammou et al., 2017).
- **More open research:** citizen science often goes hand in hand with open data access and data sharing policies.
- **More relevant, inclusive research:** the contribution of citizens brings about more responsible, fair and inclusive research. It can also shift the research agendas towards more applied and relevant questions, for instance in the case of nature conservation.

Challenges

The key barriers identified to the use of citizen science in research were:

- **Perceived data quality concern**: lack of confidence in citizen science data by policy-makers was raised as a concern, as well as establishing the right balance between ensuring sufficient data quality without creating barriers for engagement.
- **Achieving appropriate data scalability**: difficulty in providing data that can reach all required administrative levels, from EU-wide down to the local context, accounting for cultural diversity and differences in possibilities to engage. Smooth communication channels within the network of organisations needed is needed to ensure validated, standardised data for upscaling.
- **Involvement of scientific community**: scientific involvement is needed in all phases of the project to ensure quality, but not always easy to achieve, in particular for NGO-led projects.

5.6.3 Policy dimension

Opportunities

Respondents identified several ways in which citizen science can contribute to better policy making. Citizen science can make policy:

- **Timely**: citizen science allows for rapid problem identification and solution. It is particularly useful for the detection of rare, infrequent events (e.g. pests, pathogens, invasive species, diseases).
- **More reliable**: citizen science widens the evidence base used for policy, by providing new or complementary evidence, at the right scale. In particular, it can help bring local problems to light (e.g. river waste).
- **Fit-for-purpose**: citizen science can ensure policies are more relevant for society, by providing an understanding of citizens needs and expectations (uptake and use in connection to policy needs)
- **More inclusive:** citizen science can help establish a direct connection between real-life actions and policies, and it can allow to broaden participation to different stakeholders groups (e.g. Co-click'eau). It can increase the awareness

of policy-makers and stakeholders on certain environmental issues (e.g. identify new problems).

- **Better value for money**: it is argued that citizen science can provide better value for money than traditional scientific methods. In particular, it can broaden the coverage and increase the sampling power of data to provide low cost, high granularity information to decision-makers.

Challenges

The key obstacles identified by the survey respondents to achieving policy-linkages relate to:

- **Long-time scales and resources needed** was often identified as a key obstacle. Making connections with policy needs and creating a network of interest is long process that requires sustained motivation and resources. The turnover among policy officials was raised as an obstacle, since many policy-makers work on a project basis, and their successors may not continue previous work.
- **Resistance from decision-makers and government officials**: many respondents highlighted the difficulty to find interested policy-makers and to convince them of the (added) value of citizen science. Obstacles included the reluctance of policy-makers and decision-makers to embrace any change in the way they work, and their preference for working within their organisation rather than to engage with non-officials. Several respondents stressed the difficulty they faced to actively involve authorities in the design and implementation of the citizen science activities.
- **Difficulty in identifying relevant policy linkages:** the policy landscape is dynamic and can make it challenging for project leaders to identifying the relevant policy priorities for their projects. Moreover, policy linkages are complex, and a project's relevance to policy is often indirect, or linkages need to be made at multiple scales. In particular, some respondents stressed the difficulty in adapting international aims and targets to the local context.
- **Connecting with policy-makers:** a project has to stand out in order to reach policy-makers, and lack of data visibility can be an issue. Many respondents drew attention to the difficulty in connecting to the local actors and establishing linkages between policy-makers and the science/community on the ground.
- **Lack of government funding** for environmental and public health solutions.

5.6.4 Governance and resources

Opportunities

Citizen science projects can promote more integrative and sustainable forms of governance:

- **Work in partnership**: most if not all citizen science projects are multi-actors, bringing together actors and communities that would never collaborate otherwise, thereby promoting synergies and knowledge transfers. Projects can involve partners from the industry.
- **Improved legitimacy**: lead organisations can gain visibility and enhanced legitimacy through the citizen science activities, which can in turn promote partnerships and the development of new projects.

- **Improved support**: examples from successful projects can increase the funding options for citizen science. When the financing is embedded in the governance process, citizen science may provide a long-term data resource.

Challenges

The key obstacles identified for developing policy-relevant citizen science projects are generic concerns relevant to all citizen science projects:

- **Lack of sustainable funding**: the lack of adequate funding options, in particular to provide sustainable finance for the continuation of project activities and maintenance of the community, was a chief concern for many respondents, and principally for NGOs. This is a particular concern for achieving policy linkages, since achieving policy change and building the trust of communities and decision-makers is a lengthy process. Policy-relevant initiatives need mid-term/long-term maintenance (both in terms of funding and human resources)
- **Need for more support**: the need for guidance on how to organise citizen science activities was stressed, as well as request for improved academic implication and support to the NGOs that develop citizen science activities.
- **Connection to local actors**: accomplishing the linkages between policy-makers and the science and community on the ground is challenging
- **Engaging with the private sector**: the difficulty to involve industrial and business stakeholders was highlighted
- **Follow-up difficulty**: it is difficult for the project organisers to know whether their citizen science is used, by whom and how.

5.7 In summary

- Most surveyed projects provided easy engagement conditions for participants and relied mainly on websites and increasingly social media to communicate about their project. Monitoring projects attracted more participants, and government-led projects less participants than other categories of projects.
- The surveyed projects covered all temporal scales and spatial resolutions. They displayed good scientific data quality standards but often exhibited some form of restricted access and interoperability. The number of peer-reviewed scientific publications from the projects or citing the projects was greater for projects with higher number of data records, open access conditions and that received scientific endorsement.
- Contributions to policy were difficult to establish, and the survey suggests that citizen science project do not fulfil their full potential for policy, with over 80% of projects having potential to contribute to a given phase of the policy cycle, but only 16-58% actually contributing to policy. The likelihood of policy use increased with how easy the engagement process was for volunteers. Projects with high scientific standards and receiving scientific endorsement contributed to more phases of the policy cycle.
- Most surveyed projects were medium-sized, NGO-led and received their main funding from the EU or national governments. Support from the private sector was negligible. The case studies suggest that government involvement through funding and participation in the project appears key to improve policy-relevance. Government-led projects also had lower yearly investments than other categories of projects. Only 25% of the 32 projects that knew about their sustainability had a guaranteed funding structure.

- Some of the key challenges raised by respondents to achieve policy relevance are the long time scales and resources needed, as well as the resistance from decision-makers and the difficulty to connect with them. Other frequently reported issues concern identifying relevant policy questions, demonstrating data quality, achieving appropriate data scalability and ensuring sustained volunteer engagement.
- Key opportunities resulting from establishing policy linkages are the chance to promote a more open democracy, where citizens can make a difference, and the development of more timely, relevant and inclusive policy as well as research, promoting partnerships and collaborations.

6 Conclusions and recommendations

In this chapter, we draw out the key findings from our study, including the surveys and desk research, and suggest some recommendations for improving the use of citizen science in environmental policy.

6.1 Key findings

Some of the findings of the previous report of the European Commission (Science Communication Unit, University of the West of England, Bristol 2013) still hold good, in particular regarding the challenges and opportunities of citizen science. However, the present study, through a wider survey of projects, could enable insights into the relevance and usefulness of citizen science for environmental policy.

Citizen science can underpin environmental policy

The inventory shows the breadth of citizen science projects that can be of relevance to environmental policy. Citizen science projects have been developed in all environmental fields and are not limited to monitoring or occasional reporting activities, but include all types of citizen science. Nevertheless, crowd-sourcing and forms of citizen science involving use of participants resources or co-design with the participants remain scarce. This is probably more a consequence of the relative novelty of these types of citizen science activities, than because they are unsuitable. About a quarter of the selected projects (11 projects) involve such types of citizen science, and they are almost exclusively EU-funded (9 projects). Citizen science focused on the monitoring of natural resources, and nature and biodiversity in particular dominate the environmental citizen science landscape. But projects focused on resource efficiency in general (including sustainable production and consumption and waste) only represent 7% of the projects in the inventory and constitute a largely untapped potential for policy. The selection of practices highlights several examples of citizen science projects targeting resource efficiency that use more bottom-up forms of citizen engagement (crowd-sourcing, passive sensing) and lead to policy uptake (6 projects). There is also potential for developing more targeted projects, contributing to the study of environmental processes, or to more mechanistic or even experimental data collection.

Environmental SDGs are unevenly represented by the environmental citizen science

All SDGs are not equally well covered by the selected citizen science projects. In particular, projects in the inventory comprehensibly contribute less to goals with a strong socio-economic focus (e.g., SDGs 1, 5, 8, 10). Marine and terrestrial nature conservation are the goals that received the best direct contribution from citizen science projects inventory, reflecting the importance of nature and biodiversity monitoring projects in the inventory. In contrast, it is noteworthy that goals related to food and sustainable agriculture (SDG2), sustainable water management (SDG6), and to sustainable consumption and production (SDG12) received limited direct contributions from the projects in the inventory. All projects do not have the same potential for contributing the SDGs. Nature and biodiversity projects typically contributed to fewer SDGs than projects targeting resource efficiency issues (including sustainable production and consumption, waste), when considering both direct and indirect contributions. More bottom-up forms of citizen science, such as civic and DIY-engineering projects also have more potential for contributing to a diversity of SDGs. The in-depth analysis of selected projects reveals that the governance of the project is important in explaining how much a project contributes to SDGs. EU-funded projects and government-led projects contribute to a greater diversity of SDGs than other policy-relevant citizen science projects. This may be because these projects are more linked to policy processes: at least 60% of the Horizon 2020 budget is expected to involve sustainable development, and topics and selection criteria for research projects accordingly reflect the SDGs' objectives. Similar priorities are likely to apply in national governments.

Government support favours policy uptake

Based on the analysis of the selected projects, the uptake of citizen science in environmental policy is linked to a combination of governance and intrinsic characteristics of the projects. Government support, not only in the funding stages but also through active participation in the design of the project appears to be a key factor for the successful uptake of the project results in policy making. Government participation will not only facilitate policy use, but also broaden the policy relevance of projects: government-led projects typically contributed to more SDGs than other projects. It also guarantees the long-term availability of the data, an essential aspect when organisations are looking to use these data for their monitoring or for developing indicators. This study shows that government-led projects tended to attract less participants than NGOs or other actors, though – an aspect that would need further exploration to understand its underlying causes. Projects that provide a simpler engagement process for the volunteers also tend to be more used in policy. This does not appear to be linked to the number of participants in a project and may in fact suggest that projects that have developed an easy engagement process for volunteers may also better communicate their aims and outcomes to volunteers and decision-makers.

Facilitating citizen engagement promotes policy uptake

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 (Geoghegan et al., 2016). Among the selected policy-relevant projects, the likelihood for a project to be used in policy increased with the ease of engagement for participants (in terms of skills, efforts, support and feedback).

Scientific excellence increases the extent of policy use

Although the scientific dimension of the project did not affect the likelihood that a project was used for policy, it was a strong determinant how well the project could serve policy. Projects supported by academic institutions and that had high scientific standards and large geographical extent were more likely to contribute to different phases of the policy cycle. Moreover, the surveyed policy-relevant projects used good scientific data validation and quality assurance procedures. Nevertheless, the fact that several survey respondents identified data quality as a barrier to the use of citizen science for policy suggests the perception of these data by end-users remains biased, as was found elsewhere (Burgess et al. 2016). Despite an overall willingness to provide open data, the survey revealed that there are still a number of restrictions that apply to citizen science data, whether through outright restrictions to data access or through insufficient operationalisation of data licensing and downloading procedures.

NGOs are key actors of environmental citizen science

NGOs are the most prevalent leaders of environmental citizen science activities (41% of the projects in the inventory), and often key partners in projects they are not leading. In particular, NGOs often collaborate with academic institutions, to support them with the networking, communication, dissemination and community-building activities. NGOs may be well positioned to understand specific policy needs, whether at local or broader geographical scale, and give them an effective voice. The survey demonstrates that they are effective in harnessing broad stakeholders support and funding from various private and non-governmental sources. However, NGOs in our survey often reported organisational challenges, notably related to information access, funding, as well as to establish solid working relationships with academic institutions.

Policy use rests on the availability of sustainable business-models

Although 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. Moreover, end-users will only commit to using the data for policy if they can rely on a predictable data influx. This means that the sustainability of the data infrastructure and management is at least as important as that of the running of the project and maintaining the volunteer community. The survey suggests that there is a range of business models behind citizen science initiatives relevant for environmental policy, as reflected by the diversity of responses regarding the leadership and sustainability of data infrastructure, community and funding. Although citizen science appears to be more cost-effective that traditional science, it is not cheap. Survey respondents raised the need to identify funding opportunities to ensure mid-term to long-term maintenance. The private sector may currently represent an under-exploited opportunity to finance citizen science. Only 15% of the selected projects received some co-financing from private sector, and 2% had private companies as their main funder. Given that private capital investment in nature conservation and environmental projects in general has been steadily increasing over the last decade, this represents a considerable missed opportunity for citizen science funding. Moreover, the potential for contributing to citizen science by the private sector is large, both in terms of policy-relevance and volunteer engagement. The benefits such engagement can in return bring to the companies in terms of employee satisfaction and public image are similarly high.

A continuum of citizen science approaches to support policy

Our results confirm that environmental citizen science is a diverse continuum of approaches (Pocock et al., 2017), with no two projects applying similar approaches across the citizen, scientific and policy dimensions. Nevertheless, approaches seem to coalesce towards one distinct set of scientific approaches. Most projects in this study are already applying or converging towards similar approaches to training, data validation, data management and accessibility. On the other hand, it could be challenging to identify one standard for the citizen dimension. Instead, it is likely that a portfolio of best-practices, that can be tailored to the specific context of the project, based notably on the target audience, the project aims and technical requirements would be needed. It is important to match the needs for science and public involvement with the right type of citizen science project and method of participation. Regarding the policy dimension, it seems that methods to maximise impact are not fully-fledged. The analysed projects in this study highlight the importance of considering policy questions from the design stages of the project (e.g. Co-click'eau, Propage, SeaSearch, FreshWater Watch), and of governmental support and connection with policy-makers. But alternative pathways to policy use also seem to include projects that compile large amounts of data over broad spatio-temporal scales (e.g., MosquitoAlert, PECBMS, Phenowatch, Artportalen, Observatoire des Saisons), which provide policy-makers with an evidence base that can be repurposed to focus on a range of questions. An advantage of the latter option is the cost-savings that can be generated from re-purposing data to serve multiple objectives (Cooper et al., 2014). The recognition of the potential uses of citizen science for policy may still be too recent to have allowed the development of dedicated approaches to support and maximise policy linkages. Following section provides a number of recommendations for future increase of the citizen science impact, including all important policy dimensions (Figure 1).

6.2 Recommendations

6.2.1 Bridge the gaps between policy, scientists and the public

We underline a number of general recommendations to improve the linkages of citizen science and environmental policy. Some aspects of these are then taken up more specifically in the following sections.

- **Create place-based networks for collective impact** (Newman et al. 2017): while the ability of citizen science to create cross-border networks is one of its key strengths, its most unique potential for environmental policy may in fact lie in its ability create place-based network of interests, that draw on people's knowledge and affinity for their home environment to detect, collect and engage with environmental issues. There is a tremendous potential for such citizen science to increase meaningful citizen participation in local decision-making processes by capitalising on the shared sense of place of different citizen science networks.
- **Encourage active governmental support in all stages of the project:** to grant credibility to the project and promote policy linkages. Develop awareness-raising campaigns for local authorities about the potential of citizen science to leverage policy uses of citizen science at this level.
- **Pool citizen science information and resources:** Currently citizen science initiatives are disparate and a comprehensive overview of existing initiatives in a given area and topic is almost impossible to get. This hinders engagement and policy uses. Providing central networks can showcase and promote citizen initiatives, while offering opportunities for collaboration and sharing of tools and best-practices. Economies of scale can be achieved in this way, as collaborative communication platforms can be developed, or basic interfaces and tools can be shared. Such centralisation would ensure that the best possible return is achieved from investment in citizen science, and would provide a one-stop platform for accessing available citizen science resources.
- **Improve national coordination of citizen science activities:** There is a need of national coordination to promote the mutualisation and avoid overlaps/duplications among projects. National platforms should signal key national environmental targets, and current gaps and needs for their monitoring and evaluation, to facilitate the identification of key areas for the development of new science or citizen science programs.
- **Develop a rigorous methodology for the use of citizen science along the policy cycle:** The traceability of citizen science data should be improved, and good practices in reporting its use established.

6.2.2 Provide standards for interoperability of the citizen science data

The most commonly reported barrier to the use of citizen science data by scientists and decision-makers relates to lack of trust about the quality of the data (Burgess et al., 2017; McKinley et al., 2017). Although these concerns have lessened as the statistical methods to deal with large, imperfect datasets have improved, we need standards in citizen science data to provide interoperability and optimize the work done. There is already ongoing work in this direction (e.g. ECSA working group[18], CitSic.org platform). We recommend:

- **Document the data and its quality:** appropriate metadata should be provided to ensure the end-users fully understands the limitations of the data. The data collection protocols and quality assurance procedures should be documented within the metadata, to enable an assessment of potential sources of biases and uncertainties.
- **Identify global and national data repositories by specific topic of interest or environmental domain**, as well as the data standards they require, to facilitate the design of interoperable data by the citizen science project leaders. In turn, project leaders should identify a priori end user databases to guide which data needs and export formats will most easily facilitate the sharing of their data.
- **Promote open data** and platforms for data sharing, so as to increase the visibility of open citizen science data and create an incentive for project leaders to make their data fully accessible. Publish guidance about licensing issues and best-practices and resources for granting data access.
- **Develop a pipeline to connect citizen science data to policy-making processes:** Identify and compile the evidence needs to support policy across environmental domains, integrate and prioritise these needs according to their significance (urgency, size and feasibility to fill those evidence gaps) as well as taking into consideration the suitability of collection with citizen science data. Indeed, citizen science is not always the most cost-effective option, depending for instance on the type of data, the frequency, granularity and accuracy needed, or the cost of technology and risks in data collection. This can then be used to guide funding calls towards more specific aims, to ensure citizen science projects are targeted to the most relevant and pressing gaps and deliver policy-relevant outcomes.

6.2.3 Track the use of citizen science data by end-users

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 et al., 2014; Hyder et al., 2015). No systematic analysis of policy linkages is possible at present, since too many of the connections are anecdotal, potential or unmeasurable and untraceable. We recommend:

- **Inclusion of persistent identifiers to citizen science datasets.** Project owners should use persistent identifiers[19] such as Digital Object Identifiers (DOIs) used in scientific publications, to uniquely identify their datasets when they provide access. The use of some of the UK BioBlitz datasets from events that have been cited has been traced back in this way. Conversely, end-users should reference these DOIs when using the data, so as to provide traceability of datasets used in policy decisions. This would allow the owners of those

---

[18] https://ecsa.citizen-science.net/working-groups/projects-data-tools-and-technology. [accessed 12/09/2018]

[19] Some common identifiers of a publication or data include the author(s), the format, the institution, the funder, the publisher, any restrictions to access, and the repository or web site where it resides. A persistent identifier makes it easy to access a referenced source in a digital repository such as internet.

datasets to know when their data have been used, and in which context. This may in turn help them improve or complement the data collection, standards or infrastructure so as to better answer the policy questions.

- **Track environmental policy development, and progress towards its targets:** Tools could be developed to check whether a new policy is working, or how far it is still from its target, by identifying suitable indicators. The tool could be launched simultaneously with the policy and be used to raise awareness of the policy work. The data needed or used to monitor each indicator should be clearly referenced (see above), and opportunities for citizen science clearly flagged. Comprehensive assessment of progress could for instance be assessed through yearly horizon scanning of existing policies, to identify issues that need more evidence. A list could then be published to facilitate identification of those questions that need further research.

6.2.4 Match-making data needs with available resources

As accurately pointed out in a recent analysis of policy-relevant citizen science, 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 answer, with no or minor adjustments. Some recommendations to improve matching of the demand with the needs include:

- **Centralise end-user needs:** Create a central portal or interface where end-users can publicise their data needs. These portals could be made interactive by inviting citizen science projects to respond with appropriate data and methods. This could also be a way to channel citizen science efforts in a useful direction and to promote national coordination by avoiding the duplication of similar projects.
- **Centralise citizen science resources** on natural resource management and environmental protection at national level. Such national platforms have already been developed for some environmental fields (e.g. biodiversity) in some countries (e.g. Austria, France, Spain). But such platforms should not simply be a catalogue of existing initiatives, but a real portal for interaction, data integration and data visualisation, as exemplified with Artportalen. It could bring together leaders operating at different scales to develop solutions to shared and complex problems. It could also include guidance, tools and methods to help end-users make the most appropriate use of citizen science data. Finally, it could bring the citizen science community together, by highlighting opportunities, best-practices and advertising the richness of the data and impacts citizen science can have.
- **Connect with decision-makers**: there is a need to facilitate the connection and communication between decision-makers and project leaders. This may require the animation of events to offer opportunities to meet, and exchange, the promotion of professional social networks.
- **Identification of cost-effective policy monitoring options for citizen science**: expert assessment may be better suited and less costly than citizen science for some indicators.

6.2.5 Maximise the potential of environmental citizen science

This study revealed a number of unexploited, or insufficiently exploited opportunities to maximise the relevance of citizen science for environmental policy. These include:

- **Promote resource efficiency projects:** Citizen science targeting issues related to resource efficiency have a high impact potential, with clear policy relevance and many technology and engagement-based opportunities for contributions. For instance, the Smart citizen project provides an open source sensors for citizens to collectively monitor and share urban environmental data (about pollution, air quality, soil), or the Waste4Think project that develops citizen science activities to improve waste management (e.g. to map waste resources or games to foster the development of more sustainable products, such as coffee capsules). Financial and policy incentives should be provided to trigger the development of innovative citizen science projects that can help monitor the impacts of production and consumption, and share knowledge and resources.
- **Develop a database of bottom-up/community led projects:** It is unclear whether these projects simply do not exist, or whether they are not included in any databases or web pages. A comprehensive survey of bottom-up/community-led citizen science projects is needed, as well as policy to increase their visibility and connections, and possibly their number.
- **Provide tools and methods to promote the scalability of citizen science projects:** One of the key benefits of citizen science inputs is its ability to collect data across spatio-temporal scales. However, this is not without its challenges, to ensure appropriate standards and replicability is guaranteed across different contexts. The development of guidance, tools and networking resources would help project leaders achieve adequate scalability for their project.
- **Seek evaluation 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 provide a strong business case for their financing. Evaluation requirements should be embedded in EU or governmental funding of citizen science, with supporting guidance and criteria for how this should be done.
- **Improve support for NGOs:** Our survey shows that NGOs are the most prevalent leaders of citizen science activities in environmental domain, but often lack organisational, academic and financial support. Research funding or other dedicated funding mechanisms (e.g., LIFE, Structural Development Funds) should promote NGO participation, and NGO-academic partnerships in citizen science.
- **Increase the participation of the private sector:** The potential of the private sector to contribute to environmental citizen science, both in terms of person-time and financing, is largely unexploited. Businesses present high opportunities for meaningful citizen engagement in environmental research, that can increase employee satisfaction and retention, and increase employee commitment to take environmental action in their company. For example, Earthwatch has been working with the corporate sector for over two decades by providing different options for employee engagement in environmental research. Additionally, business sites themselves can be the subject of citizen science activities with high potential to support biodiversity conservation (Snep et al., 2011). Finally, private companies can financially support citizen science activities, and even chose specifically activities that align with their business activities. We recommend increasing the awareness of private actors about the potential impacts of environmental citizen science. This could be achieved by sharing best-practices, or demonstrating the multiple benefits to be gained by companies. This promotional work could lead to the creation of a dedicated

portal, or add on to existing portals and business networks (e.g., the Business and Biodiversity platform). Incentives should be provided for the financing of environmental citizen science activities by the private sector (e.g. in the form of competitive grants, calls for innovation), or through innovative ways to grant companies sustainability credentials for financing such activities, if they contribute to environmental policy. Such programs should however ensure credible commitment from companies to improve their environmental sustainability.

6.2.6 Provide sustainability options

Citizen science can be cost-effective, but requires investment, and long-term sustainability needs to be ensured to facilitate policy uses. It is important to:

- **Ensure adequate resources are available**: this requires not only start-up budgets, but ensuring financing options for the project continuation, and making sure these are adequately communicated to the project leaders.
- **Promote the sharing and re-use of data management tools**: provide a repository of data methods and tools in an open-source format, to allow for updating existing tools before designing purpose-built ones *de novo*.

6.3 Conclusions

The value of citizen science thus spans across the scientific, social and political dimensions. Citizen science projects can pursue basic or applied science, and be a cost-effective way to collect evidence, fill in knowledge gaps, monitor environmental baselines, respond to crises and inform management actions. They can tackle issues at local, regional or global scales. Volunteers can participate in scientific processes and feel invigorated by the fact that they can make a difference through their contributions. Citizen science encourages engagement between members of the public and decision-makers and may help to enhance the debate around the science policy interface. The role of science in policy-making has changed over time, and co-production of knowledge by technical experts and members of the public is likely to be very important in future decision-making and can help develop trust. It is a great tool to implement more adaptive forms of management. The process of engaging many actors in the collection of monitoring data could also enhance public engagement in addressing global concerns, and transform international agreements to instruments of change (Theobald et al., 2015). But care must be taken not to erode support and trust for environmental policy in the process, as expectations from citizens may be too high, and decision-making processes can be long, complex. Whilst many of our recommendations urge for improved centralisation, standards and sharing of citizen science resources, this should not be seen as a call to streamline citizen science activities, but rather as a tool to foster its diversity and maximise its impact.

7 References

Arlettaz, R., Schaub, M., Fournier, J., Reichlin, T.S., Sierro, A., Watson, J.E.M., & Braunisch, V. (2010) From Publications to Public Actions: When Conservation Biologists Bridge the Gap between Research and Implementation. BioScience, 60, 835–842.

Battistelli, F., Minutolo, A., Scialoja, A., Zampetti, G., Schäfer, T., Kieslinger, B., García González, M., Egger, S. (2017) Engagement and empowerment report for citizen science. Horizon 2020 project Collective Awareness Platform for Tropospheric Ozone Pollution, Deliverable 4.4.

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 late lessons project.

Bikhchandani, S., Hirshleifer, D., Welch, I. (1992). A theory of fads, fashion, custom, and cultural-change as informational cascades. J. Polit. Econ. 100, 992–1026.

Blaney, R.J.P., Pocock, M., & Jones, G.D. (2016) Citizen science and environmental monitoring: towards a methodology for evaluating opportunities, costs and benefits. UK Environmental Observation Framework.

Boakes, E.H., Gliozzo, G., Seymour, V., Harvey, M., Smith, C., Roy, D.B., & Haklay, M. (2016) Patterns of contribution to citizen science biodiversity projects increase understanding of volunteers' recording behaviour. Scientific Reports, 6, 33051.

Bonn, A. (2016) Green Paper. Citizen Science Strategy 2020 for Germany. Projekt "Bürger schaffen Wissen-Wissen schafft Bürger"(GEWISS).

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

Bonney, R., Shirk, J.L., Phillips, T.B., Wiggins, A., Ballard, H.L., Miller-Rushing, A.J., & Parrish, J.K. (2014) Next steps for citizen science. Science, 343, 1436–1437.

Burgess, H.K., DeBey, L.B., Froehlich, H.E., Schmidt, N., Theobald, E.J., Ettinger, A.K., HilleRisLambers, J., Tewksbury, J., & Parrish, J.K. (2017) The science of citizen science: Exploring barriers to use as a primary research tool. Biological Conservation, 208, 113–120.

Chandler, M., See, L., Buesching, C.D., Cousins, J.A., Gillies, C., Kays, R.W., Newman, C., Pereira, H.M., & Tiago, P. (2017a) Involving Citizen Scientists in Biodiversity Observation. The GEO Handbook on Biodiversity Observation Networks (ed. by M. Walters and R.J. Scholes), pp. 211–237. Springer International Publishing, Cham.

Chandler, M., See, L., Copas, K., Bonde, A.M.Z., López, B.C., Danielsen, F., Legind, J.K., Masinde, S., Miller-Rushing, A.J., Newman, G., Rosemartin, A., & Turak, E. (2017b) Contribution of citizen science towards international biodiversity monitoring. Biological Conservation, 213, 280–294.

Coletti, M., Hultquist, C., Kennedy, W.G., & Cervone, G. (2017) Validating Safecast data by comparisons to a U. S. Department of Energy Fukushima Prefecture aerial survey. Journal of Environmental Radioactivity, 171, 9–20.

Conrad, C.C. & Hilchey, K.G. (2011) A review of citizen science and community-based environmental monitoring: issues and opportunities. Environmental Monitoring and Assessment, 176, 273–291.

Cooper, C.B., Dickinson, J., Phillips, T., & Bonney, R. (2007) Citizen Science as a Tool for Conservation in Residential Ecosystems. Ecology and Society, 12.

Cooper, C.B., Shirk, J., & Zuckerberg, B. (2014) The Invisible Prevalence of Citizen Science in Global Research: Migratory Birds and Climate Change. PLoS ONE, 9, e106508.

Crowdsourcing and Citizen Science Act of 2016 (15 USC 3724). https://www.citizenscience.gov/about [accessed 09/09/2018]

Danielsen, F., Pirhofer-Walzl, K., Adrian, T.P., Kapijimpanga, D.R., Burgess, N.D., Jensen, P.M., Bonney, R., Funder, M., Landa, A., Levermann, N., & Madsen, J. (2014) Linking Public Participation in Scientific Research to the Indicators and Needs of International Environmental Agreements: Monitoring environmental agreements. Conservation Letters, 7, 12–24.

Davies, L., Gosling, L., Bachariou, C., Eastwood, J., Fradera, R., Manomaiudom, N., Robins, S. (Eds) (2013). OPAL Community Environment Report: Exploring Nature Together. Open Air Laboratories (OPAL), London. 1-84.

Devictor, V., Whittaker, R.J., & Beltrame, C. (2010) Beyond scarcity: citizen science programmes as useful tools for conservation biogeography: Citizen science and conservation biogeography. *Diversity and Distributions*, **16**, 354–362.

Dickinson, J.L., Zuckerberg, B., & Bonter, D.N. (2010) Citizen Science as an Ecological Research Tool: Challenges and Benefits. Annual Review of Ecology, Evolution, and Systematics, 41, 149–172.

Donald, P.F., Green, R.E., & Heath, M.F. (2001) Agricultural intensification and the collapse of Europe's farmland bird populations. Proceedings. Biological sciences / The Royal Society, 268, 25–29.

Dunn, G. & Laing, M. (2017) Policy-makers perspectives on credibility, relevance and legitimacy (CRELE). Environmental Science & Policy, 76, 146–152.

Emilia, C., Lorène, P., Laurence, G., & Raymond, R. (2014) Re-thinking agricultural practices to improve water quality: two participatory methodologies for collaborative learning. 688–700.

European Environment Agency. (2011). Summary report of the EEA workshop lay, local, traditional knowledge and citizen science: their roles in monitoring and assessment of the environment; 27-28 June 2011.

Earthwatch Institute, (2017). Report and financial statements 2017. https://earthwatch.org.uk/who-we-are/annual-reviews-and-reports

Forrester, G., Baily, P., Conetta, D., Forrester, L., Kintzing, E., & Jarecki, L. (2015) Comparing monitoring data collected by volunteers and professionals shows that citizen scientists can detect long-term change on coral reefs. Journal for Nature Conservation, 24, 1–9.

ECSA (2015) Ten principles of citizen science. European Citizen Science Association, September 2015, London.

Forrester, G., Baily, P., Conetta, D., Forrester, L., Kintzing, E., & Jarecki, L. (2015) Comparing monitoring data collected by volunteers and professionals shows that citizen scientists can detect long-term change on coral reefs. *Journal for Nature Conservation*, **24**, 1–9.

Fritz, S., Costa Fonte, C., See, L. (2017) The role of citizen science in Earth observation. Remote Sensing 9(4):357-370. DOI: 10.3390/rs9040357

Gardiner, M.M., Allee, L.L., Brown, P.M., Losey, J.E., Roy, H.E., & Smyth, R.R. (2012) Lessons from lady beetles: accuracy of monitoring data from US and UK citizen science programs. Frontiers in ecology and the environment.

Geoghegan, H., Dyke, A., Pateman, R., West, S. & Everett, G. (2016) Understanding motivations for citizen science. Final report on behalf of UKEOF, University of Reading, Stockholm Environment Institute (University of York) and University of the West of England.

Gold, M. (2018) D2.1 EU Citizen Observatories Landscape Report - Frameworks for mapping existing CO initiatives and their relevant communities and interactions, WeObserve Final draft report.

Hadj-Hammou, J., Loiselle, S., Ophof, D., & Thornhill, I. (2017) Getting the full picture: Assessing the complementarity of citizen science and agency monitoring data. PLOS ONE, 12, e0188507.

Haklay, M. (2015) Citizen science and policy: a European perspective. The Wodrow Wilson Center, Commons Lab, .

Hames, R.S., Rosenberg, K.V., Lowe, J.D., Barker, S.E., & Dhondt, A.A. (2002) Adverse effects of acid rain on the distribution of the Wood Thrush Hylocichla mustelina in North America. Proceedings of the National Academy of Sciences, 99, 11235–11240.

Hochachka, W.M., Fink, D., Hutchinson, R.A., Sheldon, D., Wong, W.-K., & Kelling, S. (2012) Data-intensive science applied to broad-scale citizen science. Trends in Ecology & Evolution, 27, 130–137.

Holmes, J. & Clark, R. (2008) Enhancing the use of science in environmental policy-making and regulation. Environmental Science & Policy, 11, 702–711.

Hurlbert, A.H. & Liang, Z. (2012) Spatiotemporal Variation in Avian Migration Phenology: Citizen Science Reveals Effects of Climate Change. PLoS ONE, 7, e31662.

Hyder, K., Townhill, B., Anderson, L.G., Delany, J., & Pinnegar, J.K. (2015) Can citizen science contribute to the evidence-base that underpins marine policy? Marine Policy, 59, 112–120.

INRA, 2016. Les sciences participatives en France: Etat des lieux, bonnes pratiques et recommendations. Rapport d'etude pour le Ministere de l'Education, Enseignment Superieur et de la Recherche, Fevrier 2016.

Jiguet, F., Devictor, V., Julliard, R., & Couvet, D. (2012) French citizens monitoring ordinary birds provide tools for conservation and ecological sciences. Acta Oecologica, 44, 58–66.

Kieslinger, B., Schäfer, T., Heigl, F., Dörler, D., Richter, A., & Bonn, A. (2017) The Challenge of Evaluation: An Open Framework for Evaluating Citizen Science Activities..

Kullenberg, C. & Kasperowski, D. (2016) What is citizen science?–A scientometric meta-analysis. PloS one, 11, e0147152.

Leidenberger, S., Käck, M., Karlsson, B., & Kindvall, O. (2016) The Analysis Portal and the Swedish LifeWatch e-infrastructure for biodiversity research. Biodiversity Data Journal, 4, e7644.

Levrel, H., Fontaine, B., Henry, P.-Y., Jiguet, F., Julliard, R., Kerbiriou, C., & Couvet, D. (2010) Balancing state and volunteer investment in biodiversity monitoring for the implementation of CBD indicators: A French example. Ecological Economics, 69, 1580–1586.

Lin, Y.-P., Deng, D., Lin, W.-C., Lemmens, R., Crossman, N.D., Henle, K., & Schmeller, D.S. (2015) Uncertainty analysis of crowd-sourced and professionally collected field data used in species distribution models of Taiwanese moths. Biological Conservation, 181, 102–110.

McKinley, D.C., Briggs, R.D., & Bartuska, A.M. (2012) When peer-reviewed publications are not enough! Delivering science for natural resource management. Forest Policy and Economics, 21, 1–11.

McKinley, D.C., Miller-Rushing, A.J., Ballard, H.L., et al. (2017) Citizen science can improve conservation science, natural resource management, and environmental protection. Biological Conservation, 208, 15–28.

Newman, G., Chandler, M., Clyde, M., McGreavy, B., Haklay, M., Ballard, H., Gray, S., Scarpino, R., Hauptfeld, R., Mellor, D., & Gallo, J. (2017) Leveraging the power of place in citizen science for effective conservation decision making. Biological Conservation, 208, 55–64.

Pereira, H.M., Ferrier, S., Walters, M., et al. (2013) Essential Biodiversity Variables. Science, 339, 277–278.

Pocock, M.J.O., Chapman, D.S., Sheppard, L.J., & Roy, H.E. (2014) Choosing and using citizen science: a guide to when and how to use citizen science to monitor biodiversity and the environment.

Pocock, M.J.O., Tweddle, J.C., Savage, J., Robinson, L.D., & Roy, H.E. (2017) The diversity and evolution of ecological and environmental citizen science. PLOS ONE, 12, e0172579.

Roy, H.E., Pocock, M.J.O., Preston, C.D., Roy, D.B., Savage, J., Tweddle, J.C., & Robinson, L.D. (2012) Available at: http://www.ukeof.org.uk/documents/understanding-citizen-science.pdf.

Schade, S., Manzoni, M., Tsinaraki, C., Kotsev, A., Fullerton, K.T., Sgnaolin, R., Spinelli, F., Mitton, I., European Commission, & Joint Research Centre (2017a) Using new data sources for policymaking.

Schade, S., Tsinaraki, C., & Roglia, E. (2017b) Scientific data from and for the citizen. First Monday, 22, 8.

Schade, S., Tsinaraki, C., European Commission, & Joint Research Centre (2016) Survey report: data management in citizen science projects. Publications Office, Luxembourg.

Schuttler, S.G., Sorensen, A.E., Jordan, R.C., Cooper, C., & Shwartz, A. (2018) Bridging the nature gap: can citizen science reverse the extinction of experience? Frontiers in Ecology and the Environment, 16, 405–411.

Science Communication Unit, University of the West of England, Bristol (2013) Science for Environment Policy In-depth Report: Environmental Citizen Science. Report produced for the European Commission DG Environment, December 2013. Available at: http://ec.europa.eu/science-environment-policy

Science Europe, 2018. Briefing paper on citizen science. June 2018. D/2018/13.324/2

Shirk, J.L., Ballard, H.L., Wilderman, C.C., Phillips, T., Wiggins, A., Jordan, R., McCallie, E., Minarchek, M., Lewenstein, B.V., Krasny, M.E., & Bonney, R. (2012) Public Participation in Scientific Research: a Framework for Deliberate Design. Ecology and Society, 17, .

Snep, R. P. H., WallisDeVries, M., & 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.

Socientize consortium (2014). White paper on citizen science for Europe.

Socientize (2014). Citizen science for Europe: towards a better society of empowered citizens and enhanced research. Green paper on citizen science for Europe.

Sullivan, B.L., Phillips, T., Dayer, A.A., Wood, C.L., Farnsworth, A., Iliff, M.J., Davies, I.J., Wiggins, A., Fink, D., Hochachka, W.M., Rodewald, A.D., Rosenberg, K.V., Bonney, R., & Kelling, S. (2017) Using open access observational data for conservation action: A case study for birds. Biological Conservation, 208, 5–14.

Theobald, E.J., Ettinger, A.K., Burgess, H.K., DeBey, L.B., Schmidt, N.R., Froehlich, H.E., Wagner, C., HilleRisLambers, J., Tewksbury, J., Harsch, M.A., & Parrish, J.K. (2015) Global change and local solutions: Tapping the unrealized potential of citizen science for biodiversity research. Biological Conservation, 181, 236–244.

Thornhill, I., Loiselle, S., Lind, K., & Ophof, D. (2016) The citizen science opportunity for researchers and agencies. BioScience, 66, 720–721.

Tregidgo DJ, West SE, Ashmore MR (2013) Can citizen science produce good science? Testing the OPAL Air Survey methodology, using lichens as indicators of nitrogenous pollution. Envir Pollut 182: 448–451.

Tulloch, A.I.T., Possingham, H.P., Joseph, L.N., Szabo, J., & Martin, T.G. (2013) Realising the full potential of citizen science monitoring programs. Biological Conservation, 165, 128–138.

Turrini, T., Dörler, D., Richter, A., Heigl, F., & Bonn, A. (2018) The threefold potential of environmental citizen science - Generating knowledge, creating learning opportunities and enabling civic participation. Biological Conservation, 225, 176–186.

Tweddle, J.C., Robinson, L.D., Pocock, M.J.O., & Roy, H.E. (2012) Guide to citizen science: developing, implementing and evaluating citizen science to study biodiversity and the environment in the UK. NERC/Centre for Ecology & Hydrology,

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

Vorisek, P., Foppen, R., Gregory, R. (2015) The European bird monitoring programmes as examples of citizen science relevant to policy and research. Proceedings of the conference New Techniques and Technologies for Statistics, Brussels, March 2015. DOI: 10.2901/EUROSTAT.C2015.001

Weichselgartner, J. & Kasperson, R. (2010) Barriers in the science-policy-practice interface: Toward a knowledge-action-system in global environmental change research. Global Environmental Change, 20, 266–277.

West, S. & Pateman, R. (2016) Recruiting and retaining participants in citizen science: what can be learned from the volunteering literature? Citizen science: theory and practice, 1(2): 15, pp. 1–10, DOI: https://doi.org/10.5334/cstp.8

Ziegler, D., Mascarenhas, A. (2017) Networks for citizen science in Europe and Germany. Future of food: Journal on Food, Agriculture and Society,5 (3), 68-71.

Annex 1 – EU Survey

Survey format

The survey was launched on the 28th of January 2018 via email and social networks. It was opened for a month, but answers received after the closure were retained. The main message that was spread is shown below, with some minor adaptations according to the target audience.

`** Apologies if you receive multiple copies of this mail`

`The European Commission is increasingly recognizing the potential of citizen science to support environmental policy decisions, notably by contributing to the knowledge base needed for policy-making and by improving public engagement. However, this potential still remains largely untapped. The European Commission would thus like to take a step towards the better integration of citizen science into policy by exploring the conditions for its reliable and efficient use in policy.`

`A consortium formed by BIO Innovation Service, Ibercivis and the Natural History Museum in London is developing an inventory of environmental citizen science initiatives taking place at EU, regional or national level to explore their contribution to environmental policy-making.`

`If you are leading, funding or know about relevant citizen science initiatives or platform in your country with potential or actual effects on any step of the policy cycle (awareness-raising, early-warning, policy development or implementation, monitoring or evaluation, compliance or complaint handling), then please let us know – https://goo.gl/forms/GwpIvp8TOyCH8clJ2.`

`We will acknowledge your contribution in the study report. Do not hesitate to share this mail with your contacts. We would be grateful for your contributions by 2nd February 2018 preferably. Thanks in advance.`

Dissemination list

The survey was disseminated to 12 citizen science e-mailing lists, such as those of the ECSA, Lifewatch, and CSEU, as well as to a mailing list of 517 representatives of EU-funded citizen observatories or activities within the professional network of the project team. The survey was also spread through Environmental Knowledge Community (EKC) on citizen science, including DG ENV, DG RTD, JRC, EEA, EASME.

List name	Contact
EU citizen science association (ECSA)	ECSA-ALL@listserv.dfn.de
ECSA Steering Committee	ECSA-SC@listserv.dfn.de
CSEU network	cseu-info@listserv.dfn.de
EU COST action CA15212	citizencostwg3@googlegroups.com
EU Biodiversity Observation Network distribution list	associates@eubon.eu
European BioBlitz Network	mailing list c/o Gaia Agnello
LifeWatch Competence Center	cc-lifewatch@mailman.egi.eu
Science communication mailing list	psci-comm@jiscmail.ac.uk (4438 recipients)
Cornell Citizen Science discussion list	CitSci-discussion-L@cornell.edu
Foro de ciencia ciudadana	CITSCIENCE@listserv.rediris.es
BES Citizen science	BES-CITIZENSCIENCE@jiscmail.ac.uk
UK National Biodiversity Network	
LinkedIn groups	
Sustainability professionals	
Biodiversity professionals	
Cambridge Conservation Forum	
Natura 2000 International	
Society for Conservation Biology	
Professional contacts	
Personal email	516 colleagues working with citizen science
EC policy network	
EKC on citizen science	

Annex 2 – Data analysis

Table A1 - Effect sizes and standard errors of minimum adequate linear model explaining the diversity of SDGs directly contributed by the projects in the citizen science inventory of environmental relevance. Significance levels are shown: * p<0.05, ** p<0.01, *** p<0.001. Empty cells are for variables that were dropped during the model selection process.

Table A2 – Effect sizes and standard errors of minimum adequate linear models explaining the (i) number of participants, (ii) number of scientific publications, (iii) policy uptake, (iv) diversity of policy phases, (v) diversity of sustainable goals and (vi) yearly budget of best-practice citizen science projects of environmental policy relevance. Significance levels are shown: * p<0.05, ** p<0.01, *** p<0.001. Empty cells are for variables that were dropped during the model selection process.

Table A.1

		Diversity of SDGs (direct)
Intercept		3.84 ± 0.42
Environm	Air quality (reference)	-
	Nature and biodiversity	-0.44 ± 0.25
	Climate	1.01 ± 0.39*
	Cross-cutting	1.12 ± 0.52*
	Efficient use of resources	-0.23 ± 0.42
	Environmental health	2.45 ± 0.55***
	Land and soil	-0.57 ± 0.41
	Other	0.83 ± 0.55
	Sustainable production and cor	1.40 ± 0.46**
	Waste	0.00 ± 0.53
	Water	0.14 ± 0.34
Project ca	Civic science (reference)	-
	Crowd-sourcing	-1.75 ± 0.40***
	DIY engineering	-0.44 ± 0.48
	Monitoring	-2.06 ± 0.36***
	Occasional reporting	-2.34 ± 0.38***
	Passive sensing	-2.54 ± 0.76***
	Volunteer computing	-3.84 ± 1.37**
Lead organisation		NS
Project age		NS

Table A.2

		Number of participants	Number of peer-reviewed publications	Policy uptake	'sity of policy phases	Diversity of SDGs	Yearly budget
		Linear model, n=39	*Linear model, n=33*	*Binomial model, n=39*	*Linear model, n=39*	*Linear model, n=39*	*Linear model, n=31*
Intercept		2.35 ± 0.61***	-0.77 ± 0.26	4.91 ± 2.59.	-0.48 ± 0.83	3.20 ± 0.56***	1,164,028.00 ± 340,696.00
Project category	Crowd-sourcing (reference)	-	NS	NS	NS	NS	NS
	Monitoring	1.34 ± 0.57*	-	–	-	-	-
	Occasional reporting	0.31 ± 0.64	-	–	-	-	-
	Other	-0.60 ± 0.76	-	–	-	-	-
Lead organisation	Academic (reference)	-	NS	NS	NS	-	-
	Consortium	-0.05 ± 0.51	-	–	-	-0.81 ± 0.79	
	Governmental	-2.65 ± 0.80**	-	–	-	1.92 ± 1.25	*None*
	Non-governmental	-0.11 ± 0.40	-	–	-	-0.56 ± 0.71	
Main funding organisation	EU	Not in model	Not in model	Not in model	Not in model	-	–
	National					-1.90 ± 0.66**	-706,125.00 ± 268,025.00*
	NGO					-1.43 ± 0.87	-702,194.00 ± 292,101.00*
	Other					-1.24 ± 0.75	-604,318.00 ± 265,683.00*
Personnel	2 or less	NS	Not in model	Not in model	Not in model	Not in model	
	More than 2	-					
Spatial extent (n countries)		0.01 ± 0.01.	0.00 ± 0.00*	NS	0.02 ± 0.01*	-	NS
Age of the project		NS	0.00 ± 0.00.	0.08 ± 0.07*	NS	-	NS
Number of records (Log+1)		Not in model	0.28 ± 0.04***	Not in model	Not in model	Not in model	NS
Number of participants (Log+1)		Not in model	Not in model	Not in model	Not in model	Not in model	-193,707.00 ± 78,572.00*
Index Ease of engagement		NS	Not in model	-2.43 ± 1.46*	NS	Not in model	Not in model
Social media page	No	NS	Not in model	Not in model	Not in model	Not in model	Not in model
	Yes						
Main media		NS	Not in model	Not in model	Not in model	Not in model	Not in model
Academic endorsement	No	NS		NS	-	-	Not in model
	Yes	-	0.26 ± 0.17*	-	1.26 ± 0.54*		
Governmental endorsement	No	Not in model	Not in model	NS	NS	-	Not in model
	Yes			-	-		
Index of scientific quality		Not in model	NS	NS	0.16 ± 0.11	Not in model	Not in model
Access conditions	None	Not in model	NS	Not in model	Not in model	Not in model	Not in model
	Restricted		0.18 ± 0.22				
	Open		0.35 ± 0.21*				

European
Commission

KH-03-18-528-EN-N