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Citizen science and Post-Normal Science's extended peer community: Identifying overlaps by mapping typologies

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ABSTRACT

At first sight, citizen science – the opening of scientific enterprise to a wider group of people, many of whom are not professionally engaged in research institutions, seems to align well with the concept of an extended peer community of the framework of Post-Normal Science (PNS). PNS is concerned with the social robustness of applied science, science-based professional consultancy, and scientific advice for policy in situations of high stakes, high uncertainties, and contested values. Creating opportunities for engagement of citizens in science seems an obvious fit – but is that true for all diverse forms that citizen science can take? Current citizen science includes many types of activities and practices. As a result, the role of the participants within a given scientific knowledge production practice and their relation to scientists vary. This paper leverages the PNS framework to gain a more in-depth understanding of different ways in which diverse citizen science initiatives can contribute to improving the science-policy interface and provide tool sets and approaches for extended peer review, or not. For this purpose, this paper develops an analytic framework drawing on several widely used typologies of citizen science. The twenty four activities and practices of citizen science that they cover are mapped onto different zones of problem solving strategies – applied science, professional consultancy, and post-normal science, which are presented in the literature on PNS in terms of uncertainty and decision stakes while also noticing their value conflicts and urgency. The analysis shows that each of the four zones of scientific activities can be associated with citizen science initiatives. We deduce that citizen science is not automatically imbued with transformative potential, but that this potential depends on the purpose and design of the citizen science initiative. Certain types of citizen science activities and approaches are more relevant to researchers and practitioners with an interest in PNS who are actively seeking to reconfigure the science-policy-practice interface than others. This analytic framework and consequent mapping can support PNS practitioners in identifying the type of citizen science activities and designing fit-for-purpose initiatives. Moreover, the mapping exercise conveys a more nuanced understanding of different possible dimensions, merits, and limitations of the extended peer community concept. Similarly, for citizen science researchers and practitioners, the mapping of typologies within the three zones of problem solving strategies can allow a better selection of citizen science activities for those purposes.

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1. Introduction

According to Smallman et al. (2020), the late 1980s and early 1990s moved the issue of the public's interaction with the scientific enterprise into the spot-light. A series of consecutive environmental health-and-safety crises raised serious questions on the role of science and scientific experts in informing practice and policy; issues included scandals of dioxins and salmonella in large-scale egg production, bovine spongiform encephalopathy or BSE disease in cattle, and the nuclear disaster of Chernobyl. The ensuing media coverage and public debate demonstrated the flaws of the "Information Deficit Model," which suggested that the problem with public acceptance of the views of scientific experts can be solved by improving the communication of the scientific advice. Attention was directed to the value of diverse types of knowledge in relation to complex issues such as sources of direct and indirect exposure of nuclear fall-out (Wynne, 1989) when configuring the science-policy interface. The seminal paper on Post-Normal Science (PNS) by Funtowicz & Ravetz, 1993 thus fell on fertile grounds with its call for engagement of an extended peer community to review claims of science and experts, has an important role to play, particularly in situations of high stakes and high uncertainties. Ravetz describes the extended peer community as "all those with a desire to participate in the resolution of the issue." (Ravetz, 1999, p. 651). Citizen science is the participation of members of the public in scientific or research project (Haklay, 2013). Thanks to mobile phones, software applications (apps), and sensors, the quantity and diversity of citizen science projects have expanded quickly in recent decades. Based on this, citizen science is easily linked to an extended peer community, since within the area of citizen science, participants are joining scientists in addressing a problem. Hence, at a simplistic level, citizen science is a form of the extended peer community.

Yet, a second look at the wide range of diverse aims of citizen science initiatives and the declared purpose of extended peer communities within PNS raises interesting considerations. This study analyses the relationship between citizen science and the PNS framework, beginning with basic definitions to develop an analytic framework to map citizen science activities onto different forms of science-based strategies to address problems that are identified within PNS. The mapping exercise can help PNS practitioners determine if and where citizen science activities align with the extended peer community concept, providing a deeper view of the concept's benefits and limits. Mapping typologies within the three PNS problem solving zones can help citizen science researchers and practitioners plan or choose activities with distinct qualities that satisfy diverse demands at the science-policy interface. The mapping exercise gives citizen scientists and the PNS community a fresh look at how links between scientists and non-scientists might evolve based on shared purpose and activity design.

Post-Normal Science calls for the reconfiguration of the interactions between science, policy, and the public by observing that in policy problems where "facts are uncertain, values in dispute, stakes high and decisions urgent" (ibid. p. 744). In such situations, transdisciplinary dialogues are demanded to focus this interaction on decision quality and pluralistic use of scientific information. Funtowicz and Ravetz ask for a larger range of stakeholders to be included in the assessment and use of knowledge. To make them active decision makers, they propose an "extended peer community" that uses "extended facts" (Ravetz, 1999, p. 647). Extended facts mean evidence build upon experiences, knowledge, and contextual understanding that differ from the traditional linear approach used

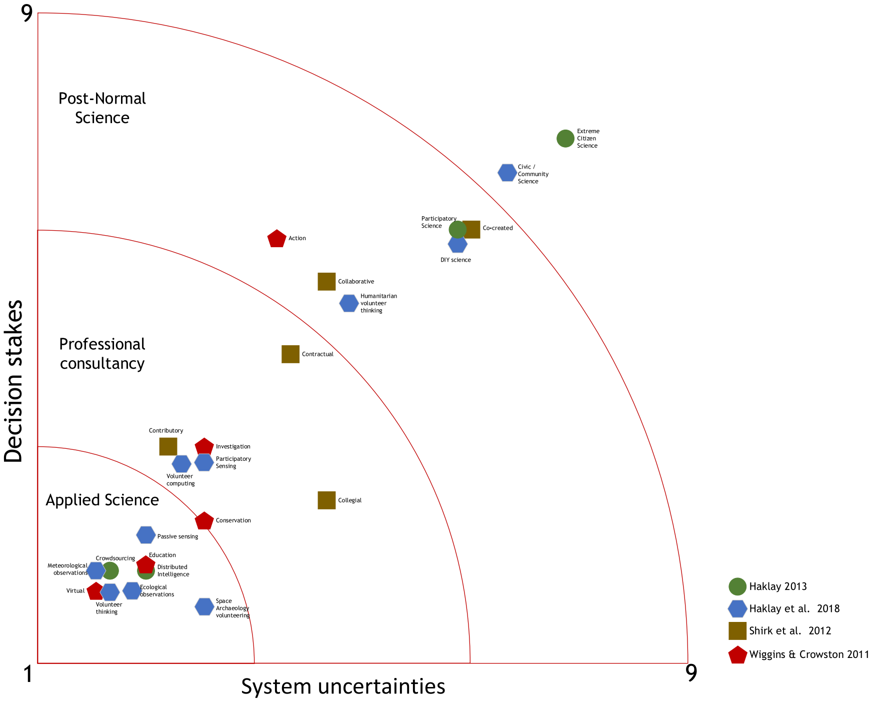

Fig. 1. Mapping the four typologies onto problem-solving strategies zones. The position of each emphasis type is the average of all evaluated. Notice that Education and Distributed intelligence are sharing the exact same values (see appendix).

by the normal practice of science, with a focus only on empirically measured and modelled "facts", which is not always a good fit for facing non-linear and urgent problems. The analysis identifies three modes (or zones) in which science, policy, and practice can interact (See Fig. 1 and Funtowicz & Ravetz, 1993, Ravetz, 1999). At the bottom of Fig. 1, where uncertainties and stakes are very low, sits "basic" or "pure" research in which curiosity-driven research takes place within the existing paradigms of a research area (e.g., answering a question about the details of the creation of galaxies without challenging fundamental theories) such research is low on the decision stakes and low on system uncertainties since there is no direct expectation of a policy impact. The next area that is "applied science." This is an area with low system uncertainties and decision stakes to such an extent that some of the scientific processes can be automated by simple or sophisticated machines. The contribution to decision making is also routine and codified. When either the stakes or the uncertainties are considerable, we move to "professional consultancy" in which the knowledge and experience of scientists, and other technical experts, such as engineers, is used to support decision making. The process is relying on state of the art in scientific knowledge as practised by experts who use their judgement, and therefore it is still within "normal" science. Finally, when uncertainty is very high or decision stakes are very high (or both), we are entering the conditions of post-normal science. The "post-normal" is to indicate that it is operating beyond the scope of Kuhn (1962) identification of normal science as a structured problem-solving activity within existing paradigms and disciplinary understanding of the world, and the normal way of policy making.

Funtowicz and Ravetz did not stand alone in identifying the need for changes in the relationships between science and society. Other researchers were also calling for the deeper involvement of the public in scientific practice. For example, by highlighting the value of local and lay knowledge (Wynne, 1991) or through the suggestion for the possibility of "citizen science" (Irwin, 1995). Irwin is addressing a similar problem to the one that PNS is aiming at — how to integrate public knowledge and views into (mostly environmental) decision-making that relies on scientific analysis. Moreover, his analysis is about achieving such integration in a way that appreciates local lived knowledge, understanding of context when there are many uncertainties and, for the communities that are involved, the stakes are high. It is noteworthy that Irwin (1995) refers to PNS in his book (p. 172) and identifies extended peer community as a highly relevant concept for his formulation of citizen science. Thus, PNS and citizen science have been linked since their early emergence. At the same time, citizen science is hinted at in Funtowicz and Ravetz (1993) in the form of popular epidemiology, in which the participants are carrying out the research from setting the question to the utilisation of the resulting knowledge.

Noteworthy is the other strand of framing citizen science, offered independently by Rick Bonney at the Cornell Lab of Ornithology (Bonney, 1996) which is linked to the empiricism that is an integral part of the natural sciences. This interpretation is seeing citizen science as public participation in scientific research through data collection and sharing of observations with professional scientists. This information is then used to achieve a common goal — such as the protection of birds. These two strands, which Cooper and Lewenstein (2016) call "Democratic" (Irwin) and "Contributory" (Bonney) are not mutually exclusive, rather they can be seen as different and at times complementary facets of citizen science, with a possibility to reconcile both within projects that find a way to allow participants to have a voice while collecting data and doing so within decision-making processes (Cooper & Lewenstein, 2016).

Yet, the contributory interpretation of citizen science opens the possibility of "citizen science without citizenship of science." This is an act of participation that is presented as apolitical, accurate and precise data collection, which contributes to an objective and disinterested scientific effort. In such cases, the participants are "subordinate labourers" as William Whewell termed the observers of his "Great Tidal Experiment." This is an experiment from 1835 in which thousands of people observed tidal patterns which he then analysed centrally. As such, they are as sensors for the study and are not involved in shaping the study or impacting the utilisation of the results (Cooper, 2016). This form of citizen science seems far removed from the extended peer community concept.

Therefore, it is appropriate to ask, "*what is the distribution of citizen science activities within the problem-solving strategies*?," with a related question "*to what degree does the current* form *of citizen science fit into the concept of an extended peer community?*".

By evaluating the implementation of different citizen science initiatives, we can learn about its potential and limitations, especially when it is used in PNS. It can clarify power asymmetries and scientists' abilities to manage knowledge production while limiting or empowering non-scientists' agency. It can help researchers adopt citizen science in PNS-framed research by indicating the best techniques. This inquiry also offers the chance to explore and explain the concept of the extended peer community and the power balance of different actors during citizen science's collaborative knowledge generation process. The scientific activity zones provide much-needed clarification about contradictions between and other ways to relate "democratic" and "contributory" citizen science to each other.

To address these questions, the approach that is taken here is relying on existing typologies of the field of citizen science. Typologies of scientific activities, by their nature, reduce the complexity of the field to several defined (and idealised) emphasis types. By that we mean specific types that are emphasised as a label for certain characteristics of activities that can be grouped conceptually or through some quantitative exercise. These classes can then be evaluated for their level of the decision stakes, the uncertainty, the level of conflicting values, and the urgency that is associated with the activity. Thus, it links these activities to the PNS conditions where "facts are uncertain, values in dispute, stakes high and decisions urgent." Furthermore, the exercise can help us to gain a deeper insight into citizen science and its role within scientific knowledge production and policy problems, particularly if we use the three problem-solving strategy zones that are discussed in PNS literature (Funtowicz & Ravetz, 1993, 1997, Ravetz, 1999): applied science, professional consultancy, and post-normal science.

This mapping exercise uses four citizen science typologies (Shirk et al., 2012; Wiggins & Crowston, 2011; Haklay, 2013; and Haklay et al., 2018). A recent study defined 13 typologies of citizen science (Haklay et al., 2021), addressing many aspects of citizen science. Among these typologies, three are the most cited classifications Namely Shirk et al., 2012, Wiggins and Crowston (2011), and Haklay (2013). Wiggins and Crowston (2011) and Haklay et al. (2018) analyse the activities' tasks and purposes to present the current state of the art. The other two (Bonney et al., 2009; Shirk et al., 2012; and Haklay, 2013) focus on engagement and involvement, revealing how scientists and laypeople might collaborate in citizen science. Other typologies focus on project qualities, educational outcomes, or implementation difficulties, making them unsuitable for this paper. Accordingly, the deduced framework provides twenty-four emphasis types for analysing the relationships between PNS and citizen science.

The remainder of the paper starts by brief examination of the PNS literature that discusses the extended peer community and its relevance to citizen science. Next, we examine citizen science typologies and their origins. After discussing the analytical process, we look at two typologies that introduce the field and the PNS four-factor categorization method. We then analyse two typologies that emphasise on engagement and scientist-public ties. Finally, we discuss the insights that this exercise provides for PNS and citizen science researchers.

2. Extended peer communities and citizen science

Before we turn to the analysis, we highlight several noteworthy papers that address the link between citizen science and post-normal science. As noted, the concept of the extended-peer community is the part of the PNS framework that provides such a link. Funtowicz and Ravetz (1993) define it as “all those with a stake in the dialogue about the issue” (p. 739) and “The extension of legitimacy to new participants in policy dialogues… With mutual respect among various perspectives and forms of knowing, there is a possibility for the development of a genuine and effective democratic element in the life of science.” (pp. 740–741). While the paper points out that extended peer communities exist in all three zones of science- or inquiry-based activity (e.g. managers in basic science as well as journalists in professional consultancy), it is only in instances of PNS with high decision stakes, high uncertainty and on contested issues, that it should be considered to engage an extended peer community in knowledge production: “The new field of ‘popular epidemiology’ involves concerned citizens doing the disciplined research which could, or perhaps should, have been done by established institutions but was not. In such cases they may encounter professional disapproval and hostility, being criticised either for lacking certified expertise or for being much too personally concerned about the problem. The creative conflict between popular and expert epidemiology not only leads to better control of environmental problems; it also improves scientific knowledge.” (p. 752). Popular epidemiology in the way that is described here fits well within the contributory and democratic paradigms of citizen science.

Ravetz (1999), progresses the original definition of extended peer community. He notes “’extended peer community,’ consisting not merely of persons with some form or other of institutional accreditation (‘stakeholders’), but rather of all those with a desire to participate in the resolution of the issue” (p. 651). By using this definition, it can be argued that non-credentialed people who join a scientist in addressing a scientific problem – such as counting the number of penguins in pictures taken by a remote camera on a beach in Antarctica to monitor their colony health – fulfil Ravetz’ criterion and therefore are part of extended peer community. Put it another way, all forms of citizen science that include public participation in scientific research are fitting into this definition.

Yet, the PNS literature indicates a higher level of engagement and knowledge production in papers that talk about the intersection of citizen science and PNS explicitly. For instance, Ravetz (2016) points towards the use of community science in Love Canal or Flint, Michigan as examples of the role of citizen science within PNS, with the ability to not only achieve an extended peer community but also extended facts that represent lay and local knowledge. For him, citizen science is “Science of the people, by the people, and for the people” and is very well aligned with PNS. Similarly, Peters and Besley (2019) are suggesting a strong link between citizen science and post-normal science, especially in areas of environmental management and sustainability science. They see citizen science as a form that opens up democratisation of science through public involvement in setting up the directions of science, especially when it is linked to policy decision-making. It also includes more egalitarian modes of knowledge co-production in which multiple views (including lay and local knowledge) are being recognised. In addition to these, many other studies link these two areas (e.g., Nascimento et al., 2014, Hyder et al., 2015, Dankel et al., 2017, Bremer et al., 2018, McQuillan, 2014, Tallacchini, 2020). In most of these papers, the emphasis is on high level of collaboration between scientists and non-scientists in many of the stages of the knowledge production process. As we shall see, the mapping in this paper allows for a more nuanced understanding of the relationships between PNS and citizen science practices. In order to do that, we need to clarify what kind of activities we examine when looking at citizen science.

3. Typologies in the landscape of citizen science

The term citizen science encompasses a wide range of activities that people associate with the notion of public participation in research. Similarly in different citizen science initiatives, there can be very different relations between the participants and scientific experts. In the same way that when an engineer, a philosopher, and a biologist will use the word “research” to mean highly divergent epistemologies, ontologies, and methodologies, so can the act of public involvement be highly divergent in these practices.

The early 2000s are a period when researchers developed and investigated an increasing number of types of activities in which the public take part in scientific and scholarly knowledge production – from creating digital maps of the world to transcribing historical documents (e.g., Goodchild, 2007, Bonney et al., 2009). This increase in number and diversity of these activities was due to both technological and societal reasons – including the increase in levels of education in the general population, the invention of smartphones with their sensors, and the creation of the infrastructure of peer-production systems such as Wikipedia (Benkler, 2006). This led to a proliferation of neologisms to describe these collaborations, with citizen science emerging as the common term (see also Eitzel et al., 2017). As a result, in the early 2010s there was a proliferation of typologies of the activities that fall under this broad umbrella term. The variety of activities, the range of disciplines, the multiple terms that are being used, and the diverse cultural contexts in which they are deployed, created a fertile ground for classifications. Moreover, the typologies are the way in which their authors tried to make sense of the field of citizen science. Therefore, many of them are revealing much about the interests and focus of their authors as much as about citizen science.

Of these typologies, the most widely used was developed by Bonney et al. (2009) and then expanded by Shirk et al. (2012). The typology provides a way to identify the roles of the scientists or project managers and the participants in carrying out different tasks, with a focus on environmental management projects. An earlier classification of similar roles is also appearing in Cooper et al. (2007) in the context of environmental and ecological management projects. Another common typology that examined the depth of participation was offered by Haklay (2013). Naturally, there are further papers that build on these early efforts, such as an attempt to identify aspects of engagement more clearly by Phillips et al. (2019). They suggested a framework with linkage to sociocultural learning theories and behavioural aspects which identified behavioural activities, affective/feeling aspects, learning/cognition, and social/-project goals as its main elements.

The environmental and ecological management area is a source for several other typologies – such as Freitag (2016) analysis of the relationship between citizen science and environmental management which suggest two axes - one between cooperative and adversarial relationships, and the other between deliberate and serendipitous data collection activities. The first axis is particularly relevant for PNS framing as it refers to values. A more technically focused framework is offered by Pocock et al. (2017) who use two axes for analysis which focus on the design and implementation of the project: elaborate approach versus simple approach, and mass participation versus systematic monitoring, and in addition computer-based projects. Another typology that emerged from the analysis of community-based environmental resource monitoring is offered by Gharesifard et al. (2019) that suggests an analysis based on the goals and objectives of the project (overarching objectives, goals of different actors, monitoring of objectives, change in objectives), technologies (reusing existing technology/novel technologies, access to technology, inclusion/exclusion by technology), participation (type of initiative, geographic scope, participant and non-participants groups, effort to participate, the support offered to participate, a pattern of communication, communication and participation method), and power dynamics (social, institutional & political context, authority and power, access and control over data, establishment mechanism, revenue and sustainability).

Another direction for the development of typologies analyses citizen science activities across disciplines in terms of the tasks that take place within them. In one of the earliest examples of such an analysis, Wiggins and Crowston (2011) focused on organisational and technical aspects of projects in a way that can support the design and implementation of appropriate information and communication technologies. They have also offered another typology in 2012 (Wiggins and Crowdston 2012), looking at goals and tasks. Similar to Wiggins and Crowston (2011), Haklay (2015) focuses on terminologies that describe the types of activity (e.g. passive sensing or volunteer computing) in a precursor to Haklay et al. (2018) in which the field is presented through different types of activities – based on long-running activities, use of technology, and degree of participant involvement in the project. In another high-level typology, this time looking at the epistemic practices that are driving the activities, and thus sidestepping the disciplinary issues, Strasser et al. (2019) identify a range of tasks: sensing, computing, analysing, self-reporting, and making. Schäfer and Kieslinger (2016), show that by combining Wiggins and Crowston (2011) and Shirk et al. (2012), it is possible to create a matrix approach that analyses projects along two axes. This helps in identifying who has produced the knowledge (citizens or researchers), and what is the project focus (addressing a research question or intervention in a socio-ecological system).

In summary, there is a proliferation of typologies in terms of the activities, practices, techniques, and methodologies that fall under the umbrella of citizen science. For our purpose, we will use two typologies that look at the initiatives that are taking place, which will help with understanding the range of activities. This will include Wiggins and Crowston (2011) and Haklay et al. (2018). With an understanding of the spectrum of activities and relations between citizens and scientists in place, we can look at the two widely cited typologies that focus on the relationships between professional scientists and the participants in the project. These will be based on Bonney et al. (2009); Shirk et al. (2012) and Haklay (2013). In another noteworthy link, these two typologies cite an influence by Arnstein (1969) seminal paper on citizen participation in decision making and therefore hold some notion of strong democratisation of the process, which is highly relevant in the context of PNS analysis. Moreover, both typologies are also influenced by PNS literature.

4. Methodology

To map the emphasis types from each typology and to decide where they should be positioned within the three problem-solving strategy zones, we used the following approach. First, each emphasis type was recorded with its definition from the original paper and was associated with examples of projects that are cited as belonging to it (see the "Classifications and Canonical Examples" table in the Appendix). For example, for the emphasis type "Action" is described by Wiggins and Crowston (2011) as "encourage participant intervention in local concerns, using scientific research as a tool to support civic agendas. At their core, most action projects employ participatory action research approaches, but unlike most published research using these methods, grassroots or "bottom-up" organising is most common. These projects are not conceived or planned by scientists, but instead by citizens, and usually involve long-term engagement in local environmental concerns for which science-oriented activities are intimately linked to the physical world." (p. 5). The example that they provide for an Action activity is: "Sherman's Creek Conservation Association (SCCA) was formed to protect a local creek and provide environmental education to the surrounding areas. The formation of SCCA was sparked by opposition to a proposed electrical generation facility that would have violated zoning regulations. Collecting 18,000 petitioner signatures—representing nearly half the population of rural Perry County, Pennsylvania— the SCCA was successful in their political action, and subsequently worked with environmental scientists to propose guidelines for revision of local zoning ordinances. The SCCA continues to engage rural citizens in watershed monitoring, stream clean-up events, and community outreach programs." (p. 5).

Next, for each element of the PNS analysis (system uncertainty, decision stakes, values, and urgency), we developed criteria with values between 1 to 9 to develop an approach for individuals to attribute quantitative ratings about the degree to which a particular scientific project in which citizen science are engaged is a 'normal scientific endeavour with a fairly fixed and straightforward problem framing by experts, or whether the science relates to a subject with high stakes and openly contested science. This range provides an estimation for the three zones with values between 1–3 mostly belonging to "applied science", 4–6 to "professional consultancy", and

7–9 to “post-normal science”. Within each zone, the low value (1,4, and 7) denotes low, the second (2,6,8) medium, and the third (3,6,9) high. This allows for a more nuanced evaluation of the relationships between a given citizen science project and the PNS aspect, in terms of the relationships between participants and experts, and the relation of participants to the knowledge they produce. In addition, it helps in positioning the emphasis type within the diagram. The criteria are provided in Table 1.

To explain the process of developing the criteria and how quantitative ratings are attributed in the evaluation process, we can look at uncertainty. For this, we followed Funtowicz and Ravetz (1993), with 1–3 noting technical uncertainty, 4–6 methodological uncertainty, and 7–9 epistemological uncertainty. Within each of these three categories of uncertainties we described further differentiations to match the three-point scales such that we had a clearly justified and reproducible way to explain whether uncertainty within that category was low, medium, or high.

Similarly, for the differentiation of the scale of decision stakes, following Ravetz (1999), we define that basic science is represents very low stakes (and therefore 1), while professional consultancy include professional risks and judgement (5) while decisions in cases of projects with monetary stakes with diverse and contradictory interests attached, such as the expansion of an airport or the operation of an incinerator will impact many stakeholders (9).

For values, following Funtowicz and Ravetz (1993), these ‘values’ are considered as principles of standards that underlie what is judged to be important in life, which are closely tied to different social norms. In certain projects, disputes over what is valued, and how things or actions are valued is low (e.g., classifying galaxies). In contrast, environmental justice applications with stakeholders that defend disparate notions of environment and its intrinsic value, are an area where values will diverge significantly. Finally, the urgency of the decision or action can also be evaluated on a similar rating scale. In some research, this can be very low on issues of basic research or digitising archival material, to issues that are highly urgent such as addressing the impact on wildlife from a proposed development.

The criteria also require a robust definition of what it is that we evaluate when examining a given project. A very good example to the contradiction that evaluation can create is the contrast between a topic that is used to recruit participants, and may seem urgent, while the practice of running the project itself is much closer to basic research. A good example is volunteer computing that is used within the network ClimatePrediction.net. There is no doubt that the issue of climate change is matching all the criteria of PNS. Yet, the volunteer computing project itself does not. This can be explained by noticing that climate scientists have access to significant computing resources for their modelling. Therefore, for their core work, they do not need the additional resources that the public can provide. As expected, that the type of tasks for which ClimatePrediction.net is used for are the type of computation on which the researchers don’t want to waste their core computing resources. That means that the project itself, within its internal operations, is one

Table 1
criteria for evaluation of association with zones.

	System Uncertainty	Decision Stakes	Values	Urgency
1	Technical uncertainty - low: lots of data, clear methodology to handle it	Low - pure/basic research, little consequences for failure	Values as a blind spot	Low or non-existent (e.g., basic research that is not clear if it leads to anything other than curiosity)
2	Technical uncertainty - medium: some novelty for the field, but can rely on common techniques and approaches	Low - Resources allocated and the research process is clear, fairly routine	Values are unspoken, assumed to be irrelevant	Low urgency that is coming from the project
3	Technical uncertainty - high: novel methodology for the field, but within standard concepts and paradigms. Requires different handling to bring it under common practices	Low/Med - potential implications if the research yield unexpected results	Values are shared, with divergence in understanding of the problem	Commitment to different stakeholders regarding timescales and outputs at the level of the project
4	System uncertainty - low: within routine judgement of a competent technical expert based on experience	Med/Low - clarity about the task, the costs, and the benefits, but need for professional judgement	Values assumed to be shared among stakeholders that are dealing with the issue, even if the methodology to reach them is not agreed	Timescales and activity schedule create certain urgency on decisions
5	System uncertainties - medium: require high expertise and experience to make the judgement	Med/Med - professional routine, known how to carry it out, parallel examples	Different values are taking into account, but consensus is easy	Some existential risk exists to a group or to an organisation
6	System uncertainties - high: require judgement of multiple experts and fields	Med/High - high level of professional judgement, risk for the expert and to clients	Different values but consensus is possible, but require deliberation and facilitation	Some existential risk to some actors with time pressure
7	Epistemological uncertainty - low: inescapable complexity but parallel problems and experiences exist	High/Low - conflicting interests and purpose among stakeholders, but the scale of the controversy is limited	Values are in dispute between different groups	Urgency to address collective risks concerning different groups
8	Epistemological uncertainty - medium: complexity but within a given sector of society or activity	Conflicting evidence and views about the science and what it means	Values are in dispute between experts, scientific areas and what they mean to the issues	High urgency in delivering a decision
9	Epistemological uncertainty - high: novel problem with very little know how on how to address it (early pandemic, when knowledge is very limited)	Very high stakes for the experts, the clients, and to the community, major controversy	High level of conflict in society and contradiction in science	Very high urgency - a disaster or emergency that require addressing the issue without delay

where stakes are low, values are not in dispute – since the volunteers that joined are interested in the topic, and uncertainty is technical.

More generally, we captured our principle of evaluation as follows: to evaluate an emphasis type using the cited example, we do not check the topic of the project (e.g., about climate or endangered species) but what the project outputs and the participation of non-professional people are used for. In addition to Climate Prediction, we can also notice that the birdwatching app eBird is aimed at building a database of bird observations that can be used for ornithological research, in terms of an empirical basis and it shouldn't be evaluated as an urgent project due to the concern over species decline. In addition to the examination of the cited project, the evaluators are asked to consider the full context of the emphasis type and the stakeholders beyond the specific project.

Using the criteria, four evaluators classified the 24 emphasis types independently. The resulting values for each emphasis type is an average of the judgments of this "collective intelligence" exercise. We have also captured the degree of disagreement between the evaluators by calculating Standard Deviation as an indication (see more in the discussion below and in the supplementary material). Based on this assessment, we created a chart that positions these emphasis types within the three problem solving zones (Fig. 1). In addition, we have visualised the results of the evaluation for values and urgency (Fig. 2).

The mapping was developed by four experts in citizen science, who co-designed the categories, and first individually developed these maps, then explored any differences in attributions in dialogue until all mutual questions were resolved.

We now turn to a short description of the mapping of the four typologies. The decision about the mapping process is, by necessity, subjective, and represents a judgement about the meaning of the emphasis type and how the typical project within each class acts in the world. We provide some illustrative examples beyond the canonical ones to assist readers who are not familiar with citizen science.

5. Mapping relations of purpose, situations, and forms of participation

We first examine two typologies of the activity that is occurring within the citizen science project. Because of the variety of activities that fall under citizen science, both typologies are inconsistent in the purpose of the emphasis types. For example, including in some of the emphasis types the main aim of the project (education, conservation) at the same time as including reliance on technology (virtual). This means that a project may belong to two emphasis types. In the case of Haklay et al. (2018), this is done deliberately to introduce the reader to different dimensions of citizen science. Yet, despite this potential confusion, it is helpful to look at each of these emphasis types to position them within the zones.

First, we look at the Wiggins and Crowston typology (2011). The typology was developed through a comprehensive study in which a landscape sample of projects was analysed using 80 key dimensions. The results were then clustered manually into five types of projects. The Haklay et al. (2018) classification is relying on different terms that are used to describe groups of activities within citizen science and is aimed to demonstrate common activities, especially across three areas – first, activities that belong to scientific areas with a long acceptance of volunteer data (e.g. ornithology or meteorology), the second group is looking at citizen cyberscience (Grey, 2011) which are projects that cannot happen without the proliferation of computers and the Internet, and finally a group of community science projects which are giving a bigger role to the participants in shaping the projects. The 15 emphasis types of projects in these typologies are provided in Table 2 (1–5 Wiggins & Crowston, 6–15 Haklay et al.). A concise description is added to explain the emphasis type to readers, and the full definition is provided in the additional material.

To understand the rationale behind the mapping and notice areas of disagreement within the evaluation process, we will examine a few of the emphasis types.

For the emphasis types of *action-oriented projects* from Wiggins and Crowston (2011) and *Civic/Community Science* from Haklay et al.

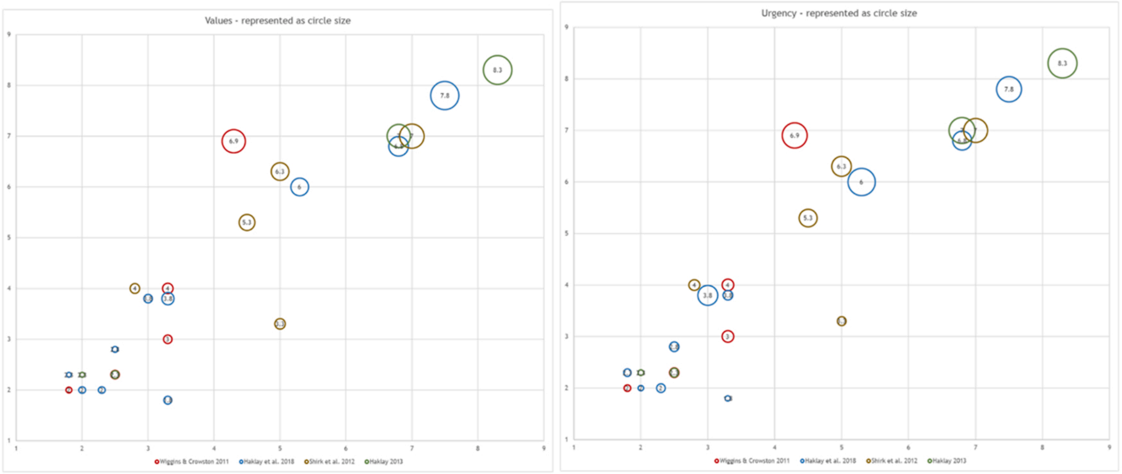

Fig. 2. (A) Mapping values (left) and (B) urgency (right) using the locations in Fig. 1. The size of the circle is proportional to the value. As expected, the four aspects are correlated.

Table 2
mapping Wiggins and Crowston (2011) and Haklay et al. (2018) along the four PNS aspects. The shaded cells are emphasis types that fall within the PNS zone. For each emphasis type the zone is indicated as AP, PC, or PNS in brackets.

Type	Emphasis Type	Concise description /purpose	Uncertainty	Decision Stakes	Values	Urgency
1	Action (PNS)	Addressing local concerns	4.3	6.9	6.5	6.3
2	Conservation (PC)	Stewardship and management of natural resources	3.3	3.0	2.5	3.0
3	Investigation (PC)	Focused on scientific (basic) research	3.3	4.0	3.0	3.0
4	Virtual (AS)	Web-based with a scientific (basic) focus	1.8	2.0	1.8	1.8
5	Education (AS)	The main goal is to support educational activities	2.5	2.3	2.5	2.5
6	Ecological observations (AS)	Data collection about biodiversity and the environment	2.3	2.0	2.0	2.3
7	Meteorological observations (AS)	Data collection about weather and climate	1.8	2.3	1.5	2.0
8	Space Archaeology volunteering (AS)	Online analysis of aerial images	3.3	1.8	2.3	1.5
9	Volunteer computing (PC)	Sharing unused computing resources	3.0	3.8	2.5	5.0
10	Volunteer thinking (AS)	Using cognitive resources to support a scientific task	2.0	2.0	2.0	1.5
11	Volunteer thinking (Humanitarian) (PNS)	Using cognitive resource to address a humanitarian problem	5.3	6.0	5.0	6.8
12	Passive sensing (AS)	Data collection through sensing with little intervention	2.5	2.8	1.8	2.5
13	Participatory sensing (PC)	Data collection through sensing with some decisions by participants	3.3	3.8	3.5	2.5
14	DIY science (PNS)	Participants develop tools and methodologies	6.8	6.8	5.5	4.8
15	Civic/Community science (PNS)	Addressing community goals and problems	7.5	7.8	7.8	6.3

(2018), it is noticeable that the former describes action projects within environmental restoration, while the latter describe projects with an environmental justice emphasis. Both emphasis types are addressing local concerns and using scientific tools and methodologies to support a civic agenda and interests. As a result, there is a high level of disagreement between the evaluators about the action projects, and while they are located within the PNS zone, it is at a lower level than the civic/community science projects. We can see that in such projects, values are clearly in dispute, as it is likely that the emergence of a controversial issue will galvanise the community to act (Marres, 2005), and the stakes and urgency, from the point of view of the community, can be very high. Yet, in *action* projects the terms in which the project itself is conducted can bring it closer to professional consultancy than to PNS. In contrast, *civic/community science* is commonly occurring in environmental justice contexts (Rey-Mazón et al., 2018), when the sensing of the environment and collecting evidence is part of activities that are challenging the information and the framing of local conditions. This can include, for example, balloon mapping of an oil spill in areas that are no-fly zones. This class also includes elements of *DIY science* (see below) in the construction of instruments that allow for alternative sensing (e.g., the case of Safecast after the Fukushima disaster in 2011 – see Brown et al., 2016).

Another contrast exists between *Investigation* projects aimed at scientific discoveries and research that require data collection from the physical environment, and *Virtual* projects, which are similar in their aims but in a computer-mediated environment. An example for an *investigation* project is the data collection to evaluate evolutionary changes in snails across Europe (Silvertown et al., 2011). Galaxy Zoo (Lintott et al., 2008) is an example for a *virtual* project in which volunteers classify images of galaxies from the Sloan Digital Sky Survey and assist astronomers in building datasets, which can be analysed statistically to understand common morphologies of galaxies. The need to interact with the environment and the reduced ability to streamline the task of the volunteers result in the classification of *virtual* projects within the applied science zone, while positioning *investigation* in the professional consultancy one.

Moving to examples from Haklay et al. (2018), we find within citizen cyberscience activities that rely on digital information and communication technologies to operate. This includes *volunteer computing* in which participants download software to their computers or devices (e.g., smartphone) and when it is not in use, it carries out a processing task that the scientists who coordinate the project set. A package of data and processing algorithms is sent to the device, and once the processing task completes, the output is uploaded to the project's server. All this is done automatically, without intervention of the participant. The origin of this method is in the project SETI@Home (Anderson et al., 2002), in which volunteers analysed data from radio telescopes in search of extra-terrestrial intelligence (SETI). Yet, the classification of *volunteer computing* within citizen science has been an area of disagreement within the literature and in our exercise. On the one hand, the act of contributing computing resources is done with an intended effort to support scientific research. Yet, as noted above, these are usually projects that are less important in the scientific agenda, commonly used for volunteer computing. The high priority projects have access to core computing resources that are available to scientists. The complexity and the evaluation of the role of the participants made this emphasis type the most controversial, with the highest standard deviation values within the exercise, indicating high diversion of views. This resulted in positioning it within the professional consultancy zone.

A very striking difference was identified with the two types of *Volunteer thinking*. When used within a core scientific area (as in Galaxy Zoo), *volunteer thinking* is classified in the applied science zone. However, when volunteer thinking projects include humanitarian goals, such as mapping after a disaster to assist the response and recovery efforts in the OpenStreetMap project, these projects can belong to post-normal science. In terms of evaluation agreement, there was more disagreement in the classification of the humanitarian case, which reflects the influence that a particular agenda can have in this type of projects.

The final emphasis type that belongs to PNS is *Do-It-Yourself science*. This includes practices of people outside traditional research institutions, who are developing their instruments and projects and include adapting (hacking) equipment and making devices, with areas of research from the life sciences to environmental applications (Ferretti, 2019). Of particular attention here is DIY Biology

(DIYbio) where participants carry out genetic studies in hackspaces. DIY science represents a systematic uncertainty since those that are involved in it as operating outside common research structures, although in many cases they adhere to institutional science practice (e.g., codes of practice, laboratory operation manuals). The values are in dispute as the activities of the DIY researchers are represented frequently in contrast to the activities of established science, as different value systems play out (e.g., against the current practices in academic research), the stakes are usually not especially high, since the projects are carried out at a small scale and are more focused on exploration than action. As a result, the urgency is also lower than emphasis types that are in the PNS zone.

6. Diverse relationships of participants and scientists in citizen science

We can now turn to the typologies that focus on the relationships between the participants (non-credential researchers), and the researchers who create and run the project. The emphasis types that were presented in the previous section will help to understand the kind of activities that belong to the different emphasis types in the typologies by Bonney et al. (2009), Shirk et al. (2012), and Haklay (2013). The fundamental aim of these typologies is to find a way to express what control level the participants have over the scientific project, from identifying the research question to the use of the outcomes and outputs. While Bonney et al. (2009) offer three emphasis types (*contributory, collaborative, co-created*), Shirk et al. (2012) add further two classifications (*contractual* and *collegial*) and therefore provide a more detailed analysis. Haklay (2013) classification offers four degrees of engagement (*Crowdsourcing, Distributed intelligence, Participatory science, Extreme Citizen Science*) with a special attention to bottom-up projects. Table 3 provides an overview of these emphasis types (16–20 Shirk et al., and 21–24 Haklay) and the results of the evaluation.

Contractual projects happen when community members approach professional researchers with a request to carry out a piece of research and report the results so those who commissioned it can use them to address an issue of concern. This involvement of researchers can be either pro bono (as in the model of science shops which Shirk et al., 2012 cite) or paid. While there was a general agreement between evaluators that the level of uncertainty is low, there was a disagreement about the decision stakes, values, and urgency. This is partially because the mode of participation maintains a separation between the expertise of the researchers and the community members who commission them, and maintains science as an objective and disinterested practice, beyond the setting of the topic of research. As a result, this emphasis type is in the professional consultancy zone, although at its upper end.

Both *Collaborative* and *Co-created* projects are classified as PNS. In *collaborative* projects*,* the researchers design the project and invite participants to join the project, but then open it up to a discussion. This can be done by engaging participants in the analysis of the data that was collected, or by refining the research questions or data collection methodology, or by assisting in the dissemination of the results. Shirk et al. (2012) indicate the water quality projects across the USA, in which the participants are monitoring local streams and water sources quality are frequently collaborative in nature. There are also rare cases, in which a *contributory* project opens — as in the case where a participant in the Galaxy Zoo project, Hanny van Arkel, noticed an uncommon type of galaxy. Through communication with the scientists that lead the project raised the question of what this object is. Eventually, this was recognised as Hanny's object (Hanny's Voorwerp) (Lintott et al., 2009). However, the occurrences of collaborative elements at the margins of a contributory project should not be seen as altering the main thrust of the project. This emphasis type was complex to assess as expressed in the standard deviation.

The *Co-Created* projects, which are designed by researchers and people with an interest in the issue together but with a leadership from the researchers are further into the PNS zone. These projects require the scientists to accept the participants as contributors to multiple stages of the research process, and therefore these projects fit within the post-normal science zone.

In Haklay (2013) classification both the *participatory science* and *extreme citizen science* were classified within the PNS zone, with the latter receiving the highest values in our criteria. While graphically both *extreme citizen science* and *civic/community science* are beyond the boundary of PNS, they should be considered as part of it.

7. Discussion

As noted in the introduction, our goal in the development of the mapping is to raise questions on the compatibility of different forms of citizen science with the extended peer community concept. More specifically, the mapping provides insights into design attributes

Table 3
Mapping Shirk et al. (2012) and Haklay (2013) along with the four PNS aspects. The shaded cells are emphasis types that fall within the PNS zone. For each emphasis type the zone is indicated as AP, PC, or PNS in brackets.

Type	Emphasis Type	Scientist-participant relationship	Uncertainty	Decision Stakes	Values	Urgency
16	Contractual (PC)	Participants asking scientists to address a problem	4.5	5.3	4.5	4.5
17	Contributory (PC)	Design by scientists, participants provide data	2.8	4.0	2.8	2.8
18	Collaborative (PNS)	Design by scientists, participants refine research question	5.0	6.3	5.0	5.0
19	Co-created (PNS)	Co-designed project and executed. Scientists lead	7.0	7.0	6.8	6.0
20	Collegial (PC)	Non-credential researchers doing professional research	5.0	3.3	3.0	2.3
21	Crowdsourcing (AS)	Only provision of resources from scientists	2.0	2.3	1.5	1.5
22	Distributed intelligence (AS)	Utilising the cognitive capacity of participants	2.5	2.3	2.3	2.3
23	Participatory science (PNS)	Problem definition by participants, methodology by scientists	6.8	7.0	6.5	6.5
24	Extreme citizen science (PNS)	Participants-led, scientists as helpers if asked.	8.3	8.3	8.0	7.3

As with the previous section, we review the emphasis types that fall within the PNS zone.

and which types of citizen science activities are compatible with PNS and most suitable in relation to science and policy-making in different situations.

The first observation is that out of the twenty four emphasis types that are explored, only a third (eight) are within the PNS zone. If we take into account that all the typologies are ignoring the scale (geographical, temporal, number of participants) and numbers of projects in each type, this difference is even more significant. Projects in the category of volunteer thinking, most of which would be in the applied zone can reach millions of participants, whereas projects that fall in the PNS zone and that address more complex issues are often have more limited participants numbers, as participation often relies on the building of personal relationships with or between participants. In their review of over 500 projects within the area of environmental citizen science, Pocock et al. (2017) found that 93% of projects are *contributory*. It is likely that this contributory form (or *distributed intelligence*) represents the vast majority of citizen science projects. Therefore, most of the practices of citizen science fall into the realm of normal science (which cover the applied science and professional consultancy areas). The projects that belong to the types within the PNS zone frequently include a limited number of participants. For example, the ground-breaking clinical study of the impact of lithium on amyotrophic lateral sclerosis (ALS) on the PatientsLikeMe platform which was initiated and led by the patients themselves in collaboration with the platform owner, included over 100 participants and is one of the largest examples of collegial projects (Stilgoe, 2009). Similarly, many *DIY science* projects engage less than ten participants.

Second, it is clear – and somewhat unsurprising – that the four variables that are evaluated here (uncertainty, decision stake, values, and urgency) are correlated. The result is that concentration of the emphasis types along the diagonal. It can be expected that the mapping of individual projects might provide different positions within the different zones.

Third, taking the PNS zone on its own, we can see that the mapping shows that there is a gradation in the level of decision stakes and system uncertainties inside this zone. Compare the *collaborative* projects, which are led by scientists, to the *extreme citizen science* which is led by community members. In terms of implementation, that will mean that for a PNS practitioner, there are different levels of complexities that are associated with implementation of citizen science activities, and there is a selection of activities, according to the willingness of the stakeholders to take the associated risks with higher level of common control over the project and its outcomes. As noted above, contributory projects have a much larger scale of participation, and for some problems, including policy ones, this will be the right approach. If we want to maintain the spirit of deeper engagement and deliberation that the wider PNS literature implies (e.g., Bidwell, 2009), then appropriate mechanisms for large scale deliberation are needed. It is also important to note that large scale participation in the contributory mode which require lower engagement and separation of experts and contributors can be effective in awareness raising and shared knowledge production.

Fourth, and linked to the previous point, the activities that fall within the PNS zone are identified within the PNS literature that was noted in Section 2 (Nascimento et al., 2014; Hyder et al., 2015; Dankel et al., 2017; Bremer et al., 2018; Ravetz, 2016; McQuillan, 2014; Tallacchini, 2020; Peters & Besley, 2019). They have also received much attention in the wider science and society literature (e.g., Stilgoe, 2009, Ferretti, 2019). Yet, despite at least four decades of a continuous stream of examples and forms of participation in scientific practices outside research institutes — from Love Canal, to the altering of the medical testing protocols by ACT UP activists, to Safecast and Public Laboratory of Open Technology and Science of today — these practices remain small and receive attention because they are exceptional and divert from common practices. Lack of funding and support is a major criticism from researchers and community groups. This refers to a structural dilemma in which people who might fund societal aims regard such activities as scientific research and hence outside their purview, while scientific funding is focused on established institutions and therefore outside the grasp of individuals engaging in citizen science that fulfil the notion of PNS.

Fifth, citizen scientific literature emphasises co-production of knowledge and collaborative research. Common practice does not show progression from bottom-left to upper-right. Again, there are exceptions to the general trend with participants assuming increasing roles (such as the case of Hanny van Arkel). Most normal-zone projects limit participants to data collection and basic analysis. This can be explained by the ongoing distrust of citizen science data and lack of acceptance that the public can actively participate in research (Lowry & Stepenuck, 2021; Golumbic et al., 2017). This is part of a wider reluctance (occasionally hostility) that society can tell scientists what to research and how (Winston, 2011). Long-held beliefs that only scientists can do science properly, collect high-quality data, and conduct adequate analysis may be influencing their impressions of citizen science and its place in scientific practice. This may explain why citizen science is used in low-stakes situations and in issues that are not in dispute.

As for uncertainty, those who are engaged and design citizen science projects are facing an ontological and methodological challenge within their discipline, in which the question of how knowledge is produced is conflated with who is producing it. Therefore, while the projects open up the potential of the “who” in scientific data collection and analysis, they restrict their participants as a way to double down on their quality assurance efforts, to the degree that most projects are using multiple quality assurance methods (Wiggins et al., 2011). The result of this is that the scientists who run the project will try to keep the uncertainty under control, and thus limit the role of participants. Our mapping exercise invites reflection on design attributes of citizen science projects in situations of high uncertainties and high stakes, which could be adopted to counter the confusion of qualification of the producer with quality of the results.

Sixth, a potential way to address the challenge above is to notice that the mapping does provide a potential route towards higher engagement by participants and the wider public. Indeed, not every scientific question and every issue will reside in the PNS zone, but as more and more issues require such an approach, we can consider how participation in projects that are more within the parameters in which scientists feel in control (the applied area in particular) can provide the scientists with an introduction to working with non-credentialed participants and increase the potential of higher engagement when it is needed. We might take inspiration from projects like Wikipedia and OpenStreetMap (which we have encountered in humanitarian *volunteer thinking*). These projects have started outside established traditional knowledge production institutions and have maintained a significant self-organisation and control within their practices. They have reached millions of participants and thus are successful examples of accepted quality control mechanisms by an extended-peer communities in a peer-production system. However, they are not matching the category of *collegial* projects. They have many of the characteristics of professional consultancy. This is because for most of their participants, these projects operate like a *contributory* one. For example, when editing a page of Wikipedia as an occasional editor, the participant is not aware of the intricate community-norms and editing practices. Only the much smaller number of participants (counted in fraction of a percentage) are the ones for which the project is co-created and shaped by. There is, however, a route for participants who have enough time and resources to get engaged in the project at a higher level and move from the *contributory* mode to the *collegial*.

For the PNS community, insights from the wide range of different types of relations between scientists and non-professional participants can help the design of more fruitful extended peer review approaches for expert advice in situations of high stakes and high uncertainty. How and at what cost can extended peer community activities be structured and organised? How will participants engage and relate to experts and the advice they produced given different framings of purpose and different types of activities? What can be expected from different types of interactions of scientific experts and people who resort to other forms of knowledge to interpret a particular policy relevant situation?

From the extended peer community perspective, this analysis can help to understand the scope of participation that is expected in citizen science projects, as well as their expectations. Just like the scientists who design and lead project, participants have different degrees of uncertainty, values, stakes, and urgency, especially in projects aimed to co-produce knowledge about problems within the science-policy interface. The demand for higher levels of participation in research and policy processes linked to citizen science projects requires a deeper understanding about the degree of widening participation in knowledge production targeted for specific goals, as well as how participants expect to be involved, which can range from contributing to data collection with equally valid facts, to actively shaping with values what needs to be studied. The analysis provides insights about PNS aspects to include not only in the design of projects, but also when assessing their impacts about gaps that are intended to be fulfilled. Furthermore, it can lead to find new frameworks for potentially justify, based on evidence, future financial options, which demands either for research or policy-based projects, its linkages to issue-driven purposes.

Finally, the mapping is calling for further discussion and refinement of the extended-peer community concept. Just as Arnstein (1969) identified on public participation in general, those in position of power have at their disposal, a wide array of techniques. Yet, when examined in terms of power relationships, it is possible to identify approaches that are only about placation in contrast to full participation. What we need to understand are the conditions under which those in position of power within a scientific knowledge production process will be willing to share it with their extended peers.

8. Citizen science and extended peer community – summary and future directions

In this paper the activities and practices of citizen science have been analysed using the three problem solving zones of PNS theory. Focusing on four typologies of citizen science, each classification was mapped according to a typical project that belongs to it in terms of uncertainty, stakes, values, and urgency. Twenty-four classes of citizen science activities were analysed and mapped within the PNS framework (Tables 1 and 2 and Fig. 1). The analysis highlights five insights. First, activities within citizen science span the full range of the zones — from applied 'normal' science to science on complex subjects with high stakes and uncertainties and values in dispute - PNS. Second, most citizen science activities and participants are operating within applied science and professional consultancy; in such cases it is unusual that scientists open up the problem framing or assumptions, or even the insights gained from analysis and interpretation up to real public scrutiny – scientific experts remain on top, and citizen participants allow crowdsourcing of their intelligence on tap, in a convenient manner. This raises the potential of a (very) shallow extended peer community, which is still influencing knowledge production, in a way that is acceptable for experts and policy makers. Third, there are examples for activities that fall under PNS, in which volunteer participants are invited for a similar purpose as in a situation of extended peer review to engage in the framing of, or at least in critical scrutiny of the project and approach itself. Whilst examples of such projects have been carried out over at least four decades, this approach to citizen science in most cases experiences challenges relating to funding and adequate resources. The fourth insight we would like to highlight is that one reason for the relatively limited role that is offered to participants within citizen science projects is according to the literature mostly related to the lack of general acceptance of the public's role in science. In addition, the analysis brings to attention the need for a more nuanced and detailed conceptualisation of the extended peer community concept. It shows that it is not enough to just open up the technical part of the knowledge production process to other, but to identify the processes and techniques that will force scientists to collaborate with wider groups. This is challenging culturally and technically. In sum, the analytic framework provided in this paper, and insights gained open up new ways of thinking about design options for citizen science initiatives that aim to contribute to improving the science-policy interface on specific issues. to the analysis of citizens science initiatives according to the PNS framework furthermore invites to consider new pathways for inclusion and an increased role for members of the public within policy relevant scientific enterprise.

Conversely, the analytic framework, and in particular the very concrete nature of the citizen science projects explored in relation to the rather abstract PNS framework also invites new nuanced thinking about the PNS framework itself: For example the diversity of relations of scientists and citizens and relations of citizens with the scientific knowledge they produce, invite a systematic analysis of the activities that are within the PNS zone and understanding their characteristics, interactions with institutional science, and impact on decision-making. The richness of cases that emerged over the past four decades reveals diverse modes and forms of interactions between different actors across a range of scientific areas — from the environment to health and to post-disaster mapping. The lessons from these cases can be used to chart a better route for the integration of citizen science in decision-making.

Declaration of Competing Interest

No conflicting interests.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.futures.2023.103178.

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