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# Actionable Knowledge in Citizen Science: definition, complexity and best practices

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# Actionable Knowledge in Citizen Science: definition, complexity and best practices

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### 2.3.1 Actionable knowledge in citizen science: definition and potential for a positive change

Actionable knowledge refers to the insights and information generated through scientific research, which creates the condition for positive change. It can be understood as the translation of collected data into information that can be used concretely in the public debate, in education and awareness campaigns, informing decision-making and ensuring a real impact on citizens empowerment. Its value lies in the potential to affect change and address specific societal needs. Actionable knowledge is a crucial concept in citizen science (CS), as a democratized form of CS should address the needs and concerns of citizens, thus creating practical benefits for communities, the environment, and society at large (Irwin, 1995). As an emerging and interdisciplinary area of inquiry, the science of actionable knowledge is considered a form of meta-research, as it examines the processes, the practices and the pathways by which knowledge informs action (Arnott et al., 2020).

Actionable information can be used for multiple purposes. The cases illustrated in 2.1, 'Literature review on citizen science [initiatives] for environmental monitoring' have shown that actionable knowledge empowered Tarragona civil society through engaging and accessible data visualization. Actionable knowledge was also used to mediate environmental conflicts, and to catalyse local communities' legal battles, and leading to the reduction of thresholds for exposure to pollutants in Marseille and Louisiana, and to ban gas flaring activities in Ecuador. Further, it has instigated follow-up monitoring and the expansion of institutional monitoring initiatives in Milazzo and Pennsylvania.

There are always more ways through which actionable knowledge can be generated are expanding, as the modes of constructing science-society relations are evolving rapidly. While the core principles of CS remain consistent encompassing public participation in scientific research – the scope and understanding of what constitutes citizen science is unstable. In effect, CS projects can employ wide-ranging research approaches and modes of citizen engagement, including practices from community-based participatory research, street-science (Corburn, 2005), popular epidemiology (Allen, 2003), community-engaged research (Israel, et al, 2010), consensus conferences (Guston, 1999). Each of the former share a ground with CS, creating various means for a positive change. Haklay (2013) defined CS according to four levels of citizen engagement. Level one, or 'crowdsourcing', engages citizens in gathering information and empirical data for experts; level 2, or 'distributed intelligence', engages citizens as basic interpreters of scientific issues shaped by experts; level three, or 'participatory-science', includes citizens both in the problem definition and data collection; level four, or 'extreme CS', defines a practice in which citizens delineate the problem, collect data and carry out the analysis. These different levels of engagement hold different potential for producing actionable knowledge.
Science, Technology, and Society (STS) scholar Barbara Allen claims that 'extreme' or 'strongly participatory science' produces more actionable data than other levels of citizen engagement in contested situations (Allen, 2017, 2018). By conducting a series of participatory studies that focused on unanswered health questions of residents in two polluted towns in an industrial region in southern France, Allen showed that when citizens are involved in the development of science from start to finish, they produce powerful tools for implementing their choices (Allen, 2018). By deeply contextualizing knowledge – exploring local health conditions through and with citizens, including their narratives of

living with illness and pollution – Allen's study in southern France has co-produced information that enabled citizens' voice to become more robust. Eventually, this project has led the local population to promote environmental change, and institutions to implement it.

To what extent actionable knowledge resulting from CS projects have produced positive change so far? Leona et. Al. (2021) produced a systematic review of environmental justice-related projects analyzing 232 case studies, of which 26 resulted in a structural change outcome. These cases were defined as 'participatory research', referring to projects that engaged communities in one or more of the following: formulating research question, developing research methods, interpreting results. Projects with limited community involvement (or Level 1 in the previously mentioned Haklay's definition) were excluded from this analysis. Leona and co-authors intended structural change as outcomes affecting macro, or meso-level determinant of health, such as zoning policy, economic policy, political power, built environment, public services provision or environmental policy reinforcement (Asada et al.2017; Cole and Farrell 2006; Frohlich and Abel 2014; Rüttenand and Gelius 2011, in Leona et. Al, 2021).

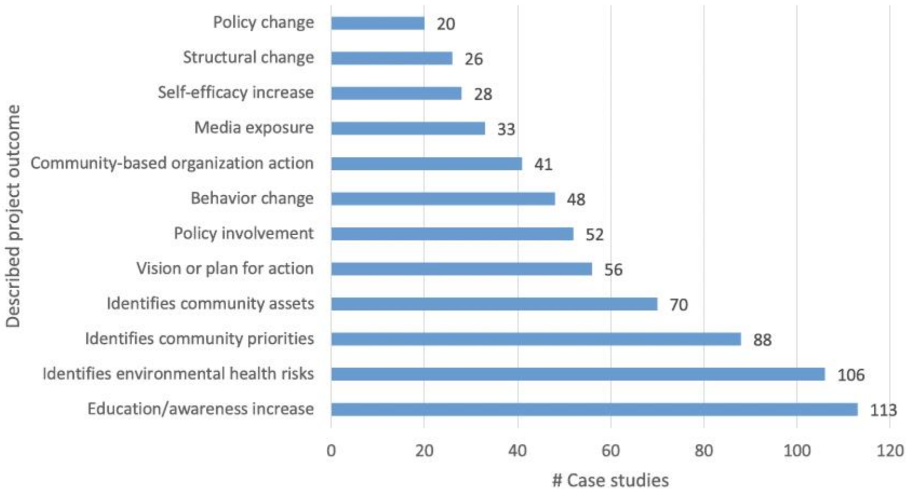

Fig. 1: Frequency of case studies' outcome in the study conducted by Leona et. Al. (2021)

The closing argument of the Leona et al.'s review stated that Environmental Justice (EJ) community-related participatory research is more likely to produce structural change when: a) community members hold formal leadership roles; b) project design includes decision makers and policy goals; c) long-term partnership are sustained through multiple funding mechanism (Leona et. Al. (2021 ).

In essence, actionable knowledge in citizen science bridges the gap between scientific research and practical, real-world applications, ensuring that the efforts of citizen scientists lead to tangible benefits and positive change, including structural change. However, as Arnott et al. (2020) remarks, actionable knowledge isn't simply about the effects produced by knowledge, but also about the ways of understanding how knowledge systems can be drivers of change. This fact implies pondering the complexity embedded in the process of knowledge production, considered as contested ground of theory and praxis.

### 2.3.2 The socio-political complexity of actionable knowledge

The knowledge used to produce change is a pivotal issue in public life and politics in the contemporary conjuncture – the acceleration of eco-social crisis and mounting environmental conflicts meet a turn towards extreme right-wing politics, in a context of "crisis of the truth". Effectiveness of actionable knowledge resulting from CS projects depend on its legitimacy – an issue that goes beyond data consistency and accuracy, accessibility or temporal suitability. Actually, legitimacy arises from the interplay of technical, ethical, social, and political factors.

STS scholar Noortje Marres highlights how the category and genre of "fact" is undergoing a transformation in contemporary societies (Marres, 2018), making a case for 'knowledge democracy'. He argues that in the current state of post-truth and spreading disinformation, the solution isn't reinstating a strategy for securing the role of facts in public debate though authority and normative hierarchy of knowledge. Instead, we need to recover the central role of experimental facts in public life: that is, statements whose truth value is unstable (Marres, 2018, p.423). For Marres, in order to achieve knowledge democracy, the experimental validation of public knowledge must happen in the public domain. In effects, validation of knowledge though authority does not escape the relativization that can undermine the foundation of scientific knowledge. This aspect is well illustrated by a CS case in Viggiano, Italy, that took place between 2015 and 2017. Here, experienced scientists conducted a participatory epidemiological study around an oil pretreatment plant owned by major oil and gas corporations ENI and Shell. This first study was later dismissed by a counter-argument presented by a scientific committee commissioned by ENI (La Repubblica, 14/7/2017). Both arguments were legitimated and delegitimized by the authority of academia.

Besides that, validating knowledge through normative hierarchies of authority risks to reproduce unjust power dynamics in the legitimation of some knowledge over other. Postcolonial development scholar Shiv Visvanathan's (2005) coined the terms 'cognitive justice' to address the need of recognizing and valuing diverse ways of knowing and understanding the world. Visvanathan highlights the dominance of Western scientific knowledge and the relative epistemic injustice, meaning the legitimization of some knowledge, while certain groups' knowledge is devalued or ignored. He advocates for the legitimacy and value of other knowledges, including traditional, indigenous and local knowledge systems. Cognitive justice is closely related to what philosopher Miranda Fricker defined as 'testimonial injustice', which occurs when a speaker's credibility is downgraded due to identity prejudice (e.g. race, gender, class), leading to the discontinuity of their testimony (2007). Based on these justice-oriented approaches, Allen has formulated the concept of greater 'knowledge justice' intended as a form of knowledge produced through ensuring that all communities, especially those marginalized or more impacted by environmental issues, have access to relevant scientific and technical knowledge. This means breaking down barriers that prevent certain groups from participating in the co-production of science, challenging hermeneutical marginalization – thus, the institutionalized misrecognition of certain testimonies or knowledge systems. Producing relevant and rigorous science with residents, with the aim of achieving knowledge justice, can boost local claims especially when they conflict with corporate or state agents (Allen, 2018).

Together with legitimacy and credibility across the plurality of perspectives, which depend on dynamics of power, uncertainty is another issue that characterize the socio-political dimension of actionable knowledge. The philosophical approach of ‘post-normal science’ (PNS) defined by Functowicz and Ravetz (1993) acknowledges that uncertainty is a typical factor of influence in knowledge related to environment, health, and, more generally, in complex science-related issues. ‘Post-normal’ situations arise when traditional scientific approaches are inadequate to deal with complex, high-stake issues characterized by uncertainty, contested values, and urgency. ‘Uncertain facts’ indicates that whatever the statistical test, there will always be errors, as no test can completely avoid being either too selective or too sensitive; a balance between the two must be found, and this depends on the policy framework of the test. ‘Values in conflicts’ are those defended by actors with different economic and social interests; they attribute different weigh to sustainability-related factors, hindering the convergence of efforts. ‘High stakes’ refers to the significant consequences of decisions triggered by new knowledge produced, such as the destiny of a territory, or energy transition. ‘Urgency’ indicates the need of taking decisions within a temporality that doesn’t exacerbate the problem or miss the opportunity for intervention.

In the post-normal approach, uncertainty isn’t ignored or banned, but confronted. SPS’ solution to the expansion of uncertainty resulting from the increasing turbulent changes in which science is operating, is forming ‘extended peer communities’ (Battaglia, et. Al., 2009). It implies involving a wider circle of people in the discussion of knowledge, not merely persons with some form of institutional accreditation but rather all those with a desire to participate in resolving the issues. This is not just a mode to broad democratic participation, but also the way to ensure quality of knowledge. These communities, in some cases named ‘citizens juries’, ‘focus groups’, or ‘consensus reference’ can include a plurality of legitimate perspectives, producing knowledge no longer as a rigid demonstration, but rather through inclusive dialogue (Functowicz and Ravetz, 2003).

Marres' strategy to achieve knowledge democracy and the solution offered by the post-normal science approach, converge on the principle of public and plural legitimacy. Embedded of critical pedagogies of knowledge, these approaches move away from the traditional view of science as an objective, value-free endeavor, and recognizes the complexity and uncertainty emerging with knowledge production and co-production. Based on these interpretations, it can be deducted that for actionable knowledge must be socially robust to be effective for decision-making in complex situations. In other words, it should be plurally produced, context-sensitive, explicit in terms of values, and able to manage uncertainty.

### 2.3.3 Data quality and communication: dealing with uncertainty

A way in which actionable knowledge can produce a positive change is through influencing policymaking. While policymakers generally seek a high degree of certainty (Durham et al., 2014), data co-produced with or by citizens often involves varying levels of uncertainty. Doubts on data quality is often the driver of skepticism. Nevertheless, data quality can have a different meaning for different CS stakeholders – validity, consistency, standards-based, completeness, timeless and accuracy are some of them (Balázs et al. 2021). Existent literature has focused on CS data quality as something to be achieved through socio-technical strategies, including (1) peer-verification, a sort of peer review process by qualified members within the domain; (2) expert verification, in which specific stakeholders are identified as experts; (3) automatic quality assessment, which implement software-based systems or artificial intelligence algorithms; (4). model-based quality assessments that combines experts and automatic filtering techniques to tackle errors (Balázs et al. 2021). Freitag et al. (2016) approached doubts on data quality through 'credibility', intended as the quality of being believable or worthy of trusts, highlighting the many possible pathways for CS groups to achieve it. The authors surveyed the credibility-building strategies of 30 CS initiatives that monitor environmental aspects of the California coast and identified twelve strategies illustrated in the next table.

| | Credibility-building Strategies | | | | | | | | | | | | total | Context for Strategies | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | early actions | | | in the field | | | | in the office | | | | | | | | | | |
| | prior expertise | training | science advising | ranking system | in-person oversight | re-training | technological aids | Validation of observations | cross comparison | publication | management use | Quality assurance | | sole source of data? | institutional affiliation | size of volunteer pool | group vs. individual | time commitment |
| Beach Watch | N | H | Y | N | N | optional | N | Y | N | N | Y | N | 5 | Y | Y | L | G | M |
| BeachCOMBERS | N | H | Y | N | N | optional | N | Y | Y | Y | Y | N | 6 | Y | Y | M | G | M |
| Beachkeepers | N | N | N | N | N | N | N | N | N | N | Y | N | 1 | Y | N | L | G | L |
| Black Oystercatcher Monitoring | Y | N | Y | N | N | N | N | N | N | Y | Y | N | 4 | Y | N | M | G | M |
| Blue Water Task Force | N | L | Y | N | Y | N | N | N | Y | Y | Y | Y | 7 | N | N | L | G | M |
| CA King Tides | N | N | N | N | N | N | Y | N | N | N | N | N | 1 | Y | N | L | I | L |
| CCFRP | N | L | Y | N | Y | N | N | Y | N | Y | Y | N | 6 | N | Y | L | G | M |
| CWC (First Flush) | N | M | Y | N | N | N | Y | N | N | N | Y | Y | 5 | N | N | M | G | L |
| CWC (Urban Watch) | N | M | Y | N | maybe | optional | Y | N | N | N | Y | Y | 7 | N | N | S | G | L |
| Elkhorn Slough (otters) | Y | L | Y | N | N | N | Y | N | Y | Y | Y | N | 7 | N | Y | S | G | M |
| Elkhorn Slough (algae) | Y | L | Y | N | Y | N | N | N | N | Y | N | N | 5 | N | Y | S | G | M |
| Elkhorn Slough (nestboxes) | N | M | Y | N | N | N | N | N | N | Y | Y | N | 3 | N | Y | S | I | H |
| Elkhorn Slough (shorebirds) | Y | L | Y | N | Y | N | N | N | Y | Y | Y | N | 6 | N | Y | M | G | L |
| Grunion Greeters | N | M | Y | N | maybe | N | N | N | Y | Y | Y | N | 5 | N | Y | L | G | M |

Table 1: Summary of credibility-building strategies and related context of 30 citizen science groups working in the Central Coast of California (Freitag et al. 2016, p.4). Symbols in column refers to either Y/N for yes or no regarding whether the activity exists within the project; H/M/L/N for high/medium/low/no indicating the level of the activity; S/M/L for small/medium/large depicting the size of a program component, or G/I for group or individual activity.

The results of this survey highlights the need to adopt different strategies at different stages of the project, favoring training, scientific advising, publication, and management use. However, the authors suggested that the real question isn't whether citizen science is credible, rather how it can be credible and for what purpose.

Another way for actionable knowledge to be effective is by enforcing regulation through legal disputes. Data quality is a factor of skepticism also in this domain; as Brett (2017) highlights, there is a prevalent belief in the legal community that CS-generated knowledge would not be admissible in court due to poor data quality. Brett analysed the admissibility of CS data in courts, looking at the volunteer-based water monitoring in Florida and how EPA slowly incorporated it as a key tool in the Clean Water Act monitoring. She noticed that while EPA progressively accepted a certain degree of uncertainty in data quality, the skepticism in court it was rooted in the “expertise” of citizens that gather them. Her argument is that citizens scientists, through their knowledge of environmental conditions and experience in monitoring, can be considered expert under certain legal standards. To make actionable knowledge usable in court, citizens scientists must be able to illustrate, through their training, the knowledge and experience that make them experts. This can contribute to the acceptance of the uncertainty that characterizes CS data collection (Brett, 2017).

The role of citizens as “experts” doesn’t necessarily imply relying on sophisticated scientific techniques, but rather to be able to demonstrate the magnitude of the violation through a methodical monitoring activity, conducted along a relevant length of time. This is illustrated by the analysis of the Formosa case (Berti Suman and Schade, 2021), a 2019 Court case in which local residents and fishers from the San Antonio Bay, Texas, brought the Formosa Plastic Corporation to Court for polluting local water and so violating the US Clean Water Act. Citizens’ evidence, which consisted of 12.000 photos and videos of floating debris and suspended solids collected along several years, were accepted in courts as legal evidence of environmental wrongdoing. Confirmed by key experts and testimony admissions, the simple but solid dataset easily influenced the judge’s ruling, leading citizens to obtain a legal victory.

Whether in influencing policy making or enforcing regulation through legal disputes, uncertainty emerges as a transversal factor affecting the potential of actionable knowledge to produce change. Beyond adopting socio-technical strategies to limit ambiguities on the credibility of data quality or expertise of citizens, embracing uncertainty appear as a strategy to face the complexity of knowledge resulting from a CS project. Therefore, uncertainty must be understood and communicated purposefully. Environmental and health (EH) literacy can provide a stimulating framing for dealing with uncertainty; EH was born to respond to the need of understanding environmental exposure through the comprehension of the relationships between environment and health. Bonaccorsi and Lorini (2021) contend that in EH non-experts tend to be less familiar with the concept of uncertainty and reason in absolute terms, which produce a distortion for health risk perception. They claim that the understanding of uncertainty depends on previous experiences, life context, emotionality and engagement level, and perception of risk.

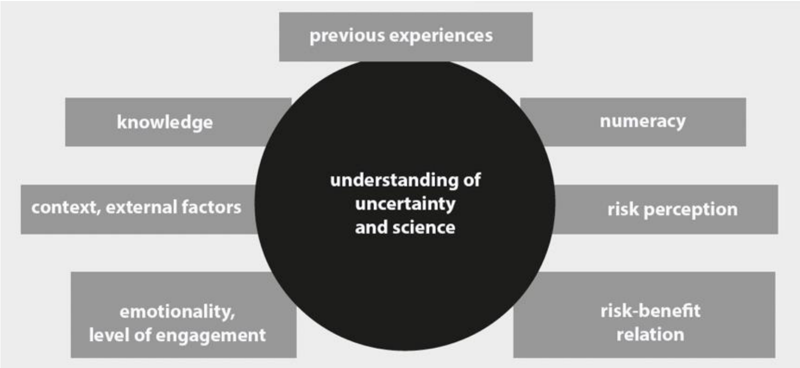


Fig 2: Translation and adaptation from ‘factors that influence uncertainty in medicine and science by the population’ (Bonaccorsi and Lorini, 2021)

Uncertainty must be understood and communicated through developing a set of cognitive and social abilities, creating trust and avoiding disorienting the stakeholders (Bonaccorsi e Lorini, 2021). The solution suggested by epidemiologist Liliana Cori, who has led relevant HE-related citizen science initiatives in Italy, suggested to organize activities to help develop a ‘sensibility to uncertainty’ through a series of activities, e.g. seminars engaging stakeholders. Cori (2021), in line with the horizontal governance proposed by Functowicz and Ravetz (1993), Cori (2021) emphasizes that practices for communicating uncertainty cannot be done through a vertical model of knowledge transfer; instead, uncertainty must be communicated transparently through a circular and dialogic dynamic, actively engaging citizens and other stakeholders. This is a method for building trust and promoting a shared understanding of complex problems, improving public debated and decision-making.

### 2.3.4 Best practices in citizen science: socio-technical and socio-political actions

The existing literature lacks a collection of best practices explaining specifically how to activate knowledge in CS projects. Existing analysis usually recommend practices to different stakeholders for making effective CS project, and they focus almost exclusively on socio-technical aspects. This section compiles a series of best practices for actionable knowledge to become effective, combining socio-technical aspects identified by earlier analysis, with the socio-political aspects described above.

The term socio-technical identifies those actions that are characterized by the interrelatedness of social and technical aspects, emphasizing technological developments and organizational changes. The socio-political category highlights actions that focus on the interplay between societal norms, behaviors and political realms. While the socio-technical actions deal with technological design, human-computer interaction, and organizational change, socio-political concerns are related to power structure and social justice.

The socio-technical best practices are selected from the following three documents. The first is a document from the European Commission on best practices in CS for environmental monitoring (EU Commission, 2020). It assessed the impact and policy applications of citizen science by providing an inventory of 503 environmental citizen science initiatives with relevance for the EU policy relevance and in-depth analysis of 45 selected initiatives. The recommendations are clustered around four main areas of intervention to support the policy-making areas: 1) matchmaking between knowledge needs for environment policy and citizen science activities; 2) promoting awareness and recognition; 3) promoting standards for data quality and interoperability, and sharing tools; 4) supporting coordination, cooperation and resources for policy impact.

A second document by Turbé et al. (2019) contains an inventory of 503 policy-relevant environmental CS project. The authors launched an EU-wide Internet survey, reviewing the databases of EU-funded projects (FP7, Horizon 2020, COST, LIFE) and performed a desk study using the results from recent systematic reviews of citizen science projects. This publication identified some recommendation for CS projects to achieve policy relevance. Here we will consider only those that relate to actionable knowledge.

the third document is a study by Hacker et al. (2018) that synthesizes results of discussions at the first international citizen science conference organized by the European Citizen Science Association (ECSA) in 2016 in Berlin, Germany, and distils major points of the discourse into key recommendations.

In summary, actionable knowledge in citizen science is not just an academic concept but a transformative tool that bridges scientific research and real-world impact, empowering communities to address pressing societal and environmental issues. This means that by converting data into actionable insights, citizen science enables informed decision-making and fosters structural changes in policies, especially in areas like environmental justice. The different levels of citizen engagement, from basic data collection to fully participatory science, demonstrate that deeper involvement often leads to more significant impacts. However, to truly harness this potential, it is essential to navigate the socio-political complexities such as legitimacy, cognitive justice, and uncertainty. Embracing inclusive, democratic approaches to knowledge production and validation ensures that diverse voices are acknowledged, heard and respected. Best practices to make actionable knowledge effective, therefore, requires a synergy of socio-technical and socio-political strategies, ensuring data quality (both in terms of data accuracy and socially robustness) and credibility while fostering trust and collaboration. Promoting knowledge democracy and justice-oriented practices in citizen science not only enhances the quality and impact of their results, but also can drives meaningful and sustainable change in our society. This approach ultimately empowers communities, influences policy, and addresses the critical challenges of our time.

Further research in this field should explore what barriers hampers knowledge produced by CS to be translated into practical applications, decisions or actions. While some authors have started to explore socio-technical barriers in CS (Burgess, et el., 2017; Lewis, 2022; Lewenstein, 2015), socio-political barriers that make knowledge ‘unactionable’ remained uncharted. Lastly, examining the role of technology, as well as techno-diversity in facilitating more inclusive and democratic knowledge production processes can uncover new avenues for addressing socio-political challenges.

**Socio-technical**

**1 Enhance visibility and good communication**

1.1 Set up an online information portal on citizen science, including a knowledge base on initiatives across Europe, topics covered, tools and resources

1.2 Communicating transparently on methodologies used and adhering to good practice

1.3 Promote availability of CS data on existing or new open platforms and ensure that official reporting mechanisms can accept and integrate these data

1.4 Engage successfully with traditional media (newspaper, TV) as well as involving science communicators; use social media networks and platforms

1.5 Organize face-to-face meetings allowing social interaction and rewarding success

**2 Link results and policies priorities**

2.1 Target environmental policy frameworks at different scale. Make explicit the relations between CS projects and the areas of the Green Deal, and the Sustainable Development Goals (SDGs)

2.2 Increase the awareness of decision makers, in particular local authorities about the relevance of the CS results, for instance organizing match-maker events to foster exchange and transfer of knowledge

**3 Data quality as accurate**

3.1 Provide training and resources on data quality management methodologies and standards of good practices

3.2 Illustrate how data reliability has been achieved, in order to be trusted and to align with environmental regulation and monitoring requirements from governments

**Socio-political**

**4 Define the appropriate mode of participation**

4.1 Acknowledge the best mode of citizen engagement for the project considering the 4 levels defined by Haklay (2013): crowdsourcing, distributed intelligence, participatory-science, extreme participation

4.2 Use strongly participatory sciences ('extreme') in environmental controversies, with the aim of providing support to environmentally polluted communities to have a voice

**5 Adopting justice-oriented approaches**

5.1 Embrace knowledge justice – ensuring that all communities, especially those marginalized or more impacted by environmental issues, have access to relevant scientific and technical knowledge, considering the existence of different knowledge systems

5.2 Aim at achieving knowledge democracy through validation of public knowledge in the public domain

**6 Data quality as socially robust**

6.1 Enhance legitimacy of data through involving a wider circle of people in the discussion of knowledge (not merely those with institutional accreditation), and forming extended peer communities, to ensure quality of knowledge, such as citizens juries, focus groups, or consensus reference

6.2 Co-producing knowledge through including a plurality of legitimate perspective and inclusive dialogue

6.3 Adopt credibility-building strategies through implementing different technique at different stages of the project, prioritizing training, scientific advising, publication, and management use

6.4 Illustrate that citizens engaged in monitoring have a level of training and experience that allow them to be defined as experts

6.2 Manage uncertainty acknowledging the complexity emerging in knowledge co-production and promoting a 'sensibility to uncertainty' through a series of activities, i.e. seminars engaging stakeholders

Fig. 3: Best practices in citizen science: socio-technical and socio-political actions

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