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How can bottom-up citizen science restore public trust in environmental governance and sciences? Recommendations from three case studies

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ABSTRACT

Citizen science is currently at the forefront of environmental scientific research and public policy for its potential to improve environmental governance, restore epistemic trust and help address some of the most stressing environmental challenges. Although citizen science is gaining increasing popularity, there is little empirical evidence to support these claims and demonstrate how bottom-up citizen science shapes public trust in environmental governance and science. In this paper we reflect on three grassroot environmental citizen science initiatives in Cameroon, Japan, and the UK to identify and present an instrumental framework which includes trustee attributes and conditions that influence how epistemic trust is shaped, and which should inform citizen science and other participatory practices. We explain that citizen science is an approach which enables political processes through the construction of well-informed techno-scientific arguments, which expose deficit assumptions about the public's ability to participate in knowledge co-production process. To avoid repeating the failures of the past and risk amplifying issues of public distrust further, we provide suggestions built around key trustee attributes which can be incorporated in citizen science practices and we urge that environmental policy needs to create clear policy frameworks to enable the generation of actionable data, especially when such approaches are initiated and implemented as instrumental public participation methods.

1. Introduction

Public participation has received attention as a mechanism for environmental protection, sustainable development, addressing environmental challenges and improving environmental governance and science. Approaches to public participation have evolved capturing different objectives and focusing on mitigating negative public attitudes and restoring public trust in science (epistemic trust) (Wynne, 2006). From the one-way communication of the public understanding of science (PUS) movement in the 1990s, to public engagement with science approaches in the 2000s, focusing on transparency (Gupta, 2008) and inclusiveness (Delgado and Strand, 2008), these approaches faced criticism for their limited effectiveness in addressing policy dilemmas, achieving legitimacy, fostering positive public attitudes (Tewdwr-Jones and Allmendinger, 1998), as well as for their poor representativeness and for failing to restore epistemic trust (Wynne, 2006; Fox, 2009).

During this period public participation rationales in the environmental context began to emphasise knowledge co-production and its role in promoting epistemic trust. Sustainability science scholars stress the need for transparent science that addresses societal needs (Kates, 2000) and bridging knowledge divides globally to enable sustainable development (International Council for Science, 2002). The concept of knowledge co-production has been adapted from science and technology studies (STS), where it is "promoted as a means of nurturing public trust in science" (Gundersen et al., 2022, 20). STS scholars argue that managing risk and uncertainty and improving scientific accountability require public participation in the production and use of scientific knowledge (Jasanoff, 2003). Irwin and Michael (2003) explain that "lay people may not only possess knowledge but have knowledge of how they know: they are able to reflect upon why they take on board some 'scientific facts' but not others [...] they can justify why they trust some expert authorities and are suspicious of others" (28).

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Normative approaches of public participation have recently stimulated policy initiatives like Open Science, emphasising diverse public engagement in scientific knowledge co-production. It is argued that the Open Science ethos can restore epistemic trust (Kønig, et al., 2017) and confront "the ongoing erosion of trust in evidence-based policy" (Guimaraes Pereira and Saltelli, 2017, 53). Within this context, there is a growing interest in citizen science (CS), while policy frameworks such as the European Open Science (European Commission, 2018), UN Sustainable Development Goals (UN, 2015), UN Environment Programme (UNEA, 2017) and many state-based policies recognise CS's role in environmental sciences and governance; for example, in terms of shaping the sustainability agenda and addressing local and global challenges.

CS encompasses diverse approaches, where lay people engage in scientific research and knowledge co-production, with or without professional scientists, using scientific protocols, methods and tools developed for this purpose. The wide array of CS activities has been captured in different typologies (Shirk et al., 2012; Haklay, 2013; Kinchy and Kimura, 2016). In top-down CS approaches (i.e. contributory projects) volunteers support scientists collect data at previously unprecedented spatio-temporal scales (Dickinson et al., 2012) leading to scientific knowledge established through peer-reviewed publications which may influence policy development (Hallow et al., 2015). Bottom-up CS approaches (i.e. contractual, co-created or extreme citizen science projects) - such as those we observe in environmental and community-based monitoring - are (co-)led by lay people and communities. Here the emphasis is on utilising the data for political pressure, advocacy purposes, local community action, policy formulation (Schade et al., 2021; Fraisl et al., 2022) at the local but also global level, further amplified by CS's potential to diversify scientific knowledge production through the inclusion of local traditional and indigenous knowledges and perspectives. It is these types of CS initiatives that have attracted the attention of scholars for their potential to support knowledge co-production on equal terms and improve epistemic trust (Irwin, 1995; Wynne, 2006; European Commission, 2020; Bedessem et al., 2021; Kahl, 2023).

Despite its trust-building potential little evidence exists to demonstrate how trust relationships are built and supported within CS, although there is growing recognition that more research is needed towards this direction (Gilfedder et al., 2018; Miller et al., 2023). In this paper, we explore whether – and if so how – bottom-up CS can restore and promote epistemic trust through the lenses of three case studies. We first introduce a conceptual framework and the trust-related tensions which exist in the field, and which set the scene for investigating trust further. Our analysis focuses on elements of risk and uncertainty, as trust pre-conditions, and the cognitive and affective epistemic trustee attributes which shape the trust-building potential of CS practices, and which should be incorporated into the design and implementation of participatory approaches in similar contexts.

2. Introducing a conceptual framework for investigating epistemic trust in citizen science

Trust has been researched across various disciplines offering different perspectives. In philosophy, trust is defined as a confident reliance on someone "to take care of something which we care about, but which they could harm or steal if they wished" (Bailey, 2002, 1). In psychology, trust is examined as a personality trait and as a social and institutional construct. Management studies focus on organisational trust. Regarding public trust in science, Barber (1987) identifies two types: trust within science and public trust in institutional science (epistemic trust), as an essential for the well-functioning of society. The complex global challenges we are facing and the uncertainty we live in (e.g. see COVID pandemic), brought renewed attention to epistemic trust with an emphasis on the scientific knowledge produced by scientists, the products of science and the way these are delivered to the public (Furman, 2020).

Despite disciplinary differences, there is consensus that trust is a multi-level concept with cognitive, affective, and social influences (Rousseau et al., 1998; Jones, 2019; Engdahl and Lidskog, 2012; Furman, 2020). At the cognitive level a trustor (i.e. the individual deciding to rely on the trustee) may establish a trusting relationship based on 'good reasons' (e.g. trustee's transparency, reputation), but by doing so undertakes some risk which places them in a vulnerable position (Levy, 2022). At the affective level, a trustor may decide to rely on the trustee based on intuition or feelings (e.g. when there is familiarity, sharing similar beliefs) (Faulkner, 2007). A trusting relationship is open to influences from cultural characteristics, trustor's educational background, information access and others. These components are presented in a conceptual framework in Fig. 1, where the examples of trustee attributes come from the epistemic trust context, as we discuss in more detail next.

Epistemic trust is often discussed within the context of trust in expertise, encompassing two dimensions. The first dimension involves assessing the trustee's competency, or strategic trust, based on concrete estimates of trustworthiness (Barber, 1987; Oreskes, 2019). The second dimension pertains to the scientific ethos defined by Mertonian principles (Sztompka, 2007). These dimensions suggest that laypeople develop cognitive trust judgments based on factors such as the quality of scientific outputs, their accuracy, scientists' reputations, and performance. When these attributes are unavailable, second-order judgments are made based on factors such as scientific consensus (Gundersen et al., 2022). However, scientific consensus does not always exist in controversial issues (Kabat, 2017), and laypeople may lack the information or resources to accurately assess such attributes. The prevalence of fake news and disinformation further complicates this, potentially leading to misplaced trust and vulnerability for the trustor.

The affective dimension of trust is less frequently analysed in relation to epistemic trust, despite numerous instances of distrust and public rejection of scientific outputs triggered by strong emotional responses. Furman (2020) illustrates this with the introduction of the contraceptive pill in African American communities and the Ebola outbreak in West Africa, where distrust was fuelled by historical abuses and disrespect for local values. Such responses are linked to "economies of suspicion" and "economies of resentment " (Furman, 2020, 718) influenced by emotional, socio-cultural, and ideological factors, and exacerbated by transparency deficits and power asymmetries between experts and laypeople.

A larger body of scholarship discusses public distrust and mistrust in science. The emphasis here has been on: the problematic mechanistic regulatory systems of accountability and transparency; fake or ill-informed science; disinformation; lack of understanding of internal and external influences and expectations/needs/values of different publics; scientists ignoring the importance of capitalising on epistemic trust; ignorance of conditions relevant to trustworthiness (i.e. building on Sheila Jasanoff's concept of 'civic epistemologies' as "understandings of what credible [knowledge] claims should look like and how they ought to be articulated, represented and defended" (249) and its affective dimensions (i.e. how feelings of vulnerability relevant to specific public, risks and uncertain contents impact trust); ideologies; and limited knowledge about science (e.g. see Jasanoff, 2005; Kitcher, 2011; Slovic, 2013; ALLEA, 2018; Rutjens, 2018; ALLEA, 2019; Jaiswal et al., 2020; Huber et al., 2022).

Although CS gets increasing attention as a knowledge co-production mechanism and its potential to promote and restore epistemic trust, the field has its own trust critiques to address. The most prominent refers to participants' skill and ability to collect high quality data. Numerous studies compare expert with CS data to demonstrate that CS produces high quality outputs (Kosmola et al., 2016; Balázs et al., 2021). The field has also matured in using automated systems, peer verification and in sharing best practices for the development of effective training protocols, education materials and other resources to improve the quality of outputs. Such critiques may reflect scientists' skepticism and mistrust in the public's ability to participate fully in scientific research, which is a

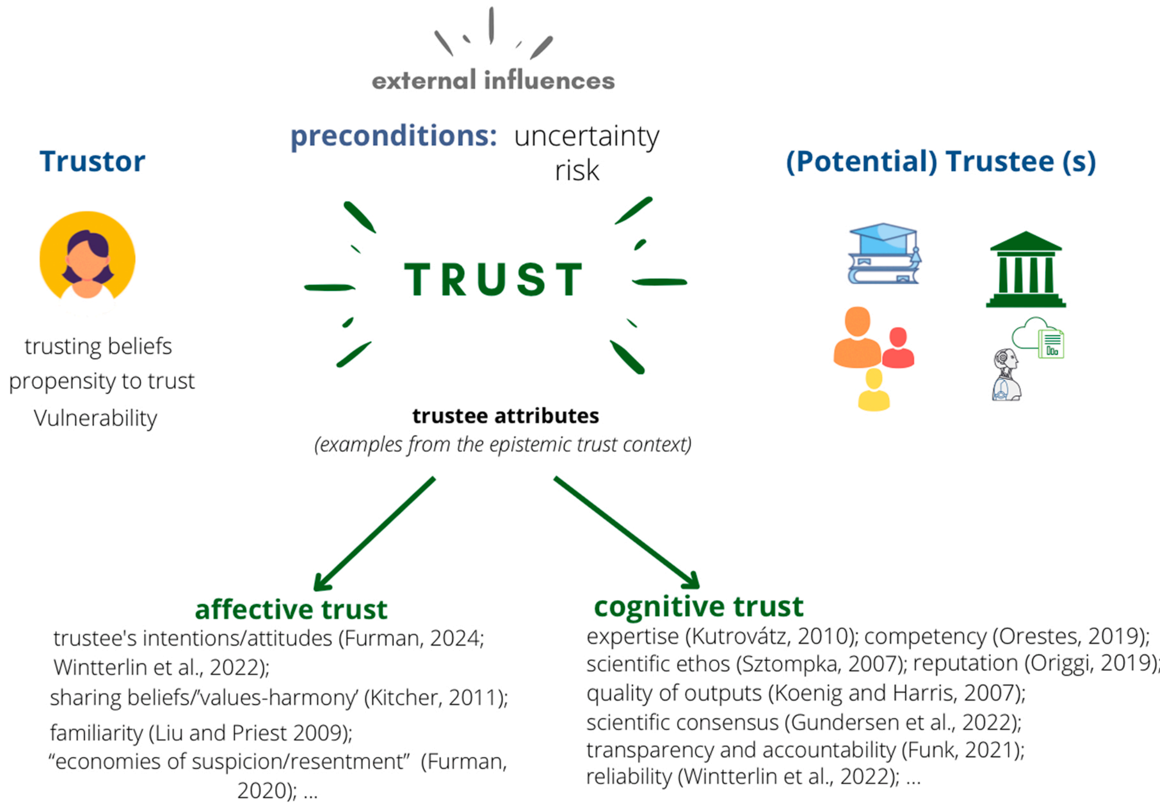

Fig. 1. Conceptual trust model, with examples from the epistemic trust context. (Furman, 2024; Wintterlin et al., 2022; Liu and Priest, 2009; Kutrovátz, 2010; Origgi, 2010; Funk, 2021, Koenig and Harris, 2007).

persistent position held by scientists (Bisley and Nisbet, 2013). Trust tensions also arise in some relationships between participants and project scientists. Participants trust the data they contribute to be reliable and that their contributions "will be reviewed through a fair process and used for an appropriate purpose" (Gilfedder et al., 2018, 293). Reliable scientific methods supported by training materials and ongoing communication across scientists and participants may increase confidence in data reliability and use. Provision of the right tools to view data serve as a verification mechanism (Pejovic and Skarlatidou, 2019). Nevertheless, an increasing number of studies report that CS requires trade-offs between data quality, privacy protection, resource security, transparency, and trust (Anhalt-Depies et al., 2019), which may influence trust.

Epistemic trust is multi-faceted, encompasses risks causing vulnerability, and cognitive, affective and socio-cultural influences, which shape the formation of trust and public action. While CS has the potential to restore epistemic trust, a significant gap remains in understanding how trust perceptions are formed in practice. This gap is concerning given existing critiques within the CS field. Considering the conceptional framework introduced in Fig. 1, it is critical to reflect on trusting relationships in CS, focusing on risk and uncertainty, their impact on trustor vulnerability and subsequently how this shapes public action. This is crucial for CS contexts where distrust prevails, as there is no evidence of how a CS approach may challenge cultures of distrust to enable engagement and encourage local action. Based on our conceptual framework in Fig. 1, it is equally important to understand how a CS approach can assist members of the public develop cognitive trust perceptions and engage affective elements, for which nevertheless we have a limited understanding not only in CS but in the broader public participation context (Kitcher, 2011). Exploring these questions is not only essential for the future of the field, but also in terms of informing institutional frameworks which emphasise the role of CS in terms of addressing some of the most stressing environmental challenges.

3. Case studies

The three case studies presented herein involve bottom-up CS initiatives, which support knowledge co-production processes, and which can be found at the top two levels of Haklay's (2013) typology (i.e. Participatory Science and Extreme Citizen Science). All cases incorporate high levels of risk and uncertainty, which are necessary trust preconditions. The case study descriptions developed independently by the paper's authors who have been working in each context for several years and captures their perspectives and experiences with respect to how trust has been shaped in each context. The case studies developed based on the conceptual framework introduced in Fig. 1 (see also Fig. S3 in supplementary materials) and include information about: Contextual characteristics, including elements of risk and uncertainty and importance of trust; Stakeholders involved (human actors taking the role of the trustor or trustee); Trustee attributes (i.e. cognitive and affective attributes and trust conditions relevant to the CS activity as a process and its outputs). The case study selection does not claim to be representative, nevertheless, special attention was paid to present and subsequently discuss cases from different socio-cultural contexts, which they are not overly political. Our intention is not to compare how socio-cultural characteristics influence different forms of trust (e.g. social, institutional and mainly epistemic), although we recognise that social and political contexts create different and often contradictory situations for implementing and practicing CS (Kinchy and Kimura, 2016). In our analysis we focus on identifying key trustee attributes that exist across all case studies and which influence how trust is formed in each context, despite the existence of different internal and external influences.

3.1. *Case Study 1: Wildlife Crime and Animal Monitoring in Cameroon*

In southern Cameroon illegal wildlife trade has become rampant due to local exclusion from the forest and rising poverty. To assert their rights and become involved in the management of their forests, forest communities since 2016 use the CS tool Sapelli (Pejovic and Skarlatidou, 2019) to collect data on wildlife crime – one of the issues they are most distressed about – as well as animal monitoring. Unique projects are created with each village through a process based fundamentally in free, prior and informed consent, community management plans ('protocols'), and interface co-design through an extreme CS approach (Hoyte, 2021). As requested by communities, data are utilised by staff of the Zoological Society of London (ZSL), Cameroon, who, through collaboration with Ministry of Forests and Wildlife (MINFOF) staff, have employed the data to conduct seizures, arrests of traffickers, and to reassess important wildlife hotspots and corridors based on community ecological monitoring. Through using Sapelli, community members have gained digital skills and become empowered to collect data on their key issues.

In this context, trust is phenomenally important. This begins with the trust between the researchers and the partner NGO (ZSL), and between the implementers and the communities, but as the project evolved expanded out to the trust between community members and other stakeholders – particularly MINFOF staff - and indeed trust between community members within villages. Distrust and conflict exist between conservation actors and communities because of: a) the perceived complicity of conservation actors in wildlife crime, and; b) the role science has played and continues to play in imposed, top-down conservation measures which significantly disenfranchise and harm forest communities (Pyhälä et al., 2016). Essentially, outsiders are regarded with great suspicion. This sets the scene for the level of scepticism and distrust in this context.

The use of Sapelli enables communities to collect their own data using their ecological knowledge and knowledge how wildlife crime operates, however as the data may be sensitive, trust has to be established in order for community teams to remain safe. For example, one community member commented: "Such a project could put us in serious trouble with other communities" and many others asked, "when the information is sent, how do you keep us secure?". In another situation, community members were concerned that the data could be used to expand the park boundaries further inflicting on their rights.

It was quick to establish that a vital element of trust is about actions rather than words. One community expressed their concern that we would not return to initiate the project, despite setting a day and time to do so. This is because the communities in this region have been repeatedly let down by false promises of collaboration by NGO staff or government actors who make claims of solving problems but fall well short, or of those who arrange plans and meetings but fail to show up. To gain trust, trustees must only promise what is realistic and always fulfil their promises. Additionally, as actions mainly inform trust, trustees must demonstrate their willingness to go beyond the level expected by the communities, for example by creating genuine relationships with community members (e.g. staying overnight, eating together) and by noticeably making time and space for local voices to be heard. Affective elements are therefore far more important in building local perceptions of trust than cognitive elements: how participants *feel* about the trustees and what kind of person they are informs a large part of how trust is created (Hoyte, 2021).

Gaining trust in a context of entrenched corruption must focus on humbleness and honesty – acknowledging the barriers and difficulties and communicating that there is no silver bullet but rather efforts to see if alternative ways of engaging can work. This affects the outputs of the project because the definition of the outputs must be informed by what is realistic and what is acceptable to the community teams, influenced of course by their perception of trust.

The designs of Sapelli projects here are co-created (in a Participatory Design process) whereby community teams decide on what data is important to collect and design icons to represent each data item. Subsequently, individual community protocols are created to formalise which stakeholders will have access to the data and for what objectives. Such geospatial data collection design, comprehensible to community members through their own icons imbued with meaning and to other stakeholders through an online map interface - the whole system governed by community protocols - attempts to create a 'third space' between local knowledge systems and worldviews and those of outsiders who subscribe to conventional science (Fowles, 2000). Despite this, community data has not been understood and equally valued alongside conventional scientific data throughout the project due to a lack of training with data recipients; carrying out training in this regard is essential to progress towards data equity (Hoyte, 2023).

Over the course of the project, trust has generally increased if community wishes and protocols are strictly followed, and the data produced becomes more in-depth. In some cases, however, community teams become disillusioned where they feel that their data is not being acted upon, threatening to erode trust. The complex situation whereby corruption and lack of resources in the ministry and logistical constraints in the partner NGO results in fewer community visits and collection of data than expected. These sorts of difficulties must be discussed openly and, where possible, before the project begins. The emphasis of the project shifted from immediate responses to longer-term shifts and policy change in how conservation is done. This was understood but needed to be balanced with more immediate community benefits (such as remuneration).

The clearest message from the case study is that co-creating CS projects can lead to rebuilding of epistemic trust, however implementers must carefully understand the context-specific barriers to epistemic trust, work hard to address them right from the moment of project design, and create the capabilities necessary to properly value and understand local knowledge systems and worldviews.

3.2. Case Study 2: The Fukushima disaster - monitoring radiation pollution in Japan

The Fukushima Daiichi Nuclear Power Plant disaster in 2011 spurred citizens in Japan to localise and evaluate radiation risks using their own monitoring devices. Driven by shortcomings in public radiation information, residents formed or rehabilitated citizen radiation monitoring organisations (CRMOs) (e.g. Tarachine in Iwaki, the Aizu Radiation Information Center in Aizu Wakamatsu and the international Tokyo-based volunteer organisation Safecast). Several of these groups still remain active, suggesting a public need for trustworthy and "actionable data" concerning actual radiation levels (Kenens et al., 2020). As acknowledged by the Diet in its official investigation report into the nuclear accident, the Japanese government and its power plant operator TEPCO failed to provide accurate information to the public when it was most needed. Whereas residents wanted to know which areas, grounds, and foods were safe, officials gave incomplete or false evidence to create an illusion of safety (National Diet of Japan NAIIC 2012). The CRMOs sought to fill this information void. Following Morita et al. (2013), their activities were driven by basic safety concerns and survival needs. Building on a longer tradition of citizen activism in Japan dating back to the 1970s, these initiatives emerged from the grassroots, challenging vested institutes (specifically, Japan's "nuclear village," comprising pro-nuclear industries, bureaucracies, government, media, and academia, among others) and expert-centric CS approaches in which citizens collect data for professional scientists (Van Oudheusden and Abe, 2021).

Although civic responses often had to be improvised and involved learning-by-doing, CRMOs gained public trust by openly and unreservedly sharing information on environmental radiation with the public (Abe, 2015). By emphasising their independence from government agencies and remaining close to local communities CRMOs were able to build communal support (Kenens et al., 2020). To this day, public trust in the Japanese government remains historically low, and is exacerbated by how Japanese authorities handled the Fukushima disaster and the

COVID pandemic (Edelman, 2021).

Public reception of CRMOs varies, even within Japan. This is partly because not all CRMOs are equally known to the public and citizen engagement in science is not always positively valued. Although CRMOs share a commitment to transparency and community action they highlight different aspects of the nuclear accident, including contamination of agricultural land, products and children's safety. The international volunteer group Safecast is driven by a core group of mostly foreigners residing in Tokyo. Its members use crowdsourcing techniques and do-it-ourselves technologies to collect and share data on radiation levels in the form of easily accessible online radiation data maps. CRMO members may choose to position themselves as neither pro- or anti-nuclear; decide to collaborate with professional scientists and local governments; or conversely, position themselves in opposition to government and other institutions (Kenens et al., 2020).

Whereas many CRMOs remain relatively invisible, some nuclear institutions have noticed them, and ostensibly approve of crowdsourcing as a means of collecting and disseminating radiation data; whilst also cautioning that data collected by citizens may not meet scientific standards (IAEA, 2014). Yet, for members of CRMOs, transparency about the measurement process, the applied procedures and equipment, and the interpretation of measurement values, are key in assessing data quality. The failure on behalf of the government to communicate openly radiation data generated more public distrust and spurred citizens to act. As a member of the international Tokyo-based organisation Safecast has stressed, "[t]rust is not a renewable resource. […] People have many sources of information to turn to – if they don't feel they can trust you they will simply look somewhere else and not look back" (Bonner and Brown, 2020).

Government agencies and vested nuclear institutes are less approachable to the public than CRMOs and citizen scientists. Spokespersons of the former have recurrently raised concerns that the public lacks a clear understanding of nuclear science, and consequently, cannot make good decisions without professionally-trained scientists. Deficit thinking about the relationship between experts and citizens is still pervasive in scientific and nuclear communication campaigns. During fieldwork, a citizen scientist in Iwaki narrated how professional scientists tend to offer help and insights but ignore the expertise and knowledge citizen scientists have accumulated over the years. Therefore, she only works with scientists who are willing to collaborate as partners and to respond to questions and needs expressed by citizen scientists. As this example illustrates, the CRMOs are intent on resolving problems by sharing knowledge and by learning-by-doing. In these groups, information is used to tackle an urgent problem that requires input from multiple stakeholders. In this perspective, knowledge generation and dissemination are commons-based, and no one has exclusive rights to organise the effort or "capture its value" (Benkler, 2004, 1110).

CRMO members may employ and rely on skills, knowledge and connections acquired prior to participation. By combining these resources with new expertise, these groups can generate community impact and function as knowledge brokers within or among communities, or between the spheres of society, science, and policy. In the process, 'data' takes on a broader meaning than in the language of radiation protection agents and experts, enabling CRMO members to connect and develop personalised care and communication strategies that are adapted to individual and community needs.

Close connection with local communities helped these organisations generate public trust and develop new expertise (e.g. air pollution for Safecast), demonstrating the flexibility of CS work, which emphasises transparency, education, and participation. Some CRMOs take care not to infringe on individual privacy and consider the potential harm the publication of data might cause to private homeowners or farmers. Hence, they opt at times to not publicly share data. What this suggests is that trust issues emerged in response to divergent aims, values, and needs, grounded to different ways of knowing and valuing data. For instance, for residents the question as to whether an area is safe to inhabit relies on more than getting the measurements right in a technical/scientific sense. The question of safety equally concerns questions about which data to select (and why), how data are handled and made actionable. In the case of Safecast, data accuracy and scientific standards remain a crucial measure of gaining scientific and public trust and legitimacy. Other CRMOs are concerned with generating "just good enough data" (Gabrys et al., 2016) to point out blind spots (e.g. radiation exposure of children), close knowledge gaps related to living in a contaminated environment and incite policy action directed towards helping concerned community members. To this day, many vested nuclear institutes fail to see these differences between formal and community approaches to gathering and interpreting radiation data (and the differences between various CRMOs), continuing instead to emphasise the importance of scientific literacy, data accuracy and reliability. This is unlikely to generate public trust in established institutes in the case of a new crisis or emergency.

3.3. Case Study 3: Dealing with pollution in River Evenlode, UK

The River Evenlode, Oxfordshire, UK, is a rural river and a tributary of River Thames, known to be affected by pollution from agricultural fertilisers, treated and untreated domestic wastewater. The Evenlode Catchment Partnership (ECP) convenes a multi-stakeholder group with the goal of improving the river environment. Since 2018, ECP has received funding from Thames Water via their Smarter Water Catchments programme, which aims to co-create river management plans with local communities (Thames Water, 2018). Via ECP, the community has undertaken monthly CS monitoring of river water quality at strategic locations, including upstream and downstream of suspected pollution sources including Thames Water sewage treatment facilities. This monitoring is led by community and is facilitated by the environmental NGO Earthwatch Europe via the FreshWater Watch project. Through the monitoring, volunteers identified the locations and timings of negative impacts on water quality, including several related to the treatment plants. They are now in direct dialogue with Thames Water, the Environmental Agency and other stakeholders about developing potential mitigation actions.

The success of the project relies on building trust within the partnership, and between Thames Water and volunteers. The project sits within a context of growing public distrust in water utilities companies (Ofwat, 2023). The UK water industry was privatised in 1989 after decades of dwindling investment. This process created ten privatised regional companies, with each having a regional monopoly. The industry is heavily regulated to compensate for this financially and with regards to environmental performance. Nevertheless, over half of the UK public believe that the entire sector is profit-driven and that water companies do not act in the interests of the local community or the environment (Ofwat, 2023). In 2010 the responsibility for monitoring environmental impacts of water company operations shifted away from the independent regulator and to the water companies themselves under a system called Operator Self-Monitoring. This has been described by citizen activists and media as allowing polluters to "mark their own homework" (Laville, 2023) and has led to public mistrust in data and information about the impacts of wastewater pollution on river health (Hammond et. al., 2021). The dynamics of trust within the ECP are therefore complex. Thames Water are funding the project, but some would argue that they have a vested profit-based interest in ignoring findings. It could be argued that volunteers who pay Thames Water for wastewater treatment are similarly invested in the findings, with the results acting as a measure of the company's paid-for performance. Within the project, everyone's propensity to trust depends on a multitude of preconditions including experience and views on sector privatisation; technical knowledge of the water sector and its relationship to the environment; exposure to popular media coverage of poor water company performance; individual consumer – customer relationships; and personal experience of the river environment.

The SWC programme was initiated by Thames Water to facilitate partnership working. The need to build trust with external stakeholders – including the public – is implicit. The key mechanism for achieving this is co-design: a) to improve the availability of water quality data across the catchment, potentially enabling pollution sources to be detected, and b) to increase public visibility of water quality issues in the river via open access data and public participation. Project objectives were initially designed in workshops with volunteers, Thames Water representatives, and other key stakeholders, and regular management meetings continue throughout the project. Thames Water representatives initially entered the meetings with an awareness of mistrust and therefore took a 'listening first' approach, allowing community volunteers and other stakeholders to voice their concerns. Spending time together and building a mutual understanding of the values of all individuals involved is an important part of these meetings. Earthwatch Europe acted as an independent scientific advisor as the research approach was designed, helping to ensure that the project is scientifically objective and providing monitoring tools and training via their FreshWater Watch platform. Volunteers initially selected monitoring locations based on perceived problem areas and agreed to collect data monthly. Data and basic interpretation are shared with volunteers instantly via a web app. Findings are then discussed with the water company directly by volunteers in regular meetings, and summary findings are presented for the public in an annual report.

Throughout the process there have been moments of disagreement. A significant one involved the response of Thames Water to volunteers' data. Water quality in rivers is dynamic, and this means that prolonged monitoring over several years was required before the data could be considered reliable by the water industry. However, volunteers began to see clear patterns in the data much sooner than this. Even after one volunteer produced 18 months of data showing significant differences in water quality upstream and downstream of one sewage treatment facility, Thames Water were unable to respond promptly because sewage treatment work upgrades must be incorporated into company business plans, which are heavily regulated by Ofwat. There is a clear misalignment between volunteer timescales and water company timescales, since volunteers receive instant feedback on their data, but water companies are unable to act on findings for months or years. To combat this, volunteers decided to write a "position statement" about 12 months into the project to communicate and agree on their positionality with regards to the way they work with Thames Water. They outlined their findings and follow-up actions that they hoped the water company would commit to and existing areas of mistrust (e.g. a fear that Thames Water wished to use the project as a form of 'greenwashing' and were not committed to following up on the findings). This statement was sent to Thames Water, who then agreed for it to be released to local press (Norris, 2021). This helped to clarify to onlookers that, despite the project being funded by the water company, it was run by volunteers. This could not have been achieved had mechanisms for elements of trust and mistrust to be communicated freely and openly not been established. Regular multi-stakeholder meetings provided a way for relationships to be built, enabling participants to recognise that neither Thames Water nor the community could be viewed as having a single set of values. The project continues.

4. Analysis and discussion

We use the conceptual framework for epistemic trust to group our key findings (as shown in Fig. 2) which we discuss in detail in this section.

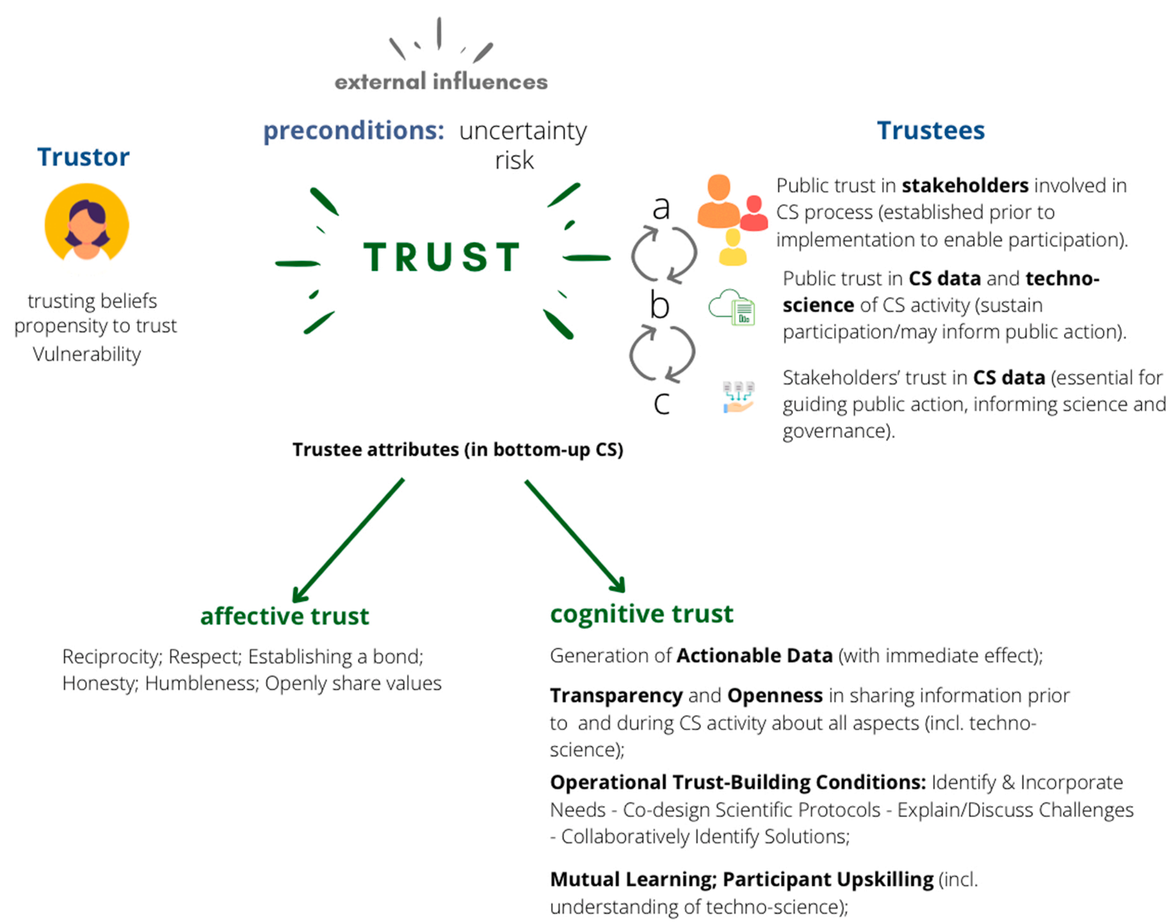

Fig. 2. Citizen Science - Epistemic Trust Components.

4.1. Whose vulnerability and trust matters?

All cases incorporate risk and uncertainty, which make trust an important concern. CS in Cameroon unfolds in a context of corruption and distrust; communities feel distressed about the lack of respect for their land and wildlife crime. To tackle this, they are collecting animal monitoring data and report wildlife crime, putting their own safety at risk. Another important risk is introduced by the possibility of inappropriate use of the data collected against participants' interests. Therefore, trust is not only essential throughout the implementation of the initiative and beyond, but mainly prior to it, considering the culture of distrust and power asymmetries. Measuring radiation in Fukushima has also been the result of distrust; local communities and individuals were in a vulnerable position being unable to rely on publicly available information about radiation levels. In a socio-cultural context where citizen engagement in science is not positively valued, people started collecting radiation data and they have now gathered over 150 million observations (Safecast, 2020) which shows the magnitude of the issue and how people have resonated with it. Similarly, the growing public distrust of the British public towards water utilities companies, and the (lack of) responsibility to monitor their operations' environmental impacts ethically and efficiently sets the context for case 3.

Our cases emphasise three kinds of interconnected trust relationships, which are all essential for the success of the initiative and for restoring and promoting epistemic trust. First, communities need to trust the stakeholders involved in the participatory process (e.g. government officials, local NGOs). When there is distrust towards institutional actors, communities may trust those who manage the process (e.g. research teams) or those who represent distrusted organisations (as in case 3) based on a judgement of the values these individuals bring. Here affective and interpersonal trust become significant, or participants may refuse to engage in the process. Second, communities need to trust the data they collect - and as an extension the techno-science that governs each initiative - to inform their actions, and eventually reduce risk and uncertainty. Third, stakeholders involved need to trust the CS data to subsequently utilise it and support communities to take local action. A notable example can be found in case 3, where although Thames Water is a project partner, they weren't able to conclusively trust volunteers' consistent monitoring data collected over 18 months. According to Thames Water employees this was due to the lack of a clear framework to incorporate CS into regulatory monitoring. Case 2 also highlights governmental and nuclear agencies' deficit assumptions about the public's ability to generate high quality and reliable data. This, as we discuss in the next sections, poses a significant barrier in terms of restoring epistemic trust.

4.2. Affective trustee attributes: Reciprocity and value-sharing

The second case study's point of departure is based on a trusting relationship with stakeholders who create the conditions, establish the technoscience, manage the data and make them publicly available. This trust towards CRMOs is not universally established, but it nevertheless provides different contextual foundations from the other two cases. As we discuss next actionable data promotes trust, nevertheless some level of trust is required prior to all initiatives' materialisation. Case 1 shows the role of external researchers and scientists, unrelated to local distrusted stakeholders and case 3 discusses trusting the intention and values of those involved even if they represent a distrusted organisation. In initial stages affective trustee attributes play an important role and through value sharing, honesty and familiarity, trust perceptions are further shaped by cognitive trustee attributes in later stages. In understanding the key steps of establishing trust during initial stages, Case 1, is the most complex, as participants are coming from a socio-cultural context where there is little trust towards outsiders. This case emphasises trustee's acts of reciprocity and humbleness, which establish a bond and subsequently develop affective trust. The other cases, too, describe, affective elements for establishing a trust relationship (e.g. in cases 2 and 3 stakeholders emphasise value-sharing and their disconnect from distrusted organisations, to promote familiarity and trust based on sharing common views with those affected). Important in this process of affective trustee attribute identification, which informs the establishment of trusting relationships, is incorporating the operational conditions (Section 4.5) to support the identification of participants' needs, concerns and values, which should be fully integrated into the initiative's design and implementation.

4.3. Challenging cultures of distrust through actionable data

All cases emphasise the importance of generating actionable data as a necessary step for promoting epistemic trust. In Case 2, vulnerability and risk are reduced as a direct outcome of the data being released. In Case 1, people emphasise that taking action is fundamental; therefore, the stakeholders that communities agreed to collaborate with, have the responsibility to utilise community data in line with their wishes, such as taking quick action against traffickers and improving conservation planning. In Case 3, data and basic interpretation are also shared with volunteers instantly, but volunteers are not able to act on the findings aside from sharing them with the water company, which risks damaging trust. Generating actionable data with immediate effect provides the foundations for promoting trust in the CS process, those involved and most importantly the generated outputs. Inability to generate some form of action continuously or at key project stages may cause frustration and if not managed properly will break public trust even further and have communities subsequently disconnect from these initiatives. This is common across several CS projects of both invited and uninvited participation, where although policy change may be a top priority little action is taken towards this direction. To this end there are already calls for better-funded long-term CS and for policy-makers, who although already engage in discussions on the political dimensions of CS and its role in policy formation, little action is taken to create effective regulation for CS as a policy instrument (Haklay, 2015; Haklay et al., 2023).

4.4. Cognitive trustee attributes for CS outputs: Openness and transparency

Transparency and openness are identified as important cognitive trustee attributes across all cases with respect to openly sharing information, collaboratively shaping the initiatives' aims and the techno-scientific infrastructure (e.g. protocols, technology(ies) utilised, interfaces etc) (e.g. see cases 1 and 3). It is through transparency that participants improve their knowledge of various scientific, technical, and organisational aspects, and build confidence in co-creating outputs with acceptable levels of risk. In a bottom-up CS process, participants shape the project to address their concerns, and through openness and transparency become fully aware of how various challenges may impact outputs and inform policy change. Although participants in case 2 may not be involved in shaping the initiative at its preliminary stages (i.e. what will be measured, and how), CRMOs openly share knowledge and rely on Do-It-Yourself (DIY) equipment, which facilitates participants' technical upskilling. Transparency is important here with respect to what the equipment consists of, how it is being utilised, the applied procedures, the measurement processes and how results are being interpreted. Although issues of data reliability and quality have received much attention and criticism in CS, it appears from all cases that it is the mechanistic of transparency and openness, which provides participants with the knowledge, skills and confidence in supporting their cognitive trust assessments with respect to CS outputs.

4.5. Knowledge co-production in citizen science: Trust-building conditions

A knowledge co-production process has the power to positively influence the interconnected trust relationships across multiple stakeholders, when it offers 'spaces' and conditions to promote epistemic trust. Knowledge co-production is motivated by democratic ideals inspired to support the integration of multiple voices. Participatory design - which is the method used in cases 1 and 3 to inform the participatory process - generates a 'third space' where communities and scientists work together in a process of mutual learning, understanding and respect. In establishing trust, we saw particularly from case 1, that the process is designed in a way that enables an open discussion of barriers, challenges and their impacts to outputs, to subsequently manage expectations and collaboratively identify solutions. It is important that this collaborative space provides the means for participants to express concerns about the design and framing of the scientific process (e.g. as we saw particularly in cases 1 and 2 how participants' privacy concerns are considered in terms of how the project is managed and how data are subsequently shared). Equally important in terms of promoting epistemic trust is to support the development of participants' scientific knowledge, learn from peoples' local knowledges and the expertise they gain from participating in the process. All case studies emphasise the existence of these conditions which act as cognitive and affective trustee attributes, and which are therefore essential in terms of designing bottom-up CS practices which may have the potential to restore epistemic trust.

5. Conclusions

We explored through three CS cases, the interconnected trusting relationships shaping epistemic trust and the cognitive and affective trustee attributes influencing trust perceptions. Affective trustee attributes (e.g. reciprocity) mostly influence the formation of trust perceptions before the initiative and during implementation. Cognitive trustee attributes are mostly important at subsequent stages; they influence trust assessments of CS outputs (i.e. generation of actionable data, openness and transparency – e.g. how data are gathered, what represent, how it is used - which mobilise data quality assessments) and the CS process (i.e. a participant-centric design and implementation which enables knowledge co-production at multiple levels and of all stakeholders involved). In this respect, our cases emphasise how the practice of CS requires scientists/researchers 'un-learn' engrained perceptions of scientific superiority (Tilley, 2017) and embrace the ability to step back and hand over power to participants.

The need for actionable data is an important cognitive trustee attribute, bringing to the forefront a significant risk for epistemic trust in CS. We saw three types of trusting relationships (i.e. i. participants' trust in stakeholders involved; ii. participants' trust in CS data; iii. stakeholders' trust in CS data) and our cases show institutional stakeholders still carry deficit assumptions about participants' ability to generate actionable data. Yet when actionable data is not provided, the CS process may generate negative public attitudes, suspicion and erode epistemic trust, which we saw happening in the past through other participatory methods. Nevertheless, CS differs from other participatory approaches as it enables participants to engage in science-protected politics (Wynn, 2017) exposing the mistrustful paternalism of specific "experts" in the public's ability to co-produce scientific knowledge. In this respect, CS is not destined to intrinsically restore epistemic trust, if scientific and policy institutions do not create the necessary conditions to support CS's transformative potential, especially when these same institutions initiate or participate in CS activities.

We recommend more emphasis on creating institutional and policy capacity to support ongoing exchanges between diverse stakeholders and serve as an infrastructure implementing bottom-up CS approaches on a "system level". We provide an initial instrumental framework for epistemic trust, but acknowledge that more research is needed to better understand and capture additional conditions and attributes in broader CS contexts, while considering their unique internal and external influences. The emphasis should be further on "demystifying" trustee attributes such as transparency and openness into actionable steps that can be incorporated into operational procedures. This will create a replicable framework across multiple contexts, supporting thorough evaluation processes and even the development of trust-related performance metrics.

The potential of bottom-up CS to engage people in authentic and value-transparent conversations, address local issues and identify solutions to environmental global challenges is enormous. So, is the potential of CS to promote epistemic trust, but this depends on the complex interplay of internal and external influences, which may be unique to specific contexts. An instrumental framework emphasising the trust-building potential of CS will help improve efficiency, reinforce normative CS ideals, and support participants to develop well-informed, rational trust perceptions based on the presence of relevant cognitive trustee attributes. Within such instrumental framework we should always pay further attention to inclusivity and representativeness, as these are essential for the legitimacy and fairness of any form of democratic public participation in environmental science and governance.

CRediT authorship contribution statement

Michiel van Oudheusden: Writing – review & editing, Writing – original draft, Methodology, Investigation. **Isabel J. Bishop:** Writing – review & editing, Writing – original draft, Methodology, Investigation. **Muki Haklay:** Conceptualization. **Simon Hoyte:** Writing – review & editing, Writing – original draft, Methodology, Investigation. **Artemis Skarlatidou:** Writing – review & editing, Writing – original draft, Supervision, Project administration, Investigation, Formal analysis, Data curation, Conceptualization.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability

All data is available with the files submitted

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Appendix A. Supporting information

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