CITIZEN SCIENCE:
THEORY AND PRACTICE

Challenges, Strategies, and Impacts of Doing Citizen Science with Marginalised and Indigenous Communities: Reflections from Project Coordinators

RESEARCH PAPER

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ABSTRACT

Citizen science is growing and increasingly realizing its potential in terms of benefiting science and society. However, there are significant barriers to engaging participants in non-Western, non-educated, non-industrialised, non-rich and non-democratic contexts. By reflecting on the experiences of 15 citizen science project coordinators, this paper contributes to the small but growing body of knowledge attempting to identify barriers and opportunities of doing citizen science with marginalised and Indigenous communities. Challenges affecting participation in the analysed projects include issues that range from lack of basic infrastructure and participant safety to unbalanced knowledge hierarchies and data rights. We found that, to overcome these challenges, projects have used several strategies, from promoting decentralized and low-tech solutions to engaging in bottom-up actions from a human-rights approach. Finally, our analysis of project impacts supports the idea that doing citizen science with marginalised and Indigenous communities might have a greater impact for participants than for science, as scientific achievements

(although valuable) were not among the most important impacts highlighted in terms of project success. By providing stories from the field in a structured way, we aim to guide, to inform, and to inspire other citizen science projects, and to, ultimately, contribute to broader participation in citizen science in the future.

INTRODUCTION

Technological ubiquity and a series of social trends have lowered citizens' entry barriers for engaging with science (Newman et al. 2012). This has a major impact on the ways in which citizen science is practiced, and multiplies the potential benefits for both science and participants (Skarlatidou and Haklay 2021a). For instance, the Zooniverse platform, with over 2 million registered participants, has seen daily contributions continuously increase, with participants submitting galaxy classifications equivalent to 48 years of research (Dinneen 2020). Citizen science has also economic impacts, as hundreds of citizen science projects engage millions of participants across the world, annually contributing up to US$2.5 billion in-kind (Theobald et al. 2015).

For participants, documented benefits of engaging in citizen science projects include: improved health and well-being (Den Broeder et al. 2017); increased scientific literacy (Aristeidou and Herodotou 2020); enhanced perceptions, behaviours, and attitudes (Chase et al. 2018), especially with respect to the environment (Requier et al. 2020); increased feelings of responsibility and success (Turreira-García et al. 2018b); and cognitive, political, social, and economic empowerment (Danielsen et al. 2021). Despite these benefits, citizen science projects tend to be developed mainly in Western, educated, industrialised, rich and democratic (WEIRD) contexts. Indeed, citizen science initiatives rarely engage populations with Indigenous or non-Western epistemologies (Tengö et al. 2021). Moreover, they often engage participants with a formal education background, with access to infrastructure and technologies, with sufficient economic resources to afford the equipment and the time for volunteering, and who live in areas that have certain political stability (Mahmoudi et al. 2022). Consequently, people from marginalised and Indigenous communities are largely excluded from participating in citizen science projects or are simply unaware that opportunities exist (Dawson 2019). This represents a significant proportion of the global population, mostly people living in the Global South but also marginalised communities of the Global North, that is, those confined to the margins of society and lacking power and privileges (Cooper et al. 2021).

The current focus on WEIRD contexts creates a huge bias in citizen science, as it was first described in psychology (Henrich, Heine, and Norenzayan 2010). Acknowledging participation biases in citizen science has resulted in calls for targeted action to eliminate digital and socioeconomic divides (Soleri et al. 2016). This implies reaching people who live in rural/remote, low- and lower middle–income communities, and those who might not have the necessary resources or skills to participate. Only through such efforts can citizen science become a tool to capture all people's voices, knowledge, and struggles, and ensure that no one is left behind in addressing our global challenges, a goal particularly important for the UN 2030 Agenda for Sustainable Development (Fraisl et al. 2020).

However, there are significant barriers to engaging marginalised and Indigenous communities in citizen science. For example, Pocock et al. (2018) identified limited awareness of opportunities, limited organisational capacities, and limited access to relevant technologies as barriers to participation in East Africa. Paul et al. (2020) identified bureaucratic and financial hurdles, and poorly understood motivational and institutional hierarchies as barriers in low- and lower middle–income countries. And Benyei et al. (2020) found that technological uneasiness and knowledge hierarchies that consider non-scientific knowledge as non-valuable were preventing elders and rural communities from engaging.

These barriers can be reduced/eliminated through different strategies. For example, the Extreme Citizen Science group at University College London (UCL) identified several strategies that can increase participation, from establishing a trusted relationship with communities to selecting appropriate and co-designed technologies that consider local knowledge and culture (Chiaravalloti et al. 2022). Working with illiterate participants in Argentina, Requier et al. (2020) also suggest using recruitment strategies that reach different participant profiles, and a high number of local coordinators. Finally, Paul et al. (2020, p. 2) suggest providing compensation or designing community-led projects that "meet local needs by targeting relevant socio-environmental problems."

In this paper, we reflect on our practical experiences of working in 15 citizen science initiatives with Indigenous and marginalised communities in non-WEIRD contexts. We highlight challenges, strategies, and impacts of conducting citizen science in these contexts. Although our selection of case studies is biased towards technological and environmental projects, by sharing these stories in a structured way, we aim to guide, inform, and inspire future projects and encourage broader participation in citizen science.

We are not representatives of Indigenous Peoples and marginalised communities, nor do we claim to speak on their behalf or represent their knowledge systems. Their voices are mostly absent from this manuscript. We speak from the position of project coordinators with diverse backgrounds and origins but largely as people formally educated and articulate in English. We acknowledge that this is only a first step and that future work should consider exploring these issues together with project participants and people from the communities involved.

METHODOLOGY

We followed the methodological approach proposed by Anokwa et al. (2009) and used an online questionnaire to invite citizen science project coordinators to participate in this study. It had 10 open-ended questions, including a description of the projects' context, goals, volunteer characteristics, methodologies, technologies, challenges, and impacts. It also asked respondents to share three stories from the field. The questionnaire was shared through citizen science mailing lists, working groups, social media, and by word of mouth.

We collected responses from 16 initiatives, from which we retained 15 that (a) worked with marginalised or Indigenous communities; (b) used citizen science methods (e.g., participatory monitoring, data crowdsourcing, or research co-production); and (c) actively involved participants (see Table 1).

Project coordinators were invited to three 90-minute online workshops respectively addressing challenges, lessons learned, and strategies (on 8th, 15th, and 22nd of April, 2021).

#	NAME	AIM	LOCATION	COMMUNITY
1	CONECT-e: Sharing Traditional Ecological Knowledge	To document, share and protect traditional plant/landrace knowledge in an online platform	Spain	Rural
2	Local Indicators of Climate change Impacts Observation Network	To adapt a citizen science online platform to make it useful to Indigenous peoples	Global	Indigenous
3	Prey Lang: It's our forest too	To collect documentation about resources and illegal logging in Prey Lang forest with an app.	Cambodia	Indigenous
4	Green Care Cameroon	To educate communities about environmental issues and training them in new skills for better livelihoods through citizen science programmes	Cameroon	Rural
5	SEEDAct – Participatory 3D Modelling in Babille Elephant Sanctuary	To assess the sustainable coexistence of people and wildlife at Babille Elephant Sanctuary (BES) by using Participatory 3-Dimensional Modelling (P3DM)	Ethiopia	Rural
6	Indigenous Navigator	To provide online accessible data, by and with Indigenous Peoples, that will support self-determined development and grounded advocacy	Global	Indigenous
7	Remote Access – decolonizing technology for land defence	To support land defenders in the Amazon by co-building technology enabling them to do Citizen Science around oil spills, illegal logging, contamination from mining, and mapping natural resources	Amazon	Indigenous
8	PPG astronomical club	To involve children and teenagers living in the favela Cantagalo Pavao e Pavaozinho (RJ, Brazil) in citizen science astronomy projects.	Brazil	Urban
9	Serra do Mar Participatory ethnobotany	To conduct ethnobotanical surveys with the active participation of local collaborators.	Brazil	Rural
10	Yakutia Community Based Monitoring	To achieve more sustainable and more democratic management of the natural resources in Yakutia through participatory environmental monitoring.	Russia	Indigenous
11	Extreme Citizen Science in Pantanal	To map the traditional territory of a fishery community in the Pantanal wetland	Brazil	Rural
12	Palestine Institute for Biodiversity and Sustainability	To include more citizen involvement into the biodiversity knowledge generating process, to both support conservation and advance scientific knowledge (data gathering).	Palestine	Urban
13	Night Walks	To adapt and design Citizen Science and creative engagements with refugee communities for their social well-being and cohesion	UK	Refugees
14	Being and Becoming Indigenous	To revive the local biodiversity richness and to reconnect youth with their local agrarian resources	Indonesia	Indigenous
15	ActEarly UKPRP	To improve the health and opportunities for children living in two contrasting areas of high child poverty; Bradford, West Yorkshire and Tower Hamlets, London.	UK	Urban

Table 1 List of analysed initiatives.

They were encouraged to share their experiences to support the questionnaire answers, as well as any additional claims. We collected qualitative data during these workshops using a shared online document in which participants could write their stories in more detail. The three workshops were also audio recorded with the consent of participants.

Using an inductive approach drawn from the principles of grounded theory (Corbin and Strauss 1990), we identified themes and subthemes that emerged from the questionnaire and workshops. We then counted the number of initiatives that identified those themes/subthemes as highly relevant to their work (see our database in Supplemental File 1).

For further information on our methods and the initiatives, see Supplemental File 2.

RESULTS

Here we discuss the challenges, strategies, and impacts identified from the study, and the interactions between these topics.

CHALLENGES OF DOING CITIZEN SCIENCE WITH MARGINALISED AND INDIGENOUS COMMUNITIES

We organised the emerging challenges into 19 subthemes, largely by referring to external and internal issues (Figure 1).

External challenges mostly referred to the local political context (e.g., lack of governmental support, political instability, participant safety; identified by 13 initiatives). For instance, there were reports of local governments' "*imposition of restrictions... granting rights to land concession companies, threatens with violence and arrests the local (Indigenous) patrollers, corruption of government rangers, harassment of human rights and environmental defenders*" (Initiative #3). Poor digital infrastructure was raised by 11 initiatives, especially limited internet access, which would inhibit, for example, "*communication, such as planning meetings and other logistics*" (Initiative #10) and the ability to "*provide remote support and training*" (Initiative #7).

Other external challenges included a constrained local economy (i.e., community poverty; identified by 8 initiatives), funding limitations (8 initiatives), or geographic remoteness (7 initiatives). Indeed, "*local poverty is an issue ... and financial support is low – we have to include funds for travel and meals in order to facilitate participation*" (Initiative #13). Also, there were concerns about the "*difficulty in finding long-term funding ... funding could only be secured for one year at a time*" (Initiative #10).

Internal challenges mostly referred to technologies, data, and participants. Common sub-themes describe technological challenges referred to usability and appropriateness (8 initiatives) and the lack of resources and skills to maintain technologies in the short and long

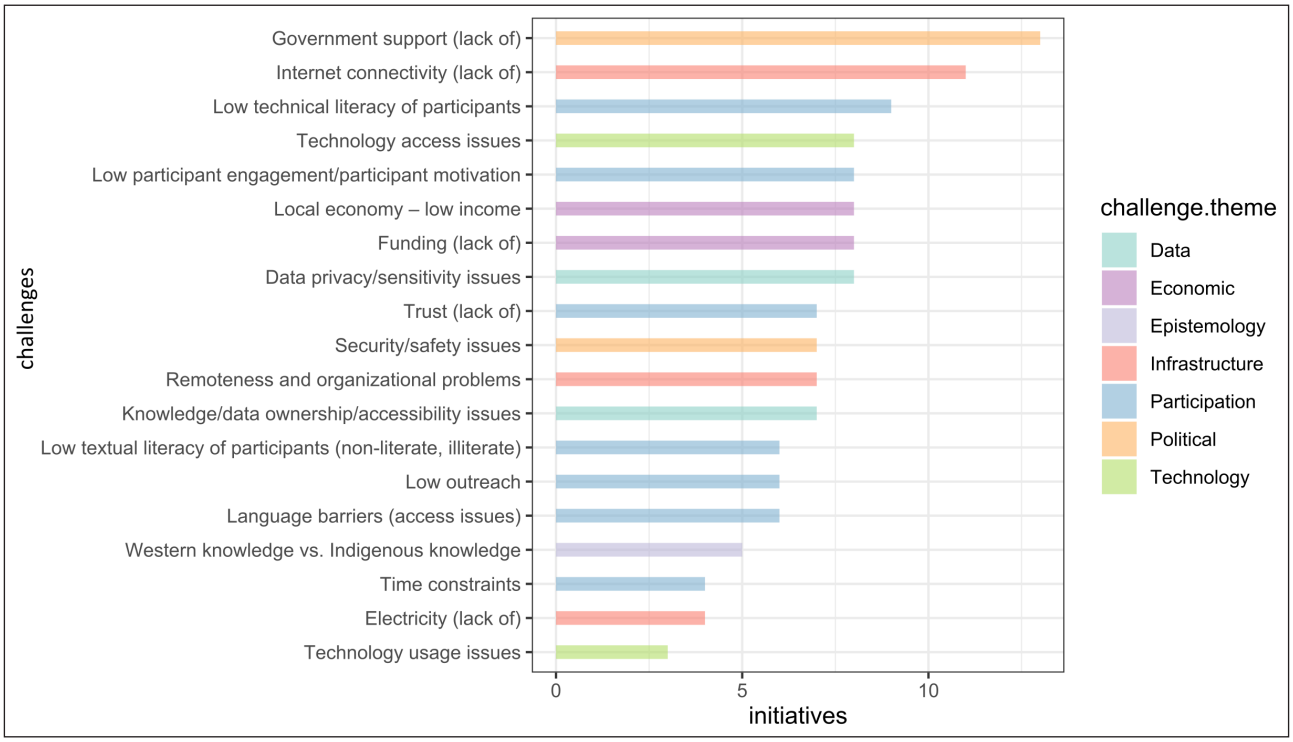

Figure 1 Challenges identified and number of initiatives mentioning each as highly relevant to their work.

term (3 initiatives). "The harsh environmental conditions led several phones to stop working" in one case (Initiative #11), and several initiatives commented that "*continuous external funding is needed to maintain the technologies*" (Initiative #1, ID3).

Data management challenges referred mainly to data privacy or sensitivity issues (8 initiatives) and data ownership and accessibility issues (7 initiatives). Project functioning and implementation was sometimes constrained by "*fears of database security, challenges related to digital literacy, and the digital divide (more security threats/risks as a result of lesser fluency in digital spaces)*" (Initiative #6).

Challenges regarding participants related to their low technical literacy (9 initiatives) and low engagement and motivation (8 initiatives). For instance, there were issues with participants "*not being familiar with programmes and materials*" (Initiative #8) or having "*low technical skills to maintain technology and technological usability*" (Initiative #9). In some cases, "*the project is not the highest priority for the participants. So sustaining motivation and participation is a challenge*" (Initiative #13).

Additional internal challenges include the lack of trust between participants and project coordinators (7 initiatives) and. For instance, "*working with refugee families involved considerable preparatory work with managers at the forum, for reassurance and confidence building*" (Initiative #13). The issue of conflicting epistemologies was raised by five initiatives, for instance, "*it's a challenge to bridge Indigenous knowledge and cosmovision with western worldviews, and it is especially exacerbated by the colonial imposition of hierarchy among knowledge systems*" (Initiative #7). This was also true within teams: "*sometimes interdisciplinarity was a challenge when trying to bring together views from different disciplines, plus local epistemologies*" (Initiative #1).

STRATEGIES OF INITIATIVES DOING CITIZEN SCIENCE WITH MARGINALISED AND INDIGENOUS COMMUNITIES

Project coordinators reported the strategies used to overcome these challenges and elaborated on the lessons learned (Figure 2).

To tackle political challenges, projects focused mainly on promoting a human-rights approach to strengthen communities' claims to land or other resources, and to contest human rights abuses (13 initiatives), and doing advocacy work to build alliances with participants and community organizations (9 initiatives). For example, ID6 noted that "*alongside community, municipal, regional, national and inter-regional dialogues, we also support communications and participation of representatives in international fora (…). Participation at this level brings the stories and experiences of the communities to light and help expose these communities to additional opportunities (…). This helps to maximise impacts and enhance the return to the communities who participate*".

Economic challenges were tackled by seeking alternative funding sources and provide economic incentives for participants. Ten initiatives referred to these as central to their work. Funding sources not tied to specific research activities or outcomes allow researchers to shape the

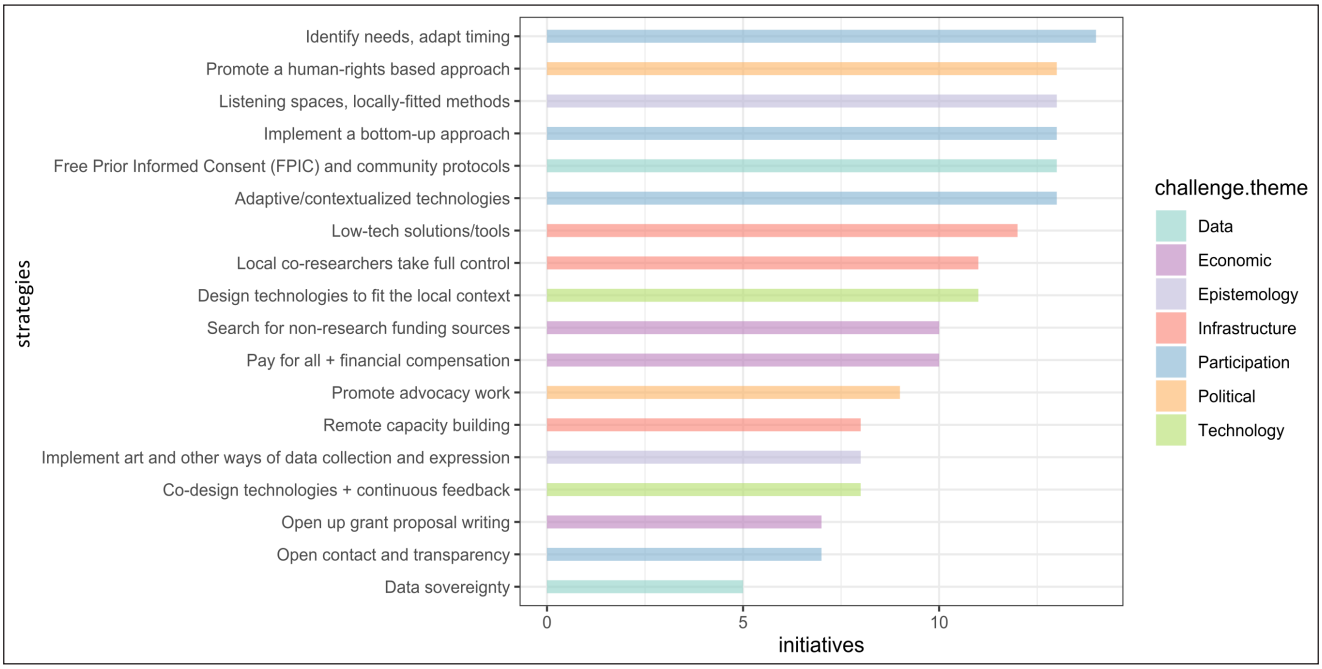

Figure 2 Strategies identified and number of initiatives mentioning each as highly relevant to their work.

initiative based on participants' needs, as well as have the flexibility to allocate resources to support non-research activities (e.g., community infrastructure and capacity building, paying participants, supporting local NGOs) essential for long-term engagement. For instance, "*to be able to work from a more bottom-up approach, a strategy was to apply for 'proof of concept' funding allowing more applied and less research work*" (Initiative #2).

Infrastructure challenges (e.g., limited access to electricity or the internet) were addressed using a design process in which participants are as independent or self-organized as possible ("co-researcher strategy", 11 initiatives) or using low-tech methods and technologies (12 initiatives). For instance, several initiatives reported "*using methods and tools which are suitable for offline conditions and the problematic access to technological infrastructures*" (Initiatives #7, #14, #9 and #4). Moreover, and especially since the COVID-19 outbreak, some initiatives have strengthened their remote work, designing remote activities to compensate for the lack of physical access (8 initiatives). For instance, some adapted training sessions and materials and engaged in "*developing a methodology to train local people to be trainers of the digital tools, creating more accessible training materials (such as video tutorials, mobile-friendly guides and remote courses) and using new platforms for support (such as Telegram and WhatsApp groups)*" (Initiative #7).

In response to technological, data and epistemological challenges, the main strategies employed were the use of locally fitted methods and technologies (11 initiatives), establishing community consent protocols (13 initiatives), and providing spaces in which participants' needs and ways of thinking are expressed and so taken into account in programme design and implementation (13 initiatives). In addition, some initiatives use technological and initiative co-design (8 initiatives), arts and other forms of expression (8 initiatives), and data sovereignty (i.e., full data control and access by communities) approaches (5 initiatives).

For example, ID11 noticed that "*co-designing the interface is essential for technology and citizen science initiative adoption*" and that "*people want to instantly view the data they are collecting or we run the danger they lose interest/or they become less motivated in further collecting data*". Also, ID9 expressed that "*in addition to the local residents being the holders of the data, they were the ones who actually decided the project's objectives, collected these data and chose what would be done with them, as well as the form of its registration (audio-visual and books).*" This is particularly important when data is directly linked to addressing local concerns and challenges chosen by the communities themselves.

In several initiatives, data were owned by communities, which decided on their use and sharing mechanisms, and participation was guided by a Free Prior and Informed Consent (FPIC) process, by which participants need to explicitly consent to the development of any activity. For instance, one initiative highlighted that "*FPIC is an ongoing process, and must be continually re-assessed and reviewed. It is not only in the preparatory work (programme and grant design), but also in implementation and follow-up in how the data is used and licensed and what licensing agreements mean … A lesson learned would be allocating sufficient resources and support to ensure this can be carried out*" (Initiative #6).

Finally, strategies used to address challenges related to participation included: (1) adapting technologies and timing to be culturally appropriate and to fit participants' daily schedules (14 initiatives); and (2) promoting bottom-up engagement, that is, communities leading the initiative and how they choose to engage with researchers and not the other way around (13 initiatives). A major lesson learned was "*to really spend more time on identifying the needs of the community and be clear about the priorities, especially if different needs are expressed by different participants in a diverse group. This will make people more motivated and engaged*" (Initiative #1).

In terms of building trust, seven initiatives mentioned the need for openness and transparency throughout implementation. Ideas that came out of the workshops include: "*Trying to make everything we do as open and accessible as possible, from website design choices to field implementation and return of data*" (Initiative #6); "*[c]ommunity holds ownership of all produced data, training sessions happening at regular intervals and feedback sessions are set after each major change while consultation through the network's core group meetings is continuous*" (Initiative #3); "*[e]ngaging community researchers to spearhead the projects and build trust with community members*" (Initiative #15); or "*[w]e are less interested in "building trust" and instead being authentic, transparent and focused fully on empowering our partners in our entire process. Trust should be an equally authentic result of this process*" (Initiative #2).

IMPACTS OF DOING CITIZEN SCIENCE WITH MARGINALISED AND INDIGENOUS COMMUNITIES

The survey and workshop outputs highlight that doing citizen science with marginalised and Indigenous communities can have significant impacts (see Figure 3).

Most project coordinators reported significant socioeconomic and policy impacts (e.g., community empowerment, reconquering rights/access to resources, fighting legal battles). Although these were not often directly measured, project coordinators considered them to be more important for the project's success than the

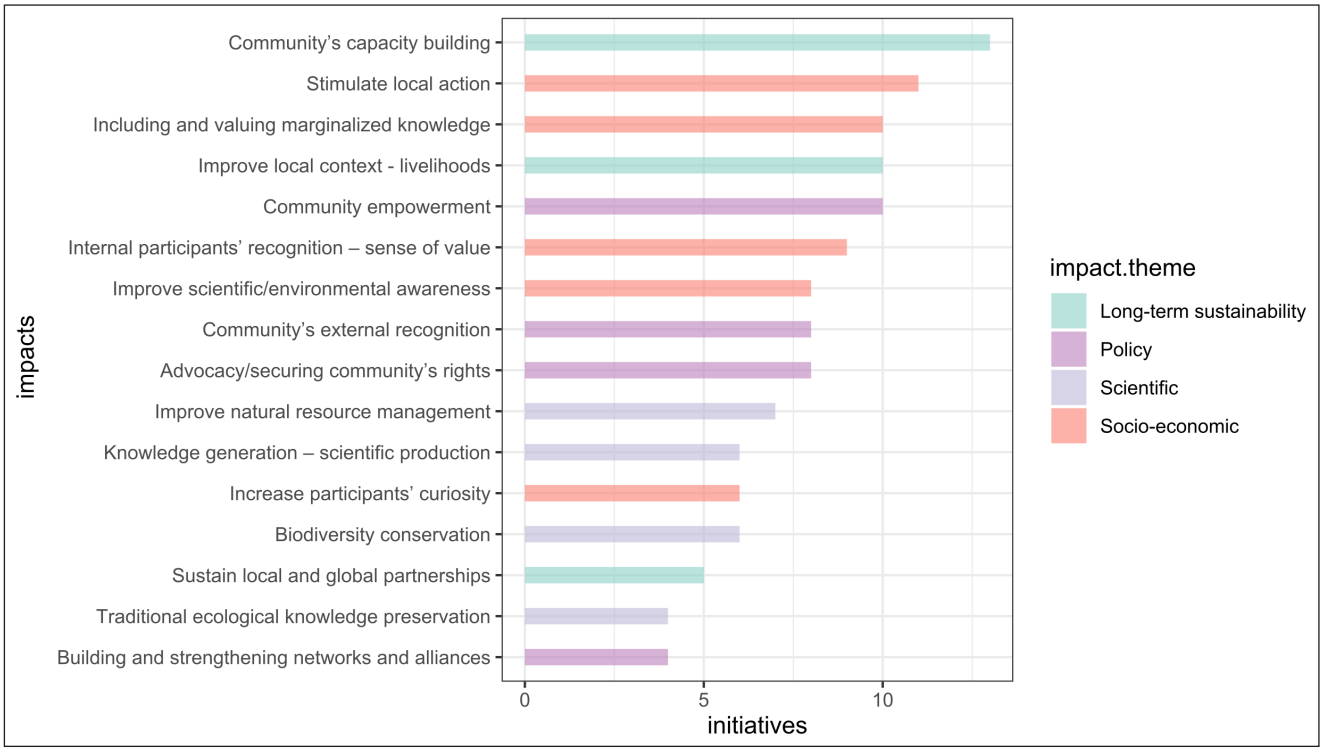

Figure 3 Impacts identified and number of initiatives mentioning each as highly relevant to their work.

scientific impacts achieved (e.g., understanding natural resource management, documenting traditional plant uses, tracking biodiversity).

The most salient themes were recognizing marginalised views and knowledge (11 initiatives), which resulted in increased self-value (10 initiatives) and stimulated awareness (8 initiatives), curiosity (6 initiatives) and local action (11 initiatives). For example, "'*citizen science can be a way of changing the way the communities think of themselves and value their knowledge and agency in science and society*" (Initiative #1). For some initiatives, the work done "*resulted in an improved appreciation by other community members, who began to value more both citizen scientists and their own culture*" (Initiative #9) and "*the main element is the opportunity to involve different members of the community – especially women and young people – in the activity. This helps to empower them to make positive (environmental) changes in their region*" (Initiative #4).

Policy impacts mostly referred to supporting the recognition of community rights and advocacy actions (9 initiatives), building networks and alliances (4 initiatives), and achieving external recognition of a community's knowledge and agency (9 initiatives), which in turn had significant impacts on empowering communities to confront threats (11 initiatives). For instance, "*maps done with Mapeo were used by the Waorani, Ecuador, to protect their territory from oil extraction. In other communities, maps are used to report oil spills and other impacts that have not been reported by the operating companies, making them accountable and resulting in fines and remediations*" (Initiative #7). Similarly, "*input from the community-based monitoring groups (information, analysis and recommendations) has been used by RIPOSR/ the local Indigenous Peoples organization to seek influence on resource management issues both at Republic and District level*" (Initiative #10). Also, "[citizen science] *has the effect of sensitizing communities about their own situation and rights. It has empowered them to fight for the effective realization of these rights and to identify their development priorities, creating a sentiment of ownership. These initiatives have the potential to provide quality, evidence-based tools and resources to communities to advocate for a better, brighter and more just future*" (Initiative #6).

Other impacts referred to increased community capacities (e.g., technical literacy, initiative design and implementation, or negotiation and advocacy; 14 initiatives); sustained strategic partnerships with like-minded initiatives and public resource managers (6 initiatives); and improved local socioeconomic conditions (e.g., generating new forms of income or improving community's access to resources and livelihood activities; 11 initiatives). For example, initiatives contributed to "*outreach and capacity building to align with a human-rights based approach and the Convention on Biological Diversity process, ensuring the community members could access support materials and knowledge regarding their rights and how to interact with the system*" (Initiative #6). Also, citizen science was considered

a tool to "*help to understand fragile complex contexts and to co-design alternative livelihood mechanisms that can generate additional incomes for the community*" (Initiative #5). All these changes could contribute to the sustainability of community's engagement in the long term, according to project coordinators.

CHALLENGES, STRATEGIES AND IMPACTS: A SYSTEMIC VIEW

Although discussed separately, the challenges, strategies, and impacts described above interact in important ways, specifically when looking at the impact for communities (see Figure 4, where we have focused on non-scientific impacts for clarity).

Local economic and political landscapes shape the existing infrastructure, but also impact the local epistemology, technology, data, and participation. For instance, in contexts of low income and lack of government support, the infrastructure (e.g., internet), skills (e.g., technological literacy), and motivation (e.g., time constraints and other priorities) to run a citizen science project are more likely to be lacking. Thus, to stimulate local action, increase community's capacities, or stimulate partnerships, strategies could simultaneously facilitate independent local control over projects, engage in remote capacity building, and offer financial compensation to participants.

Similarly, in places where the political context compromises basic human rights and participant safety, participant data and intellectual rights are also compromised. To have an impact in terms of a community's internal and external recognition, empowerment, or even environmental awareness, strategies related to securing data sovereignty or co-designed locally fitted method development should run in parallel to advocacy work and invest in strengthening networks.

DISCUSSION

Our results reveal that citizen science done with marginalised and Indigenous communities contrasts to citizen science done in other contexts. Before discussing these issues, we highlight some caveats that might influence our results and that should be considered in any future work.

CAVEATS TO OUR STUDY

First, the 15 initiatives analysed will not represent all citizen science done with marginalised and Indigenous communities, and we acknowledge that the inclusion of different initiatives might have resulted in different results. However, our work is a first exercise of theorising inductively about these topics, and is valuable because it

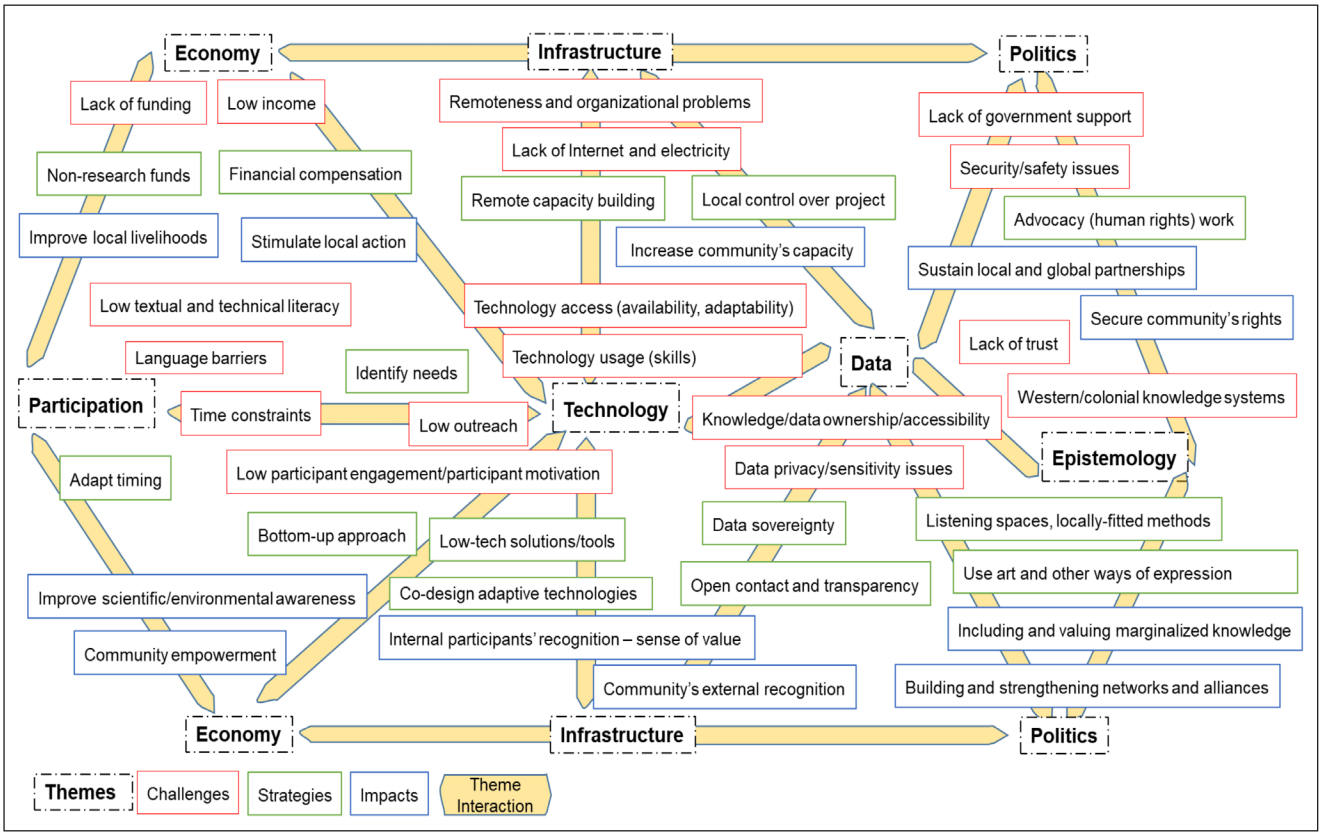

Figure 4 Conceptual map showing the interactions between challenges, strategies, and impacts.

initiates discussions about ways of doing citizen science that are different to the usual Western contexts.

Second, we report the comments and perceptions of project coordinators; these are not neutral and might provide a biased view. For instance, very few negative impacts of initiatives emerged, and the conversations focused more on the challenges *faced* when encountering the context, than the challenges the initiatives might *bring* to the context.

Finally, the most active project coordinators in the workshops tended to be articulate English-speaking academics with access to the internet. We did include participants from the actual marginalised and Indigenous communities where the initiatives are being implemented, although there were fewer of them and they were often quieter. We are still missing the voices and perceptions of the community in some cases, who might challenge our results.

DOES CONTEXT MATTER? REFLECTIONS ON EPISTEMOLOGY, TECHNOLOGIES, ECONOMIC INCENTIVES AND HUMAN RIGHTS

Many of the analysed initiatives rely on participants' Indigenous and local knowledge for data collection. Initiatives using Western methods and research designs, and built around Western-scientific research institutions and funding schemes, could be inappropriate and even extractivist in nature, where project data is not governed by participants (Leach and Fairhead 2002). This can be tackled by recentring initiatives around communities' ways of knowing, and facilitating spaces and methods that allow community expression in their own ways, as described by other projects in the Global North (Sorensen et al. 2019). Also, it is important to enforce codes of conduct and data management protocols that avoid reproducing colonial practices in which Western ways of knowing and doing are considered superior—for example, enforcing Indigenous Data Sovereignty (Reyes-García et al. 2022). Although efforts to be epistemologically inclusive are especially relevant when working with Indigenous peoples in the Global South (Johnson et al. 2021), they might also be so in Western contexts of the Global North. For instance, in Western contexts, certain methods and frameworks systematically exclude or marginalise people based on their knowledge status (lay knowledge) or their ethnic and gender identity, thus limiting the diversity of epistemological standpoints in Western science (Dawson 2019). Indeed, the issue has been extensively theorised by authors such as Tengö et al. (2014), who highlight the need for a multiple evidence–based approach, or Harding (1995), who proposes that research projects should overcome the idea of neutrality and embrace instead strong objectivity—or the idea that the diversity of standpoints is positive for the project.

Another commonality across projects was that formal educational divides made participation uneasy for some people, and sometimes reinforced mistrust in the initiative, as previously reported by other studies (Fiske, Prainsack, and Buyx 2019). Strategies to overcome this challenge include dedicating more time and resources to identify participants' needs, strengthening initiatives' capacity-building efforts, and engaging in the co-creation of decolonized methods and technologies that consider participants' non-formal knowledge and skills (see, for instance, the methods proposed by Davis, Ramírez-Andreotta, and Buxner 2020). Although these challenges and strategies might not seem relevant for initiatives working in WEIRD contexts, in fact, educational biases in participant engagement have been highlighted by studies on citizen science inclusiveness in places such as the UK (Pateman, Dyke, and West 2021). Indeed, there are calls for rethinking design and development of citizen science activities to open up the space for more diverse participation in terms of educational background even in WEIRD contexts (Pandya 2012).

Most of the initiatives analysed were developed in rural/remote contexts and thus common challenges were related to the lack of basic infrastructures. Strategies implemented in response to these challenges include the use of tools and methods that make project implementation and coordination less dependent on internet/electricity and scientists, as described previously for citizen science conducted in similar contexts (Requier et al. 2020). Although in most WEIRD contexts, internet and technology access is normally granted, it comes with an environmental and economic cost (Plepys 2002). Thus, the use of low-tech and de-centralised solutions (with reduced reliance on the presence of researchers and technology/travel costs) could be applied elsewhere, and help support lower-carbon citizen science.

Working with people in low-income and underserved communities reportedly had an effect on participant engagement and motivation in our work. Some strategies to address this were paying for participation and materials, and finding flexible funding sources that allow for these expenditures—a strategy previously reported (Khoi et al. 2018). Indeed, paid participation can bring gender or racial diversity into projects (Fiske, Prainsack, and Buyx 2019). Given the intersectionality of poverty and the demonstrated impact that payment for participation has as a way towards equitable collective action (Soleri et al. 2016), this is a strategy that is also valid in WEIRD contexts. However, these strategies challenge the common idea of citizen science participants' as unpaid volunteers (Vohland, Weißpflug, and Pettibone 2019), and providing compensation for participating can be also problematic after external funding is over (see, for example, Funder

et al. 2013). Indeed, some argue that compensation is not as significant a success factor as having a community initiate and design project activities and agendas, therefore responding to their own needs (Turreira-García et al. 2018b).

Finally, given our work in settings where democracy is fragile and political context unstable, with constant risks of human rights violations, a major common challenge was maintaining participant safety and well-being. These issues have not been very well described in the citizen science literature before (although they have been a major focus of the environmental justice literature; see Temper, Bene, and Martinez-Alier 2015). In response, strategies mentioned include strengthening local and global networks and partnerships for human-rights advocacy work, and using citizen science project results to enforce policies that protect participants (see Danielsen et al. 2022). These strategies are also relevant in democratic countries, because sometimes the pressure of corporations or other agents can also put at risk communities engaging with citizen science in the Global North (Kinchy 2016).

IMPACT OF CITIZEN SCIENCE WITH MARGINALISED AND INDIGENOUS COMMUNITIES

One of the most striking results in terms of impacts was that scientific achievements, although still valuable, were not among the most important impacts highlighted. This contrasts with most citizen science literature, which highlights the scientific impacts of citizen science initiatives in terms of advancing research agendas, making new scientific discoveries, or generating new knowledge (Theobald et al. 2015). The difference might be because most initiatives working with marginalised and Indigenous communities have a human-rights advocacy approach, for which they focus more on stimulating local action, empowering communities, or improving local livelihoods and capacities. Indeed, even if most of the analysed initiatives included scientists and a scientific objective, they actually aimed to advance local agendas through the generation of diverse types of knowledge. Thus, the initiatives described in this study counteract the ongoing criticism that citizen science and participatory environmental monitoring often engage local communities only to advance an externally predefined agenda (Turreira-García et al. 2018a).

Likewise, changes in environmental perceptions or behaviours were not mentioned as impacts in the analysed initiatives, although these are frequently described in studies on the benefits for citizen science participants (Chase et al. 2018). In the same line, increasing scientific literacy was not at all discussed, in contrast to other citizen science literature (Aristeidou and Herodotou 2020). This difference could be explained by our focus on initiatives that value the non-scientific knowledge systems that communities share, rather than a focus on Western scientific literacy building. Moreover, we mostly work with communities that are already highly connected and aware of their environments, and thus measuring environmental behavioural impacts is less relevant in our contexts.

Finally, looking at the impacts reported by the analysed initiatives, one might conclude that doing citizen science with marginalised and Indigenous communities has a greater impact for participants than for science *per se*. This is especially true in situations in which the data obtained mainly serves the purpose of empowering communities and conquering/maintaining their control over resources or advancing human-rights issues. However, for these important impacts to materialise, several systemic barriers need to be addressed.

CONCLUSIONS AND RECOMMENDATIONS

In this piece, we present barriers and opportunities for conducting citizen science with Indigenous and marginalised communities. Our results have to be understood as a first, potentially biased, attempt to study the issue, since we examined only 15 initiatives, which are mostly technological and environmental projects, and did so through the eyes of project coordinators rather than those of participants. Even so, our work points out several important issues.

Doing citizen science with marginalised and Indigenous communities in non-WEIRD contexts is very important, especially for the communities, given that it can empower them by helping gather data to fight legal battles and reconquer a community's rights/access to resources. However, several issues must first be addressed, including guaranteeing participants' safety and human-rights; ensuring methodological and technological appropriateness, tackling data privacy, ownership, and access; and considering the systemic socioeconomic aspects such as income, gender, and race that impact participant's motivations and engagement.

In order to do so, here we present several specific recommendations.

1. Dedicate time and resources to strengthening local and global networks. These can use gathered data in human rights advocacy work to enforce policies that protect participants and provide a voice to Indigenous and local communities in national and international policy fora. A concrete example would be the work by the International Work Group for Indigenous Affairs (IWGIA, https://www.iwgia.org), which has

strengthened communities' participation in high level international fora, such as the United Nations (UN) High Level Political Forum on the Sustainable Development Goals or the UN Permanent Forum for Indigenous Issues, among others.

2. Re-centre projects around communities' ways of knowing and participants' needs by establishing open contact and co-creating the project in terms of design, implementation, dissemination, and evaluation. An example would be to use platforms such as AGU's Thriving Earth Exchange (https://thrivingearthexchange.org/) to contact communities that are calling for experts to explore certain issues, which can become central to researchers' funding applications. More examples can be found in the work of the Participatory Monitoring and Management Parthership (PMMP 2015).
3. Enforce codes of conduct, protocols, and data-management practices that enable communities to be heard while at the same time avoiding reproducing colonial science practices (Johnson et al. 2021). A concrete example would be incorporating frameworks and tools as the ones described by Reyes-García and colleagues (2022) and by the Citizen Science Association Data Ethics Toolkit (https://citizenscience.org/data-ethics/).
4. Use adaptive and low-tech methods and tools that fit the local context, and coordinate with local organizations and intermediary/proxy participants that serve as local coordinators and can decentralize project management. Examples of how to do this can be found in the work of the Extreme Citizen Science group of the UCL (see Skarlatidou and Haklay 2021b), which has developed tools such as Sapelli (https://www.sapelli.org/), Community maps or GeoKey.
5. Pay for participation and find flexible funding sources that allow for this type of expenditure and that value the diversity of non-scientific outputs of a project. An example would be applying to non-scientific funds such as proof-of-concept funds (e.g., ERC-PoC), development aid funds (e.g., EuropeAid, USAid), and private foundations (e.g., DiCaprio Foundation). More examples about funding strategies can be found in the work of Doering and colleagues (2022).

As the citizen science community increasingly questions the diversity, inclusiveness, and equity of the field (see, for example, the recent Inclusive, Diverse, Equitable, Accessible, Large-scale (IDEAL) Citizen Science initiative in the United States), we hope our work providing stories from the field in a structured way can directly guide and inform future work, and open discussions about best practices in citizen science.

DATA ACCESSIBILITY STATEMENT

The data in which this manuscript is based can be found as a supplemental file to this article (Supplemental File 2).

SUPPLEMENTAL FILES

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

- **Supplemental File 1.** Data set. DOI: https://doi.org/10.5334/cstp.514.s1
- **Supplemental File 2.** DOI: https://doi.org/10.5334/cstp.514.s2
  - Appendix A. Supplemental methodological clarifications
  - Appendix B. Questionnaire template
  - Appendix C. Workshop templates

ETHICS AND CONSENT

All participants in this study are co-authors of this manuscript and thus have read and consent to the publishing of their data.

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COMPETING INTERESTS

The authors have no competing interests to declare.

AUTHOR CONTRIBUTIONS

PB, AS, DA, RH, IT, NTG, and DFL contributed to this study's conception and design, and to data analysis. All authors contributed data. PB and AS wrote the first draft of the manuscript and all authors contributed to reviewing and editing the manuscript.

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