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Enhancing citizen science impact in environmental monitoring: Targeted engagement strategies with stakeholder groups

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Understanding the motivations and benefits of citizen science (CS) participants is critical to the success of environmental science projects that rely on data collection from engaged citizens. Tailored communication with citizen scientists is essential, leading to the need to target specific societal groups for extensive and high-quality data sets. The purpose of the study was to apply marketing concepts such as stakeholder analysis, value proposition canvas (VPC), and key performance indicators (KPIs) to CS projects. The study examined the extent to which these strategies can be applied to CS projects and add value, resulting in improved recruitment and retention of participants, as well as improved project management. The dynamic landscape of CS projects requires adapted business-oriented approaches supporting ongoing participation with high motivation, acknowledging community needs, and recognizing institutional scientists, akin to targeting potential customers. The case study focuses on the CityCLIM initiative, an EU-funded project collecting urban climate data, especially air temperature, using mobile weather stations. The CityCLIM VPC, analyzing stakeholder groups, facilitated tailored communication strategies by analyzing stakeholder groups and highlighting the effectiveness of the CS cycling initiative within the "Stadtradeln" program. Impact KPIs served as a roadmap for strategic refinement, while data quality KPIs identified deficiencies, guiding adjustments to the campaign. Applied marketing tools improved project planning, engagement, and evaluation, demonstrating the potential of this concept. Adapting marketing tools to recruitment and communication strategies benefits CS projects by targeting specific groups. The holistic integration of stakeholder analysis, VPC, and KPIs streamlines project management and creates a framework for sustainable success. This adaptation forms a robust toolkit for CS project coordinators, contributing to

effective communication, engagement, and impact assessment. Applying marketing tools significantly increases CS projects' reach and impact, ensuring long-term success and meaningful scientific contributions.

KEYWORDS

citizen science (CS), environmental monitoring, urban climate, stakeholder analysis, value proposition canvas (VPC), key performance indicators (KPIs), business marketing strategies

1 Introduction

This study presents an approach to increasing the effectiveness of Citizen Science (CS) projects by using an adequate recruitment and communication strategy. CS projects in environmental sciences are often based on data collection by engaged attendees and require customized communication with the participating citizen scientists. Therefore, targeting specific groups in society can help reach more extensive and high-quality data sets in CS projects. Furthermore, the approach emphasizes the importance of marketing approaches for science in terms of adapting best practices in customer-facing fields to keep the motivation and retention of the participants high. This paper illustrates the diversity of stakeholder groups among citizen scientists, which can be activated.

Furthermore, it shows that targeting an audience for CS projects in terms of qualification, motivation, and skills can increase the impact of CS. This paper points out and explains the potential stakeholder groups involved in CS projects. Lastly, their profiles are identified to classify their needs and requirements for successful and continuous participation. For example, in CS projects, different stakeholder communication strategies are applied to determine their influence on participation rates. Furthermore, best practices are derived from this approach to be applied in future CS projects.

Business management theory teaches that corporate success depends on a strong communication strategy. In other words, it is the measure to achieve the defined communication goals. These measures include communication instruments, such as traditional advertising using information and social media, sponsorship, event marketing, trade fairs, and public relations. One of the main objectives of corporate communications is to increase brand awareness and reach a broader customer base. Marketing, advertising, and branding professionals are not just trying to reach the market. They identify potential customers from the outset and tailor the communication strategy to them. In this way, companies become much more efficient. The purpose of the study was to apply marketing concepts such as stakeholder analysis, value proposition canvas, and key performance indicators to CS projects and to analyze the extent to which these strategies can be applied to CS projects and add value, resulting in improved recruitment and retention of participants, as well as improved project management.

In order to evaluate the performance of the applied concept, the business approach was tested and adapted to CS case studies such as the CityCLIM project. The following sections present typical marketing analysis tools that could be valuable in a scientific context. The results of the tools combined are used to develop a communication strategy to support the efficiency of the example projects.

2 Citizen science—characteristics and common approaches

2.1 What is citizen science?

Citizen science is the participation of people in scientific processes that are not institutionally linked to that field of science. It is emerging as "the favored twenty-first-century model for conducting large-scale scientific research" (Toerpe, 2013, p. 44). CS is often associated with monitoring (e.g., taking pictures using a plant ID app) or data collection (e.g., beach litter audits). This is usually referred to as 'crowd-sourced science'. However, there is a spectrum of involvement, and participation can range from short-term data collection to more intensive use of leisure time to analyze or research the topic with other scientists/volunteers (volunteer researchers may have an academic background, but this is not a prerequisite for participation). Thus, the central idea of CS is the involvement of the general public, which can include (to varying degrees) proposing, designing, collecting, managing, analyzing, and sharing scientific investigations.

According to Haklay et al. (2018), in the context of geographic information, beyond using citizens as sensors (Level 1 crowdsourcing), there are three additional levels of citizen engagement: Level 2 Distributed Intelligence (e.g., training citizens, interpretation of data), Level 3 Participatory Science (e.g., defining the problem and collecting data), Level 4 Extreme CS (e.g., defining the problem, collecting the data, and analyzing it) (Haklay et al., 2018). In the context of weather monitoring CS, the hierarchy of Haklay et al. (2018) can be applied to the following project examples: the Community Collaborative Rain, Hail and Snow Network (CoCoRaHS) consists of crowd-sourced data of precipitation observations measured from citizen backyards in the United States (Level 1, Reges et al., 2016), SmartPhones4Water citizen scientists from Nepal were trained to collect precipitation measurements (Level 2, Prajapati et al., 2021), disaster risk mapping was conducted in schools in the Philippines using scientist designed tools refined by participatory discussions with teachers and students (Level 3, Gaillard and Pangilinan, 2010), the project Extreme Citizen Science: Analysis and Visualisation (ECSAnVis): in the Congo was the result of scientists and citizens working together throughout the entire process (Level 4, Time4CS, 2024).

Overall, CS is an inclusive scientific methodology where full-time experts and volunteers can learn from and with each other on an equal footing (Bonn et al., 2022; EU Cordis, 2023). The benefits are innumerable: it increases social awareness, leads to more relevant policies for the communities they serve, and expands observational networks and databases in scope and availability to a greater extent or variety of spatial/temporal coverage.

2.2 Citizen science *versus* institutional science

While institutional science is traditionally associated with academic and professional research institutions, CS is defined as collaborative scientific research by non-professional researchers in cooperation with institutional (professional) scientists and academic institutions, often realized in heterogeneous consortia (Lukyanenko et al., 2020; Göbel et al., 2022).

Public participation in scientific research describes different approaches, including crowd-sourcing, community-based research, or volunteered geographic information (Bonney et al., 2016). Participatory data collection from the public has a long history in environmental observations (Bonney et al., 2016). Wynne (2007) distinguished two types of public engagement in science and technology research: invited (scientific expert-driven) and uninvited (public/bottom-up mobilized) participation. Further, in this sense, CS activities can be divided into two categories concerning the collaboration between non-professional volunteers and institutional researchers: the science-driven collaborative/contributory projects and the community-driven co-created/collegial projects (Shirk et al., 2012).

In CS projects, two distinct approaches to emergence must be distinguished. The first approach is driven by the interests of citizens who are non-professional researchers and are motivated by a scientific question. The second approach is initiated by institutional formations of professional researchers who aim to involve citizens in a scientific process. CS draws on the interactions and partnerships between professional academic scientists and non-professional volunteer researchers in scientific research (Göbel et al., 2022). Therefore, scholars repeatedly point to the importance of CS projects to identify the different people and communities involved, i.e., the stakeholders and stakeholder communities (citizens, scientists, policymakers, and media), and to identify stakeholders' capacities to participate, to assess their project expectations and their influence on a project, to analyze their interactions (Parmar et al., 2010; Skarlatidou et al., 2019).

Citizen and institutional science are not mutually exclusive but synergistic and mutually beneficial. Citizen scientists enhance institutional science by contributing valuable long-term data, especially in areas with limited access or scarce resources. The diversity of participants in CS projects often results in data collection on a spatial and temporal scale that would be unattainable within the confines of traditional institutional research (Wiggins et al., 2011; Forrester et al., 2015). However, by involving citizens who contribute by collecting large amounts of data, science remains its own institutional sphere with professional expertise. (Sauermann et al., 2020). Hence, institutional scientists provide critical guidance, expertise, and resources to ensure the scientific validity of CS efforts.

2.3 Common approaches for participant recruitment in citizen science projects

The motivations for engaging in CS are similar to those for volunteering, and the research conducted to understand why people volunteer often applies to CS participation (Land-Zandstra et al., 2021) but only a few studies have examined this link (Phillips et al., 2019). In particular, people are more likely to participate in CS activities when the projects address issues relevant to their lives and interests (Rotman et al., 2014; West and Pateman, 2016; Phillips et al., 2019). Participants can be recruited using a variety of online and offline approaches, such as flyers at public events, survey registration links (e.g., Facebook campaigns), or email invitations via mailing lists (Brouwer and Hessels, 2019). However, recruiting sufficient and diverse participants and keeping them engaged throughout the project is often a crucial challenge for the scientists involved (West and Pateman, 2016; Arienzo et al., 2021).

Targeted invitations to participate in CS projects, in contrast to a generic invitation strategy, have been proven to be an effective way of recruiting a wide range of participants and also reaching marginalized groups, such as elderly people and citizens with lower education (Brouwer and Hessels, 2019). Targeted approaches via recruitment through third-party organizations, such as the collaboration with the Bund für Umwelt und Naturschutz Deutschland (BUND), a German non-governmental organization dedicated to nature conservation, in the water monitoring CS project FLOW (www.Flow-project.de, Engel et al., 2023), have been proven very successful in reaching a much broader spectrum of participants and enabling the CS project to achieve nationwide participation. This is consistent with the recommendations of the recently launched Citizen Science Strategy 2030 for Germany (Bonn et al., 2022), which highlight the importance of building collaborations with established volunteer structures, such as regional associations in the field of volunteer management, for succeeding in volunteer recruitment (Bonn et al., 2022). In line with Sorensen et al. (2019), Pateman et al. (2021). point further to the importance of reaching out to key individuals who are already locally active and trusted by local citizen groups for achieving inclusivity in recruiting participants.

Involving people with diverse interests, motivations, and backgrounds (Jennet et al., 2016; Tiago et al., 2017) and creating relationships between professional and non-professional researchers remain challenging in CS projects. Regarding the engagement of broader civil society in science projects, Wynne (2007) distinguishes between "invited participation" which typically involves elite "stakeholders" who have the scientific expertise and are connected to policy-making, and the engagement of "spontaneous and independent, uninvited forms of civil participatory action". Within the different phases of a CS project, the participation of diverse stakeholders can occur in different ways.

According to Shirk et al. (2012), five levels of involvement in the research process can be identified based on the degree of participation: "Contract" (citizens hire scientists to conduct a study on a topic of particular concern to them), "Contribute" (citizen scientists participate in data collection), "Collaborate" (citizen scientists participate in research design, data collection, and analysis), "Co-Create" (joint work between professional scientists and citizen scientists on a research problem), and "Colleagues" (citizen scientists and professional scientists generate independently new knowledge in a research area). Yet, within these different types of public engagement in CS projects, discrepancies exist regarding the willingness to participate. For example, concerning participant diversity in environmental CS projects, Pateman et al. (2021) found that already marginalized social

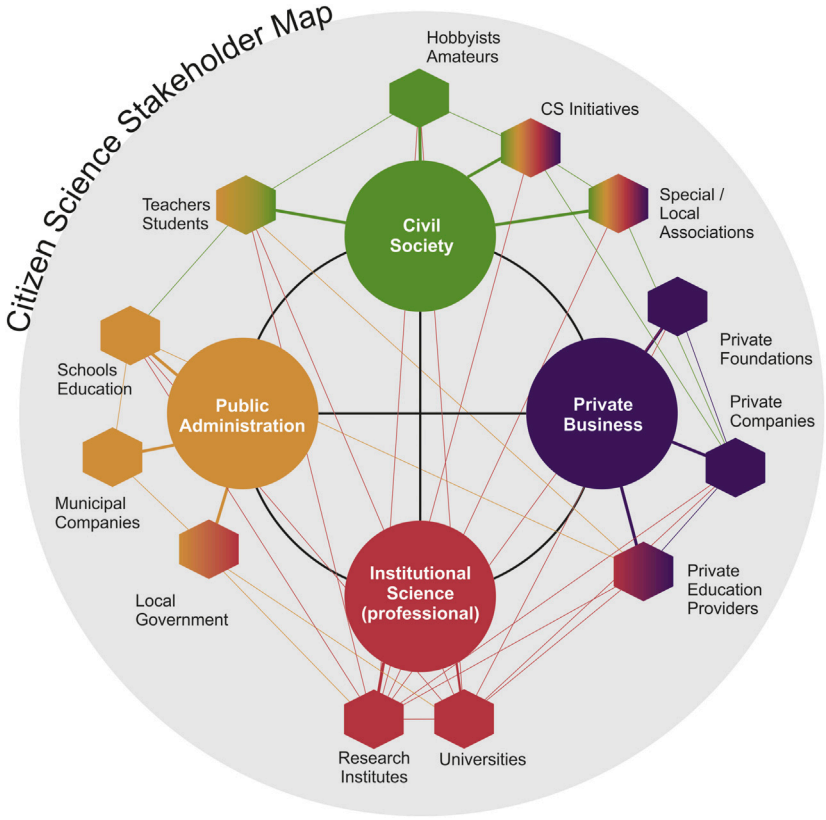

FIGURE 1
Stakeholder groups interacting in urban CS initiatives.

groups in terms of age, gender, ethnic background, education, and income are underrepresented in CS and are the least likely to participate in CS projects. The authors caution that a lack of diversity among citizen scientists has implications that CS project leaders should consider. More recently, Göbel et al. (2022) in their study on stakeholder participation in Citizen Social Science (CSS) in Germany, showed that CS activities do much more than capacitate lay people to do science. CSS activities are vital for facilitating cooperation with co-researchers and other partners in associations "originating inside and outside of academic research (or 'academic' and 'non-academic' initiatives)". Hence, the authors introduce the concept of 'cooperation capacity' which "emphasizes the ability of individual and collective actors to establish connectivity and relations inside the heterogeneous consortia as well as between them and other actors outside to generate scientific knowledge through participatory research" (Göbel et al., 2017).

3 Thinking outside the box or how a marketing approach can be helpful to enhance recruitment and retention of CS participants

In the context of CS, adopting a marketing approach involves a more thorough examination of potential participants and their motivations for participating in CS projects. This examination of the participants implies an intensive analysis of the variability of stakeholders within the research process, including the development of tailored and effective communication strategies (Hart et al., 2022). Understanding the factors that motivate participants is crucial, but equally important is identifying obstacles that may discourage volunteers or customers from getting involved (Stukas et al., 2016).

3.1 Who is taking part in citizen science?—The role of stakeholder analysis

Based on an international stakeholder analysis conducted by Göbel et al. (2017), four main stakeholder groups are involved in CS initiatives: 1) institutional research, 2) civil society, 3) public administration, and 4) the private sector. The degree of engagement and contribution varies between each group.

Building on Göbel et al. (2017) and looking at the urban CS context in which we will analyze a case study in this paper, Figure 1 shows the interdependencies between stakeholder communities: institutional Science represents the group of professional researchers, employed by a research institution. Further stakeholder groups are private businesses, civil society, and public administration. Eventually, stakeholders are directly interconnected; e.g., schools are part of the public administration and directly linked to their students and teachers, who might act on distinct projects as amateur scientists in their spare time.

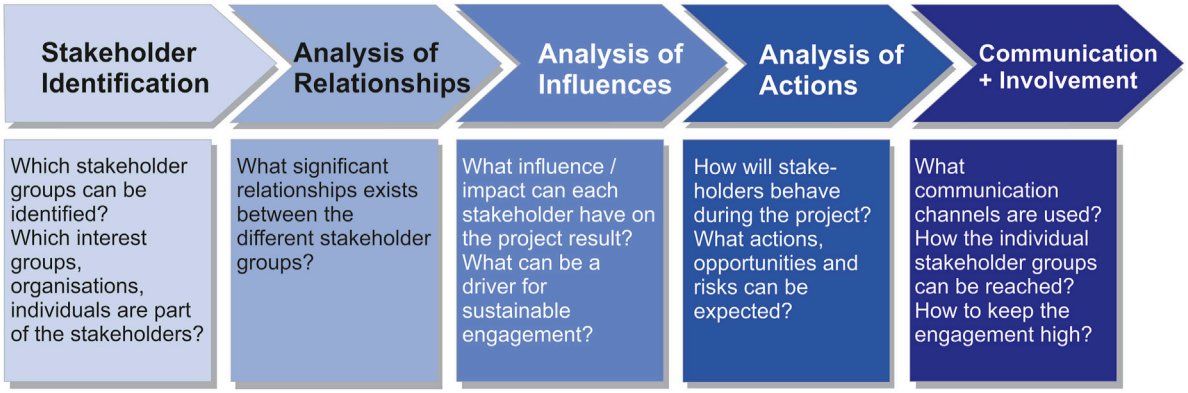

FIGURE 2
Steps of stakeholder analysis with subsequent engagement (without four).

Figure 1 also emphasizes that some groups, such as existing CS initiatives and special local associations might be related to and consist of members of all stakeholder groups.

Stakeholder analysis is an important tool in stakeholder management. It involves the systematic identification of stakeholders, the assessment of the interests, needs, and concerns of the stakeholders involved, and their relevance and influence on a project (Eden et al., 2013). It is crucial for subsequent stakeholder engagement in the implementation of actions to influence their habits. Figure 2 shows the main steps in the stakeholder analysis process and the overarching questions that need to be answered.

Thus, it is essential to devise targeted strategies for how citizens from diverse backgrounds (such as individuals in private settings, employees of companies, or members of existing organizations) can be effectively engaged and committed to participating in research tasks and comprehensive environmental monitoring. As stated in the Citizen Science Strategy 2030 for Germany, one of the main challenges is establishing a new collaboration model between scientists and volunteers in terms of more tailored roles for volunteers (Bonn et al., 2022). Providing tailored training to specific target groups of citizens typically results in collecting higher-quality data. Research also shows that people are more likely to participate in CS activities when the projects address issues of relevance to their lives and interests (Rotman et al., 2014; West and Pateman, 2016; Phillips et al., 2019) and that keeping people engaged throughout the project duration is often a challenge for the scientists involved (West and Pateman, 2016; Arienzo et al., 2021). This evidence suggests that a targeted approach is essential to understanding a citizen group's interests and the factors that would keep them motivated.

According to Tiago (2016) and Hacklay et al. (2018), applying stakeholder analysis to CS can be critical for the success of CS projects. For CS projects, a successful engagement mainly covers the establishment of a customized communication and feedback culture and the development of tailored participatory techniques for collaboration with the different stakeholder groups (e.g., co-creating project design, collecting data, data analysis, formulating results; Göbel et al., 2022; San Lorente Capdevila et al., 2020). Skarlatidou et al. (2019) highlighted the relevance of stakeholder mapping for enhanced co-creation in CS projects and "for more effective stakeholder communication, more successful implementation, and a greater impact for CS initiatives".

3.2 How to tailor CS projects to community needs?—Extending VPC to citizen science

The value proposition canvas (VPC) is a strategic tool that helps businesses understand their customers' needs and design products or services that effectively meet those needs. The VPC reflects the added value or benefit that a product or service provides to the market or customer (Osterwalder et al., 2014). This value should be as high as possible to eliminate a customer's problem or create an advantage for them.

Generally, the VPC consists of two components: the customer profile and the value map, which together identify the key features and benefits of a successful product or service. The left-hand side of the VPC is dedicated to the product or service itself. This section identifies potential pain relievers, which help reduce customer barriers, and gain creators, which are factors that improve the overall customer experience. Gain creators can be expected or even positively surprise customers. The right-hand side, the customer profile, presents the individual tasks (customer jobs) the customer/user has to accomplish in his daily life and outlines the gains (benefits) and gains (obstacles).

The VPC-based marketing approach can be innovatively adapted to CS projects by considering the individual stakeholders and their individual needs and concerns regarding different issues. Therefore, it is crucial to assess each stakeholder specifically, taking into account their gains and pains, to determine their suitability for a project. The use of the VPC allows for a more in-depth stakeholder analysis, especially the identification of approaches and tools to motivate more citizens to get involved. To achieve this, there are three essential aspects, the customer profile and value map as parts of a marketing VPC, and the communication channel as a new important aspect (see Figure 3). All these aspects must be incorporated into a CS-specific consideration, including the recognition that CS is focused on providing valuable services or tools rather than selling a product, which differentiates it from traditional business theory.

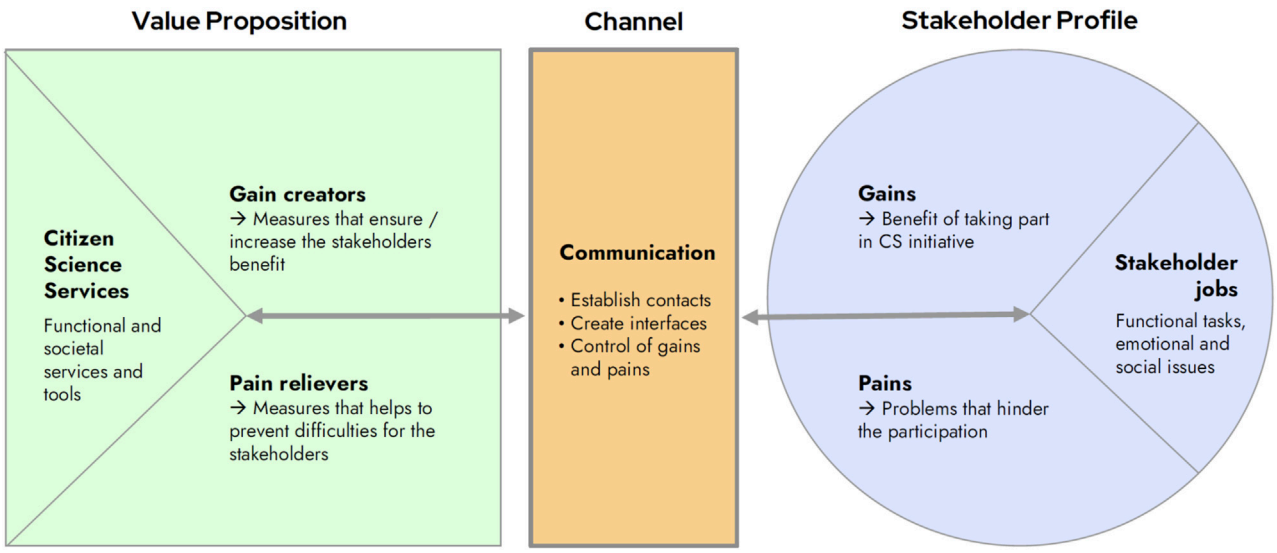

FIGURE 3
Adapted VPC for CS applications.

Hecker et al. (2018) highlighted the need for an appropriate communication strategy as a key motivating factor to retain participants and exchange information through multi-way channels. Therefore, the "Channel" object in the center of the adapted VPC is implemented to emphasize the important role of communication. Communication plays a crucial role in connecting both components. Clear and persuasive communication is the key to successful CS project implementation. Appropriate means of communication are freely available information materials (manuals, newsletters, private policies), regularly updated social channels to inform about results and upcoming events, websites, regular communication through emails, and the organization of workshops and meetings. The publication of success stories in local media also increases the recognition of the valuable contributions of citizens.

Institutional scientists, representing professional science, often take the lead in initiating academic CS projects. However, in our specific context, they are active participants in these projects, and at the same time, integral members of the stakeholder community. Therefore, they also need to define clear project goals and consider their tasks and goals in terms of benefits and obstacles as they seek to obtain long-term, high-quality data for their research. To achieve this, they must examine their own gains and pains and communicate them effectively to other stakeholders through appropriate communication channels.

In addition, there are two perspectives to gain a more complete understanding of the mutual services and tasks to be performed. This requires a thorough adaptation of the value map (gain creators, pain relievers) and the stakeholder profile (gains and pains). To facilitate this process, a number of questions can help to identify an appropriate VPC for the CS project under consideration (see Table 1).

As seen in Table 1, it is crucial to assess the requirements and the added value for, e.g., the participating citizens, in order to tailor the services appropriately. This involves clear communication of expectations from the citizens for the project. Selecting suitable, easy-to-use sensors and providing the necessary support through workshops and comprehensive manuals can serve as a gain creators and increase the citizen's motivation to invest time and effort in this activity. In addition, ongoing support in cases of problems and questions should also be provided. Nonetheless, it is essential that all services and communication are accessible in the native language of the involved stakeholders.

3.3 How is impact and data quality measured?—Extending key performance indicators (KPIs) to citizen science

The economic theory provides another valuable tool, known as Key Performance Indicators (KPIs), which organizations can use to track their progress over time, identify areas for improvement, make data-driven decisions, and measure success. KPIs are particularly useful for monitoring project objectives, with each organization setting KPIs unique to its specific project. To be effective, KPIs should be measurable, specific, realistically achievable, and have a clear deadline (Hassler, 2016).

According to the European Commission, Directorate-General for Research and Innovation, the KPIs are used as core indicators focused on assessing the impact of Horizon 2020 and will be considered in its evaluation and monitoring system (European Union, 2015). The fact, that for the first time, these KPIs are being identified before the start of the Framework Programme is a significant development, as it provides a solid and coherent basis for the monitoring and evaluation system for Horizon 2020, coupled with a focus on measuring the results and the impacts of this Programme.

Assessing the impact of CS is often challenging to quantify since activities could cover various dimensions of impact (e.g., social,

TABLE 1 Analysis of three different stakeholders (exemplarily) based on VPC: Driving issues to investigate gains and pains and to define gain creators and pain relievers.

Stake-holder	Job to do	Gains	Gain creators	Pains	Pain relievers
Institutional scientists	Increasing the understanding of environmental processes and investigating in an extended spatial and temporal context based on the implementation of citizen scientists	* Satisfying my scientific curiosity	* Clear communication of project goals	* Time consuming communication with the citizen scientists	* Availability of elaborated communication channels to ensure regular communication
		* Get to know extensive often more local related knowledge of citizens	* Connections to already established CS platforms	* Limited knowledge of the culture of citizens and capability to speak the appropriate language	* Availability of data management concepts
		* Gaining new insights and experiences by receiving more data in a smaller temporal and spatial scale	* Application of appropriate sensors in terms of performance and cost efficiency with sufficient data quality	* Time consuming data management for the heterogeneous data sources	* Application of appropriate sensors in terms of performance and data quality
		* Creating a positive impact in terms of doing something useful for the community	* Availability of suitable communication tools	* Insufficient data quality in terms of spatial and temporal coverage	* Recruitment strategies to find enough and suitable citizen scientists
		* Getting academic recognition	* Availability of appropriate funding	* Insufficient data quality in terms of sensor accuracy	
		* Identifying topics worth for funding programs	* Availability of publication platforms for scientific results	· No long-term funding perspective after project end	
		* Offering tasks for students			
Hobbyist/ amateurs	Exploring the personal environment and providing data/observations to support a research project	* Gaining new insights and experiences	* Access to all measured project data and the visualization	* Lack of time and opportunities for regular contributions	* Possibility to send feedback
		* Satisfying my curiosity and hobbies	* Gamification for an attractive implementation and to compete with the CS community	* Overly complex sensor devices in terms of handling, data acquisition and data transmission	* Clear understanding of project goals
		* Getting support from professional scientists	* Possibility to obtain participation certificates and rewards	* Feeling of being overwhelmed by the tasks and the project goals	* Gamification for an easy implementation of the tasks into the daily life
		* Combing other daily activities with data collection	* Public awareness due to press release and websites	* Missing communication of the project goals and added value	* Availability of appropriate sensors in terms of performance and handling
		* Being part of a larger community with same interests		* Missing data security and privacy issues	* Availability of suitable communication channels to get regular updates
		* Creating a positive impact in terms of doing something useful for the community		* Lack of recognition for the contribution made	* Availability to get rewards by the project
		* Interests in analyzing own data collections		* Not enough money to support a CS project	
		* Recognition from community			
		* Protecting the environment			
Municipal enterprises	Doing sustainable business and providing data/observations to support a research project	* Surveying data also relevant for the company	* Access to all measured project data	* Lack of financial and/or personnel capacity to support a CS project	* Availability to get funds or to be part of a joint research project

(Continued on following page)

TABLE 1 (*Continued*) Analysis of three different stakeholders (exemplarily) based on VPC: Driving issues to investigate gains and pains and to define gain creators and pain relievers.

Stake-holder	Job to do	Gains	Gain creators	Pains	Pain relievers
		* Combing company activities with data collection	* Possibility to obtain participation certificates and rewards	* Lack of recognition for the contribution made	* Rising awareness due to participation certificates or awards
		* Creating a positive impact in terms of doing something useful for the community	* Public awareness due to press releases, websites and social media	* Missing options for direct participation	* Availability of suitable communication channels
		* Protecting the environment	* Rising awareness to find potential new business areas and partners	* Mismatch between project goals and enterprise goals	* Availability of appropriate sensors in terms of performance and handling
		* Getting societal recognition	* Rising awareness within the CS community to find potential new employees and trainees	* Undesired attention to company properties (vandalism, thefts)	* Appropriate concepts to fulfil data protection
		* Gaining positive public awareness		* Missing data security and privacy issues (Data Protection Regulation)	
		· Increasing the attractiveness as an employer			

scientific, and policy). Within these dimensions, aspects of success are difficult to measure (e.g., how do you measure innovation?).

The selection of measurable KPIs is essential for assessing the impact of project activities and whether the overall project objectives have been achieved, and it also serves as a tool for recognition.

Additionally, project funding should include evaluating the project's impact (Citizen Science Strategy 2030 for Germany) (Bonn et al., 2022). Demonstrating impact and tangibly showing that aims have been achieved is beneficial for the long-term sustainability of a CS project (e.g., evidence of success, further recognition, applying for future funding, upscaling). An evaluation and assessment framework of impact for CS projects is often set by funding agencies or an aspect of the project management. For example, during the funding period, a project may be required to submit interim reports detailing future milestones and goals, with subsequent reports addressing how these goals were met. However, as mentioned above, an impact assessment should not only be used to ensure effective project self-management; adapting an open framework for impact evaluation would also promote recognition for the project, for example, through a "score" that the project meets/exceeds a certain standard.

When evaluating CS programs, inputs, activities, and outputs tend to be easily quantifiable through KPI's (Sauermann and Franzoni, 2015; Burgess et al., 2017; Sauermann et al., 2020; Schaefer et al., 2021). As an example, Liñán et al., 2022 proposed the following KPIs to measure the achievement of the scientific project goal and its accumulated value at the end of the project: 1) number of observations; 2) number of quality checked observations; 3) number of participants; 4) number of participants uploading observations to the data portal; and 5) number of volunteers repeating the activity. Furthermore, KPIs can be introduced to evaluate data quality and reliability by establishing metrics that assess the accuracy, completeness, consistency, and timeliness of the provided data. Thus, the defined measures could focus on data completeness and timeliness, such as measuring the percentage of data that is collected within a specific timeframe or the percentage of data that is complete and not missing any required information. By regularly tracking and analyzing these KPIs, project coordinators can gain insights into the quality and reliability of the data and identify areas for improvement. This information can be provided to stakeholders and reflects that the data is reliable and can be used confidently.

4 Case study: acquisition of mobile urban climate data

The case study discussed here relates to CS initiatives aimed at collecting mobile urban climate data, particularly air temperature, collected from different modes of transport, e.g., walking and cycling. The above-described methods were selected to show the potential perspectives in contrast to the current activation of citizen scientists and the newly established process of recruiting participants. This approach aimed to dissect the citizen scientist's profile using the adapted VPC. The stakeholder groups participating in CS projects were analyzed and considered as target groups for developing an appropriate communication strategy.

4.1 Realization

The public participation in the scientific research framework developed by Shirk et al. (2012) spans a continuum from institutionalized science-driven "contributory" research projects

to public-driven "collegial" projects. To illustrate the possible added value of marketing approaches in the context of CS, we started with the consideration of two projects representing two individual cases on this spectrum. One is a locally initiated collegial CS project (project "Meteorologie hautnah" ["Meteorology Up Close"]) at the Leipzig Institute for Meteorology, University Leipzig (Germany), which was funded as part of the "Deutsche Hochschulwettbewerb 2022". The 3-month project period was divided into three phases of 1 month each. 20–30 people took part in each phase, and became aware of the project through various media reports and social media platforms. The participants from the cycling and meteorology interest groups and members of the university were then invited to an opening event and allocated to the project phases. The aim of "Meteorology Up Close" was to communicate the scientific process to a broad section of the population and to jointly investigate the urban heat island.

The other case is a science-initiated and science-driven CS project called CityCLIM-project, funded by the European Union's Horizon 2020 research and innovation program and comprising six consortium partners and four participating pilot cities (Karlsruhe/Germany, Valencia/Spain, Thessaloniki/Greece, and Luxembourg.

An essential aspect of both projects was the involvement of citizens to better understand climate impacts in cities by collecting *in situ* sensor data in urban environments using miniaturized mobile weather stations called MeteoTracker (meteotracker.com, Italy). This MeteoTracker is a miniature weather station specially designed and patented to measure air temperature, relative humidity, and air pressure on the move.

The method of stakeholder selection varied between the two projects. The "Meteorologie hautnah" project advertised the project to the general public in various media. With such a general call, the project reached a wide and non-targeted group of people interested in meteorology and urban climate. No stakeholder analysis or other tools were used in the project "Meteorologie hautnah" to analyze the requirements of the participants. The main objective was simply to find citizens who, for example, cycle regularly and would be interested in a mobile measurement. For example, travel times or routes to achieve an even coverage of the area were not considered. We could see this as a non-targeted approach because the main aim was to find a broader group of people interested in cycling. Such a non-targeted approach is applied to many CS projects.

The CityCLIM project, on the other hand, specifically identified a target group consisting of citizens who use the bicycle primarily for commuting or as a hobby and who have specific requirements in terms of route, duration, and frequency. The main difference to "Meteorology hautnah" is the main focus on the collection of well-distributed meteorological data on a temporal and spatial scale. The German-wide initiative "Stadtradeln" program ('City Cycling') encourages various groups in the participating cities to cycle as much as possible within 21 days to promote climate action (STADTRADELN, 2023 - www.stadtradeln.de). Therefore, CityCLIM contacted this regional cycling initiative to involve different stakeholders. It should be emphasized that targeted actions such as the "Stadtradeln" program are intended for specific temporary campaigns rather than long-term data collection. In the following sub-sections, the aim is to explain our targeted participation strategy.

4.2 CityCLIM stakeholder analysis

The 'Stadtradeln' initiative represents a competition that involves completing as many daily journeys as possible in an environmentally-friendly manner using the bike over a 21-day period. The aim of the initiative is to encourage more people to cycle and reduce carbon emissions, and to show where the city is already cycle-friendly and where improvements are needed. With this idea, this program involves a representative cross-section of society from all kinds of stakeholder-groups.

As shown in Figure 2 the CityCLIM stakeholder analysis of the 'Stadtradeln' initiative included several steps that focused on the different stakeholder groups associated with the "Stadtradeln" program.

Stakeholder identification: In our case, we will focus on three key stakeholder groups that have to be analyzed in the stakeholder analysis: the institutional scientist, the "Stadtradeln" association, and the participants in the "Stadtradeln" initiative. The institutional scientists are interested in collecting high quality spatial and temporal environmental data for a wide area in urban areas. The 'Stadtradeln' initiative is a climate alliance of participating cities in Germany with the goal of promoting climate protection by strengthening local cycling. In addition, the "Stadtradeln" association provides comprehensive support in finding sponsorships and promoting sustainable urban mobility in general. Typically, this competition involves a representative cross-section of society from all kinds of stakeholders, shown in Figure 1. The large community of participants consists of individual, hobby, company or club organized cyclists who are interested in this competition to do something for the environment and their health. All participants can combine various daily activities (e.g., cycling to work, going to the gym, shopping) with the aspect of collecting data on the number of kilometers traveled or their own health indicators, such as calories burned. However, the data shows that the 'Stadtradeln' program is mainly targeted at companies/organizations within cities, that formed teams for the competition aspect and the aim of winning the game for their company/organization. Of course, other stakeholders, such as local politicians or decision-makers, also play a role. However, they are not considered here in detail.

Analysis of relationships: Institutional scientists need data to answer recent research questions, such as the impact of climate change on urban environments. CS approaches can be applied here, and people who are willing to take part in CS projects collecting environmental data are required. The "Stadtradeln" association can provide a connection to interested people who like to combine cycling with collecting data and being part of such a competition. Based on this collaboration and the added value of environmental data collection, the program can also be used to formulate a specific environmental goal in that city. This may also attract additional participants who are particularly interested in the urban climate or local climate actions. The "Stadtradeln" initiative also enables local politicians and decision-makers to learn how to improve cycling infrastructure in their city by providing them with information from participants. Normally, all participants share an interest in cycling and in participating in this competition. Therefore, there is a strong sense of a larger community with the same interests. In addition, this initiative shows a broad cross-section of society building a unique

network of interactions between local associations, the community's activities, local companies and organizations, and individual interests. Numerous stakeholders can be reached through such a platform initiative.

Analysis of influences: The main influences of the "Stadtradeln" association lie in coordinating the initiative, setting the framework for the competition, and providing all the necessary means of communication. Institutional scientists can use these main influences to enhance the impact of the initiative in terms of achieving their scientific goals. Hereby, they can create sufficient motivation for the participants to invest more effort in collecting additional environmental data during their bike ride. The competitive nature of the 'Stadtradeln' program is the main incentive for all stakeholders involved. The team spirit, including the prospect of winning for the team as well as the reward of kilometer points for the cycling teams, influences the activity of the participants to use the bicycle instead of the car. Another influencing factor is the potential combination of several daily activities (e.g., cycling to work, to the gym, to the store) with the aspect of data collection, e.g., the number of kilometers cycled or personal health indicators such as e.g., calories burned. All these influencing factors can be used to motivate participants to collect urban climate data for the CityCLIM project.

Analysis of actions: The "Stadtradeln" association is responsible for the organizational framework, including various services for the participating cities and cyclists. This includes, e.g., the provision of IT infrastructure and apps, participant events, award ceremonies, and keeping the communication channels up to date. The institutional scientist can use the established communication channels to inform the interested cyclists about the opportunity to support a specific task involving the measurement of environmental variables in the city and to emphasize the high value of this scientific work. It is up to the scientist to remove obstacles that arise and to assess and respond to the needs of the participants throughout the duration of the initiative in order to keep the citizen scientists informed and the motivation high. The participants are able to provide a valuable amount of measured data when cycling, if they use devices to collect environmental variables. However, depending on the daily behavior of the participants the collected data may not be evenly distributed over time and space. While commuters may collect most of their data during peak commuting times (7–9 a.m.; 3–6 p.m.) on their way to and from work, recreational cyclists may be data providers mainly in their free time and at weekends. The consideration of all groups involved led to better spatial and temporal coverage of the city.

Communication + Involvement: The "Stadtradeln" association has a user-friendly website to inform about the initiative, upload the kilometers ridden, and show the current ranking. Typically, the collected data is ingested directly into a web dashboard, showing the amount of carbon dioxide emissions avoided and the current ranking of the participant's company/organization. In addition, the use of local communication channels such as billboards, press releases and TV reports are particularly effective in reaching a broad local audience and motivating people to participate in that "game". Institutional scientists provide comprehensive information about the additional scientific programs that these communication channels offer to help participants. Social media plays an important role in providing information about the interim results of the competition or the first results of the measurements. It is important to make it as easy as possible to give feedback and to raise questions and concerns.

4.3 CityCLIM value proposition canvas (VPC)

It is important to consider that activating different groups will result in different distributions of data, depending on the everyday "jobs" to be done (as referred to in the VPC) The CityCLIM VPC for understanding the recruitment and motivation of the targeted approach using the "Stadtradeln" group is presented in Figure 4. The described VPC is created to investigate the needs and perspectives of the "Stadtradeln" target group.

(1) **Target group analysis:** The crucial aspect of the "Stadtradeln" target group - the participating cyclists-is that the participating citizens already possess a certain level of exposure or motivation to engage in climate action. As expected, pre-motivated individuals in the targeted group might be more involved and engaged in the campaign compared to a non-targeted selection group. However, if individuals are already actively engaged in climate action, the Value Proposition Canvas analysis needs to assess the additional value that the CityCLIM project can provide in conjunction with their current efforts.

(2) **Gains and pains of the target group:** This target group consists mainly of people who want to do something useful and contribute to environmental protection during their daily commute. In addition to using their bikes for transportation and fitness purposes, a particular benefit lies in the goal of collecting environmental data with the provided sensors. Technically complex devices and complicated data handling (e.g., manual uploading or pre-processing) can be deterrents. Therefore, devices must be user-friendly and easy to operate, the installation of required software or applications should be simple, and information material should be easily available and understandable. In addition, the data products (e.g., temperature maps) should be accessible to all. Another important aspect lies in the competition among different teams during "Stadtradeln" participation. The goal is to collect as many kilometers by bike as possible, which also means as much data as possible (gamification issue). Participants within the target group expect positive recognition for their actions and acknowledgment of their scientific contributions. However, there may be some security concerns to ensure the anonymity of the participants, as anyone can evaluate the data and analyze the daily tracks. The privacy policy needs to be clearly communicated, and it should be clear to citizens why some data and attributes are not visible for security reasons.

(3) **Provided services by the project:** The CityCLIM project addressed the "Stadtradeln" target group by offering the mobile MeteoTracker sensors, which can be conveniently controlled via a mobile phone and directly transmit data to an open data portal. This enables users to seamlessly integrate daily cycling activities with collecting environmental data. Additionally, the collected data could be accessed through an

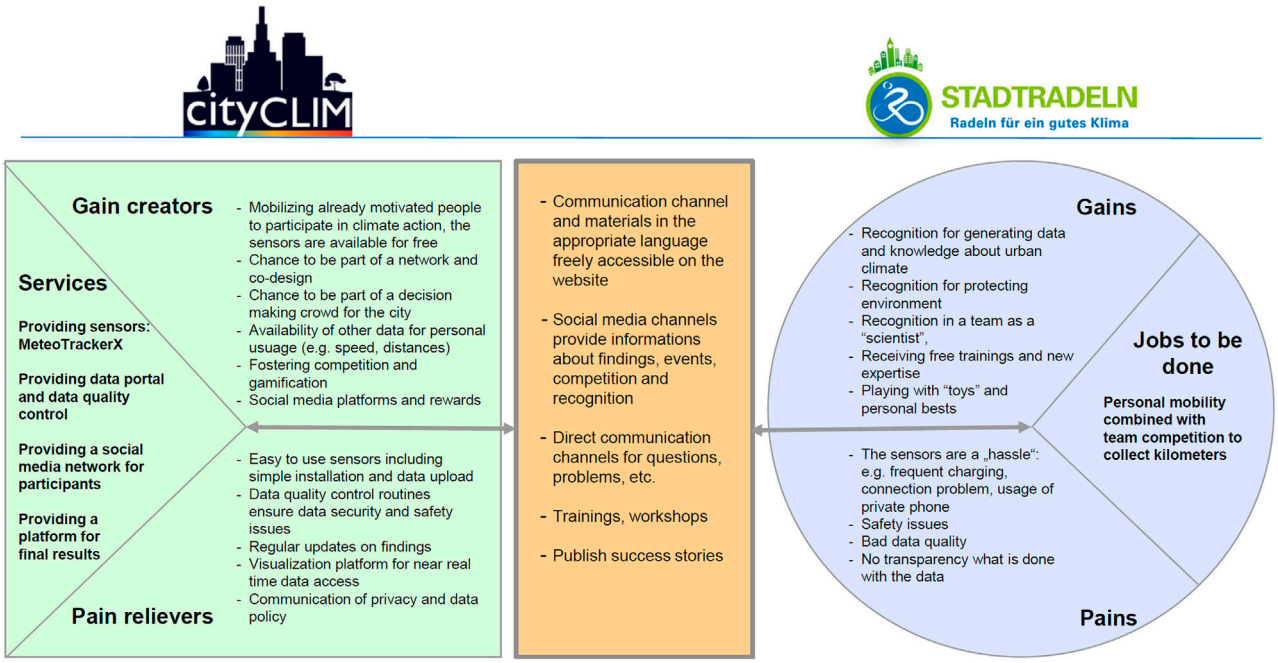

FIGURE 4
Adapted CityCLIM VPC to understand better "Stadtradeln" participants and aid recruitment/retention for the *in situ* sensor data collection campaign.

online map and compared with data contributed by other users, providing near-real-time information on urban climate conditions. CityCLIM also offered the opportunity for participants to receive public recognition through various social media channels. Moreover, an additional gamification factor was deployed to assess these rides based on factors such as main speed, daily distance, measured temperatures, and the number of collected data points per day. Another distinguishing aspect is that the CityCLIM CS campaign goes beyond mere data collection, incorporating scientific evaluation and analysis of research findings. Participants can co-design city policies based on their collected data or information on the Climate Portal.

(4) **Appropriate communication channels:** Another important issue considers communication via different channels (e.g., apps, websites, and workshops). The project's aims and the data acquisition and analysis process were presented in various workshops and training sessions. Furthermore, basic materials (guidelines, standard operating procedures (SOPs), manuals, and flyers) were provided through a project website. As the "Stadtradeln" program had an element of competition (groups competing for the longest distance cycled and cities competing against each other), a communication approach with a gamification aspect could be an effective strategy for this group in a future application.

4.4 CityCLIM key performance indicators (KPIs)

The definition of KPIs depends on the exact research questions. The measurement of urban climate data (air temperature, pressure, and humidity) in a suitable temporal and spatial coverage was the primary task to be solved by CS in the CityCLIM project. Hence, KPIs were defined to cover two aspects:

- The impact of the targeted approach within the CS initiative and
- The quality of the acquired data.

The determination of the impact is related to the number of participants per target group and the received feedback. The overall data quality can be evaluated by the number of measured data points, the number of quality-controlled data points, and the spatial and temporal distribution of quality-controlled data points. Table 2 provides a list of defined KPIs.

4.5 First results

Despite the limited duration of our 15-day measurement campaign, our data contained substantial and comprehensive information concerning the significant research question and the further elaboration of the presented approach. Figure 5 compares the daily accumulated data points resulting from the targeted individuals (CityCLIM group). The CityCLIM group demonstrated high engagement in the measurement campaign, contributing a larger number of data points than originally expected (see KPI list in Tab. 2). Additionally, the non-uniform distribution of weekly data becomes evident in Figure 5.

The achieved results revealed the performance of the CS biking initiative (see Tab. 2): The impact KPI evaluation slightly underscores the targeted results, but it also serves as a guide for strategic adjustments in terms of a clearer and more detailed

TABLE 2 List of defined CityCLIM KPIs.

KPI aspect	KPI definition	Targeted result	Achieved result by CityCLIM
Impact	Satisfaction of citizen scientists, agreed for further involvement *Would you continue to use the provided device (beyond the "Stadtradeln" period)?*	11/11 yes (100%)	11/11 yes (100%)
	Satisfaction of citizen scientists, agreed for further active support and involvement	4/11 yes (36%)	Clear yes: 2/11 (18%), Depending on the results: 2/11 (18%)
	Would you support the initiative by buying an own device?		
	Number of Participants	100%	100%
	Number of devices available = devices used		
Data	Number of raw data points	5,000 points/day, 75.000 points in total	83.600 data points
	Number of quality-controlled data points (e.g., checking for (data uncertainties, thresholds, outliers) of the target group	90%	77.800 data points (93.1%)
	Spatial coverage of the target group data (quality controlled)	Equal spatial coverage (should include all central parts as well different urban land use types)	60% (western and northwestern areas of the target area) were missing
	Daily coverage of the target group data (quality controlled)	Equal temporal coverage in terms of daily data availability	54.2% of the data are acquired in rush hours (7–9 a.m., 3–5 p.m.) → reduced coverage in the noontime and the nighttime hours
	Weekly coverage of the target group data (quality controlled)	Equal temporal coverage in terms of weekly data availability	88.2% of the data are acquired during the working days → reduced coverage at weekends

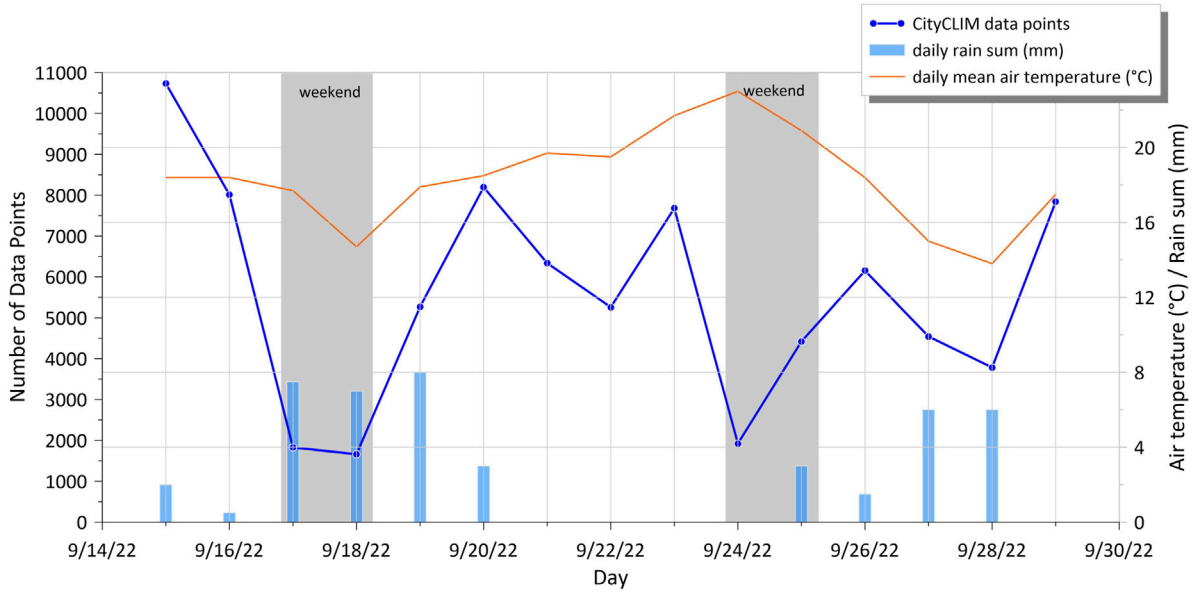

FIGURE 5
Daily accumulated data points for targeted participation approach within the CityCLIM project. Daily weather conditions such as measured mean air temperatures and daily rain sums are included for the subsequent interpretation.

definition of the objectives. The KPIs to evaluate data quality uncover gaps in temporal and spatial data coverage. This information can be used to identify critical deviations and allow for timely adjustments, for instance, in order to effect recruitment of new participants.

A noticeable decline in the quantity of data points at the weekends can be observed. However, the prevailing weather conditions significantly influence the availability of the data. Specifically, inclement weather, such as rain, leads to the absence of measurement data as it adversely affects the use of bicycles. A first

analysis of the data showed an anomaly in the daily data distribution due to the specific use of cycling in the morning and evening hours for the targeted CityCLIM group. Such an observed distribution might be unsuitable for assessing the temporal variation of the urban climatic conditions during the day and must be considered to evaluate the target group. These results have to be included in the recruitment of new target groups (e.g., to fill the arising data gaps) in terms of a data-driven adaptation of the targeted approach.

5 Discussion and outlook: Lessons learned and how marketing approaches can be applied to citizen science projects

Engaging diverse community target groups in CS projects requires tailored strategies to effectively engage individuals, schools, local associations, supra-regional networks, and various professional entities. Understanding what motivates citizen scientists to participate in a project and then tailoring the project to those motivations will help project leaders recruit the most appropriate citizens and keep motivation high. Challenges include defining roles for volunteers, addressing project relevance to participants, and maintaining engagement throughout the project. In CS initiatives, four primary stakeholder groups—institutional research, civil society, public administration, and the private sector—exhibit varying degrees of engagement.

Marketing tools such as stakeholder analysis and the VPC are widely used in the business context to help organizations understand their target customers and develop effective strategies to reach them. The integration of different marketing tools, guided by lessons learned from successful commerce, is essential to optimizing the recruitment, retention, and management of CS project participants. Stakeholder analysis in citizen science projects involves a comprehensive examination of the various parties involved, including relations and actions between the different stakeholders. Therefore, stakeholder analysis is crucial to successful CS initiatives that emphasize tailored communication, a culture of feedback, and participatory techniques and to ensuring that project goals are aligned with the needs and expectations of all stakeholders. Conversely, the VPC aims to create a compelling value proposition that resonates with citizens, addressing their motivations for participating, the benefits of their contributions, and the overall impact of their involvement. The VPC also helps pinpoint pain relievers and gain creators, contributing to a positive customer experience. Based on the deployment of the VPCs, citizen science projects may strategically design their approaches to increase citizen engagement and retention, thus improving the sustainability and outcomes of the project.

The successful implementation of CS projects often requires adapted marketing strategies to meet the project goals and objectives. This includes the selection of suitable participants with the help of an adapted VPC. Tailoring CS projects to the needs of the community requires extending the VPC to consider the communication channels, recognizing institutional scientists as active participants, and adapting the value map and stakeholder profile to gain a complete understanding of mutual services and tasks. The integration of these elements ensures a more comprehensive approach to the design and implementation of CS projects that addresses the diverse interests and motivations of stakeholders.

In addition, the establishment of measurable KPIs is critical for determining the achievement of CS project goals and serves as a recognition tool that contributes to long-term project sustainability. When evaluating CS projects, quantitative indicators are able to measure inputs, activities, and outputs, ensuring reliable data quality and identifying areas for improvement. Regularly tracking and analyzing these KPIs provides stakeholders with confidence in the data's reliability and usability. The CityCLIM KPIs were selected to evaluate the impact of the targeted approach and the quality of the acquired data.

The presented case study explores a CS initiative that collects urban climate data, focusing on air temperature using mobile weather stations. While stakeholder analysis was used to systematically identify stakeholders, assess relationships, influences, and options for action, the VPC provides a much clearer picture of the interests, needs, and concerns of the stakeholders involved. Based on the VPC, the study dissects the profile of Citizen Scientist's and analyzes stakeholder groups for tailored communication strategies. The EU-funded CityCLIM project involved citizens and specifically targeted cyclists through the "Stadtradeln" biking program. The CityCLIM VPC was used to understand the recruitment and motivation of the targeted cycling community. The application allows for a thorough examination of both project goals and participant needs, ensuring a well-aligned and mutually beneficial collaboration. The obtained outcomes highlighted the effectiveness of the CS biking initiative: While the assessment of impact KPIs modestly highlights the desired outcomes, it can also serve as a roadmap for strategic refinements, particularly in communicating objectives with greater clarity and detail. The KPIs employed to appraise data quality reveal deficiencies in both temporal and spatial data coverage. This data can help identify significant deviations and facilitate adjustments to the campaign, such as recruiting new participants if necessary. KPIs are therefore essential to ensure the quality and reliability of the data gathered, to build trust among stakeholders, and to enhance the credibility of the scientific input from participants.

The applied marketing tools enhanced project planning, engagement, and evaluation in the CityCLIM initiative. Therefore, it was crucial to consider that activating different groups will result in different data distributions, depending on their daily "jobs" (as referred to in the VPC). The "Stadtradeln" program targeted companies/organizations within cities so that teams could be formed for the competition/gamification aspects of the program. For future analysis of urban climate impacts, new target groups must be initiated to fill the resulting data gaps (e.g., during the night-time hours). This results in a data-driven adaptation of the targeted approach. However, this example shows the exceptional potential of this concept. CS projects can benefit from adapting marketing tools and best practices to recruitment and communication strategies. This approach can help increase the impact of CS by targeting specific groups in society, such as those with particular qualifications, motivations, and skills. By identifying different stakeholder groups and their needs and requirements, communication strategies can be developed to increase participation rates and achieve defined communication goals.

In summary, the holistic integration of stakeholder analysis, VPC, and KPIs into CS projects not only streamlines project management, but also strengthens the collaborative nature of these initiatives, creating a framework for sustainable success and meaningful contributions. The adaptation of these marketing strategies forms a robust toolkit for CS project coordinators, empowering them to effectively communicate, engage, and assess impact. These strategies collectively contribute to the success and long-term sustainability of CS projects by enhancing participant engagement, ensuring data quality, and refining project objectives. Overall, applying marketing tools and best practices to these initiatives can significantly increase the reach and impact of such projects.

Data availability statement

The raw data supporting the conclusion of this article will be made available by the authors, without undue reservation.

Author contributions

UK: Conceptualization, Data curation, Investigation, Methodology, Project administration, Writing–original draft, Writing–review and editing. PD: Conceptualization, Funding acquisition, Writing–original draft, Writing–review and editing. TH: Writing–original draft, Writing–review and editing. CL: Writing–original draft, Writing–review and editing. OR: Writing–original draft, Writing–review and editing. JR: Writing–original draft, Writing–review and editing. FS: Writing–original draft, Writing–review and editing, Data curation. SS: Writing–original draft, Writing–review and editing, Methodology. JT: Writing–original draft, Writing–review and editing. CS: Conceptualization, Data curation, Investigation, Methodology, Validation, Visualization, Writing–original draft, Writing–review and editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher’s note

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