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LONG PAPER

Engagement and accessibility tools for pro-environmental action on air quality: the SOCIO-BEE paradigm

Ekhi Atutxa[1] · Sofia Garcia-Torres[2] · Charalampos Kyfonidis[3] · Dimitrios Karanassos[3] · Evangelos Kopsacheilis[3] · Christina Tsita[3] · Diego Casado-Mansilla[4] · Alexandros Emvoliadis[3] · Georgios Angelis[3] · Diego López-de-Ipiña[4] · Maite Puerta[4] · Anastasios Drosou[3] · Dimitrios Tzovaras[3]

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Abstract

The involvement of citizens and all stakeholders is crucial in tackling environmental and social matters. This, addressing equity and diversity issues, although challenging, is a necessary condition for achieving positive outcomes and ensuring that no one is left behind. To help ease this challenge, this work presents a systematic approach to ensure inclusive participation and leverage non-technical and technical elements to maximise stakeholder engagement in scientific activities to successfully address sustainability concerns. For that, it builds on the interim results of the H2020 SOCIO-BEE project, a Citizen science (CS) proposal to reduce air pollution through inclusive community engagement and social innovation. As part of an interdisciplinary CS project, an abductive systematic combining methodology was employed, which allowed for dialogue and collaboration between theory and practice throughout the whole process, during which separate groups of experts and potential end-users were involved. The article presents (i) the stakeholder engagement strategy codified in the SOCIO-BEE toolkit as a robust, actionable and inclusive foundation of engagement to CS activities; and (ii) the digital platform UX that allows setting up campaigns for measurements and assignment to citizens, incorporating the requirements for flexibility, accessibility, limited digital literacy, inclusion and legal and ethical considerations. Their combination and mutual interaction aim to leverage the pros of CS and technology whilst reducing their cons to ensure the four pillars of applicability, scalability, actionability, and inclusion. This is supported by the presented hybrid model which combines physical and virtual spaces and individual and collective action.

Keywords Air quality · Citizen science · Stakeholder engagement · Inclusive technology

1 Introduction

When attempting to address the mounting environmental and social challenges [1], it is crucial to involve citizens and other stakeholders [2]. Their effective inclusion can significantly enhance the likelihood of successful interventions and decision-making impact [3]. Moreover, it enables a more comprehensive understanding of the sustainability challenges at hand [4] and a better grasp of cultural, historical, and community-based values, as well as technological concerns [5]. However, achieving these positive outcomes are contingent upon addressing equity and diversity issues [6]. Solutions to environmental and social challenges must be just, fair, and equitable, tailored to meet diverse needs and perspectives. Only then can we expect genuine progress and positive change in the face of these pressing issues. Amongst the numerous environmental problems, air pollution stands out as one of the most serious issues affecting the European Union (EU), particularly its urban areas, which are home to over 340 million people [7]. According to the European Environment Agency (EEA), air pollution causes about 400,000 premature deaths per year in Europe and reduces life expectancy by an average of 2.5 years [8]. Air pollution also has significant impacts on ecosystems, biodiversity, climate change, and human health, such as respiratory and cardiovascular diseases, allergies, and cancer [8–11]. The main

Sofia Garcia-Torres, Charalampos Kyfonidis, Dimitrios Karanassos, Evangelos Kopsacheilis, Christina Tsita, Diego Casado-Mansilla, Alexandros Emvoliadis, Georgios Angelis, Diego López-de-Ipiña, Maite Puerta, Anastasios Drosou and Dimitrios Tzovaras contributions were equal, the first author's contribution was more substantial.

Extended author information available on the last page of the article

sources of air pollution in Europe are energy production and consumption, transport, industry and agriculture. Amongst these sectors, energy demand and mobility are particularly important drivers behind pollution levels in cities [12, 13]. These emissions are influenced by various factors such as fuel types, technologies, weather conditions, and urban planning. To improve air quality in European cities, several measures have been implemented at different levels of governance, such as setting standards for emissions and ambient concentrations, promoting renewable energy sources and public transport systems, encouraging behavioural changes amongst citizens and businesses, and supporting research and innovation on clean technologies. However, more efforts are needed to achieve compliance with EU legislation on air quality and to protect human health and the environment from the harmful effects of air pollution.

In this context, it is crucial to make progress in increasing the participation of different interest groups, particularly the most vulnerable, in scientific efforts aimed at addressing environmental problems [3, 14–16]. Building upon the scientific progress achieved so far in the H2020 SOCIO-BEE project (https://socio-bee.eu/), this paper aims to contribute to the definition of systematic approaches capable of gathering the voices and participation of all stakeholders, including those facing difficulties in engaging. By building engagement and accessibility tools, this research specifically aims to address how we can effectively combine both the non-technical and technical elements essential for inclusive participation, thereby maximising the benefits derived from stakeholder engagement in scientific endeavours. To do so, SOCIO-BEE aims to encourage citizens to take an active role in the fight against climate change through inclusive Citizen science (CS) using disruptive technologies such as drones and wearables all being articulated by a digital framework called AcadeMe. More specifically, SOCIO-BEE will carry out three different pilots aiming to involve different segments of EU citizens in three European cities (young people under 16 years of age, older adults over 65 years, and people who commute by car or through public transport in large cities or suburbs) in the air pollution fight (either by identifying environmental issues related to air quality; raising public awareness, stimulating behavioural change and/or creating new public policies for environmental protection). The two main challenges faced by the SOCIO-BEE project are, on the one hand, to involve citizens (both people who are already aware of environmental issues and those who for some reason are less aware or passive regarding climate action). On the other hand, the project seeks to encourage scientific vocation amongst the target population and foster the use of emerging technologies to develop evidence-based proposals for enhancing air quality. All this takes into account that the main objective of the European Green Deal is to leave no person or place behind.[1] As a result of this inclusive approach, the SOCIO-BEE project produces valuable outcomes. These results come in the form of theoretical and practical road maps and toolkits for building communities (named beehives in this project as the whole project revolves around the bees' metaphor). In these communities, stakeholders engage in co-creation to conduct CS-based interventions, actively striving for equity, inclusivity, and a commitment to avoid any form of social exclusion or discrimination. In essence, in the context of this paper, SOCIO-BEE has emerged as a platform that facilitated the advancement of systematizing CS through the hybridization of technical and non-technical elements. In fact, this piece of research serves as the focal point of this paper, which aims to further the cause and how an inclusive and sustainable green transition based on citizens' observations and collaboration may occur using emerging technological tools. The rest of the manuscript is organised as follows. Section 2 outlines the methodology employed for constructing frameworks and developing toolkits. In Sect. 3, the frameworks used to comprehend the establishment of inclusive and engaged pro-environmental communities are presented. Section 4 details the primary outcomes, categorised into non-technical and technical tools and explores methods for refining and tailoring them to various target groups. Finally, Sect. 5 discusses the key findings and outlines potential future avenues for research and work.

2 Methodology

As part of an interdisciplinary CS project that collects and gathers evidence from different frames of reference, we adopted an abductive systematic combining approach [17] as our methodology. This approach enables co-creation and dialogue between theory and practice. Abduction involves using the most plausible explanations/theories to account for the results/evidence obtained in a research process that integrates theory and practice. This systematic combining offers structure and guidance for the iterative and bidirectional process of aligning deductive and inductive methods and outcomes [17].

[18] This approach enabled us to utilize all the available scientific inputs, establishing a robust theoretical foundation that was further enriched and validated through expert discussions and insights. We decided to take this methodology to interweave all the inputs gathered to define the Communities of Practice's (so-called hives in the project SOCIO-BEE) characteristics, the roles of the participants in the communities,

[1] European Commission 2019: https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal_en.

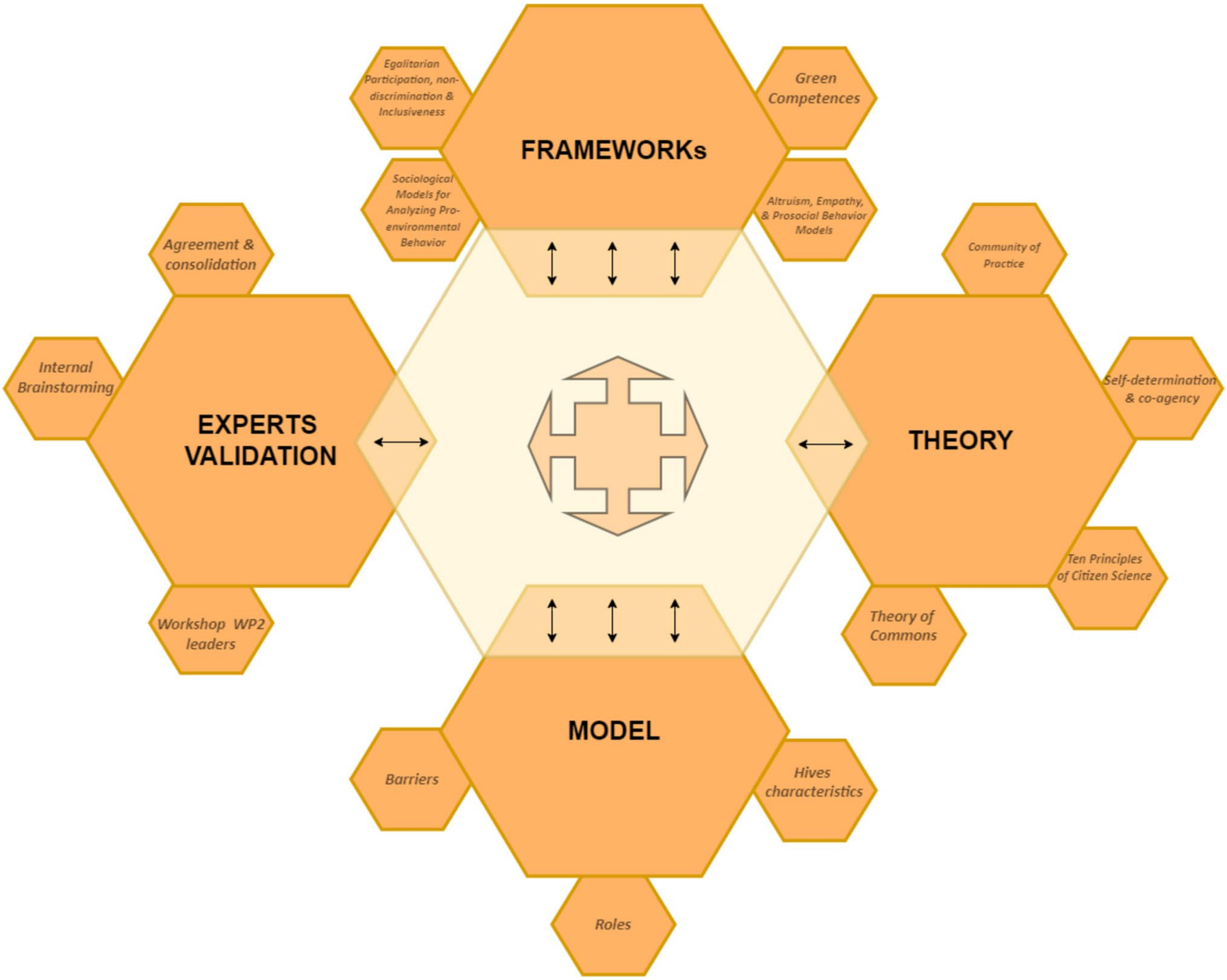

Fig. 1 Own elaboration based on Dubois and Gadde, p. 555 [17]

and the barriers that emerge for creating communities and participating in them. This double process afforded us a comprehensive understanding of all the collected inputs and their interconnections, leading to the creation of a new tool that will not only guide participants' involvement in CS-based collective actions in SOCIO-BEE but also define the key characteristics of the beehive. Figure 1 summarizes the main elements of the abductive systematic combining approach carried out that has facilitated the interaction of all elements. As can be seen, it consists of a combination of theoretical background, models, experts' validation, and tech and not-tech frameworks. In the following sections, each of the different four angles is described.

3 Frameworks and theories: how to build inclusive and engaged pro-environmental communities

Together with individual initiative, collective action is a relevant factor for pro-environmental behaviour. Both individual and collective agencies play a key role in forming societies that are more aware of and active in addressing environmental and scientific challenges [19–21]. To analyse them, we considered science and scientific processes as Commons [22] and we used the theory of *Community of Practice* (CoP) [23] to study the interactions amongst participants. Therefore, both theoretical foundations of the Commons and the CoPs helped dramatically to frame the involvement and future collaboration in the communities (bee hives). Starting from the principles and characteristics of *CS* [24] and relating them to the previous theories, this section focuses on how egalitarian participation, non-discrimination, and inclusiveness should be ensured.

3.1 Egalitarian participation, non-discrimination, and inclusiveness

The interdisciplinary make-up of the SOCIO-BEE team that has developed the emerging model reflects an initial commitment to ensure that the composition of the participants in the hives, the data that are collected and analysed, and the events and environments generated by the project are all governed by social inclusion and a clear intersectional approach [25]. In the context of CS projects and in the implementation of technological projects there may be a lack of knowledge about the basic issues related to the processes of inclusion of the many existing vulnerable groups and, amongst others, mainstreaming of the gender perspective. Therefore, in SOCIO-BEE, the process of designing the model has always encouraged the collaboration of a multidisciplinary team including social scientists and gender experts. The three fundamental axes to ensure egalitarian participation, inclusion, and non-discrimination are described hereafter.

3.1.1 Community participation and representativeness

Academic literature argues that the production of science in a more inclusive way achieves not only greater influence but also legitimacy [26, 27] as it considers many different perspectives. An implicit objective of any inclusive social research should be that all people in the sample, regardless of their functional characteristics, can participate in it with equal opportunities and appropriately provide information. CS processes involve the democratisation of science through the inclusion of participants from different groups, statuses, ages, and genders. As stated by Paleco et al. [28], for CS to be inclusive, it must involve people from these diverse groups. However, this inclusion is not always easy. Thus, Pandiya et al. [29] point out that these CS processes often do not reflect and include all demographic profiles. The practice of design for all should be present from the contact phase, adapting communication channels to the functional characteristics of the target population. The aim is both to enrich research with the perspectives of all citizens [30] and not to reproduce segregating practices that could result from incorporating only the “educated part of the society". In addition, SOCIO-BEE makes a clear commitment to our communities and our hives to have an intersectional approach, our adherence to the European strategy for gender equality [31].

3.1.2 Inclusive data and data analysis

The 2030 Agenda for Sustainable Development commits to leaving no one and no place behind.[2] Regarding data collection, this means getting more granular data to understand the needs and experiences of the most marginalised in society. Up to date, too many people are invisible in data, and too little data are routinely disaggregated. That is why the SOCIO-BEE model builds on already existing strategies to ensure the inclusiveness of the data by subscribing to the principles that inform the Inclusive data Charter.[3] Crowd-sourcing science [32]; “distributed intelligence”, “participatory Science” or “Extreme Citizen science” (ECS), the literature identifies several classification/types or levels of participation in CS from which data can be derived [33]. Such a classification relies on the involvement of citizens in the scientific process and not only in the data collection. For instance, ECS "Specifically seeks to make scientific tools and methods available to anyone. ECS proposes that all people, regardless of literacy levels, should be able to benefit from the scientific process, from the definition of local problems and collaboration in data collection to the use of the results to address and resolve issues identified by the communities themselves" [33]. Although in our case, the dynamics of the bee hives in the project do not necessarily correspond to any of these typologies strictly, we share the authors 'concern about data sovereignty and eventual risks for vulnerable groups. To ensure the protection of participants from vulnerable groups and other local communities, SOCIO-BEE has ensured a proper Data Protection strategy and revised all the informed consents handled by the partners to make sure that each participant understands the nature of the data they are gathering and the impact that it might have. This way, participants are placed at the centre of the process as will be discussed in the section related to requirements extraction.

3.1.3 Secure spaces and inclusive participation

The model designed for reaching participants in SOCIO-BEE' combines personal interactions face to face (overall related to onboarding, engagement, and raising awareness) and through the platform designed for the project (i.e. the AcadeMe) for conducting CS campaigns based on air quality observation. The design of this hybrid model seeks to

[2] https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal_en.

[3] http://www.data4sdgs.org/sites/default/files/2018-08/IDC_onepager_Final.pdf.

ensure that both physical and virtual activities will respect the well-being of the individual and promote respect, good treatment, and non-discrimination of any group. To this end, the research staff involved in the design of the model has reviewed the legal standards and safe environment policies carried out in similar projects (e.g. Youcount[4]). In this way, the followings are identified as key elements for safe environments and non-discrimination: 1) the creation of welcoming, respectful, and safe environments, both physical and virtual; 2) the promotion of good treatment amongst all participants; and 3) the care for any person in a situation of vulnerability. Moreover, despite the harassment and discrimination can be directed at both men and women, SOCIO-BEE is aware that women either children, young adults, or old adults face more harassment than men and the nature of the harassment is harsher, as it focuses on social issues, ranging from body shaming to questioning their professional suitability and qualifications. Therefore, special attention will be devoted to ensuring a gender-inclusive and secure space. Following ECSA principles, the bee hives should not tolerate (nor in the face to face, nor in online interactions) attitudes that include verbal comments that reinforce discrimination based on gender, gender identity and expression, sexual orientation, disability, physical appearance, body size, race, age, and/or religion; the share of sexual images in project spaces, intimidating or stalking behaviours; photography or recording without the consent of the subject; inappropriate physical contact; or unwelcome sexual attention. These criteria are validated in each CoP (bee hives) through a checklist provided by SOCIO-BEE.

3.2 Validation and models: involving stakeholders and citizens in participatory projects

3.2.1 Co-design and co-exploit: how to jointly produce scientific commons

Co-creation is a management initiative that brings different parties together (e.g. company, group of customers), to jointly produce a mutually valued outcome [34]. Multi-stakeholder engagement processes and co-creation activities have major advantages: they produce results that are truly adapted to the reality of concerned people and thus allow more sustainable changes [32]. Involving stakeholders in developing innovative climate mitigation and adaptation actions are even more relevant as climate change is global, but also highly contextualised, and local, and often requires changes in society [35]. In the context of pro-environmental behaviour and based on the Commons and Community of Practice theories, for SOCIO-BEE co-creation means that

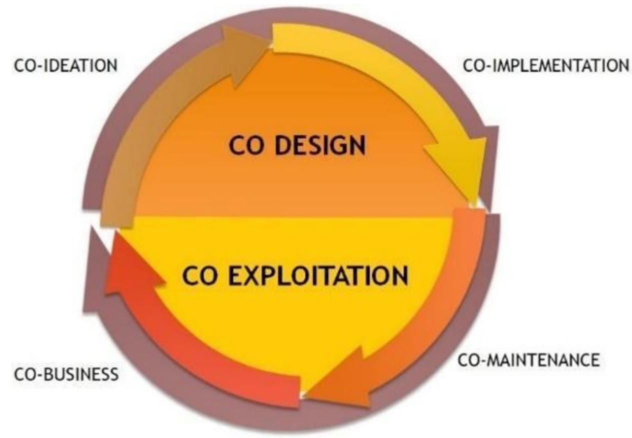

Fig. 2 WeLive CO-CREATION methodology adopted and adapted in SOCIO-BEE

"government, companies, and citizens initiate, design, or implement programs, projects, or activities together, associated with climate change and air quality concerns" (WeLive project[5]). In turn, the co-creation process is divided into co-design and co-exploitation phases (Fig. 2). Co-design implies that stakeholders jointly co-ideate and co-implement, i.e. they collaborate in the specification of an idea that is turned/implemented as an app/experiment or any other type of open/CS enabling asset.

Egalitarian Participation, non-discrimination, and Inclusiveness also need co-exit, that is to say, at any stage, the collaboration process may be stopped. Co-design is followed by co-exploitation where those involved in the ideation, and no other external people and then, implementation collaboratively devise a deployment and exploitation strategy for the derived asset, e.g. CS experiment together with its realisation approach. Such exploitation consists at least of two stages, namely co-maintenance where the produced asset is deployed, and maintained (in the case of SOCIO-BEE, it would correspond to the actual experiment execution during a timespan), and sustained and co-business where different sustainability approaches might be adopted to ensure the asset keeps providing service (in the case of SOCIO-BEE this could be used to make the experiment design and lessons learned during the execution turn the experiment into a replicable experiment for further use in other pilots and even domains). The SOCIO-BEE co-creation process is managed by the AcadeMe platform. As such, the public can be involved to varying degrees and partake in several steps of a CS process, like defining the questions, developing explanations/hypotheses, collecting data, interpreting data, or drawing conclusions. To make an idea of what kind of

[4] https://www.youcountproject.eu/.

[5] https://cordis.europa.eu/project/id/645845.

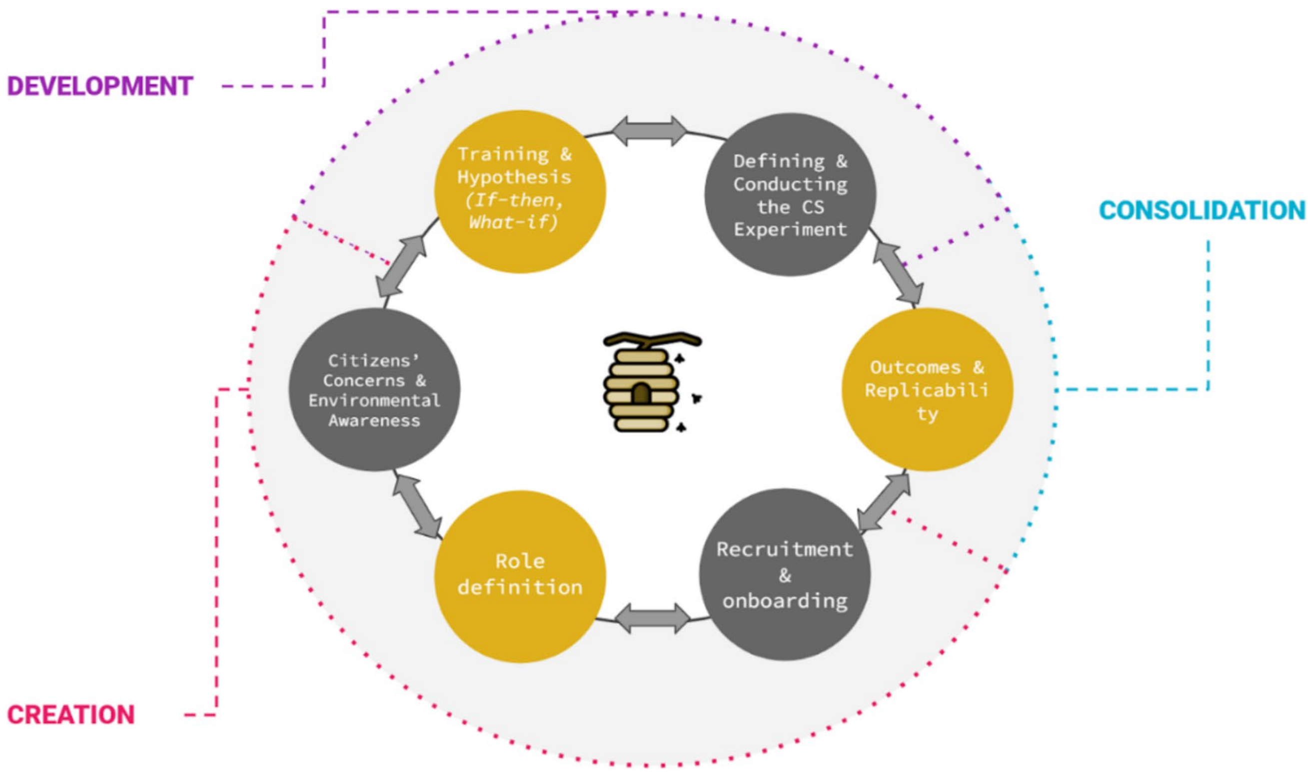

Fig. 3 Engagement cycle in SOCIO-BEE through phases. Prepared by the authors based on previous CS projects and inspiration of CoPs

citizen collaboration we envisage, projects are often classified on a ladder of participation [36] that includes contributory projects (mostly data collection); collaborative projects (data collection and refining project design, analysing data, disseminating results); and co-created projects (designed together by scientists and public where the public shares responsibility for most or all the steps in a scientific project/process). This level of involvement is also connected with the type of Bonney's participation process [33], which identified involvement in contributory, collaborative, and co-created projects. Similarly, but putting the focus on the users, Haklay [37] defined the level of participation and engagement, and cluster projects as crowd sourcing, distributed intelligence, participatory science, and ECS. In such articles, inquiry activities that citizens are involved in many ranges from contributing data (contributory or crowd sourcing) to participating in the entire process and taking part in publications (co-created or ECS). Finally, we found a piece of research [38] that focuses on the level of participation considering the behavioural traits and personal needs finding five types of users in online CS: hardworking, persistent, loyal, lurking, and visitors. However, this work does not relate to the cooperation amongst peers in a co-creative process as SOCIO-BEE envisages. With this review of participation in co-creative CS endeavours, the co-creation methodology devised for SOCIO-BEE fosters sustainable continuity in time and is feasible in economic terms. In essence, beyond just defining how the people will collaborate, the SOCIO-BEE proposal consists of the co-design and co-exploitation phases which are further divided into co-ideation and co-implementation, and co-maintenance and co-business stages, respectively, ensuring the sustained cooperation in the bee hives. Indeed, the co-creation process does not end when a new service or product is delivered, e.g. a CS experiment is designed and rolled out, it must also be supported afterwards; a business and sustainability model (results publication, dissemination, and communication to bears and main public (citizens), open source publication, license, documentation) should be developed to make the service sustainable, and replicable in other CS hives is needed.

3.2.2 Engage: how to jointly build a community of practice in phases

Communities are created in SOCIO-BEE (see Fig. 3) through three main phases: Creation (which includes, recruitment, role definition, and raising awareness), Development (which includes training, simulation, hypothetical questions, and conducting the experiments) and consolidation (which includes scientific and structured outcomes,

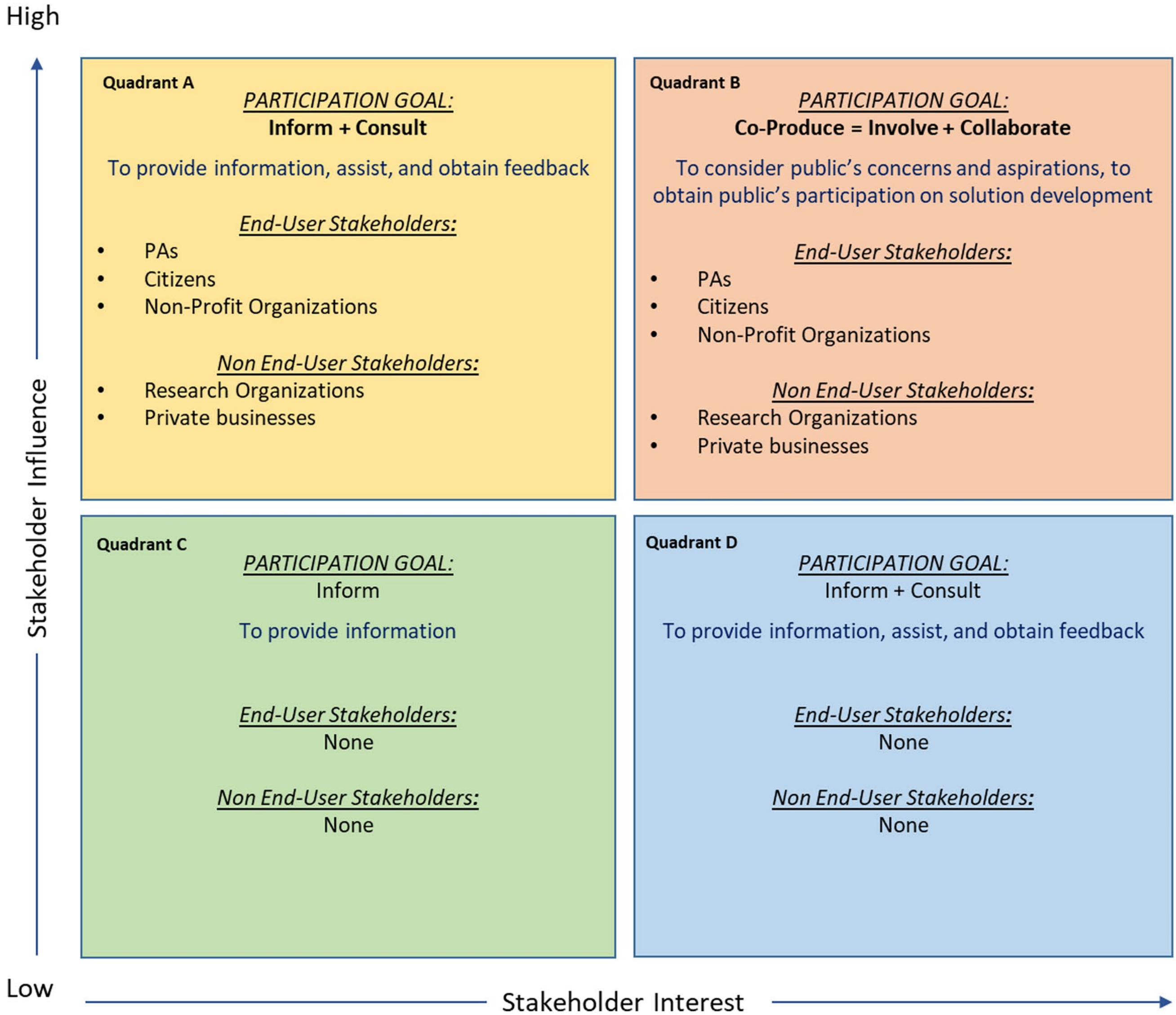

Fig. 4 SOCIO-BEE stakeholders' influence vs interest matrix

evaluate success, learn from pitfalls, and outreaching for ensuring further adoption and replication).

s Considering these phases and the co-creation methodology of the previous section, we sought to understand which actors should be involved in each task, overall, and the questions that should be addressed to ensure that the hives will be created with the SOCIO-BEE soul. Thus, cooperation, egalitarian participation, mutual exchange of ideas and knowledge, and sustainable development should be kept in mind. Therefore, drawing from existing literature on examples where CS and co-creation have been accomplished, the researchers from the SOCIO-BEE project started by interacting with the pilot cities to create a stakeholder map. Stakeholder mapping is the visual process of laying out all the stakeholders of a product, project, or idea on one map. The main benefit of a stakeholder map is to get a visual representation of all the people who can influence your project and how they are connected portraying the interest the stakeholders may have (Fig. 4).

We identified the stakeholders' influence vs interest matrix in which we can better understand when to expect contributions from them depending on their level of interest. Influence is very subjective. One might think that a certain stakeholder has a high level of influence in an engagement, but they may not. Hence, identifying and gauging the interest and influence levels of stakeholders is critical for stakeholder prioritisation. Constructing the stakeholder map ensures that you have considered the full range of people and organizations that need to be included. Analysing stakeholders, grouping them based on their posture, and understanding their concerns will also help target your communications and engagement strategy.[6] As can be seen in Fig. 4, it helps to understand the need for communication and potential resistance to change. Interest indicates stakeholders' likely concerns, whilst Influence indicates their ability to resist your recommendation or change. In the context of SOCIO-BEE, drawing from the knowledge acquired in the project INTERLINK, we follow this map and we have accommodated it to our objectives. Therefore, we should envisage the quadrants A and B where the level of influence will be top having more or less engagement on the activities carried out in the context of the project. Therefore, we can foresee that if the Public Administrations (PAs), organizations, or assemblies of citizens are less concerned or interested, we can only aim at informing or consulting them. However, if SOCIO-BEE can attract their interest, we will witness scenarios of real cooperation and co-production of experiments and air quality campaigns. The produced stakeholder maps have been very important for better understanding the names of existing associations, entities, or institutions, across the three different pilots in SOCIO-BEE. This exercise also helped to connect the different roles needed in the creation, development, and consolidation phases of a hive (Fig. 3). In fact, to ensure inclusiveness and the principles of CS, initially, hives will not emerge spontaneously or organically; they will be driven by the project partners of the three cities that we call beekeepers (to maintain the bee metaphor). With those actors identified, we enhanced the proposal of how SOCIO-BEE hives should be created based on the Commons paradigm and the Community of Practice to devise a toolkit that can be used to assess the inclusiveness, the sustainability and the equal participation of citizens in the hive.

4 Results: engagement and accessibility tools

4.1 The SOCIO-BEE toolkit: from design guidelines to applicability

Theories used for the understanding of science as a Commons and collective action as a Community of Practice and (based on them) the methodologies designed for implementation have led to the creation of a Manifesto and a range of tools that altogether constitute the SOCIO-BEE toolkit. In this section, we will cover the tools we consider relevant to green digital accessibility.

4.1.1 Applying the SOCIO-BEE paradigm for an inclusive green transition and digital accessibility: barriers to participation and beehive creation

In the context of the project, several tools were created to foster the engagement and onboarding of citizens. To cite some of them, SOCIO-BEE designed and developed tools such as: "How to organise a CS project", "How to check on inclusion", "How to measure engagement", "How to create your own hive manifesto" or "How to involve stakeholders map". As the list is quite extensive, the focus of this subsection will be put on only one of them: "How to check for barriers to participation and beehive creation".

4.1.2 Barriers to create beehives

When it comes to creating new hives for citizen participation in SOCIO-BEE, barriers will be present to impede their creation, development, or consolidation (see Fig. 3). Specifically, the principles, characteristics and role of the hives must ensure that the actions developed are capable of collaboratively generating the expected value for CS projects. The theories of Community of Practice and the Commons made it possible to define these dimensions and also potential barriers that should be removed. Taking up the objective of creating a tool capable of managing the multi-scale character of CS, the information contained in Annex 1 allows the definition of guiding questions for the proper creation of the hives in SOCIO-BEE. This material will be given to pilot initiators to understand the main barriers that can appear and the ways to overcome them. As the technology can be helpful in that direction, it has to be accompanied by face-to-face onboarding materials. Again, this is the main strength of the presented hybrid model.

4.2 The SOCIO-BEE technological platform for unlocking barriers

The concept of collaborative and democratic air quality CS of SOCIO-BEE will be delivered through the SOCIO-BEE platform. This platform will comprise of a web and a smartphone interface. The smartphone will be paired with a wearable sensor, through which the air pollution will be recorded. The smartphone setup (application + wearable) will be used by citizens during measurement campaigns and to explore air pollution along with their exposure and footprint. The web interface will be used by citizens and organizations to manage the campaigns and their interlinked

[6] https://thinkinsights.net/strategy/stakeholder-analysis/.

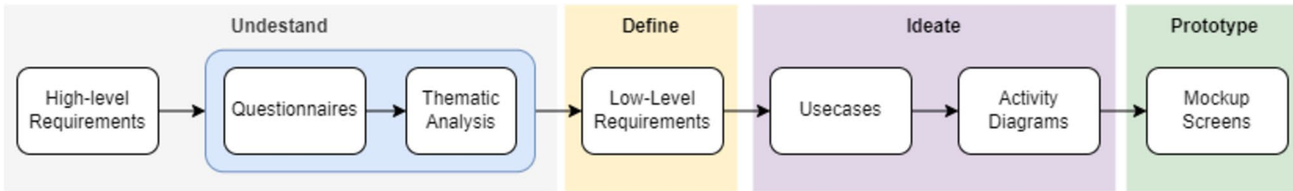

Fig. 5 The process for the design of the SOCIO-BEE platform

citizen communities, but also to extract data about the air pollution findings. The process through which the platform has been designed and implemented is presented in the following subsections.

4.2.1 Requirements elicitation process

The requirements elicitation was designed as an iterative process through which requirements were extracted from a set of data (questionnaires, interviews, documentation, etc.). The first phase of this process was to extract the high-level requirements that the system is aiming at, i.e. the Goals of the system. The system goals describe the scope and the purpose of the system from the perspective of the different involved stakeholders. The second phase was to extract the lower-level requirements and determine the constraints. The lower-level requirements are derived by decomposing/refining the project goals. The refinement process is iterative and is based on evidence. The refinement is typically done by asking "how?" - a widely used methodology in the requirements elicitation literature [39, 40]. The refinement process continues until the requirements at the lowest level cannot be further broken down. From the lower levels of this refinement, one can go up to the roots of each requirement by asking the question "why?". The constraints, on the other hand, are blockers to the satisfaction of requirements.

4.2.2 Extraction of high-level requirements

The project initiation documentation, which was based on initial research on the topic and was peer-reviewed and accepted by the European Commission for funding, was considered the initial information source. It included a literature review, the different stakeholders' perspectives and the project's goals. Hence, the high-level requirements were extracted from it.

4.2.3 Extraction of lower-level requirements

In order to refine the high-level requirements and extract the lower-level requirements, we conducted a qualitative inquiry, in order to get direct input from potential end-users. Thus, a set of "requirements extraction questionnaires" was produced and distributed to citizens of three cities across Europe: Ancona, Maroussi, and Zaragoza. The questionnaires were distributed to potential end-users through the city municipality workers, who were part of the project's consortium. Potential end-users included individual citizens, municipality workers, and schools. The questionnaires were designed with three sections. The first part of the questionnaire was the demographics section so that we could cluster the users based on basic demographic details and identify any trends. The second part was the profiling section so that we could identify the likely role the responder would wish to have in the SOCIO-BEE ecosystem (related to the Bee-Hive metaphor). The third part was the requirements extraction section, based on open-ended and multiple-choice questions, to determine the user requirements from the end-user's expectations. In total, 95 people responded to the questionnaires: 27 from Zaragoza, 35 from Ancona, and 33 from Maroussi. For the analysis of the questionnaires, and overall for the analysis of the free-text questions, a thematic analysis (TA) was chosen [41]. TA is a powerful and flexible approach for analysing qualitative data. TA started with the extraction of quotes (pieces of text that contain a meaning), then codes (categories) were generated by grouping the collected quotes and finally, themes were produced by grouping codes. The themes were used to extract the requirements. The questionnaires were analysed by two researchers of the team who coded individually to ensure inter-rater reliability. When the coding process was finalised, these researchers were met to cross-check the extracted themes and compile the final list of themes. Through the aforementioned process, in total, 50 high-level requirements, 52 low-level requirements (46 Functional (FR) and 6 Non-Functional (NFR)) and 8 constraints were identified for creating the tools. Once the requirements of the platform were defined, the next step was to specify the functionalities of the platform. In software design, the functionalities of a system are also called use cases. Use cases encapsulate all the possible actions that a user can execute using the system. Use cases have multiple viewpoints that they can be described from, each one with a different level of detail. For this project, we chose to employ the most widely used viewpoints, the summative use case diagram, the use case description, and the use case activity diagrams. The two aforementioned diagrams follow the standards of the UML 2.5 modelling language. The use cases were formulated by distilling the FRs of the system, by trying to answer what functionalities need to be in place for each FR to be fulfilled. The formulated use cases were grouped into 9 categories, based on their functionality. These groups were: User Profiling (UP), Campaign Volunteering (CV), Campaign Management (CM), Working Bees Management (WBM), Hive Management (HM), Individual Exposure Analysis (IEA), Automated Analysis (AA), Data Mining (DC). The total number of use cases was 102. For each one of these use cases, a detailed description of the task and usage context was compiled, and also an activity diagram, to ideate the flow of activities to achieve the use case's goal. Lastly, the use cases and the activity diagrams were translated into prototype screens. The aforementioned design process is described in Fig. 5.

4.2.4 Legal and regulatory requirements

The drafting of Legal and Regulatory requirements in the context of SOCIO-BEE is a process initiated at the early stages with a thorough investigation of the landscape of relevant legal and regulatory frameworks. The legal framework refers mainly to the provisions set in the General Data Protection Regulation (GDPR) [42]. Also, the existing EU legislation as well as other resources that refer to CS [24, 43] and the use of drones [44, 45] had been under consideration. As soon as the identification of the legal and regulatory landscape was completed, we conducted a thorough elaboration of the impacts on the SOCIO-BEE use cases. We examined a series of legal and regulatory considerations that relate to the main aspects of the project, which are CS, air pollution, the use of drones, the use of wearables, and artificial intelligence and machine learning. The outcome of this process was the drafting of 42 legal requirements and 38 ethical requirements. All these have been embedded into the design of the system (end-user functionality, end-user data handling, layered user permissions, security and confidentiality measures, etc.). They also incorporated the overall approach towards the deployment of the solution (e.g. content of information sheets and consent forms for the recruited users offered voluntarily to participate in the air quality measurement campaigns).

4.3 The GUI prototypes encompassing inclusion and co-designing criteria

The overall rationale and the strategy adopted aimed to increase user participation and increase their motivation whilst respecting the inclusion and co-designing criteria is explained hereafter. The ideation process through which the designs were translated from use cases and requirements into prototypes/mockups can be described as follows. The interface design process considered Nielsen's interaction design heuristics [46, 47]. More specifically, the design focussed on enabling the defined UCs considering the application's context of use in the real world. Additional important goals were to minimise memory and cognitive load, as well as to ensure interaction feedback (visibility) and consistency across the application. Based on the use case (UC) groups, the visualisation of the web platform was designed for each user role (in SOCIO-BEE the participant's roles mimic the roles in a real hive) and each device (pc, mobile). The first step was to understand the UCs in each UC group and classify them to be depicted together in the same screen view for each user role (Fig. 6). For example, three UCs from the group Campaign Volunteering (CV) were classified to be displayed in the same view for the user role "Working bee" (WB). In detail, the WB can view the campaigns he/she is participating, has completed, and has resigned from in the screen "Campaigns". In the same view, the user can filter the campaigns and select a campaign for details and further relevant actions. Similarly, all other UCs were grouped into views, for different user roles and screens (web, mobile). The second step was to add/adjust visual elements horizontally in all designed views, based on the data input or output from other UCs groups and user roles. For example, the "Queen Bee" (QB) user, in the context of the Campaign Management (CM) UCs group, can view all of the Campaigns, including the proposed campaigns from other users. The campaigns can be proposed by WBs, as an output from the CV UCs group. Thus, the QB displays the proposed campaign and decides whether to accept it or not. This scenario generates visual elements and indicators for the interaction between the WB and the QB that were adjusted in the various designs (e.g. the user name of the proposed campaign creator is visible to the QB interface, a notification with the proposed campaign request, accept/decline button, notification for accepted/declined campaign). This process allowed us to prototype the user flows and ensure that the designs enabled the intended scenarios. The final step was the creation of high-fidelity mockups to i) depict the look and feel of the SOCIO-BEE brand; ii) communicate the proposed User Interface (UI) components for mobile and web development; and iii) to present the most important user flows in a sequence (e.g. create a campaign; monitoring campaign; collect data for a campaign; create hives; assign bees, etc).

4.4 Continuous evaluation and assessment of the previous technical and non-technical results

In order to refine and better craft the tools for different target groups, the pilots in SOCIO-BEE will be used to get insight into what tools are used and with what expectations, and which tools are less likely to be used and why. Of the

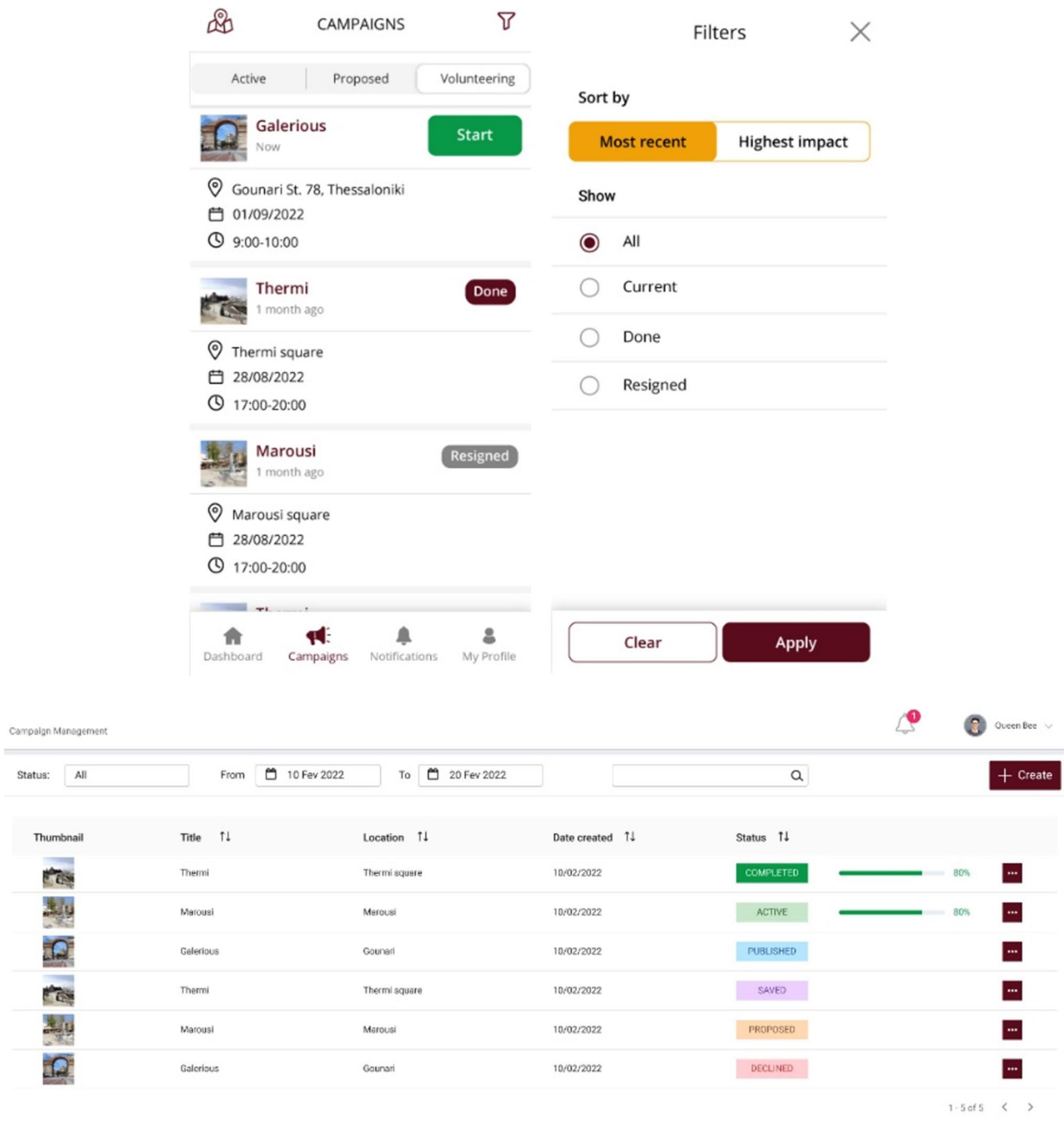

Fig. 6 Web and mobile designs (high-fidelity mockups) for "Working bee" and "Queen bee"

used tools, we will compare expected use with the experienced use after the pilots. The tools that are not used will be evaluated on perceived value, created expectations, and communication. The result can be an improved tool or an elimination from the toolkit. After the first round of pilots, involved stakeholders will be contacted for an interview with a questionnaire about the used tools as the underlying script: Did you use the tool as planned? [Y/N]

- If not, how did you change the use?
- Did the tool meet your expectations?
- What were the tangible outcomes?
- Do you have any suggestions on how to improve the tool?

By using these five questions for all three pilots and stakeholders in different capacities within them, possible patterns for iteration will become apparent. The results of these interviews will be analysed and a plan for the iteration towards second-round pilots will be made. Furthermore, SOCIO-BEE formulated several design guidelines which inform choices that will guide any upcoming activities related to the (re)formatting and redesign of the toolkit components. The evaluation of the tools created to accomplish the SOCIO-BEE phases will pay special attention to the possible adaptation, creating variants to cater to the specific needs of the target groups we address in the three pilot cities (youngsters, old, adults, and commuters). These adaptations will be based on four areas: Replicability, scalability, actionability, and inclusion.

4.4.1 Replicability

In many projects like these, replicability of the results beyond the scope of the project can be an Achilles heel. Even though our pilot cities are different in many respects, they form a small sample of the potential outreach we would like to achieve beyond the scope of this project. Specific local circumstances, whether cultural, political, linguistic, organizational, or other will pose different demands on the materials, we develop in the context of our project. To deliver materials that would suit all needs in all contexts is nearly impossible, we treat our component materials as templates or inspirational examples. But these materials will inevitably have to be adapted to local needs and circumstances. To achieve this, we like the materials to be cheap, easily modifiable with simple means, printable, and easily distributable. Therefore, we will refrain from advanced or complex graphical design, since any complexities in that realm might be an obstacle for local stakeholders in the communities/hives to be able to modify or adapt the components. We will follow the design adagio Keep It Simple, Stupid (KISS) to maximise the usability of the components by non-expert user groups.

4.4.2 Scalability

Another design consideration is the scalability of the components. Again, the various user perspectives should be able to adapt, distribute and use the component materials with the simplest means possible. A computer with widely used basic software tools, a printer, and internet access should be the basis of operation for participants to be able to execute the campaigns.

4.4.3 Actionability

We aim to maximise the practicability of the components and make them as actionable as possible. This implies that any predominantly text-based component needs to be revisited towards its most actionable version, which may imply using (inclusive and KISS) technologies and replacing text with visuals when possible. This already advances towards the last point of the inclusion.

4.4.4 Inclusion

Being inclusive is an important point of attention throughout our project because it ties into the essence of CS, to democratise access to both methods and results and the resulting data. Inclusion ties in across the board with our other considerations. Special attention will be given to the use of visuals and language. Part of this consideration is to try to minimise text and maximise visual support. Limiting the amount of text has to do with (a) translation efforts to minimise adaptability thresholds, (b) cognitive workload and accessibility for younger age groups, people with dyslexia, or other limitations to processing complex verbal messages.

5 Discussion and future work

CS seeks to promote an integrated understanding of complex phenomena and problems that occur in our daily lives—Air pollution and Climate Change in the case of the project SOCIO-BEE—to educate scientifically literate citizens who are capable of thinking, participating and critically making decisions. The how to for achieving the challenging goal of CS cannot be left to improvisation. Thus, projects that embrace this approach must always seek a systematic approach capable of collecting the voices and participation of all affected stakeholders; including those who, for the various reasons previously described, have difficulty participating. The identically challenging problems of air pollution and climate change force us to put in place and leverage all resources in place to fight against their causes and for their remedies and calls for immediate and global action, for which technology is a key ally, although frequently labelled as non-inclusive. The combination and mutual interaction of the SOCIO-BEE toolkit and the technology platform presented in this article aims to leverage the pros of CS and technology whilst reducing their cons to ensure the four pillars of replicability, scalability, actionability and inclusion. This is supported by the presented hybrid model which combines physical and virtual spaces and individual and collective action. The first outputs of the SOCIO-BEE project described in this paper contribute to progress in this direction. The toolkit created ad-hoc to foster the inclusive engagement and onboarding of citizens, as well as the methodologies used for their conformation, guarantee that all future CS initiatives that may arise within the framework of this European project are sensitive to the principles of CS. The consideration of Science as a Commons and the creation of Communities of Practice has everything to do with the elimination or attenuation of the different personal and contextual barriers that exist so that a person and/or a community can decide to and indeed participate actively in the formation of CS. In other words, every one of the initiatives to be developed in the three pilots will make use of the tools created to ensure egalitarian participation, non-discrimination, and inclusiveness and, even though they were developed for the SOCIO-BEE project, they were designed to be reproducible in any other setting. This eventual toolkit, as envisioned, is a complete set of tools that enable the stakeholders in SOCIO-BEE (and eventually in any CS project) to plan, develop, execute and evaluate/iterate a CS campaign for measuring air quality and evoke changes in their community building on the outcomes. Considering the wide definition of target groups, we also have to aim for a wide variation of maturity and background of stakeholders. Therefore, the toolkit is not organised as a linear process with steps to follow, but as a cascading, circular process in which stakeholders on different levels and different phases of a campaign can choose tools that are relevant for them or complementary to their existing competencies. In fact, this circular process is already patent in the interconnections and positive feedback loop between the toolkit and the technological platform in search of replicability, scalability, actionability, and inclusion resulting in the hybrid model presented here. The interdisciplinarity of the team together with the rounds of validations and inquiries with experts and users have helped bridge the non-inclusive side of technology, fostered its actionability and in turn allowed for a replicable and scalable model of SC. Thus, we are faced with a versatile toolkit capable of adapting to the various circumstances in which a particular community may find itself. This versatility also ensures its scalability. Whilst it is true that the toolkit has been designed to respond to the objectives of the SOCIO-BEE project, its consciously sought adaptability makes it possible to be used in other current and future CS projects. The knowledge generated in these first phases and collected in this paper allows us to conclude that truly citizen-based scientific projects must make systematic but not rigid use of methodologies and tools that promote egalitarian participation, non-discrimination, and inclusiveness. This versatile system applied in SOCIO-BEE—and applicable in other CS projects—will allow adaptation to the specificities of each community, to the factors and barriers that in each case encourage or discourage citizen participation in science.

Appendix A: The barriers tool

Principles	A hive.	Potential barriers The hive.	Stage/Phase
1. Human development, autonomy and agency	1.1 Tries to be self-sufficient and to sustain itself through selfgovernment	Once consolidated, continues deeply depending on external financial sources	Consolidation
	1.2 Builds internal and/or external capacities and stimulate learning	Does not establish processes for continuous internal and external capacity building	Development
	1.3 Has as its main objectives social and environmental scientific challenges	Is focussed on direct commercial goals subordinating social and environmental aims	Creation
	1.4 Generates new knowledge to help people transform their practice	Does not transfer the new knowledge generated to those who could use it for transformative actions	Consolidation
2. Reciprocity and co-activity	2.1 Connects people, provides a shared context and enables dialogue	Due to the organization of the projects and/or spaces, it is not enabling internal/external connections	Creation
	2.2 Is governed cooperatively	Has an excessively hierarchical organization, decision-making is concentrated without sufficient transparency	Development

Principles	A hive.	Potential barriers The hive.	Stage/Phase
3. Egalitarian participation, non-discrimination and Inclusiveness	3.1 Allows inclusive participation in multiple stages of the process and experiments 3.2 Has mechanisms to promote equality and reduce the risk of exclusion	Does not have the necessary processes in place to incorporate diversity in all its dimensions at every stage of the experiments or, if it does, does not allow an egalitarian participation	Creation/Development/Consolidation
4. Sustainability	4.1 Uses environmental technologies	Does not think of technology in terms of its ability to monitor, model and conserve the natural environment and resources, and to curb the negative impacts of human involvement	Development
	4.2 Tries to make its activities as circular as possible	Does not close cycles in each of the experiments carried out It does not try to reduce produced waste and pollution and to circulate products and materials Does not cooperate with other geographically close hives in order to reduce pollution and unnecessary use of resources	Development
5. Citizen involvement	5.1 Allows voluntary (dis) association	Has barriers to both entry and exit of participants or does not allow different levels of participation and commitment Neither enables members to be aware of their act of Development participation nor facilitates a deliberate intention of being involved in the experiments	Creation/Development
	5.2 Introduces collaborative processes	Does not apply clear mechanisms for participation in decision-making Spaces don't invite the shared and collective (re)configuration of the hive and/or participants are not encouraged to critically question it	Creation/ Development
	5.3 Helps people organise around purposeful actions	Participation is confined to micro-tasks that prevent the participant from understanding the whole purpose and impact of the action	Creation

Principles	A hive.	Potential barriers The hive.	Stage/Phase
6. Social and environmental impact	6.1 Delivers tangible results, such as scientific outcomes	Neither have a clear definition of the expected outputs, outcomes and impacts of their experiments and actions nor monitor their achievement	Consolidation
	6.2 Captures and diffuses existing knowledge and provides educational outcomes	Does not have a systematic and scientifically rigorous process for the management of knowledge and/or does not design educational activities for the dissemination of the results obtained	Consolidation
	6.3 Measures its social and environmental impact	Does not assess social and environmental value created or destroyed in its experiments because it has not implemented proper mechanisms or there is a lack of resources (time, knowledge, etc) to do so	Consolidation
		In cases in which impacts are measured, such information is not used to (re)align the hive with the rest of its principles	

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Authors and Affiliations

Ekhi Atutxa[1] · Sofia Garcia-Torres[2] · Charalampos Kyfonidis[3] · Dimitrios Karanassos[3] · Evangelos Kopsacheilis[3] · Christina Tsita[3] · Diego Casado-Mansilla[4] · Alexandros Emvoliadis[3] · Georgios Angelis[3] · Diego López-de-Ipiña[4] · Maite Puerta[4] · Anastasios Drosou[3] · Dimitrios Tzovaras[3]

✉ Ekhi Atutxa
ekhi.atutxa@deusto.es

✉ Charalampos Kyfonidis
kyfonidis@iti.gr

Sofia Garcia-Torres
sofiag.torres@deusto.es

Dimitrios Karanassos
dkaranassos@iti.gr

Evangelos Kopsacheilis
ekops@iti.gr

Christina Tsita
tsita@iti.gr

Diego Casado-Mansilla
dcasado@deusto.es

Alexandros Emvoliadis
alemvoliadis@iti.gr

Georgios Angelis
angelisg@iti.gr

Diego López-de-Ipiña
dipina@deusto.es

Maite Puerta
mpuerta004@deusto.es

Anastasios Drosou
drosou@iti.gr

Dimitrios Tzovaras
Dimitrios.Tzovaras@iti.gr

1 Department of Finance and Economics, Deusto Business School, University of Deusto, Unibertsitate Etorb. 24, 48007 Bilbao, Bizkaia, Spain

2 Department of Management, Deusto Business School, University of Deusto, Unibertsitate Etorb. 24, 48007 Bilbao, Bizkaia, Spain

3 Information Technologies Institute, Centre for Research and Technology Hellas, 6th km Harilaou, 57001 Thermi, Thessaloniki, Greece

4 Department of ICT, University of Deusto, Unibertsitate Etorb. 24, 48007 Bilbao, Bizkaia, Spain