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Understanding the role of cities and citizen science in advancing sustainable development goals across Europe: insights from European research framework projects

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This paper examines the potential impact of citizen science on achieving SDGs in cities. The analysis focuses on projects funded through the European Research Framework Programmes that utilize citizen science practices to involve cities and citizens in addressing sustainability issues. We analyzed a total of 44 projects active between 2016 and 2027, encompassing both ongoing and completed projects. Instead of relying solely on existing literature, we utilized a project database called CORDIS to gather project information. This approach allowed us to develop a comprehensive framework by utilizing uniformly classified data from the database, which is not typically available in literature. Using a four-stage framework analysis method, we assessed the projects' thematic areas, goals, types of solution promoted or tested to address sustainability challenges, methodologies employed, and the impacts achieved or expected. Through this analysis, we identified successful collaborations between citizen science and cities, showcasing examples of effective practice where citizens and cities co-created and tested solutions that contribute to SDGs. This highlights the active role that citizens, as participants or citizen scientists, play in the transition toward SDGs. This study focuses on more than 100 European cities that have been involved in EU-funded research projects implementing and planning to conduct citizen science activities, which directly and indirectly link to various SDGs. Our findings reveal that citizen science practices in cities predominantly address SDG3 (Good health and wellbeing), 11 (Sustainable cities and communities), and 13 (Climate action). Cities that engage citizens in co-creating solutions can enhance their capacity to improve quality of life and reduce climate and environmental impacts. Citizen engagement at the city and community levels can bolster efforts toward achieving SDGs and monitoring progress on a city-wide scale. However, to fully integrate citizen science and its contribution to cities in achieving SDGs, further research is needed to align the SDGs formulated at the national level with those at the city level. This entails exploring how citizen science can align with SDGs indicators and the quantification of SDG targets. Such efforts will facilitate the mainstreaming of citizen science and its potential to drive progress toward SDGs in cities.

KEYWORDS

citizen engagement, citizens' observatories, citizen science, living labs, responsible research and innovation, Social Science and Humanities, sustainable development goals, urban sustainability

1. Introduction

Currently, more than half of the world's population (i.e., more than 3.5 billion people) live in cities and that share is projected to rise to 60% (i.e., 5 billion) by 2030, and 70% by 2050 (UN, 2022). All regions of the world are acknowledging the reality of an urban future (Barnett and Parnell, 2016; Kotzeva and Brandmüller, 2016). In China, ∼65% of the total population lived in cities (Statista, 2021). In Latin America and the Caribbean, 79% of the population is living in the cities and in North America this rises to 82%. In Europe, over 75% of the population is already living in cities (Statista, 2022). With a higher concentration of people, jobs and economic activities, urban Europe is now at a crucial junction in time, facing a triple crisis, i.e., the lingering public health crisis created by the COVID-19 pandemic, the socio-economic crisis and deepening socio-economic inequalities and the climate and ecological emergencies (EEA, 2021; Bartonova et al., 2022). To overcome these crises will require cities and citizens to be on the frontline as major drivers and actors to make sustainable transitions to a better future that is inclusive, green, and socio-environmentally just (EU, 2016a,b; EEA, 2021).

Of relevance in this respect is the transformative UN 2030 Sustainable Development Agenda and its Sustainable Development Goals (SDGs) (UN, 2015), and the Urban Agenda for the EU (UAEU) (EU, 2016a,b; European Network of Living Labs, 2022). The theoretical framework behind the SDGs is rooted in the concept of sustainable development (UN, 1987, 2017). It recognizes the interconnectedness of economic, social, and environmental aspects of development and aims to strike a balance between them. The SDGs were adopted by the United Nations in 2015 as a successor to the Millennium Development Goals (MDGs). It provides a comprehensive framework for addressing global challenges and achieving sustainable development by 2030. They consist of 17 goals and 169 targets that cover a wide range of issues, including poverty eradication, health, education, gender equality, clean energy, sustainable cities, climate action, and biodiversity conservation, among others. The theoretical foundation of the SDGs draws from various concepts and theories from various disciplines, including: (i) systems thinking: the SDGs recognize that global challenges are complex and interconnected, requiring a system thinking approach, which means understanding the interdependencies and feedback loops between different goals and targets, as well as considering the impacts of actions in one area on others; (ii) integrated approach: the SDGs emphasize the need for an integrated approach to development that considers the economic, social, and environmental dimensions as interconnected and mutually reinforcing, recognizing that progress in one area can positively or negatively affect progress in others; (iii) equity and social justice: the SDGs are underpinned by principles of equity and social justice, aiming to leave no one behind, emphasizing the importance of addressing inequalities and ensuring that the benefits of development are shared by all, particularly the most vulnerable and marginalized populations; (iv) participatory governance: the SDGs promote inclusive and participatory governance, recognizing the importance of engaging all stakeholders, including governments, civil society, businesses, and citizens, in the decision-making and implementation processes. fostering ownership, collaboration, and collective action; and (v) planetary boundaries: the SDGs acknowledge the finite nature of the Earth's resources and the need to operate within planetary boundaries, recognizing human activities should not exceed the capacity of the Earth to regenerate and sustain natural systems, such as ecosystems and biodiversity.

In SDGs, urban challenges are particularly tackled through SDG11, which aims to "make cities and human settlements inclusive, safe, resilient and sustainable" (UN, 2015). SDG11 and other related SDGs chime well with the UAEU which aims to "promote cooperation between Member States, the EC, and cities to stimulate growth, liveability, and innovation in EU cities to ensure maximum utilization of the growth potential of cities and successfully tackle the social challenges" (EC, 2016; EU, 2016a,b). Many European cities are starting to make progress toward sustainability by planning, adopting, and delivering fundamental changes toward more stable and sustainable conditions, adopting SDGs, and contributing to the UAEU. For example, cities such as London, Stockholm, Milan, Oslo, and other major cities in Norway (e.g., Bergen, Stavanger, Trondheim) have passed legislation for congestion pricing combined with exemptions for electric vehicles to reduce air pollution, and to encourage drivers' environmentally conscious travel (Isaksen and Johansen, 2021). Such actions have significant impact on reducing private car journeys and inducing adoption of electric vehicles, in doing so improving urban air quality (SDG3) and contributing to improved citizen health and wellbeing (SDG3, 11) (UN, 2021).

Besides such top-down actions, there are also bottom-up, citizen-led actions that can contribute to making European cities more sustainable. In fact, for urban issues and policies, it is often the case that citizens themselves know what needs to be improved. Therefore, it is essential to engage citizens in the transition toward sustainability, which is also acknowledged in SDG11, target 11.3 "By 2030, enhance inclusive and sustainable urbanization and capacity for participatory, integrated and sustainable human settlement planning and management in all countries," and SDG16, target 16.7 "Ensure responsive, inclusive, participatory, and representative decision-making at all levels. Many cities are increasingly using participatory methods to engage citizens and other stakeholders in the co-creation of more sustainable solutions [e.g., nature-based solutions (NBS)] (Liu et al., 2021a; Ottaviani Aalmo et al., 2022). Citizen science (CS) is one such approach, or suite of approaches (Liu et al., 2014; Veeckman and Temmerman, 2021; EC, 2022a; Woods et al., 2022). In Europe and beyond, there is a growing recognition of the role CS can play in contributing to the UN SDG Agenda (West and Pateman, 2017; Shulla et al., 2020; Wuebben et al., 2020; Dörler et al., 2021; Liu et al., 2021b). This includes the potential role citizen-generated data can play in filling spatial, temporal and/or socio-demographic gaps in official datasets, as well as enriching and providing a deeper understanding of these datasets (Fritz et al., 2019; Campbell et al., 2020; Fraisl et al., 2020; de Sherbinin et al., 2021). It also covers the potential role CS can play in localizing the SDGs, by identifying, understanding, and tackling sustainability challenges at a local level, including city level (Pateman et al., 2021a; Skarzauskiene and Mačiulienė, 2021). Finally, there is potentially a huge opportunity for CS approaches to generate a greater understanding of sustainability challenges, to co-create solutions to these challenges (e.g., technical innovations or improvements to public services), or through the co-benefits of CS such as raising awareness of sustainability challenges, education, community engagement, or building multi-stakeholder partnerships (Lämmerhirt et al., 2018; Parkinson et al., 2022). More specifically, West and Pateman (2017) published a discussion brief on how CS could contribute to the SDGs. Fritz et al. (2019) identified gaps in traditional data sources for monitoring and implementing the SDGs and showed the potential of CS to fill these gaps. Fraisl et al. (2020) showed in a systematic review that CS is already contributing to five indicators and could contribute to 76 more indicators. Pateman et al. (2021a) carried out a systematic review of CS contributions to the SDGs in low- and middle-income country cities. Parkinson et al. (2022) developed questionnaires that can be used by CS projects to self-assess their impacts toward the SDGs. Woods et al. (2022) pointed out that the increased data quality and quantity through the networks of citizens observatories can be used to monitor SDGs indicators. Limited research has been conducted on the development of methodologies to assess the contribution of CS projects to the monitoring or implementation of the SDGs. Liu et al. (2020) analyzed institutional projects including CS projects" contribution to the SDGs. Sprinks et al. (2021) took a qualitative approach and interviewed 11 CS project coordinators to explore how they see their projects' impacts and relations to the SDGs and their indicators. Another paper on an analysis of CS and its role in environmental policy making, and the connection toward SDGs in Europe provided an overview of projects until February 6th, 2018 (Bio Innovation service, 2018). However, since the publication of these studies, many projects that use CS approaches have been funded by different funding schemes (e.g., Urban Innovation Actions, H2020 Green Deal call, Horizon Europe), and CS is being increasingly recognized and applied as a method to support environmental policy making and implementation (Radicchi et al., 2021). Despite these methodological advances, there remains a scarcity of studies assessing whether CS fully realize its potential in contributing to the SDGs.

In this paper, we are studying the potential impact of CS on achieving SDGs at city level. Our research questions can be formulated as "How can we assess the potential of CS for cities to achieve SDGs, what is the potential for CS to contribute to achieving SDGs in cities, and what are the current best practices, challenges and limitations?." We aim to gather evidence from projects funded by the European Research Framework that use CS as a method or as a study object and focus on sustainability issues in cities. We use CS as an umbrella term for a broad variety of citizen participation and engagement approaches within the R&I process, but primarily those for democratization of science and inclusion of citizens for data collection and analysis. We analyse available project information including publications and reports to investigate how cities, and in particular their citizens, are being involved in improving and monitoring progress toward the EU's sustainability targets. Our synthesis assessment of selected completed and ongoing projects allows us to understand the contribution cities and their citizens are currently making. To do so, we (1) map the multi-dimensional scope for cities and citizens to contribute to implementing the certain SDGs in European cities; (2) screen and identify projects to analyse the key roles that cities and citizens can play toward specific SDGs implementation; and (3) identify challenges for cities and citizens in these contexts. We suggest ways forward to strengthen and make visible citizens' and cities' role to support the SDGs, and the necessaries of downscaling SDGs to city level. Thus, this paper provides an overview of practices of how CS and citizens are contributing to achieving SDGs in cities, as well as challenges and barriers for successful collaboration between citizens and cities.

2. Materials and methods

2.1. Overall framework for assessing citizens' and cities' contribution to SDGs

Instead of conducting a traditional literature review, our assessment of the theoretical framework behind the contribution of citizens and cities to the SDGs was based on information extracted from a comprehensive project database of EU-funded collaborative research projects. The chosen database for this analysis is the CORDIS database, which serves as the primary public repository and portal of the European Commission (EC) for disseminating information on all EU-funded projects and their outcomes, including scientific publications in a broad sense (EC, 2022b). The CORDIS database offers a controlled environment for research projects with defined protocols, ensuring the provision of unified and verified information. This database served as the foundation for developing a framework and performing the analysis, which can then be scaled up to other types of projects. The results of this assessment can also inform the information needs for assessing SDGs contributions.

To conduct our analysis, we developed a four-stage framework analysis method, as depicted in Figure 1. This methodology enables a systematic and structured approach to examine the projects in a rigorous manner. The first stage involves an initial search of projects in the CORDIS database, which serves as the European Commission (EC)'s primary public repository and portal to disseminate information on all EU-funded projects and their results, including scientific publications in the broadest sense (EC, 2022b). The data published in the CORDIS database is verified before publishing, ensuring its reliability and accuracy.

In the second stage, we focus on the identification of initial projects that warrant further review. We accomplish this by assessing the summary descriptions of projects obtained from the CORDIS databases. During this stage, we apply specific inclusion and exclusion criteria to ensure the selection of projects that are most relevant to our analysis. The criteria applied at this stage encompass the presence and application of CS methodologies, the expected contribution of the projects to the SDGs, and the focus on cities.

In the third and four stages, we delve deeper into the selected projects and subject them to a comprehensive evaluation based on various criteria. These criteria cover different aspects of the projects, including their basic information (e.g., duration, coordinator, participants, type of project) (Section 3.1), geographic scope (e.g., local, community, city, regional, multiscale, international) (Section 3.2), thematic scope (e.g., subject areas, policy application area) (Section 3.3), participation scope (e.g.,

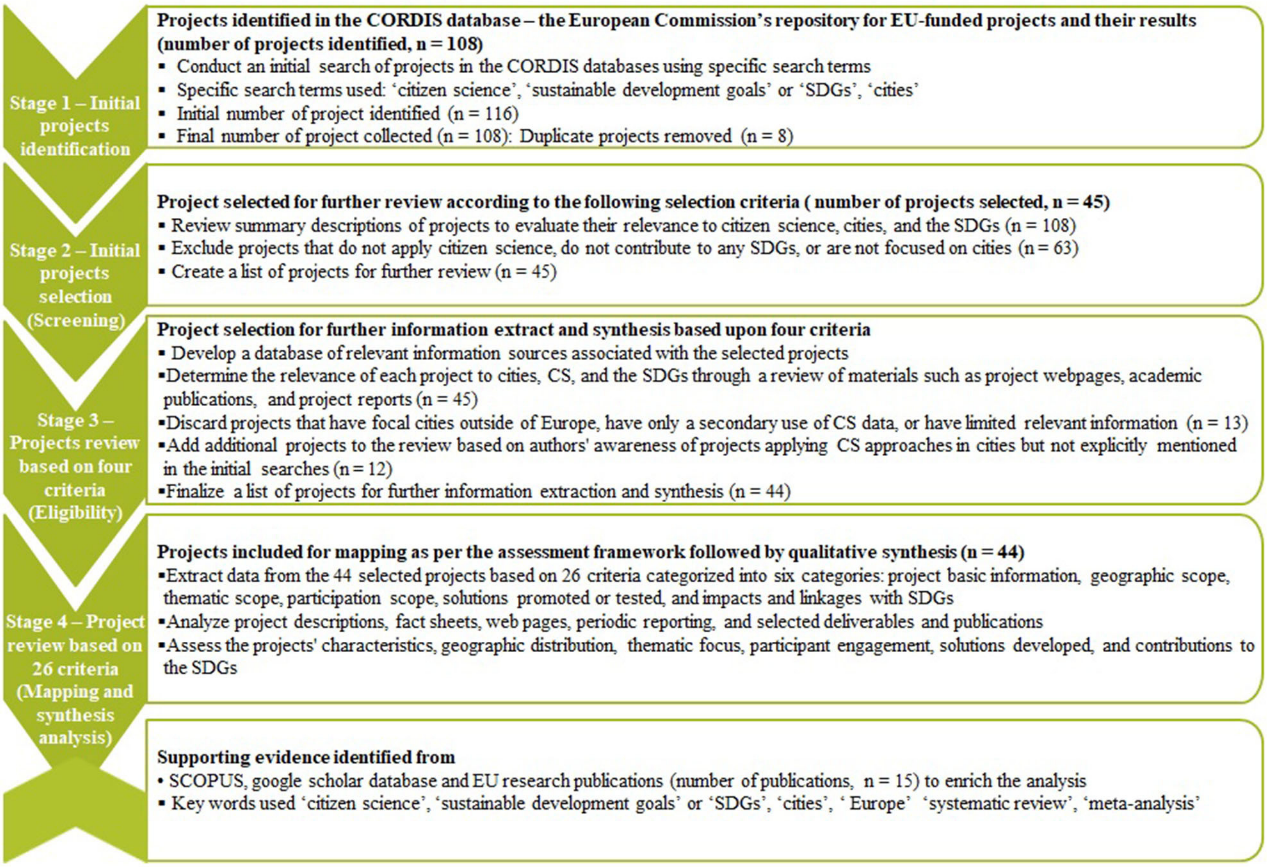

FIGURE 1
Selection process for identifying relevant projects funded by EU's Framework Programs for research and key publications.

level of engagement; type of participants; numbers of participants; engagement stage in knowledge production, participation in communication and dissemination) (Section 3.2), solution developed and/or implemented (e.g., solutions and/or actions created and/or tested for improving environmental quality) (Section 3.3), and impacts and their linkages to the SDGs (Section 3.4). We draw upon established frameworks and methodologies such as Ritchie and Spencer (2002), Oliver et al. (2008), Alvarado et al. (2020), Chan et al. (2021), and Morell et al. (2021) to guide our analysis and ensure its rigor and comprehensiveness (Figure 1).

2.2. First stage review—initial projects identification

Our focus in this stage in on projects funded under the European Research Framework. On 14th March 2022, we conducted an initial search of projects in the CORDIS. We used the following search terms: "citizen science" and "sustainable development goals" or "SDG"; "citizen science" and "cities"; and "cities" and "SDGs" or "sustainable development goals." These searches yielded14, 58 and 44 projects, respectively. After removing duplicates, we reviewed the summary descriptions available on CORDIS for 108 projects funded between 2010 and 2027, ensuring a broad temporal coverage to capture relevant initiatives.

2.3. Second stage review—initial projects review

In this stage, we thoroughly evaluate the identified 108 projects based on their relevance to CS, cities, and the SDGs. A comprehensive assessment is conducted by reviewing the project summary and objectives, applying specific inclusion and exclusion criteria. Through this process, we exclude 63 projects that (1) do not apply CS approaches; (2) projects whose outputs are not expected to contribute to any SDGs; and (3) projects that are not primarily focused on cities. By applying these criteria, we arrive at a refined list of 45 projects (running between 2016 and 2027) that demonstrate significant alignment with the objectives of our analysis. This list forms the basis for further review and analysis in subsequent stages (Figure 1).

2.4. Third stage review—projects selection based on additional criteria

In this stage, we undertake a meticulous review of the selected projects, expanding our evaluation to include additional criteria. We developed a database of relevant information sources associated with the 45 projects identified in the previous stage. To assess the relevance of each project to cities, CS and the SDGs, we thoroughly examine materials including projects webpages, academic publications, results in brief, and published project reports. This resulted in 13 projects being discarded based on the following criteria: (1) focal cities were outside of Europe; (2) there was only a secondary use of CS data (e.g., the project used data generated by CS outside the project activities); (3) there was only limited relevant information provided.

During this review, we apply additional criteria to identify projects that may have been missed in the initial selection. We account for projects that apply CS approaches in cities but may not have explicit keywords such as "citizen science," "cities," or "SDGs" in their CORDIS project description. By leveraging our awareness of such projects, we ensure a more comprehensive and accurate representation of initiatives that contribute to our analysis objectives. The inclusion of these additional 12 projects enhances the richness and diversity of our dataset, leading to more robust conclusions.

Ultimately, This thorough review process resulted in a final list of 44 projects that meet the selection criteria and are deemed relevant to our analysis objectives. For a more detailed understanding of these projects, additional information can be found in the Supplementary material, providing further insights into their implementation and characteristics.

2.5. Fourth stage review—data extraction based on comprehensive criteria

In the final stage of the review process, we extracted and analyzed data from the 44 selected projects based on 26 criteria organized into six categories (Figure 2). These criteria enable a comprehensive assessment of the projects and provide a deeper understanding of their key characteristics, geographic distribution, thematic focus, participant engagement, solutions developed, and contributions to the SDGs. This process involved analyzing project descriptions, fact sheets, web pages, periodic reporting, and results in terms of selected relevant deliverables and publications (see Supplementary material for review results including key criteria).

The first category, Project Basic Information, encompasses details such as the "project lead and consortium members" (Section 3.1.1), and "project types" (Section 3.1.2). The aim of assessing project lead and consortium members is to identify the key drivers of and stakeholders in sustainability-related CS in cities. We extracted information relating to the lead project partner and organizations involved (Section 3.1.1). To categorize organizations, we adopted the categories used by the European Research Framework (EC, 2022c) which includes: (a) universities (higher or second education establishment); (b) research organizations; (c) private for non-profit entities (SMEs and industries); (d) local governments (public bodies); and (e) other entities (NGOs, community-based organizations). Additionally, we examined the project types to identify the main types of projects and differences between these in terms of projects' CS activities and expected outputs (Section 3.1.2). To do so, the type of projects was categorized based on the EC's collaborative research funding scheme (EC, 2019, 2021). We distinguished between four projects categories: (a) Research and innovation action (RIA)—In H2020 and Horizon Europe, RIA aiming primarily to produce research results and establish new knowledge; (b) Innovation action (IA)—In H2020 and Horizon Europe, IA focusing on bringing research results nearer practice by producing plans and arrangements or designs for new, altered or improved products, processes or services; (c) coordination and support action (CSA) aiming to bring together research results from a relevant body of research through collaboration of a network of actors, contributing to the objectives of Horizon Europe (i.e., dissemination, awareness-raising and communication, networking, coordination, etc.) but excluding R&I activities; and (d) collaborative projects (CP): Prior to the Horizon programs, i.e., in EU Research Framework Programs FP6 and FP7, collaborative research which do not distinguish between the project types, was often carried out as a CP with general could serve similar purposes as either RIA or IA. RIA and IA introduced in H2020.

The second category, the Geographic Scope allow us to assess the geographic scale of projects (Section 3.2). We looked at whether they were taking place at a (i) neighborhood, (ii) city, (iii) region, and (iv) national scales. We also wanted to determine the geographic distribution of projects across Europe and so recorded the cities in which projects were active and calculated the total number of projects in each of these cities. This information enables us to identify patterns and concentrations of projects in specific locations (Section 3.2).

The third category, the Thematic Scope explores the main topic areas addressed by the CS approaches (Section 3.3). We first extracted the focal topic(s) of the projects, then grouped these projects into the following overarching themes, including: (i) environmental pollution (e.g., air, water, odor, sound/noise, light) (SDG3, 6, 11, 12, 15); (ii) environmental management (e.g., solid waste/food waste, water, wastewater) (SDG6, 11, 12); (iii) disaster management (e.g., flood, soil erosion, extreme weather events, Disaster Risk Reduction (DRR), resilience) (SDG2, 11, 13); (iv) environmental resource monitoring (e.g., biomass, land, soil, land use and land cover change, biodiversity) (SDG14, 15); (v) climate change (e.g., energy efficiency, net zero/zero carbon measures, GHGs emissions, climate change adaptation and mitigation) (SDG13, 7); and (vi) Cross-cutting/others themes (e.g., projects that used several umbrella terms to cover multiple themes like urban nexus, circular economy, food security; also projects investigated cross-cutting areas that different themes can have impacts on like mobility, health outcomes and related perceptions and so on; and projects that were harder to pin down to a boarder domain). By categorizing the projects according to their thematic focus, we gain a comprehensive understanding of the diverse sustainability challenges they aim to address.

The fourth category, the Participation Scope delves into various aspects of participant groups engagement (Section 3.2). Specifically, it includes: (i) Citizens involved: CS faces challenges in the diversity of participants it attracts (Pateman et al., 2021b) and so to assess the extent to which projects are seeking to engage diverse audiences, we looked for and extracted evidence of any target groups identified by projects including groups who are not the "usual suspects" in CS projects, e.g., marginalized social groups like elderly, minority ethnic communities, and disabled people (Section 3.2.1); (ii) Level

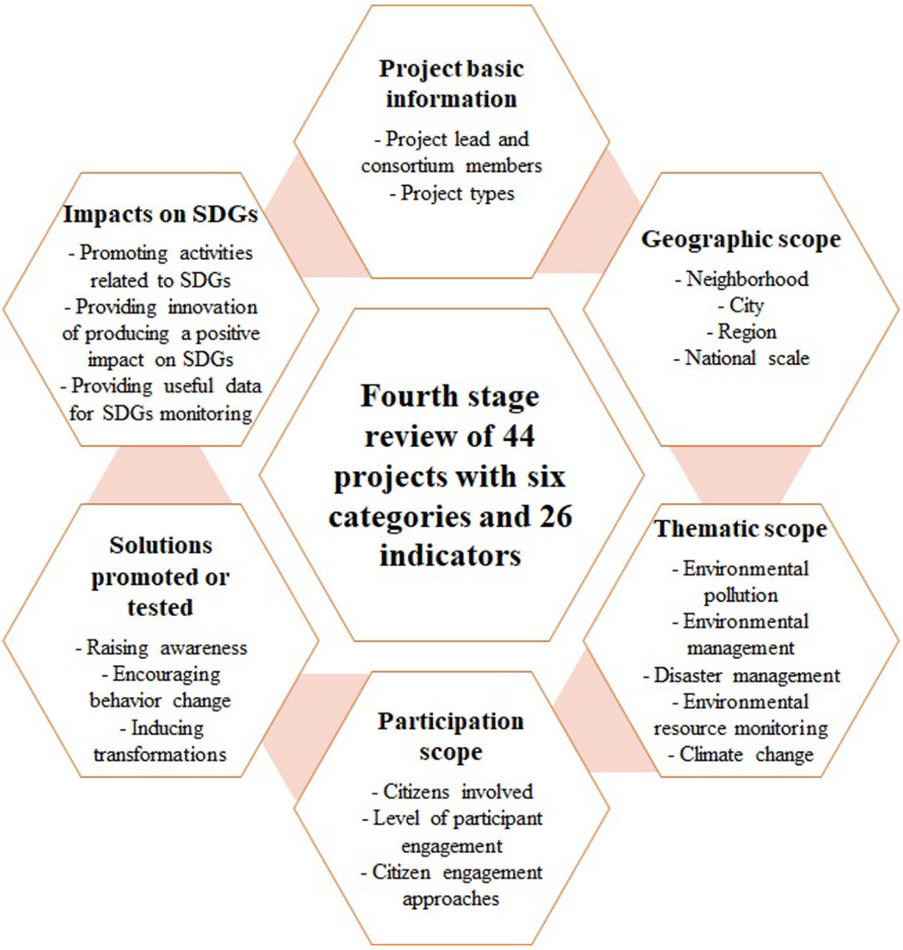

FIGURE 2
Selection and review process with 26 criteria and six categories.

of participant engagement (Section 3.2.2): There are different level of participant engagement defined in CS activities (Arnstein, 1969; Haklay, 2013; DITOs project consortium, 2016-2019; Eitzel et al., 2017; Alvarado et al., 2020; Haklay et al., 2021; Skarlatidou and Haklay, 2021). To get an overview of the level of participant engagement by projects and its connection with projects impact (Section 3.4), we adopted the level of participant engagement defined by Bonney et al. (2009) and Shirk et al. (2012). Bonney et al. (2009) and Shirk et al. (2012) considered different forms of citizen engagement in science and knowledge production and define different level of engagement as contributory (i.e., citizens are solely or primarily involved in data collection phases), collaborative (i.e., citizens tend to have deeper involvement through their engagement in data analysis and dissemination phases in addition to data collection), co-creation (i.e., by involving citizens early in the design of the research phase and thus citizens get to participate in most phases of research and knowledge production), collegiate (i.e., citizens are usually in charge of designing and delivering the research and ask researchers for input and when they deem fit to bring them in), and contractual (i.e., professional researchers are asked or contracted to conduct a specific scientific investigation and report on the results to the citizens/community group); and (iii) Citizen engagement approaches: Different engagement approaches have been developed either for crowdsourcing or as a tool or instrument for enhancing data coverage or as a movement of social capacity that enhances citizens' skills and social capacity to produce data and knowledge through project activities. These include, for example, Living Labs, Science Cafes, and citizen cyber labs. To obtain an overview of the types of public engagement approaches applied within European CS projects, we extracted information relating to the approaches of citizen engagement used by projects (Section 3.2.3).

The fifth category, the Solutions Promoted or Tested provides an understanding of the types of solutions (i.e., the means of solving cities' sustainability issues) developed or tested by CS projects to address sustainability challenges (Section 3.3). We grouped these solutions based upon their purposes into three categories, including: (i) raising awareness (e.g., awareness campaigns, engaging citizens in events such as Clean Air Day); (ii) encouraging behavior change (e.g., citizen involvement in exposure reduction programs providing information about less polluted travel routes and times of day); and (iii) inducing transformations (e.g., harvesting and reusing rainwater; using NBS and green infrastructure; optimizing waste collection system, etc.) (Section 3.3). This categorization allows us to identify the specific means through which the projects aim to achieve their sustainability objectives.

Finally, the six categories, the Impacts and Linkages with SDGs assess the overall impacts of the CS projects and their connections to the SDGs. We adopted an impact assessment methodology that, considers scientific, social, economic, political, and environmental dimensions (Section 3.4). The methodology considers more than 20 sub-dimensions and builds on state-of-the-art methods such as Kieslinger et al. (2017) and Passani et al. (2020). For assessing projects' contributions to the SDGs, we also adopted the criteria developed by Bio Innovation service (2018) and examined the projects' contributions both to direct and indirect impacts on SDGs. Direct impacts arise when project objectives and/or thematic areas are explicitly related to a specific SDG or several SDGs. Indirect impact arises when project objectives and/or expected outputs are potentially related to a specific SDG or several SDGs. In this study, we are interested in understanding if the analyzed projects provide inputs to one or more of the SDGs at the city level, by: (i) promoting activities related to them; (ii) providing innovation capable of producing a positive impact on SDG achievements; and (iii) providing useful data for SDGs monitoring (Section 3.4). This analysis provides valuable insights into how the projects align with the SDGs and their potential contributions at the city level.

By analyzing the projects based on these comprehensive criteria, we gained insights into their key characteristics, geographic distribution, thematic focus, participant engagement, solutions developed, and contributions to the SDGs. This robust analysis forms the foundation for drawing meaningful conclusions and deriving insights to support sustainable development efforts.

3. Results

3.1. Who carries out the projects and what are their main types?

3.1.1. Project leads and consortium members

Most of the projects were led by universities (19 projects, 43%) or by research organizations (16 projects, 36%). Few were by local governments (3 projects, 7%), SMEs (3 projects, 7%) or other types of organization-led (e.g., NGOs) (3 projects, 7%) projects (Figure 3A). The projects led by public sectors, SMEs and NGOs were under-represented in our study since most of them may not be funded by the European Research Framework Programs. Within the 44 projects, 12 are led from Spain, and 6 are led from Barcelona. This might be one of the reasons why Barcelona and Spain stand out for the high number of CS activities (Section 3.2). Regarding consortium members, most projects (41 projects, 93%) are multi- and inter-disciplinary consortia, with partners in disciplines covering the required roles and areas relevant for the project, including universities, research organizations, SMEs or industries, public sectors, and others such as NGOs, etc.

3.1.2. Project types

Most of the identified projects were RIA (17 projects, 39%) or IA (14 projects, 32%), followed by CSA (8 projects, 18%) and CP (5 projects, 11%) (Figure 3B). For the 17 RIA projects, most focused on involving citizens in monitoring environmental pollution (e.g., air, water, soil) or measuring environmental resources (e.g., biodiversity) by providing ICT tools or co-developing such tools together with the participants. For the 14 IA projects, in addition to involving citizens in activities like the RIA projects, most projects tested engagement and/or technical innovations in practice (e.g., co-creation and implementation of living labs, establishing CS hubs or FabLabs, developing virtual citizen platforms). For the 8 CSA projects, the focus was to create an ecosystem of CS that can systematically address the identified challenges and support CS to become more mainstream in terms of engagement, observatories, data interoperability, impact, fields of application and sustainability. The 5 CP projects were the projects funded under the EU FP7 call "Developing community-based environmental monitoring and information systems using innovative and novel earth observation applications. Projects with research and innovation focus dominate, which illustrates the EU giving priority to activities aiming to establish new knowledge and explore the feasibility of a new or improved technology, product, process, service, or solution, including prototyping, testing, demonstrating, piloting, large-scale product validation and market replication in the fields of citizens" and cities' contribution to the SDGs.

3.1.3. Geographic scope

The 44 projects varied widely in geographical scope, from neighborhood-based activities to city scale (24 projects, 55%), regional (4 projects, 9%), national (2 projects, 5%) and international (12 projects, 27%). In total, 108 cities, 8 regions and 32 countries in Europe implemented or made plans to conduct CS activities which directly and/or indirectly link to the SDGs (Figure 4A). Within these 108 cities, Barcelona (10), Amsterdam (7), Berlin (7), Ljubljana (4) and Oslo (4) are those cities with a high number of CS projects represented in the inventory (Figure 4B). At country level, Spain (29), Germany (21), Italy (16), Romania (15), Netherlands (14), UK (11) and France (10) are the countries with the greatest number of CS activities. It is worth mentioning that Spain and Romania stand out as two of the countries with numerous diverse CS activities in our inventory. Spain has made a significant endeavor by creating a CS Observatory (Lostal et al., 2017), toward a strengthening trend for growing development of CS in a decentralized manner, with multiple educational, social, and economic impacts (Lostal et al., 2017; Vohland et al., 2021a,b). In Romania, CS has made progress, including a higher rate of cooperation between academia, SMEs and NGOs, a great popularization of the practice, and the amplification of CS projects (Kruk, 2022).

3.1.4. Thematic scope

Projects had divergent thematic topics. Environmental pollution monitoring (e.g., air, water, odor, noise/sound, light) had the greatest number of projects (11 projects, 26%), followed by environmental resource monitoring (e.g., biodiversity, biomass,

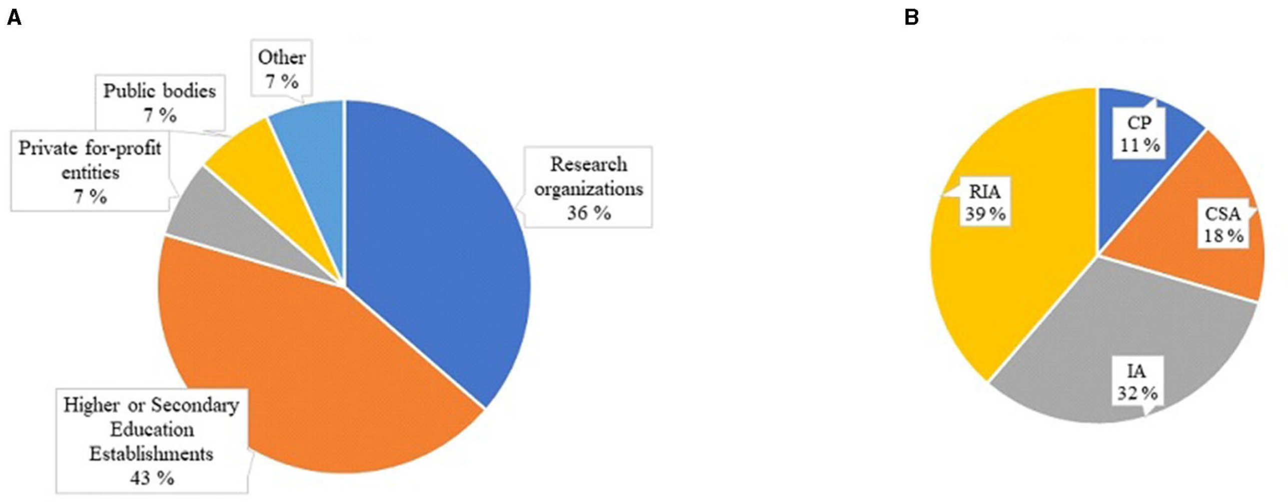

FIGURE 3
Characteristics of citizen science projects. **(A)** Lead organization, **(B)** project type.

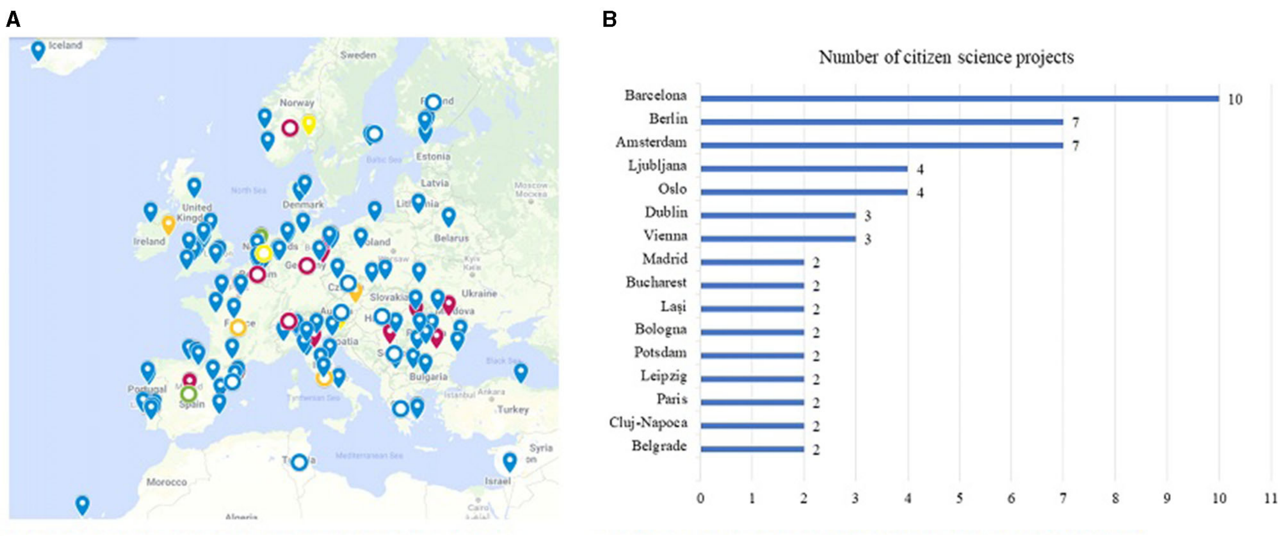

FIGURE 4
Geographical scope and distribution of citizen science activities in the inventory at city and regional levels. **(A)** Geographical scope of citizen science projects at city and regional levels: Blue–1 project; Red–2 projects; Orange–3 projects; Yellow–4 projects; Green–5 projects; Purple—More than 5 projects; **(B)** cities with multiple citizen science activities in the inventory.

land cover and land use, soil) (9 projects, 21%), and those belonging to the cross-cutting topics (e.g., urban nexus, circular economy, food security, mobility, health and wellbeing, and various perceptions) 9 projects, 21%). There were 5 projects (12%) that focusing on climate change (e.g., energy efficiency, net zero/zero carbon measures, GHGs emissions, climate change adaptation and mitigation), 5 projects (12%) that were on environmental management (e.g., solid waste/food waste, water, wastewater) (12%), and 3 projects on disaster management (e.g., flooding, soil erosion, extreme weather events, DRR, resilience) (7%) (Figure 5).

3.2. Participation scope

3.2.1. The citizens involved

Significant number of projects (20 projects, 45%) did not target any particular social groups but considered citizens in general. 7 projects (16%) considered citizens as part of the quadruple or triple helix stakeholders (i.e., involving participants from all members of society, including government/policy, private/industry, civil society/citizen groups and researchers/academic sectors). We found 13 projects (30%) which targeted particular social groups (e.g., policymakers, farmers, food start-ups, doctors with experience

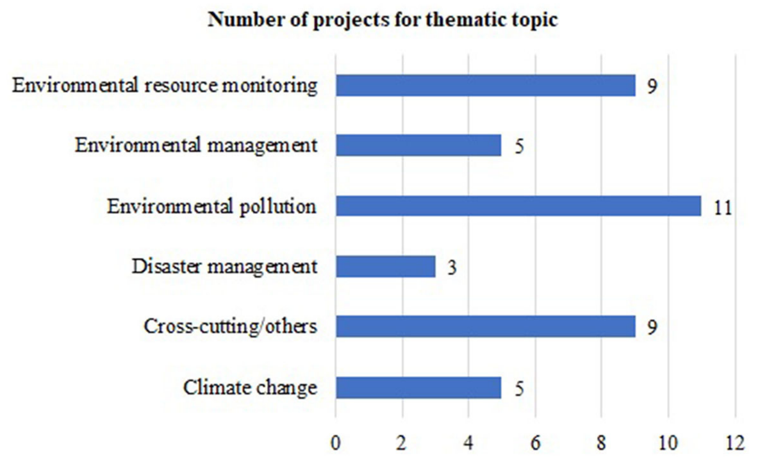

FIGURE 5
Thematic coverage of selected projects—main topics addressed.

of mental health, youth, patients suffering from asthma and allergy disease) and 4 projects (9%) on marginalized communities (e.g., people not working nor studying, people living in poor conditions in highly contaminated areas, and migrants and refugees) (Figure 6). The projects that required engagement of particular social groups are mostly topic-oriented, e.g., project STEM4youth provided a birds-eye view of STEM disciplines and job characteristics associated with these disciplines to help young people in taking conscious decisions on their future (STEM4youth consortium, 2016-2018). Also, the projects that specially targeted marginal social groups are projects which were particularly promoting citizen social science for collective action [e.g., CoAct (Tauginienė et al., 2020; CoAct consortium, 2020-2022)], participatory innovation/responsible research and innovation (RRI) and gender equity in science (e.g., InSPIRES, DNOSES, DiTOS, WeObserve). Regarding the number of citizen engagements, 25 projects did not provide any information or were not able to provide any number yet. This is especially true for ongoing projects (19 out of 44) (see Supplementary material). For the remaining 19 projects (43%), varying numbers of citizens were engaged in different CS activities, e.g., from less than 100 to more than 3 million (DITOs project consortium, 2016-2019).

3.2.2. Level of citizen engagement

In the project inventory, there were 7 projects (16%) that used contributory or crowdsourcing forms of citizen engagement, 3 projects (7%) that were collaborative and 19 projects (44%) involved citizens in the co-creation of various activities including co-designing observatories or other digital platforms, 14 projects (33%) that adopted either two (contributory, collaborative) or three forms of citizen engagement (contributory, collaborative, and co-creation), within single CS activity. 1 project that did not address any level of citizen engagement. No projects that have used or plan to apply collegial or contractual forms of citizen engagement (Figure 7).

3.2.3. Citizen engagement approaches

Most of the projects we identified had applied some form of public engagement in science activities (36 projects, 82%), except 8 CSA projects which by their nature were not doing engagement directly. Engagement approaches included Science Cafes (e.g., InSPIRES project), co-design workshops (e.g., CLEARING HOUSE), CS labs (e.g., CompAir), CS hubs (e.g., AURORA), citizen cyber labs or virtual citizen platforms (e.g., CROWD4SDG), CS festivals (e.g., CS-SDG) and social awareness campaigns and education actions through games and apps in schools (e.g., Waste4Think). Some projects (e.g., DITOS) used several different platforms, including interactive traveling exhibitions, conferences and seminars, gaming competitions and online engagement activities, science cafes and public screenings, and DIY and Doing It Together (DIT) workshops. As far as methods for citizen engagement and participation in R&I are concerned, LLs were common within the projects in inventory. We found LL approaches applied in different shapes and forms (e.g., in the PLUS project for policy design; the FabLabs project for circular products; and services design in the REFLOW project) and LLs that had been used for all levels of engagement described above (Section 3.2.2). When applied comprehensively, it effectively allows co-creation of knowledge and research within the whole project cycle, and the co-design of necessary toolkits for research data gathering, their communication and dissemination.

3.3. Key solutions promoted or tested to address sustainability challenges

Within 44 projects, through collaborative processes, 14 projects (32%) have involved citizens and other stakeholders to co-create, test and experiment with different solutions for improving environmental quality, health, and wellbeing. An example of an awareness raising solution is the iSCAPE project's LL established in Guildford as "a portable, insightful, and user-interactive platform

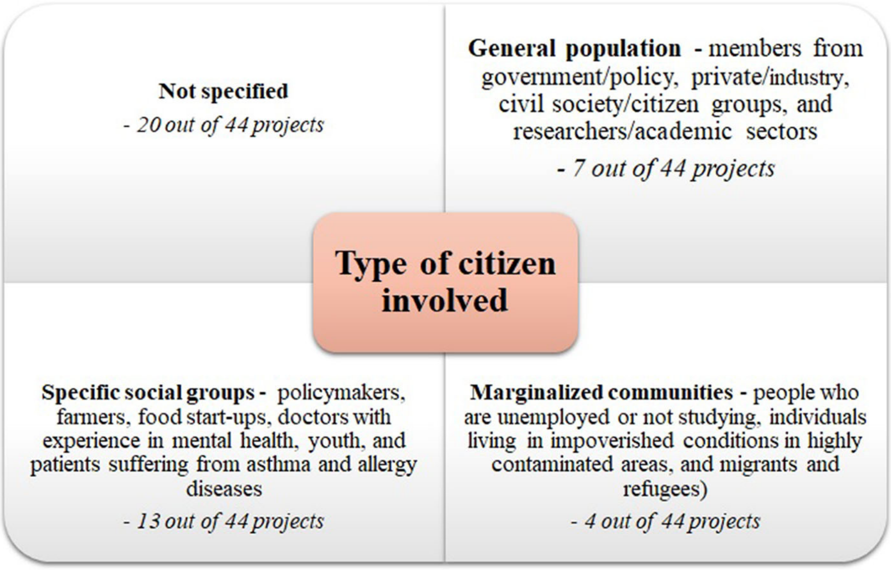

FIGURE 6
Categorization of projects and types of citizens—distribution of projects across four citizen types in the 44 reviewed projects.

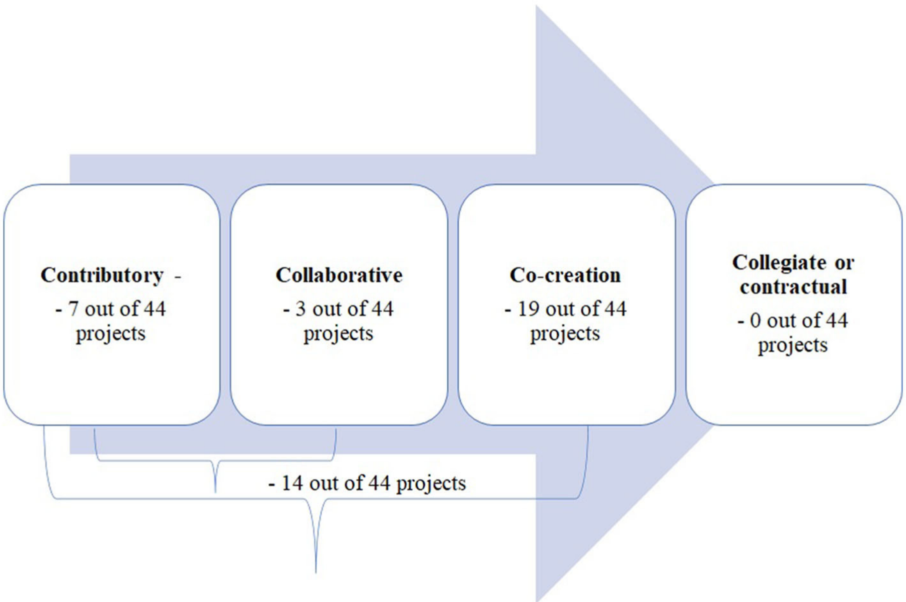

FIGURE 7
Participant engagement levels—distribution of projects across four levels of participant engagement in the 44 reviewed projects.

for raising citizens' awareness of air pollution issues in their neighborhood and the use of green infrastructural interventions (such as trees and hedges) to combat pollution exposure, thereby improving the community's health and wellbeing" (iSCAPE consortium, 2016-2019). Several approaches have been tested or promoted for citizens' behavioral change purposes. For example, in the AURORA project, interventions were planned to modify citizens' energy-related behaviors toward more climate-neutral impacts while fostering energy-savings through hands-on activities at individual and collective levels (AURORA consortium, 2021-2025). In the SOCIO-BEE project, emerging technologies and playful interactions are planned to engage citizens to encourage behavior change through experimentation, better monitoring, and observation of the environment (SOCIO-BEE consortium, 2021-2024). For transformative solutions, three projects (iSCAPE, CLEARING HOUSE, TeRRIFICA) have engaged citizens in the development of multi-purpose NBS including reducing air, water, and noise pollution, regulating water flows and mitigating

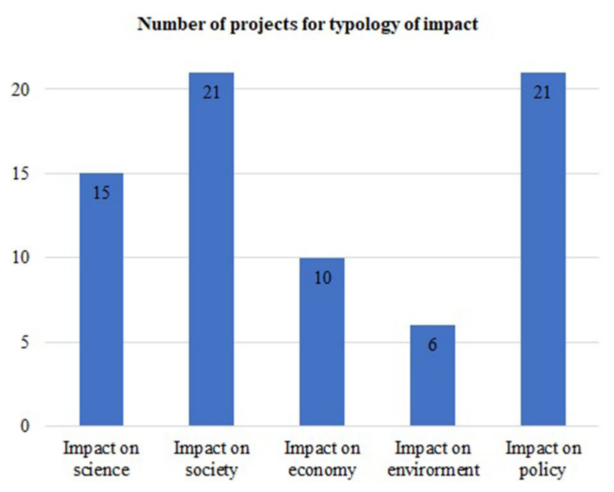

FIGURE 8
Primary areas of impact reported by projects in the inventory.

flooding. One project (WASTE4think) has engaged citizens, students, and waste management companies in the pilots of implementing collective actions for waste collection (Waste4Think, 2016-2020).

3.4. Impacts and linkages with SDGs

With reference to the impacts achieved by the observed projects, we were able to consider those of 28 projects. For the remaining ones, information about impact was not available or was not sufficient, this is especially true for ongoing projects (19 out of 44). Of these 28 projects, 15 reached scientific impacts in terms of peer-reviewed publications or new datasets made available to the scientific community; 21 reached social impacts, often in terms of positive impacts on learnings, behavioral change, and community empowerment; 10 mentioned economic impacts such as the development of new or more sustainable business models, attraction of additional funds, impact on employment or cost savings. Six projects reached environmental impacts, which are strictly related to the topic covered by the projects, such as air quality improvements or food waste reduction. 21 projects mentioned political impacts, often related to the development and promotion of recommendations or action plans, but in some cases the development of new or improved policies or regulations is observed too (see Figure 8).

We have observed the capability of projects to reach and report on their scientific, social, economic, environmental, and political impacts. Some of these impacts and the outputs can also have an impact on SDGs at city level. First, it is important to notice that, out of 44 projects analyzed, only 10 projects mentioned the SDGs in a direct way. Out of these 10 projects, only 4 projects (i.e., ACTION, Compare, CROWD4SDGs and Terrifica) identified the precise SDGs they expect an impact on. This, of course, does not mean that other of the projects considered do not contribute to the SDGs, but it shows that the analysis of projects' impacts on SDGs is not a widespread practice. This could be related to the fact that this kind of analysis was not explicitly required in the application form for EU H2020 projects, while it has been introduced in the H2020 European Green Deal and in Horizon Europe calls. A broader dissemination of the relevance the EU-funded research projects for work toward SDGs could increase the use of project results.

Considering the projects that address SDGs both directly and indirectly, we found out that at least 30 out 44 projects do address SDGs. At thematic level, the most represented SDGs are: SDG3—Good health and wellbeing, SDG11—Sustainable cities and communities and SDG13—Climate action. They are addressed, at least at thematic level by, respectively 16, 16 and 12 projects. All the SDGs are addressed by at least one project except for SDG 1—No poverty (see Figure 9). No project in fact has addressed its potential of a contribution on the level of the individual SDG targets and indicators.

Considering now the projects that contribute to SDGs by generating innovations (including those at policy level) capable of producing a positive impact on SDG achievements at a city level and those providing useful data for SDGs monitoring, a deeper analysis would be needed. However, from the analysis carried out so far it is possible to say that at least 8 projects delivered innovations, operative solutions or action plans that could be useful for achieving one or more of the SDGs' targets and 11 projects should be better analyzed as potential providers of data usable for monitoring city progresses toward SDGs targets.

4. Discussion

4.1. Scope for cities and citizens to contribute to implementing the certain SDGs in European cities

This study shows that more than 100 European cities have been involved in EU-funded research projects implementing and/or planning to conduct CS activities which directly and/or indirectly link to various SDGs. Within these cities, Barcelona, Amsterdam, Berlin, Ljubljana, and Oslo are cities with a high number of citizen engagement activities directly connected to research. An important example of a successful integration of CS into various urban processes is Barcelona. Barcelona is recognized as a hub of innovation (technological and social) and the interest of the City of Barcelona and regional authorities for innovation is testified by dedicated investments and policies. The early emphasis on CS by the City of Barcelona and the systematic collaboration of the city and academic and non-academic organizations are likely to be behind the high numbers of CS activities in Barcelona compared with other cities in Europe. In particular, the city of Barcelona is active and has a dedicated department which is responsible for CS activities. There is an ecosystem of players that collaborates and supports CS activities. This includes universities and research centers, but also innovation spaces such as FabLabs. FabLab Barcelona was the first funded network in Europe already in 2007 (FabLab Barcelona, 2022).

The SDGs that are addressed frequently by the CS activities are SDG3, SDG11 and SDG13, but other connecting SDGs are also found for an interesting proportion of the projects. This was a

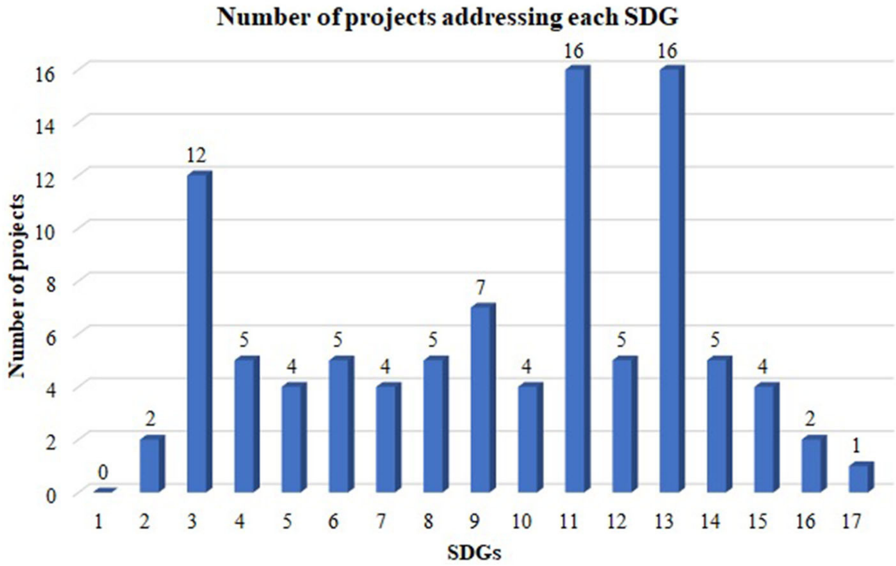

FIGURE 9
Addressing sustainable development goals at the thematic level: analysis of examined projects.

similar pattern identified by Fraisl et al. (2020) and Pateman et al. (2021a). The CS projects' contribution to the SDG3 and SDG13 are also addressed in the reviews done by Bio Innovation service (2018), to the SDGs 7, 11 and 13 by Wuebben et al. (2020), and to the SDGs 3, 4, 5, 11, 13 and 15 by Moczek et al. (2021). It is important to mention that only few projects represent themselves directly as working toward SDGs in this sense, so that a broader dissemination of the relevance of EU-funded projects for achieving SDGs could be beneficial.

4.2. Key roles that cities and citizens can play toward specific SDGs implementation

Cities need to achieve SDGs and have plans and strategies to do that. Such public plans and strategies to achieve SDGs often include urban planning and/or urban design policies. These policies play a crucial role in shaping the physical form and development of cities, and they can contribute significantly to achieving sustainable development objectives. Some key aspects related to urban planning and design, such as involving land use control tools (e.g., zoning regulations), incorporating green and blue infrastructure, and engaging citizens and communities in decision-making, are often included in SDGs-oriented strategies (UN Habitat, 2009, 2022). At the same time, there is evidence that cities also need to engage with the public, as the implementation of these plans and strategies depends on collaboration with citizens. Here, CS can play a role, e.g., in contributing to the definition of new targets and metrics (West and Pateman, 2017), as an accepted methodology and source of generating data and information (Roy et al., 2012; Fritz et al., 2019; Ferrari et al., 2021), in monitoring SDGs indicators (Fraisl et al., 2020), in supporting SDGs targets (Ajates et al., 2020), and raising awareness of SDGs (Heinisch, 2021; Moczek et al., 2021). Our study demonstrates that most CS research activities focus on environmental pollution and resources (e.g., air, soil, water, noise, waste, biodiversity, land cover and land use change) by engaging citizens into diverse types of activities, from contributory (crowd-sourcing and passive sensing) to collaborative (active sensing) and co-creation (that sometimes include co-designing DIY monitoring tools) or combining these three levels of citizen engagement together. Previous studies have found that biodiversity is the dominant topic of CS projects (Schade and Tsinaraki, 2016; Pocock et al., 2017; Bio Innovation service, 2018). Our focus on cities and their sustainability challenges explains the prevalence of environmental pollution monitoring projects in our inventory with nature and biodiversity projects being less common. Our results may indicate that citizens are being engaged toward the goals cities may have prioritized (SDG3, 11), and the city is the recipient of the results of citizen activities.

Yet, there is not a one-size-fits-all solution to solve cities' problems. There is a spectrum of needs. Cities are already developing a series of co-creative solutions. The key solutions targeting at sustainability challenges that have been tested by the CS activities are awareness raising interventions for air pollution issues, behavioral change interventions on energy toward energy saving and usage of renewable energy, and transformative interventions for various NBS to improving environmental quality, health, and wellbeing.

Examples of good practice are NBS which focus on (i) trees in Bologna (iSCAPE consortium, 2016-2019), Barcelona, Brussels, Gelsenkirchen, Krakow, and Leipzig-Halle (CLEARING HOUSE, 2019-2023); (ii) hedges in Dublin (iSCAPE consortium, 2016-2019); (iii) green roofs and walls in Vantaa (iSCAPE consortium, 2016-2019); and (iv) integration of green-blue infrastructure in Podutik, Slovenia (Oppla, 2021). Our results reflect well that NBS are included in the key priorities of the EU R&I agenda

(Liu et al., 2021a). There appeared to be an increasing trend for cities to engage citizens, policymakers, scientists, businesses, enterprises, and other stakeholders in a series of co-creative processes for sustainable solutions.

4.3. Challenges and ways forward to strengthen citizens and cities' role to support the SDGs

Our study indicates that there is enormous potential to engage the participants at large by various participatory practices (e.g., citizens help to monitor air quality, survey of citizens on certain health issues, citizens provide biological samples, citizens attending co-design events, awareness raising campaigns, research days and nights, etc.). For example, project WeObserve (WeObserve consortium, 2017-2021), through the massive open online courses, engaged with 2,100+ learners from 107 countries, communities of practice with 240+ participants from 40+ countries, and the CS challenges of the INSPIRE Hackathon with 35 participants from 22 countries. In the project HackAIR, 13000 people accessed the hackAIR platform to be informed about the quality of the air they breathe, around 800 citizens began measuring air pollution with their own Do It Yourself (DIY) hackAIR sensors, while 1,400 citizens contributed to the hackAIR community by uploading photos of the sky (hackAIR consortium, 2016-2018; Liu et al., 2019). However, challenges in citizens participation are well recognized (Mačiulienė et al., 2021; Ozaki and Shaw, 2022), majority of the projects targeted citizens in general, only a small proportion of the projects considered specific social groups (e.g., policymakers, doctors, students, women) or marginalized groups (e.g., the elderly, migrants, and refugees).

A deeper analysis of projects' deliverables and publications/papers would be needed to enlarge the analysis on projects' impact since information on achieved impacts are not always available or easily identifiable on projects' websites or in the CORDIS database. Additionally, the analysis of impacts is done at the end of the projects or after their completion, so for ongoing projects (19 out of 44), this kind of information will be available only in the future. Nevertheless, social impacts, especially in relation to spreading of knowledge, behavioral change and community empowerment and political impacts appear to be significant for the majority of analyzed projects, followed by scientific and economic impacts.

The analysis of the link between projects and SDGs has been done in most cases (34 out of 44) by the authors (see Supplementary material). More could be done to promote a wider use of SDGs by project teams, but there is also the need to acknowledge that SDGs and their targets have been designed for assessing sustainable goals progresses at country level, not at city level. As pointed out by Wiedmann and Allen (2021, p. 1) "Cities in particular have been regarded as central to driving the sustainable development agenda in several ways [...], but challenges remain in downscaling targets and indicators to the city level to support planning and policy in a local context." Some European cities (ASviS, 2021), among them Asker, Florence, Ghent, Gladsaxe, Stockholm and Copenhagen, have developed ad-hoc metrics and processes and represent important examples for other municipalities. In this paper and in previous works (Passani et al., 2020; Moczek et al., 2021) first attempts to analyse how EU-funded projects can contribute to SDGs achievements and monitoring has been done, but future research will be needed to make this analysis more rigorous and for defining standardized indicators to be monitored by EU projects during their progress.

5. Conclusions and recommendations

This study aims to explore the contribution of CS initiatives in European cities toward achieving the SDGs. We provided an overview of existing knowledge and research on CS initiatives and their role in advancing the SDGs. In our analysis of the EU funded research projects, we have learned that the projects that combine long-term focus on cities and an active engagement of citizens, have demonstrated that they play a role in the cities' efforts toward and in monitoring the achievements of SDGs. Even if the projects are limited in time, and even if the projects do not focus on long-term impacts, some conclusions can be drawn including: (i) there is already a host of science-based methodologies on how to implement CS; and (ii) there is a body of evidence on CS, and how these related engagements and social innovations are helping cities to achieve SDGs.

The four-stage methodological framework developed on how to assess projects or activities' contribution to achieving SDGs is in place and has been successfully tested on concrete projects. A first analysis of how each project contributes to achieving SDGs at urban level shows that (i) assessing projects' impacts on SDGs is not a widespread practice yet; (ii) most projects do touch upon SDGs at thematic level, but not at target and/or indicator levels; (iii) at thematic level, the most addressed SDGs are SDGs 3, 11, 13; (iv) a broader dissemination of the CS projects contribution to SDGs would be needed; and (v) a guideline on how to do a deeper analysis of CS projects contribute to which SDGs at what level would be needed as well.

There are numerous barriers (e.g., lack of financial resources, institutional and governance challenges, data and monitoring gaps, infrastructure and service gaps, social and economic inequalities, climate change and environmental challenges, lack of awareness and public engagement) identified for cities in achieving SDGs. To overcome barriers to achieving SDGs, the good practices indicate that drawing on the large ecosystem of players, the cities can engage citizens and other stakeholders in the co-creation of the solutions and co-implement actions in working toward and in monitoring the achievement of SDGs.

Moreover, more CS and other social innovations that support citizen engagement are emerging or becoming widespread practice in Europe as EU wide calls and funding criteria are recently moving more toward mandatory inclusion of Social Science and Humanities disciplines, asking for better gender participation, open science activities and more effective interdisciplinary and transdisciplinary efforts to be integrated into the work of consortiums. This changing requirement is intrinsically bringing a culture change in the way projects are being shaped and implemented with more inclination toward citizen engagements. Stronger citizen engagement, better capacity and awareness of civil society are likely to create stronger social mandate for policy changes for many challenges the cities are facing now and in future. Efforts toward reaching SDGs and monitoring progress on city level can be strengthened by citizen engagement at city and community scale.

To mainstream CS and maximize its contribution to cities' progress toward SDGs, several steps should be taken. Firstly, there is a need for further study to downscale the national-level SDGs to the city level and align CS with SDGs indicators or targets quantification. Secondly, increased collaboration and knowledge sharing among European cities involved in CS initiatives is necessary. This can be facilitated through the establishment of networks or platforms that promote the exchange of best practices, lessons learned, and research findings. Thirdly, policymakers and funding agencies should recognize and support the role of CS in advancing the SDGs. This can be achieved by allocating dedicated funding for CS projects, providing training and capacity building opportunities, and integrating CS into urban planning and decision-making processes. Lastly, efforts should be made to enhance the inclusivity and diversity of CS initiatives. This includes actively involving marginalized communities and underrepresented groups in project design and implementation, ensuring data and tools accessibility, and addressing barriers to participation. In summary, by embracing citizen engagement, leveraging CS and social innovations, and integrating CS into urban governance and decision-making processes, cities can tap into collective intelligence to tackle complex sustainability challenges, work toward achieving the SDGs, and effectively monitor their progress at the local level.

Our study encountered certain limitations that prevented us from conducting an in-depth assessment of cities and citizens' contributions to the SDGs. One limitation is the ongoing nature of many projects, with their results and outcomes not yet available, which restricted the extent of our analysis. Another challenge is related to information accessibility and language barriers. We were unable to identify and evaluate certain case studies conducted by cities themselves. These case studies involved engaging with local CS initiatives and could have provided valuable insights into context-specific factors influencing the effectiveness of CS in advancing the SDGs. Additionally, while we identified the thematic areas addressed by the projects and their potential relevance to specific SDGs, only a subset of the projects explicitly mentioned their alignment with the SDGs. This lack of explicit alignment information made it challenging to precisely assess the projects' contribution to specific SDGs and their associated targets and indicators. Despite these limitations, we believe our study provides valuable insights into the role of citizen science in advancing the SDGs in cities, and we will continue to refine our analysis as more data becomes available and as ongoing projects reach completion.

To conduct a more comprehensive study on the role of cities and citizen science in advancing the SDGs in Europe and offer valuable recommendations for policymakers, researchers, and practitioners interested in leveraging citizen science for sustainable development, we recommend employing a combined approach. This approach would involve conducting a thorough literature review, analyzing research projects funded by various sources (such as the EU, national entities, and city-level initiatives), studying case studies that involve engagement with local CS initiatives, conducting interviews with project leaders and participants, and collecting data on the outcomes and impacts of these initiatives. By adopting such an approach, we can overcome the limitations of our study and provide a more thorough understanding of the subject matter.

Author contributions

H-YL designed the study and wrote the draft with support from SA. All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

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Conflict of interest

AP was employed by T6 Ecosystems S.r.I.

The remaining 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

Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/frsc.2023.1219768/full#supplementary-material

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