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Monitoring Citizen Science Performance: Methodological Guidelines

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ABSTRACT

This research paper aims to co-design a theoretical framework and methodological guidelines to monitor the performance, outcomes, and impact of Citizen Science projects. Hence, the proposed methodology combines the previous research efforts on the engagement of external stakeholders into a composite monitoring tool, which allows measuring and comparing CS project progress towards defined objectives. The development of methodology adopted a pragmatic mixed-method research design. Firstly, analysis of the theoretical sources and available monitoring tools provided the basis for a conceptual framework and identification of measurement indicators. The rationale of the conceptual framework was based on the co-creation workshop and stakeholders' interviews. In addition, the aggregation of indicators during the expert Focus group research resulted in a meaningful design of the composite CS Performance Index. The designed methodology is a part of the three-year Horizon 2020 "Science with and for Society" project INCENTIVE (Grant Agreement No. 101005330) that brings on board four Research Performing and Funding Organizations: the University of Twente, the Autonomous University of Barcelona, the Aristotle University of Thessaloniki and the Vilnius Gediminas Technical University. Methodological guidelines set the structure for applying the monitoring in four national CS Hubs and support their coordination. In particular, the values of the indicators could be compared with the targets set, with the respective values of other Citizen Science Hubs, or to worldwide trends.

KEY WORDS:

Citizen Science, Quadruple Helix stakeholders, public engagement; co-creation.

JEL Classification: I31, O33, O35, O36.

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1. Introduction

The concept of "citizen science" emerged and developed in Europe in 1990, marked by notable early initiatives in Germany, Spain, and Austria (Liu et al., 2021). After 2012, this idea gained renewed prominence, with a surge in publications, projects, and funding initiatives that emphasized involving citizens actively in scientific endeavors (Göbel et al., 2017). Traditionally, citizens have often been viewed as passive subjects in research. The essence of citizen science challenges and reverses this per-

spective, offering citizens the opportunity to engage as active participants throughout the research process. This involvement can range from shaping research questions to data collection, analysis, and dissemination (European Commission, 2020). A core requirement for any citizen science initiative is the enthusiastic participation of non-academic individuals (Grey et al., 2016). These projects span a wide array of scientific domains, encompassing biology, astronomy, medicine, computer science, statistics, psychology, and engineering (Pérez & Costa, 2018). As citizen science continues to evolve,

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embracing diverse projects and methodologies, the role of supporting institutions becomes crucial. Online platforms and databases play a pivotal role in facilitating collaboration across countries and enabling global researcher participation. For instance, EU-Citizen.Science serves as a comprehensive Knowledge Hub for citizen scientists (<https://eu-citizen.science/>), while SciStarter is a global Citizen Science hub hosting over 3,000 projects and fostering collaboration with various stakeholders (<https://scistarter.org/>). During the past years, municipalities and state administrators have been preoccupied with fighting the pandemic. "Improvisations in public space reconfiguration have occurred on an ad hoc basis and some as informal projects by volunteer citizens" (Mittal & Woodside, 2022). Nature-focused activities also saw increased participation during lockdowns, presenting an opportunity for community members to engage in collaborative scientific activities and community building (NatureScot, 2020). According to Manzoni et al. (2019) and Mugdal et al. (2018), the communities of practice, networks, and shared platforms are the primary tools that support the performance of citizen science. Furthermore, associations dedicated to citizen science, such as the European Citizen Science Association, facilitate knowledge exchange, capacity building, and the development of a shared ethos among practitioners.

Citizen science, a relatively nascent practice, demands fundamental shifts within institutional frameworks of research-performing organizations to ensure effective implementation. This process is intricate due to researcher hesitancy, bureaucratic impediments, and the need to recalibrate evaluation criteria towards broader stakeholder engagement rather than solely relying on publication metrics. In light of this, some Research Performing and Funding Organizations (RPFOs) have established Citizen Science Hubs, which provide standardized protocols, curated resources, and specialized expertise tailored to different research fields. These hubs promote knowledge exchange and collective learning, empowering institutions to navigate the complexities of citizen science more effectively. The establishment of a Citizen Science ecosystem is essential, fostering collaboration among all Qua-

druple Helix (QH) stakeholders, including the general public, industry, researchers/institutes, governmental bodies, and funding agencies (Haklay et al., 2021).

This research paper introduces a framework for evaluating and providing methodological guidelines to monitor the performance, outcomes, and impact of Citizen Science Hubs. It addresses the multifaceted challenges of integrating citizen science within institutional contexts based on Responsible Research and Innovation (RRI) principles. Although citizen science projects have far-reaching effects on various domains, many require a more comprehensive approach to improve evaluation (Sommerwill & When, 2022). This research aims to shift the focus towards the transformative potential of monitoring and assessment, fostering greater openness, diversity, and inclusivity within the realm of citizen science. Moreover, adopting a scientifically grounded impact assessment procedure can significantly enhance project management quality and contribute to the long-term success of citizen science initiatives (When et al., 2021). Creating a practical monitoring framework was a complex endeavor that demanded input from a diverse range of perspectives and researchers. The foundation of this framework was established by analyzing existing monitoring tools, which served as a basis for developing a concept and identifying key measurement indicators. Furthermore, valuable insights were derived from co-creation workshops and stakeholder interviews, which played a pivotal role in shaping the conceptual framework.

The effectiveness of the monitoring tool was greatly enhanced through collaborative efforts involving a distinguished research workgroup composed of interdisciplinary experts and practitioners. Notably, this collaborative process culminated in the adoption of an expert Focus Group research. This approach further refined and consolidated the identified indicators, ultimately leading to the creation of the comprehensive Citizen Science Performance Index. It's worth noting that the methodology presented here is the outcome of the Horizon 2020 project "Science with and for Society" (INCENTIVE), which received support through Grant Agreement No. 101005330. This ambitious three-

year initiative brought together four esteemed Research Performing and Funding Organizations: the Vilnius Gediminas Technical University, the Autonomous University of Barcelona, the University of Twente, and the Aristotle University of Thessaloniki.

To bridge the gap between the current state of relevant scientific fields and the realm of citizen science, the literature review in the next chapter of this paper identified best monitoring practices. Drawing from these relevant and validated approaches, the third chapter of the paper presents the co-design of a theoretical framework for evaluating citizen science activities. The methodological section of the paper provides a comprehensive procedure for developing the Citizen Science Performance Index and outlines methodological guidelines for monitoring the performance, outcomes, and impact of Citizen Science hubs.

2. Theoretical Framework

Citizen science is a rapidly growing field, closely related to 'open science' and 'open innovation' concepts. Responsible Research and Innovation (RRI), a central topic of the European Commission (EC) Horizon Europe program, arbitrates the relationship between science and society. Bringing together public engagement, gender equality, science education, ethics, and governance, "RRI aims to align the outcomes of science and innovation with the values of society to address the grand challenges ahead" (Smallmann, 2018). As the following chapter will discuss, many of the objectives and outcomes of RRI also have considerable overlaps with the Citizen Science approach, such as stakeholder engagement in all stages of the research procedure and interdisciplinary knowledge creation.

Depending on the specific nature of the initiative, the field of research, the involved stakeholders, and the unique socio-demographic, economic, and technological attributes of the area of interest, diverse challenges influence the execution and evolution of citizen science in institutional settings. Recent international research has spotlighted various challenges and critical factors essential to the success of citizen science initiatives (Baek & Kim, 2015; Wildevuur et al.,

2023). For instance, Wyler and Haklay (2018) examined the integration of citizen science into universities, identifying obstacles like upholding quality and impact, enhancing transparency and openness, establishing appropriate recognition mechanisms, and augmenting funding for citizen science initiatives. Moreover, the League of European Research Universities (Wyler & Grey, 2016) suggests that universities involved in citizen science should educate researchers about criteria crucial for successful projects including standards for open science and gender diversity.

Against this backdrop, for citizen science hubs to realize their full potential and effectively serve as catalysts for impactful research, their activities must be rooted in the principles of Responsible Research and Innovation. A culture of Responsible Research and Innovation (RRI) has gained prominence, particularly within European research, over the past decade (O'Grady & Mangina, 2022). In this regard, RRI offers a comprehensive framework that ensures research is both scientifically rigorous and ethically and socially responsible. Embracing RRI means prioritizing inclusivity, transparency, and collaboration among stakeholders, including citizens, researchers, industry representatives, and policymakers (Bauer et al., 2021). Furthermore, RRI encourages anticipation of potential implications and reflexive practices, enabling citizen science hubs to adapt strategies based on feedback and emerging insights (Jakobsen et al., 2019). By adhering to RRI principles, these hubs bridge the gap between research and the broader public, contributing to a responsible and collaborative research culture.

Ensuring the effective implementation of RRI principles within citizen science hubs necessitates a robust mechanism to monitor their performance to uphold the values of inclusivity, transparency, and ethical conduct. However, the literature suggests that such monitoring exhibits distinct characteristics. First, the practice of RRI varies across countries in the European research landscape. This variation comes from how society and science interact, the rules governing research implementation, and each country's overall culture and politics. Because of this diversity, any way of

monitoring RRI needs to be able to consider the contextual differences (Stilgoe et al., 2018).

Furthermore, the advantages of RRI do not simply follow a linear path from input to impact but rather emerge from the transformative processes embedded within the ecosystem's activities. Given RRI's inherently value-driven nature, its assessment goes beyond the mere generation and analysis of indicators to uncover underlying realities. Instead, it presents an opportunity to express what is essential within the evaluation and its reasons (Van de Klippe, 2019). More precisely, it determines the significance of each project's outcomes and processes (European Commission, 2020). Importantly, "evaluation is justified only when it positively affects stakeholders and reach broader objectives, such as enhancing planning, efficiency, and knowledge generation" (Urban Innovative Actions, 2020).

In this regard, several researchers underlined approaches providing pathways to assess RRI's impact within the research landscape. For instance, Von Schomberg (2013) underscores the anchoring of RRI to fundamental ethical foundations, advocating for its alignment with the 'EU Charter on Fundamental Rights' and the overarching societal challenges outlined in the European Framework Programme Horizon 2020. This perspective emphasizes that RRI's evaluation should be guided by the principles of human rights and the addressing of pressing societal issues, ensuring that research is both ethically sound and socially impactful. In contrast, Stilgoe et al. (2013) and Owen et al. (2012) shed light on the significance of inclusive and participatory practices within RRI evaluation. Their approach underscores the pivotal role of diverse stakeholders in shaping research practices based on their unique value commitments. According to Ahmad and Talib (2013), community empowerment strategies are closely linked with social inclusion. "Social inclusion is an important mechanism for overcoming institutional barriers ... and enhancing policy structures to help the poor and other marginalized groups to access assets and developmental opportunities" (Ahmad & Talib, 2013). This inclusivity is reinforced by applying dimensions such as anticipation, reflexivity, inclusion, and responsiveness within

their evaluation frameworks. As a result, the approach empowers stakeholders to influence the research process actively and ensures that RRI aligns with societal values and needs. Response and sensitivity of management can play an important role in determining how citizens react to different incidents and is also relevant to the promotion of a Hub's success. To establish and maintain a good reputation, organizations need to carefully consider how their practices are viewed by all stakeholders. (Gorbaniuk, Zalinski, 2019).

Fochler and Rijcke (2017) introduce a thought-provoking perspective on the purpose of evaluation in RRI. They advocate for a shift from viewing evaluation as a mere bureaucratic task focused on measurement to a transformative opportunity to produce and represent the meaning and purpose of RRI. Their view emphasizes that evaluation need not be limited to producing indicators that mirror an underlying reality. Instead, it can serve as a platform to articulate what is valued within the evaluation and the reasons driving those values.

The evaluation of citizen science shares similar foundations with the evaluation of RRI, both involving intricate considerations that extend beyond quantitative measurements. Much like RRI's principles guiding ethical and impactful research, citizen science interventions operate within the framework of ten core principles set by the ECSA (2020), with their impacts spanning societal, democratic, scientific, and economic domains. These dimensions intertwine to capture the intricate fabric of citizen science's effects, emphasizing their interplay rather than viewing them in isolation. Different empirical studies aggregated knowledge, that innovation-performance relationship is context-dependent (Rosenbusch et al., 2011). Comparable to RRI, evaluating citizen science projects necessitates a context-sensitive approach that recognizes the diverse national and regional settings in which these initiatives unfold (Wehn et al., 2020). Kieslinger et al. (2018) emphasize that CS evaluation integrates the participant dimension, elevating it alongside scientific, socio-ecological, and economic impacts (Schaefer et al., 2021). This 'citizen' dimension also acknowledges that the assessment of CS goes beyond project outcomes, extending to the effects on the participants and

the broader groups of society. Furthermore, the complexity of evaluating citizen science echoes the challenges faced by RRI evaluation, particularly in constructing stable frameworks for a dynamically evolving and diverse subject matter (Coccia, 2018). For instance, evaluation frameworks for citizen science may need to transcend conventional academic metrics, such as journal publications, to incorporate broader societal indicators like news articles and social media discussions (European Commission, 2020).

Numerous studies have been undertaken to assess the impacts of citizen science. Different researchers have examined a variety of outcomes stemming from participatory research, including its effects on learning outcomes (Jordan et al., 2012; Philips et al., 2014), ecological behavior (Kaiser, 2020), social movements (Udal et al., 2020), economic activity, and sustainable consumption (Thogerso et al., 2002; Topal et al., 2020). The research results also indicate that the ability of citizens to express their opinions promotes political stability and may undermine corruption (Drebee et al., 2020). Finally, Lu and Beamish (2001) find out that “alliances with partners with local knowledge can be an effective strategy to overcome the deficiencies SMEs face in resources and capabilities, when they expand into international markets”. However, the complete scope of citizen science’s impacts remains to be fully and comprehensively understood, and contemporary methods and frameworks for impact assessment have not yet been fully integrated into practice (Somerwill & Wehn, 2022). Building upon the nuanced theoretical considerations of monitoring Responsible Research and Innovation and citizen science discussed in the preceding section, it becomes imperative to delve into the existing frameworks that endeavor to evaluate these intricate processes within the European context.

In the case of RRI, the first notable example is the MoRRI project (MoRRI, 2022), a landmark study to monitor European RRI advancements. It establishes indicators across various RRI dimensions, including gender equality, science literacy, public engagement, open access, ethics, and governance. MoRRI’s outcomes underscore the considerable diversity within Europe’s RRI landscape,

underscoring the necessity for a context-sensitive approach that hinges on a nuanced comprehension of the intricate society-science relationships in each country (Stilgoe et al., 2018). Expanding upon the achievements of the MoRRI project, the SUPER_MoRRI (2022) initiative took measures to ensure the ongoing collection, curation, evaluation, and enhancement of MoRRI indicators. It also pursued the ambitious goal of attaining a comprehensive scientific grasp of the intricate interplay between RRI policies, practices, and their far-reaching societal and economic consequences. Another noteworthy contribution within this sphere is the European Commission’s expert group on policy indicators report for RRI (Directorate-General for Regional Policy, 2018), which offers additional insights by adopting a network-based approach to engage with RRI. This expert group emphasizes the fostering of RRI agendas within stakeholder networks as a central aspect of monitoring, advocating for a governance-focused perspective that encompasses all dimensions of RRI (Strand et al., 2015).

Turning to citizen science, noteworthy progress has been made by the Multiple Indicator Cluster Surveys (MICS) project, which introduced and applied a framework for CS impact assessment. This frame designates five domains of interest including society, science, environment, economy, and governance (Multiple Indicator Cluster Surveys, 2022). An important takeaway from this endeavor is that CS impact pathways are often non-linear, making the assessment process far more than just reporting outcomes. Instead, it plays a pivotal role in facilitating significant learning for the future (Dart & Davies, 2003). The efforts of the DITO consortium (2016) propel forward the notion that monitoring citizen science transcends conventional narrow viewpoints. They aim to cultivate iterative learning among ecosystem collaborators and steer the sharing of knowledge at both public and policy levels. DITO’s diverse reports deliver valuable practical insights into the realm of efficient monitoring practices for citizen science activities, presenting a user-friendly and reproducible framework.

By discussing the theoretical framework, another

important global megatrend has to be mentioned. Information and communication technologies together with digitalization change every organization's internal and external value-creation activities. Tagscherer and Carbon (2023) provide a comprehensive literature review on the role of management in successful digitalization, potentially a critical angle given the growing importance of digital transformations. Successful implementation of digitalization in CS activities requires a visionary and customer-centered approach, such as “flat hierarchies, empowering employees, possessing digital savviness, and engaging in partnerships and ecosystems” (Tagscherer & Carbon, 2023).

Citizen science stands as a pivotal catalyst in driving sustainable societal development. Its potential extends to catalysing sustainability transitions through tasks like identifying social challenges, setting agendas, prioritizing concerns, and mobilizing both human and financial resources (Sauerman et al., 2020). On a broader scale, citizen science consistently emerges as a significant avenue for achieving societal objectives, encompassing as many as 76 out of the 231 Sustainable Development Goal (SDG) indicators, as evidenced by Fraisl et al.'s research (2020). Sustainability issues are intricately tied to diverse facets of social existence, spanning education, gender equality, health, the environment, and the development of smart cities and communities (Skaržauskienė & Maciuliene, 2021). Strong links exist between the welfare of the state, innovation outcomes, and institutional or public support for innovation-promoting measures in society. These findings have important policy implications and encourage discussing sustainability and innovation performance in a sociocultural context (Hajighasemi et al., 2020). As the UN's Sustainable Development Goals (UN, SDG, 2020) take centre stage, the challenges of engagement, motivation, diversity, and sociocultural dynamics must be surmounted by CS Hubs. Nonetheless, comprehensive insights are still required to delineate the present and potential contributions of citizen science to the SDG framework.

While the evaluation frameworks for RRI and CS have marked significant progress, they also

exhibit limitations and potential gaps that warrant consideration. These frameworks often grapple with the intricate challenge of balancing quantitative metrics with the need to capture the qualitative and transformative impacts that both RRI and CS seek to achieve. The emphasis on indicators and measurements may overshadow the broader societal, cultural, and ethical shifts these initiatives intend to bring about. Moreover, the inherent complexity and interdisciplinary nature of both RRI and CS might render conventional evaluation methodologies inadequate in comprehensively portraying the breadth of their influence.

By analyzing scholarly sources and expanding on existing RRI and CS evaluation frameworks, three pivotal pillars for effective citizen science performance monitoring within institutional settings emerged: (a) promoting CS and nurturing a scientifically engaged society, (b) creating societal impact and citizen interaction, and (c) progressing towards sustainable development goals. The proposed monitoring framework seeks to measure advancements toward these critical objectives.

3. Methodology

The present study aimed to offer a Citizen Science Hub monitoring tool that resonates with the transformative essence of both RRI and CS endeavors outlined in the previous section. Rather than relying solely on quantitative methodologies such as closed-response surveys and questionnaires to monitor CS performance, this research endeavors to accentuate the transformative potential of monitoring and assessment. The design of the Citizen Science Hub monitoring framework was guided by a series of five steps, elaborated upon in the subsequent sections (see Figure 1). Firstly, a comprehensive literature review was completed, and an analysis of previously established frameworks was executed. Secondly, the interviews with stakeholders of the Citizen Science Hubs were conducted and conclusions during the co-creation workshop were finalized. The initial monitoring framework was validated by implementing expert interviews and Focus group research. The final stage of the methodology was dedicated to the incorporation of the insights and the ultimate rendition of the Citizen Science Hub monitoring framework.

By adhering to this structured methodology, design-

ing, implementing, and refining the monitoring framework for Citizen Science Hubs was undertaken systematically, ensuring its effectiveness in capturing and evaluating societal impacts. This methodology enables the alignment of the framework with the principles of RRI and CS and ensures its suitability for enhancing responsible and impactful Citizen Science initiatives.

3.1. Co-creation Workshop with the Stakeholders of Citizen Science Hubs

Co-creation, a pivotal facet of the methodology, entails the active incorporation of users and stakeholders during the design process. This participatory approach encompasses concepts like "co-production," "public participation," "collaborative governance," and "community involvement." By leveraging the collective creativity of diverse stakeholders, each contributing unique backgrounds and perspectives, co-creation fosters innovative ideas and the joint creation of value (Lusch et al., 2007). In the operations of Citizen Science Hubs (CS Hubs), co-creation is a pivotal normative pillar. These hubs serve as spaces where a spectrum of societal actors collaborates to undertake responsible research and innovation initiatives.

To foster this co-creation endeavor, a co-creation workshop was organized in September 2021, inviting selected regional Research and Innovation (R&I) stakeholders, comprising CS experts, researchers, and representatives from civil society organizations, to participate. The workshop's objective was to collaboratively define critical aspects of the CS Hubs, encompassing their functions, goals, and desired impacts. Each of the four participating Hubs of the INCENTIVE project extended invitations to 2-6 stakeholders from the Quadruple Helix framework, representing academia, industry, government, and civil society. The workshop's outcomes were subsequently translated into critical objectives and further divided into specific focus areas for monitoring to generate precise and actionable results.

The identified objectives are organized into distinct themes, each carrying a particular significance within the Citizen Science Hub framework (Table 1).

Through the active participation of stakeholders in the co-creation workshop, this phase of the methodology guarantees that the monitoring framework is in harmony with the requirements, beliefs, and ambitions of a wide spectrum of individuals and groups who are dedicated to the achievement of success in Citizen Sci-

Figure 1
Methodological Flowchart

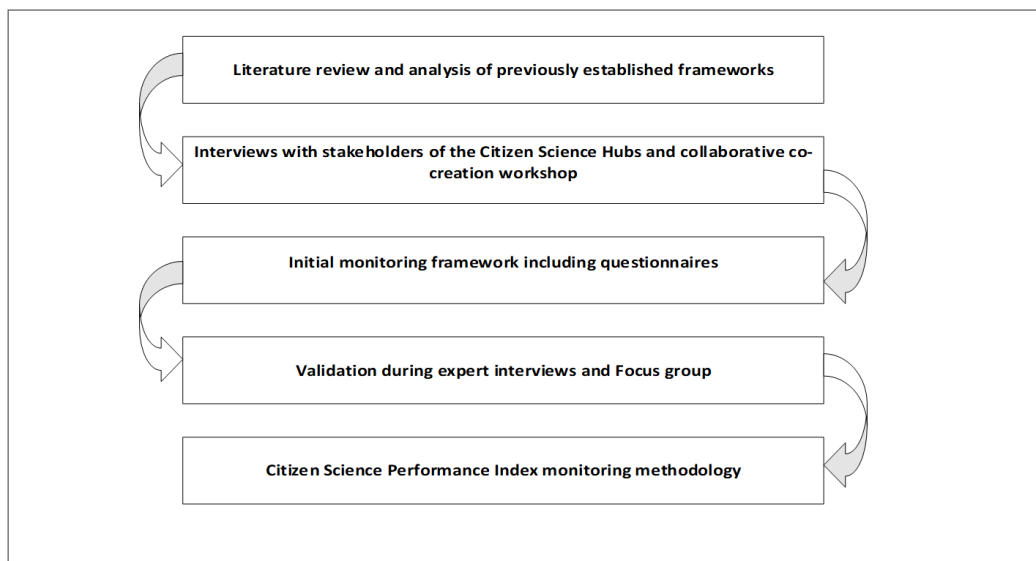


Table 1
Identified Objectives

Item	Description
Grounding RRI in society	Promoting best practices in Citizen Science. Nurturing a scientifically interested and literate society
Transforming RPFOs' Impact and Engagement	Promoting a transformative shift in the approach of Research Performing and Funding Organizations (RPFOs) towards generating impact and engaging with their surrounding ecosystems Facilitating and enhancing productive interactions among stakeholders
Advancing Sustainable Development	Making strides towards sustainable development goals Generating societal, economic, democratic, and scientific impacts that contribute to sustainable local, regional, and global development

ence Hubs.

3.2. Formulating the Initial Monitoring Framework

Following the co-creation workshop, the key objectives were further translated into the initial monitoring framework, which included formulating questionnaires and data collection tools. This framework served as the foundational structure for assessing and monitoring the progress and impact of the Citizen Science Hubs. The questionnaires and tools were designed to align with the identified key objectives and areas of focus, ensuring that the data collected effectively measures advancements toward the specified goals.

The process involved careful consideration of the indicators and metrics that would best capture the multi-dimensional nature of the CS Hubs' goals. This step aimed to balance quantitative data and qualitative insights, recognizing the diverse and nuanced aspects of CS performance that contribute to the overarching objectives. The initial monitoring framework was a dynamic blueprint that evolved based on input from stakeholders, practical considerations, and lessons learned from the existing literature and evaluation frameworks. This iterative approach was essential to crafting a robust framework that aligns with the aspirations of the CS Hubs and accurately reflects their contributions to responsible research, innovation, and societal impact.

3.3. Expert Interviews and Validation Focus Group

The developed monitoring framework underwent a pivotal phase of expert validation and enhancement

to ensure its resilience and practicality. This validation process aimed to gather valuable insights and feedback from domain experts, thereby refining the framework's effectiveness and alignment with the intricate realities of Citizen Science Hubs. The validation procedure encompassed expert interviews and a dedicated Focus Group involving field experts to achieve this goal. In preparation for the Focus Group session, a comprehensive document outlining the fundamental structure of the Monitoring and Evaluation framework and the workshop's itinerary was distributed to participants. On February 18, 2022, the digital Focus Group was convened on the MS Teams platform for a duration of 1.5 hours. A total of 27 experts took part, each contributing their specialized knowledge and perspectives to shape the final framework. These experts were identified through the author lists of European Commission H2020 public deliverables and publications related to M&E (Monitoring and Evaluation), RRI, and citizen science-related projects. The Expert validation workshop boasted participation from 27 experts, including two members of the project's Advisory Board, alongside three consortium observers.

The participants engaged in a co-validation exercise, organized in three digital breakout rooms, where they deliberated upon specific queries: (a) Which facets of the CS Hub operation require closer monitoring? and (b) What obstacles, bottlenecks, or hindrances might the CS Hubs face when generating essential data, and in what ways these challenges can be overcome? The feedback garnered from the experts yielded invaluable insights and recommendations for refining the monitor-

ing framework, catering to the distinct intricacies of CS Hubs and their impacts.

In tandem with the Focus Group, 12 semi-structured interviews were conducted with experts strategically sampled to gather criteria for evaluating progress towards CS Hubs' defined objectives. Four experts from each participating country were involved in the research, representing different stakeholder groups. The experts were defined by local CS Hub management in Lithuania, the Netherlands, Greece, and Spain. The insights from these interviews were meticulously categorized thematically, aligning with the identified evaluation dimensions.

The culmination of the Focus Group and expert interviews resulted in the integration of experts' comments into the final design of the Citizen Science Hub monitoring framework. This comprehensive validation process substantiated the framework's credibility, relevance, and capacity to assess and enhance CS Hubs' impacts and outcomes effectively.

4. Empirical Research Results: Citizen Science Performance Index and Evaluation Guidelines

The logical culmination of the Citizen Science Hub monitoring framework development is transforming the theoretical framework into a tangible and actionable measurement tool: the Citizen Science Performance Index. This index is constructed following the Social Indices design methodology (Freudenberg, 2003; Foa & Tanner, 2014; Mačiulienė et al., 2018; Ray, 2008), which incorporates qualitative and quantitative assessments to evaluate specific domains comprehensively. The index design methodology entails the amalgamation of individual sub-indices, each representing a distinct facet of evaluation, facilitating the comparative analysis of subjects under scrutiny.

The Citizen Science Performance Index is a hierarchical framework, outlined in Table 2, encompassing three pivotal sub-indices. Capacity and Engagement Index gauges how CS Hubs have fostered capacity-building and stakeholder engagement within Research and Innovation activities. It evaluates the extent to which the CS Hubs have catalyzed the involvement of diverse stakeholders, particularly citizens, in various stages of research and innovation,

thus fostering broader participation. Impact and Interaction Index quantifies the impact of CS activities on driving sustainable institutional changes. These changes align with the Responsible Research and Innovation principles (i.e., Public Engagement, Gender Equality, Open Access, Science Education, Sustainability, and Social Justice). The index underscores the transformative influence of CS Hubs on R&I practices and societal dynamics. Progress towards Sustainable Development Goals Index delves into the CS Hubs' contributions to the United Nations' Sustainable Development Goals (SDGs) and their broader influence on local, regional, and global scales. It assesses how CS Hubs' initiatives resonate with these goals and the broader societal impacts they generate.

Monitoring indicators can be categorized into two primary aspects: (a) results, which encompass measurable characteristics of specific outcomes, and (b) impacts, which signify a causal connection between activities and observed transformations (Skarzauskiene & Maciuliene, 2021). Both aspects provide insights into distinct facets and contribute to the assessment of the extent to which project objectives have been achieved. During the design of the monitoring framework, it is advantageous to establish targets for these indicators and render them quantifiable by determining their baseline values, as highlighted by Strand et al. (2015). Given the highly contextual nature of Citizen Science Hubs, a suitable approach to indicator development involves considering them from two perspectives: (a) action, encompassing both process and outcomes, and (b) the perception of key stakeholders and society, as elucidated by When et al. (2020). Perception indicators, embodied in the Capacity and Engagement Index of this research, monitor how project activities influence the perception of R&I stakeholders. Process indicators, on the other hand, monitor the implementation of project activities, accounting for predefined targets, qualities, and undertaken actions, as encapsulated within the Impact and Interaction Index. Simultaneously, outcome indicators facilitate the monitoring of the progress of interventions toward predefined objectives, encompassing both short-term outcomes and long-term impacts, as delineated in the Progress towards Sustainable Development Goals Index.

Table 2
The Structure of the Citizen Science Performance Index

Sub-Indices		Indicator
Capacity and Engagement Index (CEI)	Promoting best practices in CS	Citizen engagement
		Scientific production
		Collaboration between citizens and scientists
		Citizen participation in different stages of the research
		Generation of feedback for citizens
		Transparent research methodologies
		Open data for all CS projects
		Acknowledgement of citizen contribution
		Co-created social value for society
	Nurturing a scientifically interested and literate society	Consideration of legal and ethical issues
		Development of citizens' scientific skills and competencies
		Awareness about the value of CS
		Expansion of citizen science communities
		Promotion of transdisciplinary approaches
		Increase of knowledge generated by citizens
		Promotion of the process of learning
		Increasing R&I activities that engage citizens
		Applying codes of conduct for RRI and CS Hubs
		Enhancing engagement with society for decision-making
Impact and Interaction Index (III)	Nurturing socially responsible, inclusive, and sustainable R&I processes	
	Seeking the impacts of CS-driven R&I	
	Adoption of integration scenarios between stakeholders	
	Focusing on gender equality in CS Hubs	
	Implementing open science and open data policies	
	Initiating mutual learning processes across local stakeholders	
	Encouraging new partnerships in the CS ecosystem	
	Promoting inclusive quality education and lifelong learning	
	Focusing on absolute and sustained gender equality	
	Establishing resilient infrastructure for sustainable industrialization by fostering innovations	
	Reducing income inequalities, promoting social equality	
Progress towards Sustainable Development Goals Index (PSDGI)	Expanding sustainable cities and communities by providing safe and affordable housing, sustainable transport systems and inclusive urbanization	
	Promoting responsible consumption and production, improving green energy efficiency, ensuring a decent quality of life for all citizens	
	Promoting peace, justice, transparency, accountability, and non-discrimination at all levels of government	
	Aligning policies and goals between countries, coordinating investment initiatives	

Source: based on INCENTIVE project outcomes (2023)

Table 3
Identified Critical Aspects

Item	Description
Measuring Quadruple Helix Impact	The experts emphasized the significance of gauging the impact of CS Hubs on the Quadruple Helix stakeholders, encompassing researchers, citizens, the private sector, and local and regional administrations. This holistic approach considers how CS Hubs influence research practices, empower citizens, and foster interest among diverse stakeholders to initiate and support CS projects
Resource Constraints and Qualitative Assessment	The experts stressed the importance of addressing resource limitations in data collection and analysis, drawing from previous experiences such as the MoRRI project. They proposed incorporating narrative-based impact assessment methods to encourage stakeholders to share detailed opinions and insights, enhancing the framework's qualitative dimensions
Eurobarometer Integration	The utilization of the Eurobarometer as a data source to monitor the correlation between citizens' scientific knowledge and their engagement in scientific endeavors was highlighted as a valuable addition
Researcher Training and Understanding	The monitoring of CS Hub researchers' training levels and their comprehension of the Hub's impact on citizens, society, Research Performing and Funding Organizations (RPFs), and research quality emerged as an essential component

The conventional methodology for constructing an index encompasses three distinct levels of structural elements: sub-indices, indicators, and evaluation criteria. In the presented table above, the three sub-indices are displayed alongside their corresponding indicators. Additionally, Tables 2 to 5 outline the evaluation criteria. As indexes and indicators encapsulate attributes of analyzed subjects through diverse values, it becomes imperative to adopt a precise assessment methodology that enables accurate comparisons between individual indexes (Chakravarty, 2003). The majority of indicator values are quantitative and can be readily compared. To ensure consistency, the values obtained from the evaluation criteria responses will be translated into a numeric scale using the following procedure: high – 1; medium – 0.5; low – 0, as outlined by the methodology established by Mačiulienė et al. (2018). This transformation allows for a standardized approach to assessment, enhancing

the comparability of the obtained data and insights.

By implementing monitoring CS Hubs, some guidelines could be helpful, highlighted by the experts as critical aspects (Table 3).

The monitoring process encompasses several essential methodologies, including surveys of both participants in Citizen Science (CS) projects and participants in CS Hub activities, as well as interviews with key stakeholders utilizing the Most Significant Change approach (Willets & Crawford, 2007). The 'Most Significant Change' (MSC) approach stands as a dialogical and story-driven evaluation technique, proving effective in enhancing project outcomes by concentrating on changes that stakeholders genuinely prioritize (Dart & Davies, 2003). Stories serve as valuable instruments for comprehending the effects of projects, as they shift the focus of dialogue towards concrete outcomes instead of abstract indicators. This narrative-based approach not only aids stakeholders in

Table 4
Evaluation Criteria for the Sub-Index “Promoting Best Practices in CS” of Capacity and Engagement Index

Indicator	Criteria
Citizen engagement	Evaluate aggregated data from citizen involvement in CS projects: the sum total of participating citizens, of citizens who dropped out of the projects, of citizens believing in CS impact/Total of CS project participants. Quantity of citizens in CS projects / Total of implemented CS projects
Scientific production	Evaluate aggregated data from the sum total of the research questions aligned to the local needs of the project with the potential impact on science, number of published research papers / Total of implemented CS projects
Collaboration between citizens and scientists	Evaluate aggregated data from the sum total of citizens in CS projects, of citizens who are collaborating closely with researchers, quantity of highly motivated project leaders/Total of CS project participants from all stakeholder groups
Citizen participation in different stages of the research	Evaluate aggregated data from the sum total of citizens involved in data collection; of citizens defining together with scientists the research question; of citizens analyzing data; of citizens validating empirical research results; of citizens generating conclusions/ Total number of citizens in CS projects surveyed
Generation of feedback for citizens	Evaluate aggregated data from the sum total of citizens interested in the topics of the CS as a motivation to participate, of citizens interested in outcomes of CS projects, of citizens interested in receiving feedback on the performance, of citizens interested in receiving information about the impact of CS Hubs/ Total number of citizens in CS projects surveyed
Transparent research methodologies	Evaluate aggregated data from the sum total of reports about robust research with sufficient large groups of participants; of reports about provided adequate resources / Total of implemented CS projects
Open data for all CS projects	Evaluates aggregated data from quantity of open data basis; of follow-ups on social media, number of websites or discussion platforms; of per reviewed publications/ Total of implemented CS projects
Acknowledgement of citizen contribution	Evaluate aggregated data from the sum total of citizens motivated by financial incentives; motivated by social recognition/ Total number of citizens in CS projects surveyed The sum total of publications citing the names of all involved citizens / Total of publications from CS projects
Co-created social value for society	Evaluate aggregated data from the sum total of citizens motivated by project values, of project leaders valuing the social impact of the project, / Total number of citizens in CS projects surveyed Quantity of projects challenging societal issues defined as priority by EU/ Total of implemented CS projects
Consideration of legal and ethical issues	Evaluate aggregated data from the sum total of reports about gender-equal environment/ of reports about the absence of gender-inclusive language in the documentation; of reports about compliance with high research integrity standards; reports about concerns related to ethical and legal matters/ Total of implemented CS projects

Source: based on INCENTIVE project outcomes (2023)

Table 5

Evaluation criteria for the Sub-index “Nurturing a Scientifically Interested and Literate Society” of Capacity and Engagement Index

Indicator	Criteria
Development of citizen's scientific skills and competencies	Evaluate aggregated data from the sum total of citizens with deeper and broader understanding of science; of project leaders interested in impact on higher scientific literacy; of interested in collaboration stakeholders; of interested in science and technology innovation stakeholders/ Total number of stakeholders surveyed
Awareness about value of CS	Evaluate aggregated data from the sum total of citizens with deeper understanding of the research topics; of project leaders with motivation to reach broader audience; of citizens with increased positive image of science/ Total of citizens in CS projects surveyed Quantity of awareness raising events/ Number of CS Hubs Number of citizens participating in the events; of satisfied by the experience citizens; of citizens who were involved after awareness raising events/ Total of stakeholders surveyed
Expansion of citizen science communities	Evaluate aggregated data from the sum total of stakeholders believing that public policies must promote co-production of scientific knowledge; of stakeholders not previously involved in CS; of stakeholders with the interest to participate in CS projects again/ Total of stakeholders surveyed
Promotion of transdisciplinarity	Evaluate aggregated data from the sum total of interdisciplinary CS projects; of inclusive and diverse CS projects/ Total of implemented CS projects
Increase of knowledge generated by citizens	Evaluate aggregated data from the sum total of projects with resources and funding opportunities; of projects with large data sets and labor intensive tasks/ Total of implemented CS projects
Promotion of the process of learning	Evaluate aggregated data from the sum total of citizens with improved team-working skills; with improved critical thinking skills / Total number of citizens in CS projects surveyed

Source: based on INCENTIVE project outcomes (2023)

gaining a better grasp of a project's accomplishments but also assists in defining outcomes and highlighting the diverse values of different stakeholders. Moreover, the Most Significant Change approach unveils the project outcomes that hold significance for various stakeholder groups, aligning well with the democratic emphasis of Responsible Research and Innovation (RRI) through the equitable consideration of a wide array of stakeholder perspectives.

5. Limitations

The index-based approach utilized in formulating the methodology does come with several inherent limitations. Primarily, it has the potential to yield oversimplified conclusions. Furthermore, the selection of

indicators and their associated weights often becomes a subject of contention among researchers from diverse fields. In the absence of empirical data, the discussion surrounding the outcomes remains restricted. To enhance the reliability of research data and the validity of the newly developed instrument, experimental evaluation would be a requisite. Considering that a substantial portion of information utilized for assessing index values is qualitative, grappling with quantitative methods proves challenging. Consequently, the demand for expert evaluation becomes pronounced. Issues related to data accuracy stem from the differing periodicity of observations, the reliability of information sources, general data scarcity, and even the potential lack of comprehension by the public, which might

Table 6
Evaluation Criteria for Impact and Interaction Index

Indicator	Criteria
Expansion of R&I activities that engage citizens	Evaluate aggregated data from the sum total of quantity of CS projects conducted; of grants received for CS-related research projects / Total of CS Hubs Sum total of stakeholders believing in the value of CS activities; of stakeholders believing in value of RPFO by engaging citizens / Total number of stakeholders surveyed
Application of codes of conduct for RRI and CS Hubs	Evaluate aggregated data from the sum total of elements included in the Code of Conduct of CS Hubs; quantity of activities for implementing Code of Conduct; of activities raising awareness about ethical issues / Total of CS Hubs Sum total of project leaders supported by CS Hubs with technical expertise and implementation of RRI principles / Total of CS projects
Engagement with society for decision-making	Evaluate aggregated data from the sum total of CS activities with the involvement of citizens; quantity of stakeholders boards meetings/ Total of CS Hubs Sum total of citizens participating in CS activities; of satisfied by experience citizens; of stakeholders believing in value od decision-making with citizens; number of boards with all quadruple helix stakeholder groups; of citizens with clear role in CS activities; of stakeholders believing in quality of interaction with scientists; number of action plans for CS Hub/ Total of stakeholders surveyed
Initiatives for socially responsible, inclusive, and sustainable R&I processes	Evaluate aggregated data from the sum total of stakeholders promoting socially responsible, inclusive, and sustainable research and innovation further / Total number of stakeholders surveyed Sum total of RPFOs introducing CS as evaluation criteria for funding; as evaluation criteria for the appraisal of students; number of RPFOs with formal open access policies/ Total number of RPFOs
Increased impacts of CS-driven R&I	Evaluate aggregated data from the sum total of CS projects evaluating impact on society; of projects requiring to evaluate impact on society / Total number of CS projects
Adoption of integration scenarios between stakeholders	Evaluate aggregated data from the sum total of capacity-building activities; of awareness raising and learning activities to present/ Total of CS Hubs Sum total of citizens participating in the capacity-building activities; of citizens who gained new knowledge from activities; of scientists, participating in capacity building and learning activities/ Total of CS Hubs
Focus on gender equality in CS Hubs	Evaluate aggregated data from the sum total of female citizens in CS projects; of female members in the CS Hub Stakeholder Board; of stakeholders believing in provided sufficient standards for gender equality/ Total of citizens in CS projects surveyed Number of training activities organized on gender dimensions in research / Total of CS Hubs
Implementation of open science and open data policies	Evaluate aggregated data from the sum total of stakeholders believing in sufficient application of open science practices/ Total number of stakeholders surveyed Sum total of RPFOs with open-access policies; number of activities for open science practices; sum total of projects implemented using open-science software and repositories/ Total of CS projects
Initiatives for mutual learning processes across local stakeholders	Evaluate aggregated data from the sum total of mutual learning and networking activities/ Total of CS Hubs Sum total of citizens in mutual learning and networking activities; of satisfied with experience participants/ Total of CS Hubs
New partnerships in the CS ecosystem	Evaluate aggregated data from the sum total of stakeholders ready to sing a Memorandum of Collaboration; of policy makers who communicated during the project; of stakeholders reporting about new partnerships and contacts/ Total of stakeholders surveyed

Source: based on INCENTIVE project outcomes (2023)

Table 7*Evaluation Criteria for the Progress Towards Sustainable Development Goals Index*

Indicator	Criteria
SDG 4- Quality Education	Evaluate aggregated data from the sum total of elderly citizens participating in the CS projects; of young citizens participating in the CS projects / Total of participants surveyed Quantity of CS projects with educational resources / Total of CS projects
SDG 5- Gender Equality	Evaluate aggregated data from the sum total of CS projects performing research on gender issues; of CS projects lead by women leader / Total of CS projects
SDG 9- Industry, Innovation, and Infrastructure	Evaluate aggregated data from the sum total of CS projects which contributing to building resilient infrastructure and developing sustainable innovation / Total of CS projects
SDG 10- Reduced Inequalities	Evaluate aggregated data from the sum total of CS projects contributing to reduce of inequalities and promoting inclusion; of CS projects implementing research on inequality / Total of CS projects
SDG 11- Sustainable Cities and Communities	Evaluate aggregated data from the sum total of CS projects contributing to the development of sustainable cities and communities; of CS projects performing research on sustainable cities and communities / Total of CS projects
SDG 12- Responsible Consumption and Production	Evaluate aggregated data from the sum total of CS projects contributing to responsible consumption/ of CS projects implementing research on responsible consumption/ Total of CS projects

Source: based on INCENTIVE project outcomes (2023)

be essential for subsequent data analysis. Additionally, there remains an underexplored aspect concerning statistical inference and the reliability of indicators that gauge impact, presenting an opportunity for prospective research. In this context, a forward-looking approach could involve leveraging the Analytic Hierarchy Process (AHP) theory to synthesize priority scales (Saaty, 2008) and enhance the proposed comprehensive model.

6. Discussion

This study attempted to identify methods and strategies specific to CS monitoring. The conducted review showed an increased trend of interest in the topic of CS in research and policy-making. Different scientific projects have been assessing the impact of CS interferences, covering a diversity of influencing factors. However, the analyzed monitoring approaches follow much the same logic, focusing on societal, scientific, and economic aspects (Schaefer et al., 2021; When et al., 2021;

Wildevuur et al., 2023). These aspects are reflected in the proposed evaluation framework with the specific focus on openness, diversity, and inclusivity within the realm of CS. While many researchers highlight the difficulty in evaluating the phenomena, especially in attempting to establish complex frameworks (Coccia, 2018; Kieslinger et al. 2018), the current research is shifting attention to the transformative potential of monitoring and assessment which could lead to the improved long-term implementation of citizen science initiatives. As already implemented by some initiatives (Passani et al., 2021) and even during the INCENTIVE project, the monitoring procedure has to be designed and started before the beginning of the CS project to receive high-quality data. It is highly recommended for the practitioners to revise the provided questionnaires and adapt them to the needs of the specific project (Somerville & When, 2022).

While this research provides an encompassing perspective on the present status of evaluating citi-

zen science activities, it's important for citizen science projects to acknowledge the rapidly evolving landscape of this field and to foster continued exploration in this domain. Anticipated are additional scientific outcomes emerging from endeavors such as the INCENTIVE project and the pursuits of other researchers. The implications and discoveries should be subject to thorough deliberation and scrutiny within the widest conceivable context.

7. Conclusions

The literature review has revealed three essential pillars that serve as a foundation for gauging the impact of Citizen Science Hubs: (a) fostering citizen science and nurturing a scientifically curious and informed society, (b) generating a societal impact and fostering citizen engagement, and (c) advancing towards the attainment of sustainable development goals. The devised methodology equips evaluators with comprehensive definitions of monitoring dimensions, evaluation indicators, and criteria, while also offering a comprehensive overview of the current landscape within the Citizen Science ecosystem. The conceptual framework consolidates the latest advancements in research pertaining to the field, while the composite Citizen Science Performance Index encapsulates the intricate and multidimensional facets for the benefit of decision-makers and stakeholders.

Through this monitoring approach, the progression of CS initiatives can be effectively assessed over time. To facilitate data collection, identify data sources, and ensure seamless implementation, a set of supplementary documents has been made accessible on the project website (<https://incentive-project.eu/>). Furthermore, the initial evaluation of the CS Hubs in participating countries, including Lithuania, Netherlands, Spain, and Greece, is already underway, and both outcomes and practical implications will be disseminated on the project website.

A robust monitoring framework has the potential to greatly enhance project management efficiency and the precision of impact assessment. Enhanced evaluation methodologies contribute to a deeper comprehension of CS design principles and hold the potential to support future policy

and research endeavors. Notably, indicators' values could be compared against predefined targets, values from other Citizen Science Hubs, or global trends. Stakeholders could validate the evaluation outcomes through surveys and a selected number of interviews. By implementing this monitoring approach, the framework's strengths and areas for improvement can be identified, the unique characteristics of each CS Hub can be comprehended, and substantial evidence regarding societal, scientific, economic, and environmental impact can be amassed.

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