Development of a roadmap for the promotion of ecological and environmental citizen science in India

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University of York

Environment & Geography

September 2024

Abstract

This thesis aimed to develop a roadmap for promoting citizen science (CS) initiatives in India to address its socio-environmental challenges. This necessity arose to address the needs of growing environmental distress in the country and the exclusion of the public in the process of evidence-gathering & decision-making. CS as a process has exhibited the ability to track and contribute to developmental policies by engaging the public in scientific endeavours. Though CS has exhibited these abilities, its impacts and presence are mostly limited to developed countries. Even India, which has a rich history of participatory projects, has seen a limited presence of CS. This raises the question of why the process is not promoted to address the socio-environmental issues of the country; how impactful it has been; what restricts its growth; and who can facilitate its growth. With the knowledge from understanding these questions, I developed a roadmap that can accelerate its adoption over the next 5 years.

For this, I undertook a systematic review to identify CS projects in India that address socio-environmental issues. A total of 56 CS projects and their associated literature were identified which became the primary resources for the four investigations of this thesis through which I tried to understand: a) the characteristics of CS in India; b) their impact strength using a modified Citizen Science Impact Assessment Framework; c) their barriers & opportunities using a guiding framework; and d) the stakeholders involved using a stakeholder network analysis and interviews. The information from these assessments was used to develop the roadmap using two strategic planning tools which mapped the Strengths, Weaknesses, Opportunities and Threats of CS and its influence on Political, Economic, Social, Technological, Environmental, Legal and Ethical aspects. It provided a holistic understanding of strengths and drawbacks which helped to map ideas to overcome them.

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Acknowledgements

Wow, what a journey this has been! First and foremost, I owe an enormous debt of gratitude to my supervisors, Dr. Rachel Pateman and Prof. Steve Cinderby. Thank you for taking me under your wings and guiding me with your wisdom, insights, and patience. I learnt a lot from you during these four years and your belief in my work kept me going.

A huge shoutout to my Thesis Advisory Panel (TAP) advisor, Prof. Sarah West, whom I mailed with my intention to pursue a PhD. Thank you for steering me towards citizen science (great suggestion!) and for all the helpful feedback during our meetings. I'd also like to thank Prof. Piran White, who chaired my Progress meetings, for his valuable input and support throughout this PhD.

Now, a very special thanks to my UK family: Dr. Bidyut Baruah, John Greener, and Dr. Nabangshu Sarma. You three have been my rock, and honestly, without your help, I'm not sure I could have made it through. Thank you for making this journey a little less overwhelming and a lot more fun.

To my parents Dr. Pranay Phukan and Dr. Reeta Bora – your unwavering support and push to embark on this PhD path. You have inspired me every step of the way. And to my brother, Sabyasachi, thank you for picking me up during the low moments and keeping me going.

Lastly, a big thanks to Dr. Mridul Bordoloi for the speedy thesis proofread (you're a lifesaver!), and Ms. Trishna Das for your help with transcriptions – that saved me so much time.

To everyone mentioned and those who've been part of this journey in one way or another, thank you!

Dedication

I dedicate this PhD to my parents, Dr Pranay Phukan and Dr Reeta Bora, whose unwavering support and generosity made this journey possible. Your love, encouragement, and belief in me have been my greatest strength and made me come this far. Thank you for your sacrifices and for funding my research. This thesis is as much yours as it is mine.

And to India. The idea I am extremely proud of.

Author's Declaration

I declare that this thesis is a presentation of original work carried out by me, and I am the sole author. This work has not previously been presented for an award at this, or any other, University. All sources are acknowledged as references.

Chapter 1
1. Introduction

It is the fundamental duty of every citizen of India 'to protect and improve the natural environment including forests, lakes, rivers and wildlife'.

- **Article 51A(g),** Constitution of India

1.1. Introduction to the study

My study aims to develop a roadmap focusing on scaling up Ecological and Environmental Citizen Science (EECS) in India. Citizen science (CS) is a form of collaborative research process which actively involves lay people in scientific endeavours (Cooper and Lewenstein, 2016; Eitzel *et al.*, 2017; Haklay *et al.*, 2020; Haklay *et al.*, 2021a; Haklay *et al.*, 2021b). CS is a diverse and evolving set of practices where public engagement can be of various forms such as collecting or/and analysing data, formulating research questions, or even initiating and leading research projects (Haklay *et al.*, 2020). The concept spans a variety of disciplines from natural sciences to social sciences, humanities, and art however, it is most dominantly used in the natural sciences to understand the natural world through scientific endeavours (Follett and Strezov, 2015; Kullenberg and Kasperowski, 2016; Trojan *et al.*, 2019; Vaughn and Jacquez, 2020) however, in recent times it has seen application in domains of astronomy, history and archaeology (Zooniverse Projects, 2024). The core value of CS is that it calls for the intentional participation of individuals in any scientific endeavour such as research through a transparent and ethical engagement leading to the co-creation of knowledge and accessibility to science for addressing societal needs (Robinson *et al.*, 2018; Haklay *et al.*, 2020).

In this study, I will be focusing on Ecological and Environmental CS (EECS) in India. Based on my understanding from the literature, EECS are CS projects which concentrate on issues related to the physical environment such as air, water, noise, etc; and conservation biology that affects society (Pocock *et al.*, 2017; Fraisl *et al.*, 2022; Nardi *et al.*, 2022). The need for the study initially arose, first, from the lack of data required to develop quantifiable frameworks necessary for sustainable development in the country (Khalid, Sharma and Dubey, 2021; Goel and Vishnoi, 2022; Kumar *et al.*, 2024) and, second, from the current lack of citizens' involvement in the decision-making processes in socio-environmental issues in India (Rajamani and Ghosh, 2016; Kapoor and Dinesh, 2023). With the growing impacts of climate change and environmental degradation, India requires large or big datasets to develop plans that can strategically tackle these threats which have already impacted the livelihoods, financial security and health and well-being of its citizens (Biradar *et al.*, 2019; Cappa, Franco and Rosso, 2022). My experience in the sustainability sector before my PhD enrolment emphasised to me that India indeed is facing increased heat stress and dry spells which have led to frequent wildfires, floods, landslides and avalanches in the country (Chandra, 2015; Sannigrahi *et al.*, 2020; Ghosh and Ghosal, 2021; Khalid, Sharma and Dubey, 2021; Pal *et al.*, 2022).

Global reports have frequently ranked more than 20 Indian cities among the top 50 most polluted cities in the world (HEI, 2020; India Today, 2022; IQAir, 2023). Municipal solid waste, water pollution from sewage, lack of adequate sanitation, non-potable water and air pollution are just a few of the important urban challenges in the country (Chandra, 2015; Batth, 2020). This is despite the fact that India was among the first countries to ratify the 1972 Stockholm Declaration, enact over 200 environmental laws and regulations and integrate environmental protection as a fundamental duty of both the state and citizens (Sandhu and Sidhu, 2015).

My encounters from my previous work at the All India Institute of Local Self-Government, with the villagers in Assam, India made me realise that their knowledge regarding their local environment is limited (Phukan, 2020a, 2020b). This is perhaps due to their state of poverty and class oppression by members of both higher socio-economic and caste groups (Freire, 2020). India has a complex social setup with a variety of religious, socio-economic, caste, and ethnic groups, which has led to the marginalisation of a large proportion of the society. For example, though the society is stratified based on socio-economic conditions, beyond it, the society is also divided based on the caste system, a privileged system based on one's birth into a family. Belonging to a certain caste can be a barrier for marginalised communities in pursuit of higher education. India has four caste systems (colloquially known as Varnas) with the hierarchy as follows; *Brahmin, Kshatriya, Vaishya,* and *Shudra.* Caste can have further divisions known as *Jati.* Studies indicated that in a premier institute in India, promotions and research facilitations were lobbied based on caste (Thomas, 2020; Chrispal, Bapuji and Zietsma, 2021). People of higher caste preferred to be promoted by authorities who belonged to the same caste. This lobby developed as education, and especially scientific endeavours, have traditionally been limited and reserved for the privileged upper-caste people (Thomas, 2020; Chrispal, Bapuji and Zietsma, 2021). Thus the reach of lower caste people pursuing science remains limited. Though India has affirmative actions to promote education in the lower caste population the elitist nature of science and education in India creates a gap due to a gap in generational knowledge and wealth for the lower caste population. EECS can potentially contribute to the social upliftment of communities by being a process in India for women and other marginalised communities to break free from marginalisation in decision-making, especially in the realm of environmental governance and activism (Bela *et al.*, 2016; Muenich *et al.*, 2016; Hecker *et al.*, 2018; Weeser *et al.*, 2018; Katapally, 2020; Ebitu *et al.*, 2021). Through this process, vulnerable communities can illustrate and highlight their issues with evidence to the decision-makers, thus enhancing democracy through science.

1.1.1. Why Citizen Science?

I believe, that over time, CS projects have shown their potential to have local yet significant impacts on important sectors such as science and technology, policy, economy, society and the environment (Hecker *et al.*, 2018; Wehn *et al.*, 2021). As a scientific research method, has been shown to enhance the joint evaluation of science and scientific findings which is beneficial for both the public and scientists (Kieslinger *et al.*, 2017). It has been proven as an effective method for data collection and processing of extensive datasets (Kobori *et al.*, 2016; Groom *et al.*, 2019). Along with it, it has brought opportunities for low-cost and sustainable innovations in scientific equipment and technology making them accessible to the public (Weeser *et al.*, 2018; Longo, Zappatore and Bochicchio, 2020; Fraisl *et al.*, 2022). Overall, it has shown its potential to contribute to the democratisation of science and knowledge for society i.e., enhancing public engagement in science, fostering a better understanding of scientific and social processes among the public and promoting scientific temperament i.e., inquisitiveness (Bonney *et al.*, 2016; Turbé *et al.*, 2019; Roche *et al.*, 2020; Schade *et al.*, 2021; Brandt *et al.*, 2022).

As a political and governance tool, it can uplift communities and provide a space for individuals to share their voices and opinions on local socio-environmental issues (Conrad and Hilchey, 2011; Muenich *et al.*, 2016; Weeser *et al.*, 2018; Fraisl, *et al.*, 2020; Quinlivan, Chapman and Sullivan, 2020; Ferrari *et al.*, 2021). It can bring transparency and adherence to legal regulations, standards, and compliance through the involvement of the public in data collection and policymaking based on the data collected (Shanley *et al.*, 2019). This can help in creating effective governance systems and contribute towards achieving national and international policies such as the Sustainable Development Goals (SDGs) (Fritz *et al.*, 2019). In addition, CS could be an effective way to overcome the current lack of enforcement and poor regulatory settings of Indian institutions such as lack of enforcement on non-adherence to environmental standards by industries and businesses and create awareness amongst the Indian public on environmental degradation and climate change. The Government of India in 2023 launched the "Data for Development" (D4D) policy to support the efforts of nations to achieve the SDGs (Sarma and Sarkar, 2023). It has launched several initiatives such as the National Data and Analytics Platform (NDAP) and Open Government Data (OGD) Platform to contribute to this agenda (MeitY, 2017; Ganapathy *et al.*, 2021). CS in India can aid in contributing and building these databases.

Civil society organisations and grassroots organisations have shown great interest in social innovation and social changes that CS projects can bring to the community, thus acknowledging their capability to impact local economies and livelihoods (Hecker *et al.*, 2018; Wehn *et al.*, 2021). For example, outcomes of CS projects can support livelihood options such enhancing local ecotourism (Horns, Adler and Şekercioğlu, 2018); enhance skills which aid in career progression (Merenlender *et al.*, 2016; Maund *et al.*, 2020; Pateman, Dyke and West, 2021); and generate other valuable knowledge related to the environment which can be essential for farmers, horticulturists, etc. (Ryan *et al.*, 2018). In terms of finance and economy, CS initiatives can lower the cost of data collection and data analysis. Some projects, especially those online, utilise mass analysis and computational power provided by the participants to conduct analyses that would not be economically viable if scientists were working alone (Spitz *et al.*, 2018; Kreitmair and Magnus, 2019).

CS as a collaborative process can be seen as a pathway that can compel science education in India to be more inclusive, improve scientific literacy, engage the public in local issues and enhance their trust in science (Shirk *et al.*, 2012; Bonney *et al.*, 2014; Capdevila *et al.*, 2020). It can also help marginalised sections of the society in India access scientific and social research which they might be excluded from in traditional academic institute-based research. Thus CS can bring knowledge to marginalised communities who never had the opportunity to get involved in science under their conditions.

Despite its positive impacts, CS as a research method has drawbacks that can limit its uptake. For example, not all research can be undertaken by volunteers as they require expertise in running scientific equipment or following complex scientific protocols which can become a demotivating factor (Pocock *et al.*, 2014). The data generated by CS can be biased in spatial and temporal coverage based on the distribution of participants and their accessibility to geographic regions, time, etc. which can be influenced by socio-economic background such as age, gender, education, economic status or profession of participants (Lloyd *et al.*, 2020; Pateman, Dyke and West, 2021; Wiersma *et al.*, 2024). Sometimes, scientists can have a "source preference" where they place a greater value on the data gathered from other scientists and academics than citizen scientists; or they can have a biased notion of CS-generated data to be of lower quality, due to inconsistent data being reported from various CS projects (Burgess *et al.*, 2017; Fritz, See and Grey, 2022). For example, researchers who do not use citizen science data remain sceptical and would prefer data associated with academic institutions (Burgess *et al.*, 2017).

In addition, the context of initiating CS initiative is important. As lay participants are usually involved there can be trade-offs in the scientific rigour of projects while accommodating the needs of participants. (Camacho *et al.*, 2023; Wiersma *et al.*, 2024). Moreover, engaging participants merely as sensors, e.g., utilising their wearables to collect data instead of directly engaging them may not truly translate into the democratisation of science and knowledge (Camacho *et al.*, 2023; Riley and Mason-Wilkes, 2024). Moreover, participants from economically weak conditions often face financial constraints to participate in projects and thus projects that cannot provide incentives such as improving livelihoods, financial aid for the time given to the projects, etc., can lead to exploitations of participants (Pateman, Dyke and West, 2021; Walker, Smigaj and Tani, 2021; Benyei *et al.*, 2023).

1.1.2. Citizen Science in India

In India, CS started gaining attraction in the late 2000s (Sharma, 2019), a trend that aligns with the global rise in CS popularity from the mid-2000s which has been observed to have exponentially grown over the last two decades (Kullenberg and Kasperowski, 2016; Pocock *et al.*, 2017; Pelacho *et al.*, 2021). India can trace back its collaborative and participatory movements to the Chipko movement (in the 1970s) (Khator, 1989), a grass-root campaign primarily led by rural villagers, especially women who collectively ‘embraced trees’ to prevent deforestation. This created a space for the Indian public to engage in environmental decision-making (Iyengar *et al.*, 2021). Through this campaign, for the first time in India demonstrated community engagement in environmental conservation efforts by involving community members in gathering data to support their cause (Shiva and Bandyopadhyay, 1988; Khator, 1989).

By the mid-1980s, India became renowned for its collaborative and participatory approaches that aided the development of rural communities such as Participatory Rural Appraisal (PRA) and Joint Forest Management (JFM) and were extensively used by both researchers and government agencies (Thomas, 2004; Baum, MacDougall and Smith, 2006). For example, PRA was used to actively analyse rural communities’ living conditions, identify problems and solutions, and take a leading role in planning, implementing, and managing development projects, with external facilitators supporting rather than directing the process (Kamble, 2014; Kumar *et al.*, 2022; Chakraborty, Mallick and Kundu, 2023). Joint Forest Management (JFM) was extensively used to support local forest communities through equitable participation and representation of marginalised groups in the economic exploitation of forest resources, ensuring benefits for both forest departments and forest communities (Basu, 2021). Interestingly, Articles 48-A and 51-A(g) of the Constitution of India encourage the involvement of citizens in environmental protection and monitoring as a fundamental duty.

In India, MigrantWatch (an ornithology CS project which began in 2007, now merged with Bird Count India (eBird India) and SeasonWatch (a project on the phenology of common tree species which began in India in 2010) were among the first CS projects to gain popularity (Sharma, 2008; MigrantWatch, 2015; SeasonWatch, no date). In its initial year of inception, MigrantWatch was able to attract more than 600 amateur researchers and professional scientists and recorded over 1000 individual sightings of 140 bird species (Sharma, 2008).

However, in the context of India, the literature indicates that there are low numbers of CS projects and reporting from India (Trojan *et al.*, 2019; Pateman, Tuhkanen and Cinderby, 2021; Pelacho *et al.*, 2021). The low number of CS projects in the Global South especially in Asia, Africa and Latin America is a well-documented trend, However, in the case of India, it is unclear what the factors are that have crucially affected the scaling up of projects, its acceptance in mainstreaming research among the public and if it can be scaled up to effectively address India’s socio-environmental challenges.

No study has assessed and identified its impacts, and the barriers and challenges of CS required to meet these needs. Understanding these gaps would facilitate to identification of strengths, weaknesses, opportunities and threats of CS in India as well as its influence from/on politics, economy, society, science and technology, legal and ethical dimensions. These points are essential for developing a country-specific roadmap as they would point out areas that require attention and support for the effective incorporation of CS into national and international developmental agendas and policies. This thesis is an attempt to develop a roadmap by mapping the progress of the CS process, its impacts and shortcomings for its promotion of ecology and environmental science, and monitoring in India based on experiences of projects initiated in past years (until 2023).

1.2. Aim of the Study

The main of my study is to better understand the issues with EECS in India, i.e. CS projects that address environmental issues that affect the society (socio-environmental issues) to develop a roadmap for promoting EECS's role in research, monitoring and evaluation of socio-environmental issues in India. The idea of creating a country-specific roadmap is inspired by Fritz *et al.,* 2019 who developed a strategic framework for advancing CS contribution towards achieving the SDGs. Roadmaps are important as they serve as strategic planning tools that help define objectives, major milestones, deliverables and activities necessary to achieve a certain goal (Kerr and Phaal, 2022), in this case, the promotion of CS in India. Under Articles 48-A and 51-A(g) of the constitution, the promotion of CS in India can be aligned with fundamental constitutional duties.

1.2.1. Methodological approaches

The study looked at promoting EECS as a product, through a business perspective lens. This helped in designing the study to strategically plan the steps. My study identified two strategic management tools; Strengths, Weaknesses, Opportunities, Threats (SWOT) analysis and Political, Economic, Social, Technological, Environmental, Legal and Ethical (PESTELE) analysis as the tools to identify various factors that can help EECS to be promoted in India. These are popular tools within the business management domain which are used to analyse the market before launching a product.

1.2.1.1. SWOT Analysis

In the strategic management and planning domain, SWOT analysis is applied to identify the Strengths, Weaknesses, Opportunities, and Threats that are internal and external to an organisation, business or product arising from both customers and competitors (King, Freyn and Morrison, 2023). The tool helps in understanding market requirements, social changes, new technology and various environmental, economic, political and regulatory issues through which organisations can devise strategies for promoting their business or product. Beyond its utilisation in business management and corporates, SWOT analysis has been employed to promote sustainability technologies, not-for-profit causes data management strategies, etc. (Helms and Nixon, 2010). In the environmental domain, for example, SWOT analysis was used in West Bengal, India, to understand local perspectives on maintaining derelict wetlands and to identify strategies for better wetland utilisation and conservation (Chakraborty, Mallick and Kundu, 2023). In the field of citizen science, SWOT has been applied to identify strategic factors for promoting the CS process in Brazil through stakeholder workshops (Queiroz-Souza *et al.*, 2023). Thus, SWOT analysis helps in building a common understanding to improve decision-making for strategic planning to enhance the performance of an organisation, process or product.

In SWOT, the four dimensions can be divided into two groups, internal and external factors (Namugenyi, Nimmagadda and Reiners, 2019). Internal factors mean the inherent characteristics of the business or the product, while external factors refer to conditions that are non-inherent but influence the growth of a business or a product.

Strength refers to internal positive characteristics of a business or a product that aids an organisation or product to achieve its goals while Weaknesses are inherent constraints that can impede or hinder the growth or performance of the said business or product. Opportunities are external conditions that can be exploited for the growth of a business and product. Threats are negative conditions which can hinder or delay the achievable goals.

My understanding from the current literature on CS pointed out that the inherent qualities of CS can be broadly drawn from ECSA Characteristics of CS (Haklay *et al.*, 2020; M. Haklay *et al.*, 2021). For example, some of the few inherent characteristics that CS desires to accommodate are being cross-disciplinary, ethical transparency, variety of engagements and involvement, and contribution to society and its capabilities to contribute to low-cost scientific data collection, utilisation of data in scientific research and policymaking, etc.

On the other hand, opportunities, which are external positive conditions can be of several that vary across geography and time. For example, the acceptance of CS-generated data as a legitimate source of data for policymaking and scientific findings by governments (Woolley *et al.*, 2016; de Sherbinin *et al.*, 2021; Schade *et al.*, 2021). Using SWOT analysis, this study captured strategic factors impacting society, scientific and technological innovation, environment, economy and governance which can be demonstrated as the potential of CS (Wehn *et al.*, 2021; Queiroz-Souza *et al.*, 2023).

1.2.1.2. PESTELE Analysis

PESTELE analysis, which is a situational analysis tool, is used for evaluating different scenarios to determine and guide strategic decision-making by assessing factors encompassing *Political, Economic, Social, Technological, Enviornmental, Legal,* and *Ethical* dimensions associated with a business or a product. (Perera, 2017). The factors affecting the PESTELE dimensions are subject to the domain of interest. For example, in the business domain, government tax policies, tax regulations, changes in leadership etc., are important factors influencing the *Political* dimension (Tan *et al.*, 2012; pestleanalysis.com, 2023). For the *Economic* dimension in the same domain; inflation, interest rates, exchange rates, etc. are the core factors. However, in the case of sustainability projects, e.g., biofuel uptake; governmental support and directives are core *Political* factors (Achinas *et al.*, 2019), and factors influencing the *Economic* dimension are government subsidies, government funding, etc.

There is no particular literature for CS which has mapped out the factors affecting its PESTELE dimensions. However, my understanding of the literature indicates that evidence of external *Political* dimension can be referred to national and local governments recognising, supporting and legitimising the CS process through government policies (Shanley et al., 2019). For example, the formulation and enactment of the "Crowdsourcing and Citizen Science Act of 2015" by the US government (Sen. Coons, 2015). Similarly, in the case of the *Economic* dimension means aid and support provided towards project management such as *Horizon 2020* funding for CS by the EU, long-term and dedicated funding for CS projects to develop innovative projects and support their goals such as the (Schäfer and Kieslinger, 2016; Kieslinger *et al.*, 2017), and the financial growth or de-growth of stakeholders due to CS

The *Social* dimension looks into the needs of the society, and how the project affects the community of the area the project is taking place. Such as developing trust between the public and science, eradicating social marginalisation of weaker sections of society, solving socio-environmental and ecological issues and promoting scientific awareness and temperament (Suomela 2014; Kieslinger *et al.*, 2017). The *Technological* dimension of CS covers scientific discovery and research including technological development and innovation such as the development of low-cost sensors (Richter et al. 2015, McKinley et al. 2015, Bonn et al. 2016).

The *Environmental* dimension is affected through factors such as seasons, weather patterns, and climate conditions. They influence when and how citizen scientists can collect data. For example, bird-watching initiatives peak during migration seasons, while water quality monitoring may be affected by rainfall patterns or drought conditions. Negatively, it can the environment if we take a fossil fuel-based vehicle for birding, water collection, etc. The *Legal* dimension is the acceptance of the CS process for environmental regulations, standards and compliance (Shanley et al., 2019).

Finally, the influencing factors of the *Ethical* dimension are data ownership and intellectual property rights (Cooper et al., 2019; Bard & Sandin 2022; Guerrini et al., 2018; Riesch & Potter, 2013); inclusion or exclusion of participants based on gender, age, socio-economic conditions (Bard & Sandin 2022); maintaining research and scientific integrity (Guerrini et al., 2018; Roy & Edwards., 2019) and protecting participants health and wellbeing, and personal data (Guerrini et al., 2018; Groot & Abma, 2022).

Several studies have adopted this hybrid methodology of utilising SWOT and PESTELE analysis to identify strategies and develop roadmaps (Helms and Nixon, 2010; Shadman *et al.*, 2021; King, Freyn and Morrison, 2023). Examples of their combined utilisation include the implementation of photovoltaic energy projects in Spain (Segura *et al.*, 2023); the development of policies to strengthen Malaysia's energy security through stakeholder engagement (Shadman *et al.*, 2021); and assessing the potential sustainability of adaptive reuse projects (Vardopoulos *et al.*, 2021). This hybridisation methodology has been satisfactorily accepted by both corporates and the academic community to develop policies and strategies (Vardopoulos *et al.*, 2021).

1.2.2. Research Questions

The utilisation of these two tools helped me to determine the research questions and further develop my methodology for determining the road map. To inform the SWOT and PESTELE analyses, I first developed the following set of research questions (RQs) to build an evidence-based framework for the promotion of EECS in India:

- The first RQ that arises is **"What is the current scenario of EECS in India?"** This question helped me to explore the evolution, growth, distribution and other characteristics of CS in India (Chapter 3). These characteristics would inform me about the number of projects, their typologies, participant involvement, etc. which is essential in steering the direction of the CS process in the country. From a business product lens, this would help me to understand the product.
- The second RQ tries to understand the impacts and achievements of EECS in India since its introduction in the country. Thus in Chapter 4, I answer, **"What are the achievements and impacts of citizen science in India?"** The question would help me to identify the strengths and weaknesses, i.e. identify areas of success of the CS process in the country which is essential to prioritise activities to promote CS.
- The third RQ looks into the barriers, opportunities and challenges in Chapter 5 by answering, **"What are the barriers and opportunities of CS in India and the challenges it currently faces?"** This question aided me in identifying external factors that brought opportunities and threats to the CS process in India. This would help in understanding how the projects can be influenced externally.
- Finally, the fourth RQ tried to identify the institutional stakeholders and their roles in the CS process (Chapter 6). The RQ has two parts to it. First, I identified the stakeholders by asking **"Who constitutes the diverse array of institutional stakeholders involved in the execution of CS initiatives in India?";** next I evaluated their roles by asking **"What are the various roles and contributions these stakeholders assume that impact CS initiatives?"** These two questions helped me to understand who is involved in the CS process and how they can affect it in India.

I then identified the internal and external influences using the SWOT analysis tool, whose identification was aided by the research questions. These influences were then mapped onto the seven dimensions of PESTELE to identify strategies for the development of the roadmap (Shadman *et al.*, 2021; Vardopoulos *et al.*, 2021; Segura *et al.*, 2023).

1.2.3. Brief Introduction to the Chapters

The data for this study was collected through a systematic search using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework. The framework helped to identify records of CS projects in India from academic databases (Scopus and Web of Science) and Google web searches. The PRISMA methodology is detailed in **Chapter 2**.

In **Chapter 3,** I used the records identified in this review to present an overview of CS projects in India, their evolution over time (1987-2023), their distribution across the country and their characteristics such as participant distribution, participant involvement, etc. This chapter is essential to develop a basic understanding of CS in India. Moreover, this is the first systematic review to be conducted on CS projects in India which have comprehensively traced its progress.

In **Chapter 4**, I used a modified version of the Citizen Science Impact Assessment Framework (CSIAF) (Wehn *et al.,* 2021) to identify the strengths and weaknesses of CS in India as discussed in the records retrieved in the systematic review. The CSIAF identifies five impact domains of CS against which impacts of EECS projects in India were assessed. In addition, the existing CSIAF framework was modified to assess literature for systematic review based on the strength of the evidence provided by them. Existing impact assessment frameworks based on CSIAF such as Measuring Impacts of Citizen Science (MICS) have been developed to evaluate live projects. This modification helped in assessing projects from their published report. Contributions of EECS projects to impact domains were taken as Strengths while the lack of impact was taken as a Weakness.

In **Chapter 5,** I used the records retrieved from the systematic search to identify the 'Barriers' and 'Opportunities' of CS. To do this I developed a framework based on previous literature which has systematically discussed barriers, opportunities and factors influencing EECS (Cunha *et al.*, 2017; Capdevila *et al.*, 2020; MacPhail and Colla, 2020; Fraisl *et al.*, 2022). Through the framework, I defined the characteristics of 'Barriers' and 'Opportunities' of CS and how they create 'Challenges.' The 'Barriers' and 'Opportunities' identified were considered as threats and opportunities respectively for the SWOT analysis.

In **Chapter 6**, I identified the institutional stakeholders involved in CS in India and their roles in various CS initiatives. Stakeholders were identified from the records retrieved in the systematic review and collaborations, funding and flow of information were mapped. For this chapter, I also conducted 9 semi-structured interviews with institutional stakeholders to fill gaps which could not be answered using the retrieved data. At the end of the interviews, interviewees were asked to indicate the influence and interest of different stakeholder groups on CS in India.

In **Chapter 7,** I tried to draw on the roadmap using the findings of the previous chapters and analysing them through SWOT and PESTELE analysis. Findings from chapters were first assessed if they showed strengths, weaknesses, opportunities or threats to the promotion of CS in India. After categorising them I mapped how each of them would affect the Political, Economic, Social, Technological, Ethical, Legal and Environmental dimensions of India.

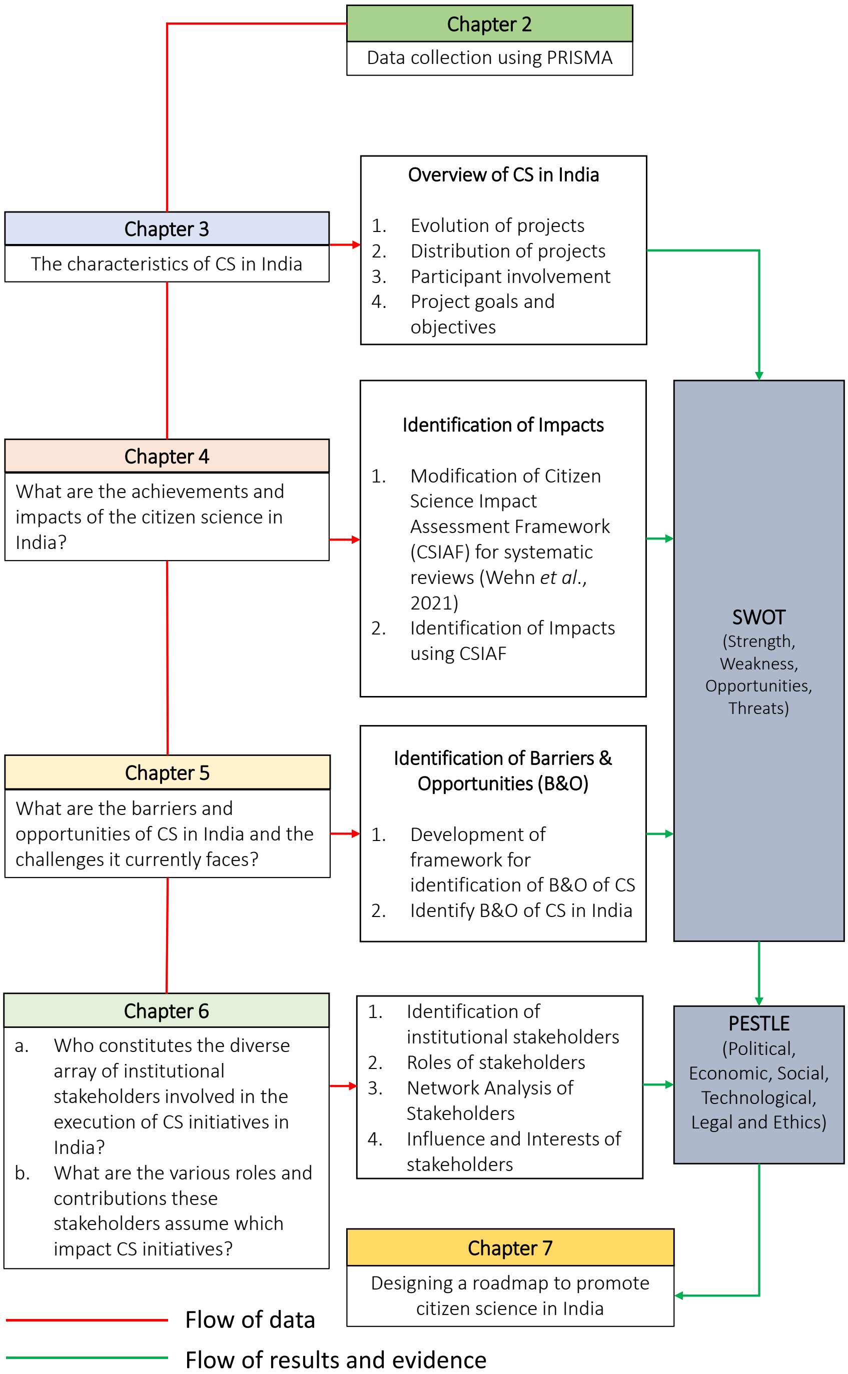

Figure 1 shows the schematic flow of the overall methodology employed in the thesis to develop a roadmap for the expansion of ecological and environmental citizen science in India.

Chapter 2
2. Methodology of data collection

2.1. Introduction

This chapter describes one of the primary data collection methods used in this thesis: a systematic review (SR) of the literature on citizen science (CS) projects in India. The chapter provides a rationale for undertaking an SR; details the methodology used; and describes how the resources identified were analysed in subsequent chapters of the thesis. This chapter also touches on the other data collection methods used in this thesis (i.e., key stakeholder interviews), but the methodology for this is detailed in Chapter 6.

2.1.1. Systematic Reviews and PRISMA Framework

Systematic reviews (SRs) are a type of literature review which have a rigorous evaluation system to clearly and logically report research findings from previously conducted primary research and existing literature (Page *et al.*, 2021). These review studies are characterised by their clearly defined set of objectives with an explicit, reproducible methodology and comprehensive search aiming to identify and critically report all studies meeting a set of criteria (Moher, Liberati and Tetzlaff, 2009).

There are numerous advantages to undertaking SRs. Firstly, SRs facilitate comprehensive and critical assessments using a defined set of research questions oriented towards addressing a particular topic to compare and identify gaps and opportunities (Munn *et al.*, 2018; Page *et al.*, 2021). Secondly, SRs help in obtaining both quantitative and qualitative data from existing data sources to conduct meta-analysis. Thus, they are used to produce guiding statements for decision-making as well as policy development (Moher, Liberati and Tetzlaff, 2009; Munn *et al.*, 2018; Page *et al.*, 2021). In this case, an SR approach was chosen to comprehensively identify CS projects in India; as well as identify their impacts and barriers, and the institutional stakeholders involved with them. This information was then used to identify the strengths, weaknesses, opportunities and threats (SWOT) of CS in India, and to develop a roadmap for the uptake of the approach.

Thirdly, SRs follow a clear set of guidelines to preserve their comprehensiveness, transparency, and reproducibility. This set of guidelines is known as Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA), which aids in conducting SRs by developing a comprehensive, inclusive and repeatable study by identifying the required information to answer research questions (Page *et al.*, 2021).

2.1.2. Rationale for conducting a systematic review

For this study, it was considered appropriate to use systematic review (SR) from existing literature data on CS in India as it provides an opportunity to comprehensively study CS projects based on resources produced by researchers and practitioners who had led or were involved with projects. Moreover, the use of existing literature helps draw information from a wide range of studies and reports without the requirement for new data collection. SR is a methodical and rigorous approach to identifying, evaluating, and synthesising existing research on a particular topic. It allows researchers to gather insights from a wide range of studies and publications, reducing bias by following structured inclusion criteria and transparent methodologies. One common framework used for conducting SRs is the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) approach, which supports replicability and transparency in reviews. The PRISMA framework was initially designed to report SRs and meta-analyses within the health science domain as a method to reduce biases in synthesis reporting (Moher, Liberati and Tetzlaff, 2009). The PRISMA framework can be briefly outlined in a three-step process:

1. **Step 1 Identification of resources to collect data:** This step involves systematic exploration of online journals and other repositories (termed 'databases') by using specific search terms.
2. **Step 2 Screening of resources to identify documents to include in the study:** This step is guided by precisely designed eligibility and selection criteria.
3. **Step 3 Inclusion and appraisal of records:** This step entails the identification and assessment of relevant data through critical examination.

SRs have been widely applied in CS to map existing practices, contributions, and theoretical frameworks. For example, Wehn et al. (2021) developed the five dimensions of the Citizen Science Impact Assessment Framework (CSIAF) through an SR of existing projects using the PRISMA methodology. Other studies, such as Cunha et al. (2017) and Capdevila et al. (2020), have employed related bibliometric techniques to explore factors influencing the success and limitations of CS projects. These reviews help to critically analyse, categorise, and interpret diverse CS initiatives by consolidating findings from multiple sources, thus providing a comprehensive understanding of the field.

For the purpose of this thesis, an SR approach was adopted to examine CS projects in India, drawing from existing literature and documented experiences of researchers and practitioners. This method was particularly suitable as it enabled a comprehensive understanding of the evolution, diversity, and distribution of CS initiatives without the need for new data collection. Previous SRs, such as those by Pocock et al. (2017) and Bautista-Puig et al. (2019), have shown how literature reviews can uncover historical trajectories, scientific outputs, and global trends in CS. Inspired by these examples, this study used a similar approach to develop the first consolidated repository of CS projects in India, addressing both historical and contemporary perspectives. Moreover, given the resource constraints, an SR offered a cost-effective alternative to primary surveys, which would have required significant funding for translation, transcription, outreach, and logistics. It also avoided the potential biases of snowball or online surveys, as demonstrated in Sekhsaria and Thayyil (2019). Sekhsaria and Thayyil (2019) sought to identify ecological CS projects across the country. While this effort was a significant step towards mapping CS activities in India, it was limited by its reliance on a network of CS practitioners already known to the researchers, which potentially restricted the breadth of insights and representation.

Thus, SR using the PRISMA framework was selected for this thesis to comprehensively and systematically search, identify, and appraise relevant data associated with ecological and environmental citizen science (EECS) in India.

2.1.3. Limitations of systematic reviews

SRs, while offering robust guidelines, are not without biases and drawbacks. First, these reviews are designed to have transparent methodologies which may inadvertently introduce biases from language bias and publication bias as the study did not consider records other than those published in English (Jansen, 2017). For example, since this particular thesis accommodates publications only in the English language, information and data published in other languages in India might be overlooked. Second, only certain information will be presented in identified resources which may result in gaps in understanding. In this case, as the study progressed, it was found that the resources identified did not provide the information needed to understand certain issues, such as the distribution of work among various stakeholders and conflicts and opportunities that arose with that. Interpretation bias may further arise during the synthesis of results, as researchers from different backgrounds might interpret findings differently (Jansen, 2017).

Thus, it was identified that further data collection was required to answer research question number 4b "What are the various roles and contributions these stakeholders assume that impact CS initiatives?", A series of key stakeholder interviews were, therefore, conducted in which stakeholders were asked about their motivations of stakeholders to initiate projects, barriers to outreach and network development, collaboration with other stakeholders, influence of governmental agencies and business on CS and their funding for sustainability of projects. This also facilitated the development of a triangulation methodology to determine the roles of stakeholders. The stakeholders to be interviewed were identified from the records identified by the SR using stakeholder network mapping in Gephi 9.2. The methodology for this is described in detail in Chapter 6.

2.2. Data collection using the PRISMA Framework

2.2.1. Protocol development and registration

As far as I am aware, this is the first SR of ecological and environmental CS in India. As such, no existing protocol exists and so a novel protocol was developed for the study. The protocol has been designed based on the PRISMA framework and adheres to its checklist as a reporting medium. The methodology has not been registered as a protocol in any databases as databases exist only for health sciences.

2.2.2. Eligibility criteria of records

To identify relevant evidence for the review, the eligibility of the records was examined on the following criteria:

1. **Years considered for records:** Records were traced as far back as possible from the date of the systematic search. This characteristic was chosen as one of the aims of the study is to understand the evolution of CS in India.
2. **Language:** Only records in English language were considered for the study. Pilot searches showed almost no publications in most Modern Indian Languages except for a blog on CS in the Tamil language. Moreover, in India, the majority of technical and scientific publications are in English (Barath, 2019). Hence, the study was restricted to publications in English.
3. **Publication status:** Only published records which were readily available online in public domains were included. This helped in easy access to the records for repeat review.

Figure 3 provides an overview of the systematic search for EECS in India using the PRISMA framework. The sections following the figure explain the steps undertaken to collect the records.

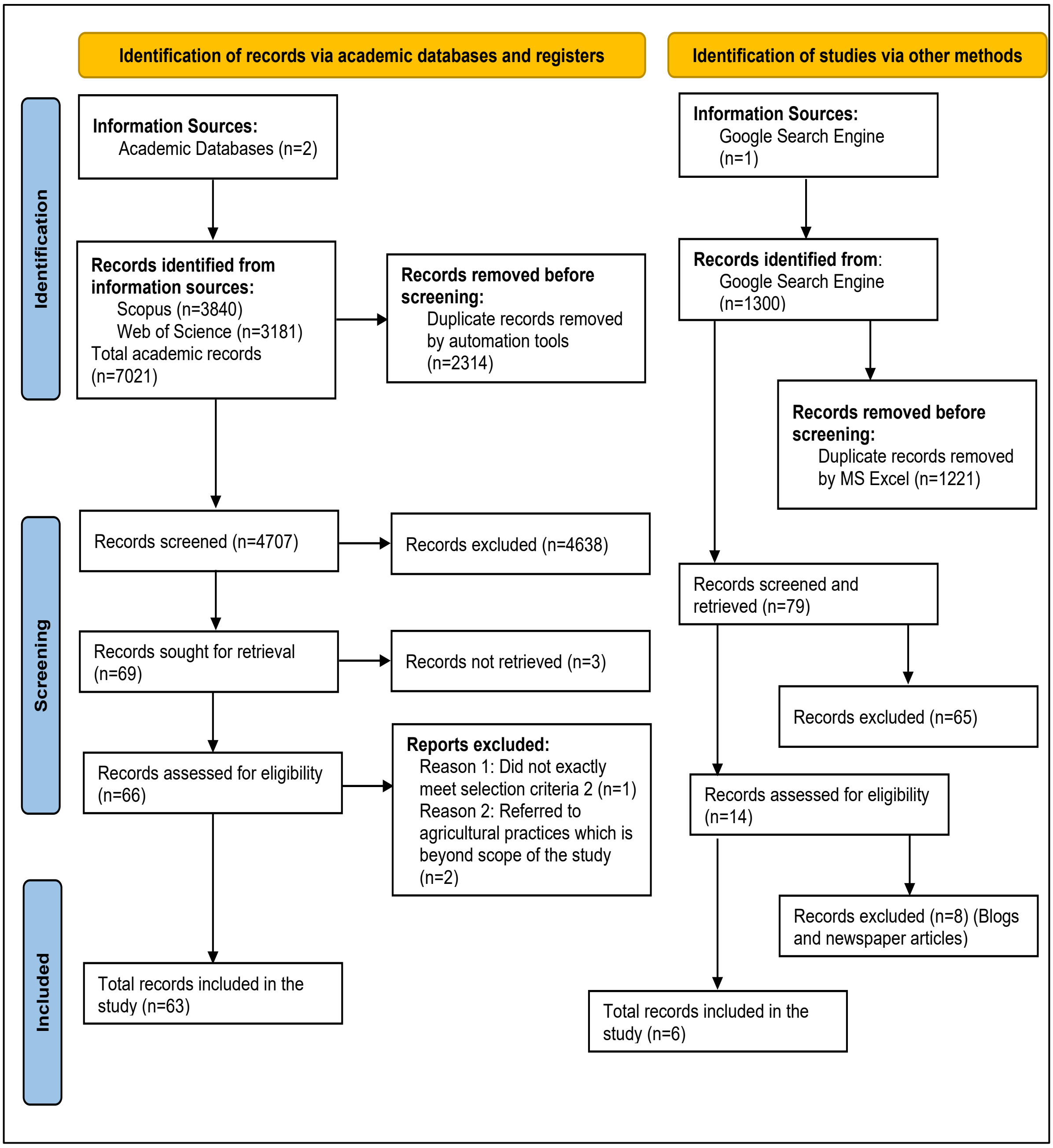

Figure 2: Overview of the PRISMA framework used for the study to collect data. Source of figure (Page et al., 2021)

2.2.3. Step 1: Identification of resources to collect data

2.2.3.1. Information Sources:

For this thesis, both academic literature (academic records) and non-academic resources (non-academic records) were accepted as records for evidence if they met the eligibility criteria. This is because not all CS projects have produced academic publications, especially if they have been recently initiated. It is important to note, therefore, that the systematic search has sourced two different sets of records with different characteristics: academic records and non-academic records.

- **Academic Records**

The information sources for academic literature consisted of two databases:

a) Web of Science (WoS) b) Scopus

These databases were chosen due to their reproducibility and consistency based on an assessment of the academic literature database and their suitability for systematic reviews (Gusenbauer and Haddaway, 2020). Gusenbauer and Haddaway's assessment also indicated a lack of precision for Google Scholar to be used in systematic and scoping reviews so this database was not used in this review.

In addition to searching these databases, back issues of one journal, Citizen Science: Theory and Practice, were also searched due to its explicit publication on CS approaches but its lack of availability in the two selected databases at the time of searching.

- **Non-academic Records**

Searches for non-academic records were carried out in Google Web Search. The non-academic records aimed to supplement the search only with the identification of ecological and environmental CS projects in India. Initial searches of both the academic and non-academic literature were carried out in May 2021 and updated on 4th April 2023.

2.2.3.2. Records identified from information sources

- **Academic Records**

To search for appropriate records online, a list of 26 search terms relevant to CS was identified. The list of search terms is important as CS has been termed and described in a variety of ways with similar meanings (Eitzel *et al.*, 2017). The list was developed from previously conducted studies on CS. The following articles were referred to develop the list of search terms: Kullenberg and Kasperowski, 2016; Eitzel et al., 2017; Pocock et al., 2017; Pateman, Tuhkanen and Cinderby, 2021.

This resulted in the development of a search query which was used to identify the academic literature from the selected databases. The search string is comprised of two substrings joined by the AND operator. The first substring comprised terms related to CS methodologies joined by the OR operator. The second is related to the focal geographic context. The search string listed below was used to search both Web of Science and Scopus. A special Google Chrome browser was created to search. This was done to reduce the influence of cookies and caches in the search.

(("Amateur Scientist") OR ("Citizen Science") OR ("Amateur Scientists") OR ("Citizen Generated Data") OR ("Civic Science") OR ("Citizen Observatories") OR ("Co-Created") OR ("Co-design") OR ("Community-Based Participatory Research") OR ("Community Monitoring") OR ("Community Science") OR ("Participatory Science") OR ("Community-Based Monitoring") OR ("Community-Based Participatory Research") OR ("Crowd Sensing") OR ("Crowd Sourcing") OR ("Participatory Data Collection") OR

("Participatory Monitoring") OR ("Participatory Sensing") OR ("Volunteer-Based Monitoring") OR ("Participatory Urban Sensing") OR ("Volunteered Geographic Information") OR ("Public Engagement") OR ("Public Participation in Science") OR ("Volunteer Monitoring")) AND (India)

- **Non-academic records**

In the case of non-academic records, each CS-related search term listed above was queried individually because Google Web Search can accommodate only 32 words at a time for a query. The search was limited to webpages published in India by using the advanced search option in Google web search. Only the first 50 URLs of each search result were collected as non-academic records.

2.2.3.3. Removal of duplicate records

- **Academic Records**

To aid the screening process, Rayyan AI, a web tool designed to help researchers work on systematic reviews, scoping reviews, and other knowledge synthesis, was used (Ouzzani *et al.*, 2016). It speeds up the process of screening and selecting studies. Rayyan helps in identifying and screening records using the filters on its dashboard. Resource information (year of publication, abstracts, author names and keywords) of academic records was extracted in RIS format and exported to Rayyan for screening.

Duplicate record removal: Rayyan automatically identifies possible duplicate records and provides a duplicate percentage i.e. the similarity of records. The de-duplicate process is accessed by using the **detect duplicate** feature in Rayyan. All 100% duplicates were detected by the software itself and were removed. However, duplicates might show a similarity percentage lower than 100%. To determine the highest percentage similarity of true duplicates for the remaining records, Rayyan help recommends reading their abstracts. After assessing the abstracts manually, records showing 96% or more duplicate percentages were taken as identical records and removed. Records with less than 96% similarity were manually re-assessed by examining the full publication. Decisions were then made by reviewer SP based on the similarity of the full text. No extra statistical assessment was conducted to find biases in the dataset.

- **Non-academic records**

A total of 1,300 URLs were collected as records from the 26 search terms. In the case of non-academic records, the URLs of the websites were collected through a Google Form for screening.

Duplicate removal: The list of URLs (records) compiled from the Google Web Search using a Google Form was downloaded as an Excel file. Duplicate records were then identified using "**special rules**" in the "**conditional formatting**" option in MS Excel. The function detects duplicate values in cells. The conditions for the cells were set to identify unique and duplicate values in the list of URLs. The duplicate records were highlighted by the function and removed. Further assessment for duplicate records was manually undertaken by reviewer SP. Out of 1300 records, 79 unique records were identified.

2.2.4. Step 2: Screening of resources to identify documents to include in the study

2.2.4.1. Selection of Records

- **Academic Records**

Selection criteria were formulated to identify records on CS from India based on the requirements of the study. Titles and abstracts of records were assessed against the following selection criteria established for this particular study. If all the below-mentioned questions (based on the selection criteria) could be answered by 'yes', the record was included.

1. Is the record referring to evidence from India? Only CS projects undertaken within the Indian geopolitical boundary as recognised in the Gazette Notification of Government of India, SO.3979 (E), dated 2 November 2019, were included. This includes records that reviewed at least one CS project from India.
2. Is there a genuine scientific contribution in the evidence found in the records? Only projects in which citizens are involved in scientific tasks, such as data collection, experiments, monitoring, etc., were included (Robinson *et al.*, 2018). This is because public involvement can be limited to outreach activities, or lack of involvement of the public in the scientific process, such as awareness campaigns.
3. Is there a consensual involvement of non-professional scientists in the evidence found in the record? Projects that only used opportunistic crowdsourcing to collect data (e.g. from mobile devices) were excluded, as these are not considered CS (Robinson *et al.* 2018).
4. Is the project related to the environment, sustainability, or climate change? Only CS projects in these domains were included. Projects related to agriculture, such as those studying crop patterns, and fertilisation techniques were not considered even though they are related to the environment and ecology as the main reviewer lacked the technical knowledge to understand the scientific process. (A total of n=57 records were rejected which were labelled as agriculture productivity-related records)

Reviewers RP, SC and SP each reviewed the first 200 abstracts independently to develop uniformity. Results were then compared and disagreements were discussed to reach a consensus and agreement over the meaning and application of the criteria (Coventry *et al.*, 2021). After establishing uniformity in the selection of journal records, the rest of the abstracts were reviewed by SP.

- **Non-academic Records**

The web pages of these URLs (records) were visited and examined to determine if they had relevant evidence. Webpages that described projects were only considered, including project databases. The selection criteria to evaluate the non-academic records were the same as the academic records.

2.2.4.2. Records sought for retrieval

- **Academic Records**

Out of the 4707 records screened, 69 records met the selection criteria after assessing their abstracts. These records were sought for retrieval, meaning the full articles, including their PDFs, were downloaded. However, 3 records could not be retrieved due to paywall barriers.

- **Non-academic Records**

Each of the identified non-academic records was manually visited and retrieved using the NCapture web browser extension for Google Chrome. The extension helps in capturing and extracting data from web and social media platforms to be easily imported into NVivo for coding and analysis.

2.2.4.3. Records assessed for eligibility

- **Academic Records**

After retrieval of the 66 records, the full articles were read to determine if the records met all the selection criteria described above, after which 3 further articles were excluded because they were written to promote CS in the agricultural sector rather than describing projects. Thus, the PRISMA framework identified n=63 records from academic databases which were relevant to the study.

- **Non-academic Records**

Of the 79 non-academic records, 14 records met the selection criteria. These records were divided into three categories based on the information presented on evidence on websites. The records referred to evidence in the form of repositories of CS projects; reports of projects and communication materials for projects; and blogs and news articles which were scientific communication to attract participants towards CS in India. The blogs and news articles (n=8) were not included as part of the review, as they were advertisement articles for projects that were already captured by the academic records. Thus, to reduce the duplicity of records, these records were not included. The total number of non-academic records selected for the study was 6 records, which included only 4 repositories of projects and 2 reports.

2.3. Results: Step 3 Inclusion of records

2.3.1. Selection of sources of evidence

Characteristics of records for selection

The records were categorised into four sources of evidence referring to CS in India. The records referred to evidence (i.e., CS projects) in the form of reporting on CS projects and their outcome, utilising data gathered by CS to report and for scientific discovery, and reviewing certain concepts, such as the motivation of participants in India, and new conceptual ideas for CS. Some evidence has been referred to by multiple types of sources as well.

1. **Records describing CS projects** (n=count of projects)**:** This source of evidence consists of two sub-groups of records. The first sub-group consists of academic records with publications related to activities or outcomes of specific CS projects. The systematic review of WoS and Scopus identified n=33 projects. The acronym **CSP-AL** has been used to denote this set of projects in this thesis.

   The second group consists of records referring to projects without academic publications. These projects were identified from non-academic resources. A total of n=34 projects were identified and selected to be part of the analysis in this thesis. The acronym **CSP-GS** is used to denote these projects in the thesis.

   To avoid duplication of projects, projects identified from academic records and project repositories (non-academic records) were reassessed for a second time to verify if there were duplicate references to the same evidence i.e. the same CS projects. This process led to the identification of 6 CS projects, which were identified multiple times in different academic records and 5 projects were identified, which were recorded by both academic records and project repositories. These projects were grouped leading to a decrease of 11 duplicate projects. Thus, a total of 56 projects were identified (33 + 34 - 11).
2. **Records referring to evidence of utilisation of data, generated by CS for scientific research** (n=count of journal articles) *(n=12)*: These articles utilised CS data but the projects themselves were not described.
3. **Records reviewing CS in India** (n=count of journal articles) *(CS-R) (n=8)*. These articles discussed various aspects of CS in India, such as its importance in monitoring environmental changes, motivation and impacts of citizen scientists, challenges in recruitment due to cultural beliefs and recommendations for good data management practices in CS projects. Two reports retrieved from Google searches were added to the collection. These records referred to evidence that assessed biodiversity conservation CS projects in India through a systematic survey and a commentary (Sekhsaria and Thayyil, 2019; Namdeo and Koley, 2021).
4. **Records describing a conceptual innovative approach for CS projects** (n=count of journal articles) *(CS-IA) (n=6)*. These articles demonstrated the potential use of technology to engage citizens in a wide range of scientific environmental endeavours. The evidence in these projects referred to very small-scale pilot projects (usually less than 4 participants) to test the technology.

The details of all the records are presented in <u>Annexure 1</u>.

2.4. Brief descriptions of methods utilised throughout the thesis

The overall aim of this thesis is to contribute to the development of a roadmap for the future expansion of EECS in India. The objective of using PRISMA for data collection in this study is to identify records and catalogue evidence of 'ecological and environmental citizen projects in India' to understand its presence and map its achievements, challenges, and stakeholders. The following questions were framed to achieve the objectives.

Table 1. Research questions and their corresponding chapters

Research Question	Chapter Number
What is the current scenario of EECS in India?	Chapter 3: An Overview of EECS in India
What are the achievements and impacts of citizen science in India?	Chapter 4: Impacts of EECS in India
What are the barriers and opportunities of CS in India and the challenges it currently faces?	Chapter 5: Barriers and Opportunities of EECS in India
1) Who constitutes the diverse array of institutional stakeholders involved in the execution of CS initiatives in India? 2) What are the various roles and contributions these stakeholders assume that impact CS initiatives?	Chapter 6: CS Stakeholder Ecosystem in India

The range of methods and datasets used in addressing these questions is summarised below. This information is expanded upon with greater detail in the relevant chapters.

Methods for Chapter 3: An overview of EECS in India

The objective of this chapter is to understand the temporal and thematic variations in CS projects in India, its distribution patterns across the country, patterns of participation across the different project types, and the basic aims and goals of the projects. The systematic review data was used to determine the temporal variations of publications on CS from India. The collated data were quantitatively analysed in MS Excel and the graphs were presented using Python.

Methods for Chapter 4: Impacts of EECS in India

The objective of this chapter is to assess and map the impacts of EECS. To achieve this, SR evidence indicating achievements, impacts and results of the CS projects was utilised. Data were collated and assessed using both quantitative and qualitative methodologies. The quantitative analysis was conducted in MS Excel to assess the cumulative impacts of the CS process with the help of the Citizen Science Impact Assessment Framework (CSIAF) (Wehn *et al.*, 2021). The qualitative analysis conducted on NVivo helped in identifying specific impacts of CS projects using CSIAF.

Methods for Chapter 5: Barriers and Opportunities of EECS in India

The objective of this chapter is to identify the barriers to CS projects in India, how some projects in India have been able to overcome them and the challenges that persist. The data was collected from the sources of evidence by using codes derived from a literature review on barriers and opportunities of CS projects across the globe and was evaluated using qualitative data analysis approaches in NVivo.

Methods for Chapter 6: CS stakeholder ecosystem in India:

The objective of this chapter is to identify the institutional stakeholders of CS projects in India to understand their influence over the political, economic, socio-cultural, technological, legal and ethical dimensions of the CS process in India. Systematic review data was supplemented through a set of semi-structured interviews with stakeholders who were identified as key nodes through a Social Network Analysis (SNA). The SNA was graphed using Gephi 9.2, a software for network visualisation and analysis.

Methods for Chapter 7: A roadmap for promoting CS in India:

The objective of this chapter is to assimilate the findings of the previous chapters to draw on a roadmap for promoting CS in India. To draw on the conclusion the findings of the chapters were evaluated using SWOT (Strength, Weakness, Opportunity and Threats) and PESTELE (Political, Economical, Social, Technology, Environment, Legal and Ethical) analysis. The resluts of the SWOT and PESTELE analysis highlighted important factors required to develop the roadmap for promotion of CS.

2.5. Conclusion

The methodology developed for this study has helped in systematically evaluating the evolution of CS, its characteristics, identifying its impacts, barriers and opportunities, and challenges in India. This would help to design an effective strategy for its promotion and expansion, by using strong logical reasoning that is guided by established frameworks to understand the gaps and prospects of CS in the country.

Chapter 3
3. An overview of ecological and environmental citizen science projects in India

"Knowing their ecosystem will be the real empowerment of the people at the grassroots,"

- **Madhav Gadgil** (Indian ecologist, writer, and environmental activist) (TheQuint, 2017)

3.1. Introduction

In this chapter, I have explored how Ecological and Environmental Citizen Science (EECS) has been used in India to date. I aimed to provide an overview of the characteristics of projects, including the socio-environmental issues they have addressed, how participants have been engaged, and the geographic distribution of projects. I also traced how the profile of projects has evolved and diversified over time. In doing this, the study provided a baseline of EECS initiatives in India, which provides a starting point for a roadmap to scaling up the method.

3.1.1. Background

India faces numerous environmental and developmental challenges. Global reports have consistently ranked many Indian cities among the most polluted in the world, highlighting the urgent need for effective management of biodiversity loss, municipal waste, and access to clean drinking water (Balasubramanian, 2018; Ghosh-Harihar *et al.*, 2019; Gugulothu *et al.*, 2022; India Today, 2022; IQAir, 2023). Moreover, the impacts of climate change and environmental degradation are evident in the increased frequency of wildfires, avalanches, and floods resulting from unpredictable rainfall patterns, which are affecting the agricultural sector, the major livelihood for 70% of the Indian population (Ahmed, Shuai and Ali, 2023; Chandole and Joshi, 2023)

India suffers from a lack of data that can be used to understand these challenges and inform local and national policy- and decision-making (Arya and Kumar, 2020; Debnath, Bardhan and Bell, 2023; Gour and Singh, 2023). CS could help reduce these data gaps, raise awareness of these issues and inform evidence-based decision-making. Over the past two decades, in other parts of the world, CS has increased in popularity to generate data and to create environmental, societal, economic, scientific, and governance change (Missingham, 2013; Eitzel *et al.*, 2017; Hecker *et al.*, 2018; Olteanu-Raimond *et al.*, 2018; Turbé *et al.*, 2019; Dowd *et al.*, 2020; Schade *et al.*, 2021; Wehn *et al.*, 2021). Researchers and policymakers have encouraged its contributions to achieving sustainability agendas such as the Sustainable Development Goals (SDGs) through monitoring and action (Conrad and Hilchey, 2011; Fritz *et al.*, 2019; Fraisl *et al.*, 2020; Quinlivan, Chapman and Sullivan, 2020; US Senate; 2015).

However, the use of and subsequent benefits arising from CS activities are not equally distributed across the globe. Currently, projects are concentrated in countries that are characterised as Annex I countries in the United Nations Framework Convention on Climate Change (UNFCCC) (i.e. industrialised nations with stable economies) or high-income countries as defined by the World Bank Group (World Bank, 2023). These countries are concentrated in North America and Europe, which are seen as being the two 'poles' of CS (Chandler, See, *et al.*, 2017; Bautista-Puig *et al.*, 2019; Njue *et al.*, 2019; Pocock *et al.*, 2019; Trojan *et al.*, 2019; Requier *et al.*, 2020; Pelacho *et al.*, 2021).

By contrast, the number of CS initiatives taking place in Non-Annex I countries (usually low- and middle-income countries characterised as having growing economies in the process of industrialisation is limited (Requier *et al.*, 2020; World Bank, 2023). A 2017 global trend assessment of biodiversity CS initiatives found only 3% of projects were in Asia, while 1% were in Africa and 1% were in Central & South America (Chandler *et al.*, 2017). This disparity is also reflected in the fact that the USA, United Kingdom, Canada, and Australia have the highest activity in publishing articles related to CS (Bautista-Puig *et al.*, 2019; Requier *et al.*, 2020) (Figure 3). Another study that evaluated participation on Zooniverse, a CS platform, indicated that the platform saw the highest participation from North America and Europe (Ibrahim, Khodursky and Yasseri, 2021). Of the Non-Annex I or low- and middle-income countries, only China has shown a substantial contribution to CS publications (Figure 4) (Pateman, Tuhkanen and Cinderby, 2021; Pelacho *et al.*, 2021).

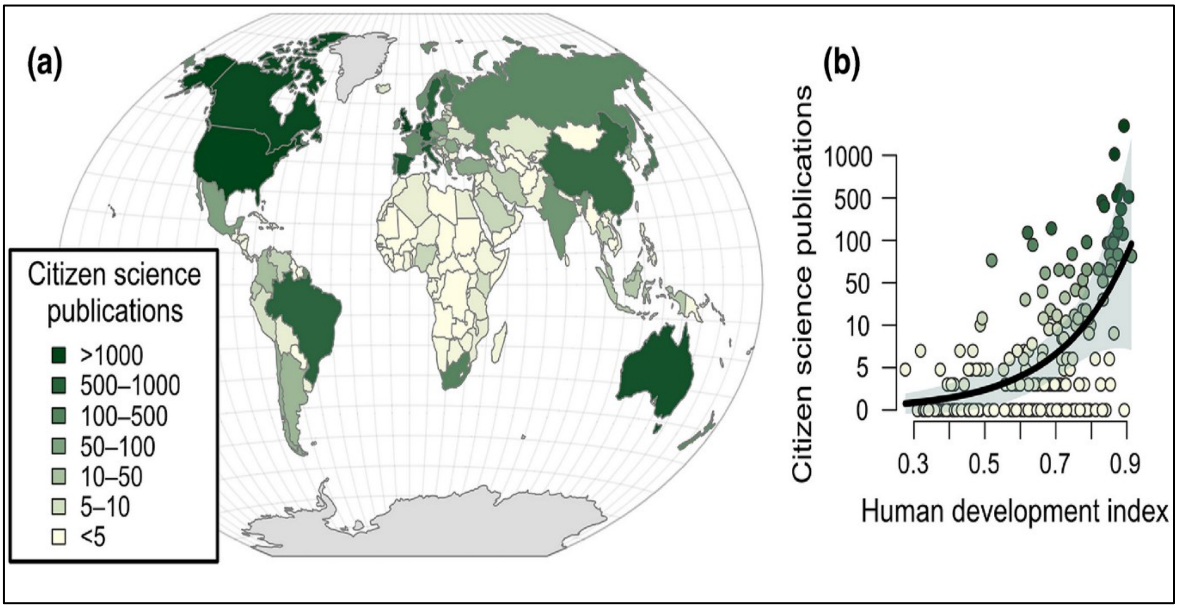

Figure 3: (a) A global overview of CS studies conducted over the past three decades shows higher number projects in the Global North mostly comprising of Annex I countries (1987–2017) (Follett and Strezov 2015). (b) Additional analysis showed a positive correlation between the number of citizen-science publications per country and its Human Development Index (HDI), according to the Human Development Report (HDR) of 2018. Source of both figures: Requier et al., 2020.

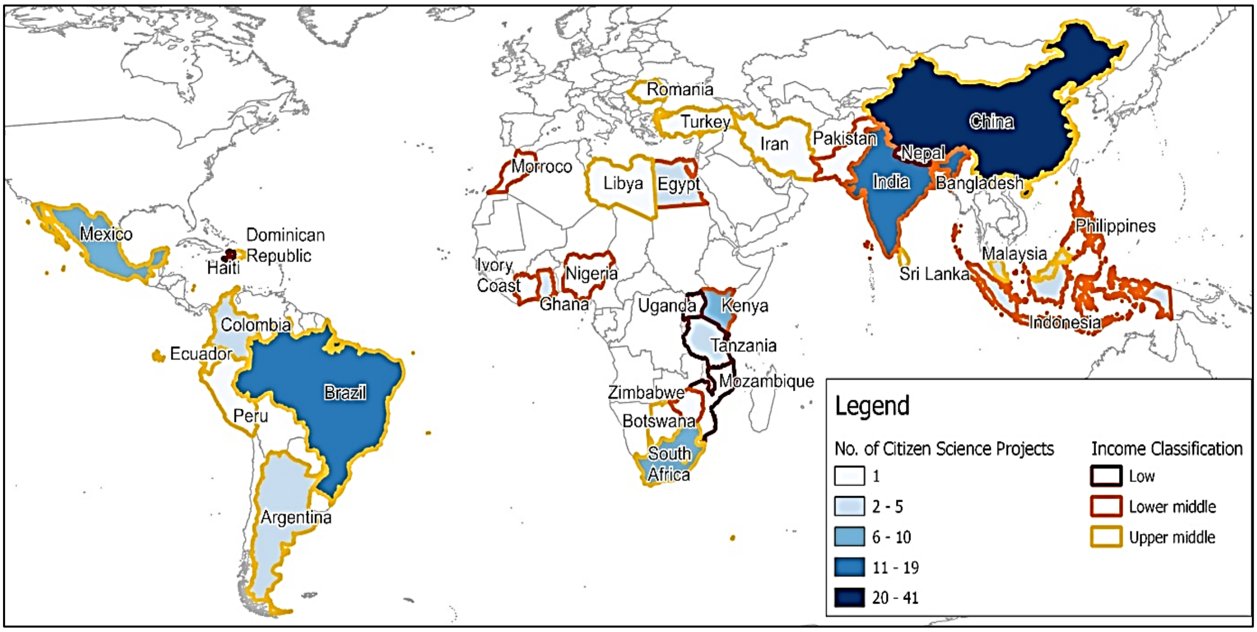

Figure 4: Distribution patterns of urban CS initiatives across low-income, lower-middle-income, and upper-middle-income countries (Pateman, Tuhkanen and Cinderby, 2021, p. 10 of 24).

A multitude of factors are likely to have driven this disparity in the distribution of CS initiatives. For example, advances in information technology and internet connectivity have been key facilitators of the growth of CS (Newman *et al.*, 2012; Requier *et al.*, 2020) and the availability of these technologies is greater in Annex I than in Non-Annex I countries (Ibrahim, Khodursky and Yasseri, 2021; Pateman, Tuhkanen and Cinderby, 2021; Pelacho *et al.*, 2021). Moreover, when looking at historical accounts of CS, it appears Annex I countries, especially in Western Europe, have been associated with participatory scientific activities for many decades (Silvertown, 2009; Dickinson, Zuckerberg and Bonter, 2010; Miller-Rushing, Primack and Bonney, 2012; Kobori *et al.*, 2016). For example, the *Transit of Venus*, a project funded by the British Empire in 1874, was supported by amateur astronomers across the globe; the Christmas Bird Count, an annual event where volunteers collect data over 24 hours, was initiated by the National Audubon Society in the USA in 1900 (Dickinson, Zuckerberg and Bonter, 2010); while Japanese courts recorded cherry blossoms over the last 2000 years which helped in understanding blooming pattern and its relation with climate change (Kobori *et al.,* 2016). These early roots of CS are reflective of structures being in place to support CS activities that continue today (e.g. volunteer support and coordination through recording societies, data verification processes etc). Furthermore, participation in these activities is embedded in at least some sections of the culture of these countries (Kam, Haklay and Lorke, 2021). In addition to this, studies have also indicated that CS publications from countries are also positively correlated with countries with Human Development Index (HDI) and all the Annex I countries have higher HDIs (Figure 3) (Requier *et al.*, 2020).

In recent years, Annex I countries have developed further supporting mechanisms for CS initiatives. The European Union (EU) has emphasised its aim to develop responsible and innovative research aligned with societal needs (Hecker et al., 2018; Bautista-Puig et al., 2019). Through its Horizon 2020 funding programme, the EU has funded many initiatives such as 'Citizens' Observatories, Collective Awareness Platforms (CAPs)' and the EU-Citizen.Science online platform, which aims to make CS initiatives and data more accessible (Roche *et al.*, 2020). Similarly, the government of the USA has shown its support for CS by forming policies such as the Crowdsourcing and Citizen Science Act of 2015-2016 (15 USC 3724) and developing platforms such as CitizenScience.gov (Sen. Coons, 2015; CitizenScience.gov, 2016). Annex I countries also supported CS activities through the establishment of facilitating organisations such as the Citizen Science Association (CSA) (now called the Association for Advancing Participatory Sciences) in North America (established in 2016) and the European Citizen Science Association (ECSA) (established in 2013). The CSA further supported the practice and theory of CS through the development of a dedicated journal (Bonney, Cooper and Ballard, 2016).

In contrast, in Non-Annex I countries, structures supporting the growth of CS initiatives are much more limited. With the recent establishment of CS associations in Asia (CitizenScience.Asia), Africa (Citizen Science Africa), and Latin America [*Iberoamerican Network of Participatory Science* (RICAP)] collaborations will increase, which can lead to more initiatives in the future. CS initiatives that do exist in Non-Annex I countries are often community-based or -led and focus on addressing local and community issues (Pocock *et al.*, 2017; Trojan *et al.*, 2019; Paul *et al.*, 2020; Fritz, See and Grey, 2022). In recent years, the establishment of the Citizen Science Global Partnership (CSGP) has shown potential in further developing the CS landscape in the Non-Annex I countries through the transfer of knowledge, experience and expertise (GCSP, no date).

Even though there have been a smaller number of CS initiatives in Non-Annex I countries, they have shown their potential to make contributions to monitoring and delivering various sustainable development policies and agendas, such as the Sustainable Development Goals (SDGs); coordinating disaster responses by providing data for rescue and recovery operations; or managing water resources (Pocock *et al.*, 2019; Paul *et al.*, 2020; Requier *et al.*, 2020; Pateman, Tuhkanen and Cinderby, 2021; Walker, Smigaj and Tani, 2021). Increasing the use of CS approaches in these countries is, therefore, likely to scale up the contribution this approach can make to tackling the dangers of climate change and environmental degradation. It is important, therefore, to understand how the scaling up of CS approaches in Non-Annex I countries can be achieved. As a starting point for this, it is important to fully understand the status quo of CS use in these countries. This is essential for understanding what the successes have been and how these have been achieved as well as identifying gaps and barriers that need to be overcome. Very few studies have systematically reviewed CS in Non-Annex I countries, although exceptions to this are Pocock et al., (2019); Waddington et al., (2019); Requier et al., (2020); Pateman, Tuhkanen and Cinderby, (2021). In this study, therefore, I systematically trace the development and uptake of CS initiatives in India which address *'socio-environmental issues'* (i.e. environmental problems that are caused by and/or impact society (Prūse, 2020; Benyei *et al.*, 2023) that have, as yet been unexplored. Specifically, I explore the extent to which CS approaches have been used; how i.e., the different kinds of socio-environmental problems they address, the geographical distribution of projects across an extensive and diverse country, who has participated and how; and why i.e., project leaders' motivations for using CS approaches.

3.1.2. Characteristics of Projects

The objective of this study was to draw on resources identified in the systematic review (Chapter 2) to provide an overview of the past and current use of CS in India. To do this, I characterised projects identified through the systematic review in different ways, which will aid in a clear understanding of the ecosystem of EECS initiatives in India, which has developed over the last two decades. The objective of evaluating each of the characteristics has been explained below.

- **Temporal dimension:** First, I examined how the number of projects using CS approaches in India as well as publications related to these have changed over time. Second, I compared changes in publication and project numbers due to global trends in CS as well as the introduction of relevant policies by the Government of India (GoI). One of the global trends reported was the increase in the number of publications in CS from 2006. This was recorded by Follett and Strezov, 2015; and Bautista-Puig *et al.*, 2019. Moreover, Follett and Strezov, 2015 also recorded that initially articles were published either as general articles on CS or specific CS initiatives. Secondly, I traced out the various environmental policies by GoI that were referred to by the initiatives in India. This is parallel to the idea that governmental policies provide a supporting structure to promote CS. National Policies in India, such as the Biological Diversity Act (BDA) 2002, Swachh Bharat Abhiyan (SBA) (Clean India Mission) (2014), the Smart Cities Mission (SCM) (2015) and the National Clean Air Program (NCAP) (2019), which were all initiated by GoI to monitor, evaluate and manage sustainable cities and environment. Though these policies have not directly referred to the CS process, however, they might be expected to influence the uptake of CS initiatives in India. These policies were selected because, during the screening process in Chapter 2, projects referred directly to BDA and SBA in their title and abstracts. Thus, bringing a scope if projects were influenced by any of the policies. Both these analyses would help in understanding the growth as well as influences that might have promoted its growth.
- **Thematic dimension:** I mapped the socio-environmental issues that were addressed by CS in India to identify particular areas of focus. Global systematic reviews observed that biodiversity and ecology-related CS initiatives were the most common (Wiggins and Crowston, 2011; Follett and Strezov, 2015; Kullenberg and Kasperowski, 2016; Pocock *et al.*, 2017; Pelacho *et al.*, 2021; Fraisl *et al.*, 2022) and this has not changed over time (Pocock *et al.*, 2017); here, I assessed if CS in India exhibits a similar pattern.

- **Geographic dimension:** India's extensive geography has fostered the development of distinct regional cultures, languages, and traditions as well as variation in sustainability achievements, literacy rates, and socio-economic conditions between states {Figure 5 (a-d)}. For example, the sustainability index, literacy rate, and GDP per capita are comparatively higher in Southern and Western India while the multi-dimensional poverty index is higher in Northern Central India compared to the rest of the country. The Northern Central India region also has lower sustainability indices, literacy rates, and GDP per capita. Here, I investigated whether these factors are related to variations in the number of projects, parallel to disparities observed between Annex I and Non-Annex I countries. Understanding the geographic distribution of CS projects across India will, therefore, help to identify possible socio-economic factors which are important in enabling or inhibiting the use of CS. A map of India is presented in Figure 6 referring to the names of different States and Union Territories in India.
  Next, I looked into how projects were distributed across urban, rural and forest areas. This helped in tracing if projects were able to reach marginalised communities who mostly reside in rural areas in India or if they are more popular in urban settings.
- **Participant dimension:** The participant dimension seeks to understand the inclusiveness of projects while recruiting participants. Through this, I tried to identify the extent to which projects conducted in India can be considered inclusive by conducting two types of analysis. Both these analyses were important for understanding if CS in India shows signs of achieving its full potential. The first analysis helped in understanding if there is a penetration of CS into various levels of Indian society and the second helped in understanding if the projects were able to integrate its participants within the scientific and decision-making process.

  The first analysis investigated inclusivity through the demographic influencing factors such as age, education, and gender background involved in CS in India. This includes the extent to which participants are representative of wider populations, which is often not the case in CS globally; for instance, the majority of environmental CS participants in the UK are white and middle-class (West, Pateman and Dyke, 2021). India, as discussed in Chapter 1, has a very complex social structure and thereby certain sections of the society are marginalised in their representation in many platforms.

  Next, I have quantitatively examined how CS initiatives were able to affect society and science, which is an integral part of the principles of CS (Irwin, 1995; Bonney *et al.*, 2009; Robinson *et al.*, 2018). For this first I considered the level of involvement of participants in the scientific process whether participation was limited to collecting data or extended to analysis, research question development, etc. These characteristics helped in understanding if the responsibilities of participants in CS were not merely limited to collecting data but extended to analysis, research question development, etc. in India. Understanding these patterns of inclusion would help to identify if CS initiatives in India had been able to integrate its participants within the scientific process (Irwin, 1995). Thus, this would indicate what has worked well so far and can be valuable for identifying the barriers and challenges that might exist.

- **Project objectives and outcomes:** Finally, I examined both the objectives and outcomes of CS projects in India. CS can have a multitude of objectives and outcomes, including generating scientific knowledge, informing policy, and/or investigating environmental issues by engaging in generating local action and influencing individual behaviour, amongst many others (Wiggins and Crowston, 2011; Kieslinger *et al.*, 2018; M. Haklay *et al.*, 2021). Identifying project goals helps to understand if project proponents are focused on utilising the full potential of CS or have a narrower view of its potential outcomes. Both project goals and outcomes were independently examined because project outcomes can be different from project goals, which can change during a project timeline due to various influencing factors (Capdevila *et al.*, 2020; Peter *et al.*, 2021). Thus, these characteristics provide a picture of both desired and actual contributions of CS initiatives in India.

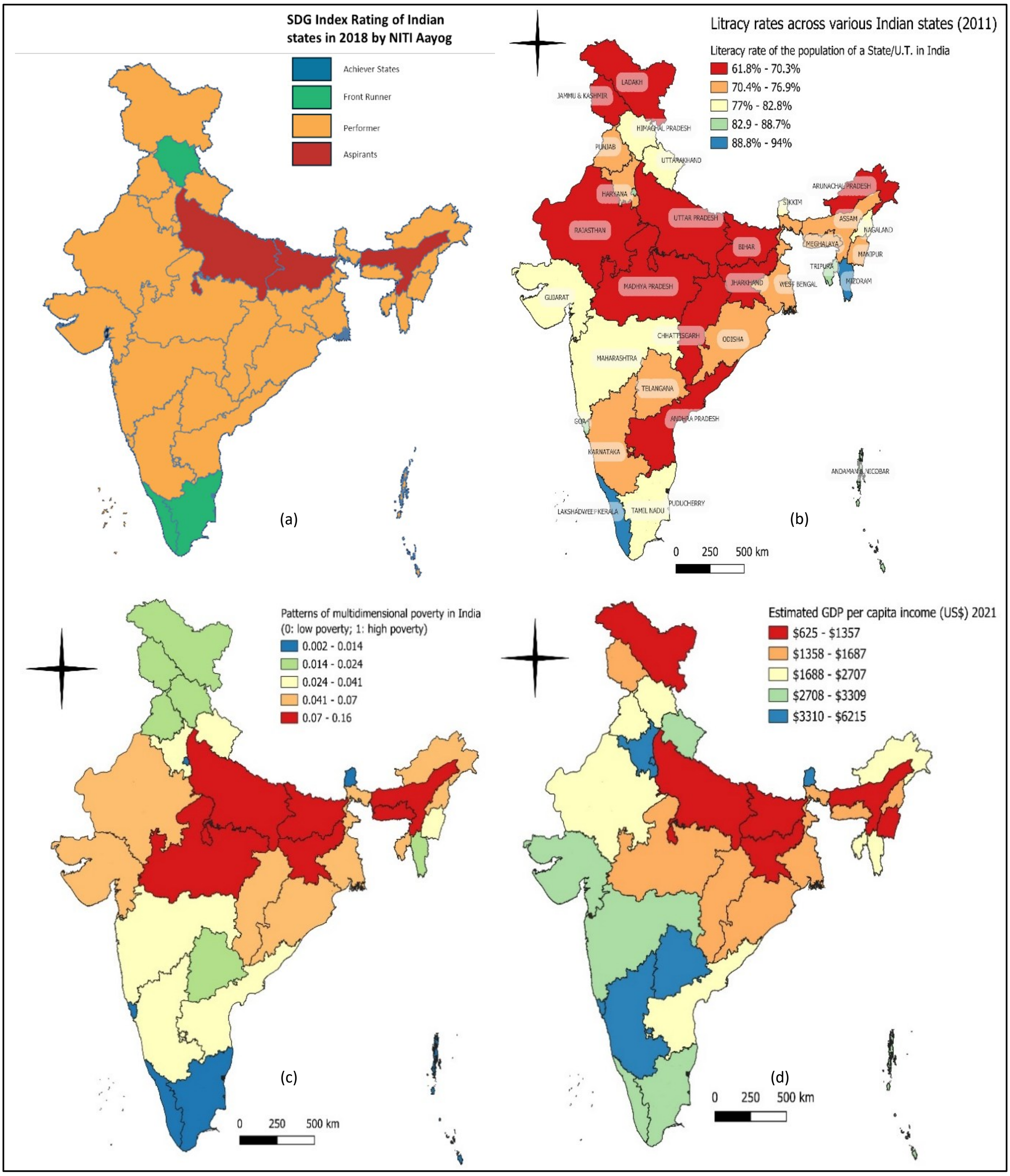

Figure 5 (a-d): a. NITI Aayog published the first baseline SDG Index which rated the various states/UTs of India. NITI Aayog was formerly the Planning Commission of India. b. The map represents the literacy rates of the population of India across its various States & UTs. c. The map illustrates the patterns of multi-dimensional poverty in India across its various States & UTs as per data shared by the Reserve Bank of India (RBI), 2024. d. The map illustrates the patterns of nominal gross domestic production per capita (GDP/capita) as per the estimates by RBI, 2024

Figure 6. The map of India with the names of its States and Union Territories as per the Gazette Notification of Government of India, SO.3979 (E), dated 2, November 2019. Source: Maps of India

3.2. Methodology

3.2.1. Selection of sources of evidence

The data for this study was extracted from the resources identified in the systematic review described in Chapter 2. For this study, four categories of records identified in the review (Section 2.3) were used:

1. records describing CS initiatives (CSP-AL+CSP-GS) (n=56)
2. records which used data generated by CS for scientific research (CS-UD) (n=12)
3. records describing participants and stakeholder experience in CS initiatives in India (CS-R) (n=8)
4. records describing CS pilot projects (CS-IA) (n=6)

3.2.2. Data Extraction and Analysis

Data were extracted and analysed for each dimension as follows.

- **Temporal Dimension:** To understand changes in the use of CS over time, I used two measures. First, project start dates were extracted from projects described in both academic and grey literature sources (CSP-AL and CSP-GS). I then traced the growth graphically to compare if there was a surge in publications and projects in India as compared to global trends in CS publications (Follett and Strezov, 2015; Bautista-Puig *et al.*, 2019).

  Similarly, a second temporal analysis was conducted using the publication dates that were extracted from journal articles or reports describing projects. This was done separately for CSP-AL, CS-UD, CS-R and CS-IA which comprised records sourced from academic databases. Assessing publication dates was relevant to understanding the change in publication patterns around CS initiatives as the process evolved in India. I then evaluated the compound annual growth rate (CAGR) of CS publications in India specifically between the year 2006-2017 and compared it with the global growth rate of CS publications at 16.14% in those 12 years (Bautista-Puig *et al.*, 2019).
- **Thematic dimension:** To identify the socio-environmental thematic areas addressed by projects, I again extracted data from CSP-AL and CSP-GS records, i.e., those that reported on a project. From these, I extracted information about the thematic focus of projects from the abstracts and keywords of CSP-AL records and for CSP-GS, the information was extracted from the homepage of project websites. I did not utilise a pre-existing thematic classification or statistical analysis such as component analysis to categorise projects as the number of identified projects was too low. Instead, I first used the extracted keywords to identify thematic areas at a broad level and then a sub-level. In addition to that, I conducted a temporal analysis to visualise changes over time in projects falling into the different socio-economic thematic areas. I calculated the total number of projects under each theme and for the period considered (1985-2023). In the end, I identified and recorded the policies that were initiated by the Government of India and referred by the projects.

- **Geographic dimension:** To understand the distribution of CS projects across India, I extracted information from records about the States and the Union Territories (UT) of India that projects were operating in. This information was extracted from CSP-AL and CSP-GS records only. Where projects were operating across the whole country, activity was recorded in all States and UTs. To understand if there is a relationship between project numbers in each State and UT and their socio-economic conditions, I conducted a Spearman's rank-order correlation. It is a nonparametric test used to measure the strength and direction of association between two ranked variables i.e., the number of projects and the values or indexes of socio-economic conditions.

  Next, to assess the distribution of projects across urban areas, rural areas and forest areas. I classified the project areas based on the classifications by the Government of India (GoI, 2015). This classification is a commonly used classification to differentiate between metropolitan cities and other urban areas. Moreover, this form of categorisation proved instrumental in identifying potential disparities in project distribution between rural and urban India (Urfi, 2012). The urban classification comprised metropolitan cities designated as X cities, such as Delhi, Mumbai, etc. A total of 8 cities are under this category. Additionally, other urban areas were designated as Y and Z cities, which consist of around 396-400 cities. For rural locations, the study referred to villages mentioned in the Census of India 2011. There are a total of 6,40,930 villages recognised in the census. The forest areas are also designated areas by the GoI and were cross-referred with government records by Google web search. To undertake this analysis, projects from CSP-AL and CSP-GS were systematically categorised based on their geographical presence in urban areas (X cities, Y, and Z cities), rural areas, or forested regions. In the case of projects that were present across multiple areas, then all applicable areas were marked. This residential classification was then cross-referred against the socio-environmental thematic areas addressed by each project using a heatmap. Since the projects can be present in all habitat classifications, a percentage method was used to represent the distribution of projects using a heatmap.
- **Participant dimension:** To determine the diversity of participants within projects, CSP-AL and CSP-GS records were searched for information about the demographics of participants, including age, education and gender. Age was most commonly reported, but this was done in a variety of ways and most often could be deduced from categorisations of participants as school students, university students (encompassing both undergraduate and postgraduate levels), adults, and professionals.

  Recognising the need for a systematic approach, a categorisation scheme was devised to amalgamate age information with the educational level of participants. The resultant age categories are delineated as follows: participants under 18 were classified as school children or students, those aged 18-25 encompassed university students, incorporating both undergraduates and postgraduates, while individuals aged 25-65 were categorised as adults or professionals, which included a diverse range of roles such as villagers, bankers, shopkeepers, housewives, etc. Finally, participants aged

65 and above were designated as senior citizens, a classification utilised whenever such information was expressly mentioned in records.

This devised categorisation scheme aimed to facilitate a more structured and standardised analysis of participant demographics. The subsequent analysis of these age categories was then employed to ascertain the extent of participant involvement in various socio-environmental thematic areas. This analysis was important to identify if there is a probable trend in recruiting participants based on age and education. In this case, a percentage-based method was utilised to represent the distribution pattern of participants from different age groups using a heat map.

Box 1: Example of extracting participant information (age) from literature.

Example

"Volunteers from local schools and employees of the HSBC bank volunteered and were trained to sample water quality monthly between December 2014 and June 2016." (Yardi, Bharucha and Girade, 2019)

This information was taken as an indication that the project was undertaken by adults aged 25-65, and school children under the age of 18 since no other information was provided otherwise.

The review was not able to address the gap in knowledge on gender diversity, as only four articles reported on it. A short report based on the extracts has been presented. These articles also described the impacts, barriers and opportunities to recruiting women in their studies. These features will be discussed in detail in later chapters.

Next, to examine participant numbers in projects, the count was divided into 5 ranges. The ranges used are less than 50, 50-100, 100-500, 500-1000 and 1000 and more. This categorisation accommodated cases, especially long-term projects, which did not furnish exact participant numbers due to periodic changes. This categorisation was inspired by the CitSci India project dashboard. The idea behind this analysis was to understand how participation in CS projects varied in India, and across projects based on their requirements.

Finally, to examine the extent to which CS initiatives are inclusive of their participants in project activities, i.e., the level of involvement of participants in project activities, I used Veekman *et al.,* (2019) categorisation which assimilates previous categorisation by Haklay *et al.,* (2013) and Bonney *et al.,* 2009 and classifies CS projects based on the type of involvement participants (Table 3). I extracted information from the records and selected the best definition that defined the level of involvement in the project. Box 2 provides an example of how information from a record was used to classify a project. Next, I compared the variability in the level of involvement that is being utilised to address the various socio-environmental thematic areas. This helped in understanding how deeply participants are involved in the scientific process. The overall patterns of distribution were identified using a heatmap where the project numbers for each level of involvement were compared against the thematic areas.

Table 2. Types of CS projects based on the level of involvement by citizen scientists (Veeckman et al., 2019).

Level of Involvement	Definition
Crowdsourcing	Members of the public offer their time and devices only.
Distributed intelligence	Members of the public sift through gathered research material and provide simple interpretations or help categorise the material.
Participatory science	Volunteers are engaged at the start of the project. They help define the problem, collect data and then help the scientists analyse the material. However, the researcher/expert has a high level of control over the analysis and interpretation.
Extreme citizen science	Researchers and volunteers develop the various steps in the research process together. But here the role of the scientist is confined to that of facilitator. The volunteers run the CS project and do the work.
Contributory project	A CS project run from the top down by research scientists, in which citizens are generally invited to gather data. The researchers decide the research focus.
Collaborative project	The research scientist decides the research focus. Citizen scientists can take part in different phases of the scientific process (e.g. analysis, interpretation, and presentation of the data gathered).
Co-created project	A co-created project begins with a question set by members of the public. All of the steps leading on from this are taken by the participants in consultation with the researchers.

Box 2: An example of inferring the level of involvement from collected records.

Example: "*One of the volunteers completed her master's dissertation on the diet of the Rusty-spotted Cat based on scat collected (Gawari 2018). This was perhaps the first systematic analysis of the diet of the species. Another volunteer completed his internship with data collected on the project and participated in analysing camera trap data."* (Mukherjee *et al.*, 2021, p. 19932)
This information was taken as an indication of a collaborative process where participants contributed to the research process and beyond just data collection. Thus, the projects were marked as a collaborative process.

Additionally, I considered training and feedback as indicators of participant experience, as these are important ways of fully integrating participants in projects (Kosmala *et al.*, 2016; Merenlender *et al.*, 2016; Rosas *et al.*, 2016; M. Haklay *et al.*, 2021). Training ensures participants have relevant skills and knowledge to collect high-quality data (Chase and Levine, 2016; Peter *et al.*, 2021) as well as promoting scientific awareness and literacy, which is a core value of CS (Bonney *et al.*, 2009). Thus, this evaluation aimed to identify whether training initiatives were an integral part of these projects.

Originally, the intention was to categorise and analyse the diverse types of training imparted to participants, as suggested by Haklay *et al.,* (2021). However, due to inconsistent reporting across records regarding the specifics of training methodologies, a binary classification system was employed. This system recorded the presence or absence of training, denoted as 'Yes' or 'No', respectively. Box 3 explains how text segments were identified to infer training using two examples.

Box 3: Two examples of how and why the above-mentioned methods were used to identify training provided to participants from collected records.

Example A: *"A one-day workshop was organised at a college in Valanchery for teachers and student representatives from 14 schools, the three arts and science colleges and the teacher's training college. The focal theme of the workshop was the protection of biodiversity at local level and the necessity and potential of involving the student and teacher community as active participants in the conservation programmes."* (Binoy, Radhakrishna and Kurup, 2017).

This indicated that training was given to the participants but did not provide a holistic picture of the training. However, records from the latest period have a more detailed description of training, as seen in Example B.

Example B: *"A brochure for citizen science training workshop was prepared and circulated among the colleges conducting undergraduate (UG) and postgraduate (PG) courses in biology, fisheries and environmental sciences in the districts Ernakulam, Alappuzha and Kottayam straddling the lake. A training manual with detailed instructions on the operation of the 3DMSD and TurbAqua was prepared. The first training workshop was conducted at ICAR-CMFRI, Kochi on 9th August 2019 in which 282 students from 16 colleges and institutions (Figure 2) participated. Both theoretical and practical training on the operation of the 3DMSD and TurbAqua were given to trainees."* (Menon *et al.*, 2021)

- **Project dimensions:**

Finally, I examined the objectives and outcomes of the projects. To do this, I extracted information from CSP-AL and CSP-GS records relating to the stated aims, goals and/or objectives of projects. I then used categorisations of the purpose of project activities from Haklay et al., (2021) to classify these (Table 4). In Box 4, Example A, I have illustrated an example of how the decision was made to refer to one of the categories of definition in Table 4 (Purpose of project activity).

Secondly, I have also determined how the data collected and knowledge generated were utilised. Again, I used a categorisation by Haklay et al. (2021), which summarises the different purposes of knowledge generated in CS (M. Haklay *et al.*, 2021). In Box 4, Example B, I have illustrated an example of how the decision was made to refer to one of the categories in Table 4 (Purpose of knowledge generated). For both of these analyses, I compared results for each of the socio-environmental thematic areas using heatmaps. As projects can have multiple goals and outcomes, a percentage-based representation was used where a particular goal or outcome was measured against the number of projects it was referred to in each of the thematic areas.

Table 3. Logic table for guiding the identification of various project activities and utilisation of knowledge generated by CS projects (M. Haklay et al., 2021).

Purpose project activities	Scientific research—scientific or research-focused activity
	Policy outcome—e.g. environmental management monitoring, action or other policy actions
	Public engagement—the main purpose is the engagement of lay people.
	Education—focus on educational outcomes.
	Game—focus on the gaming environment
	Reuse of social media—reuse of images or other information that was submitted to social media
Purpose of knowledge generated	Scientific discovery—producing a scientific research paper
	Scientific management—producing data for policymaking
	Personal discovery—personal level learning
	Local knowledge sharing—sharing local lay knowledge within the community (not necessarily with researchers)
	Alternative knowledge—non-science knowledge: e.g. perceptions and opinions
	Commercial knowledge—for commercial applications

Box 4: An example of inferring the purpose of project activities from collected records.

Example A

'This study aims to increase scientific understanding by enabling public participation in data collection and monitoring. With public support a database on the water clarity of Vembanad Lake was created, which has the potential to grow into a time-series, which can aid climate-related research in the long-term' (George *et al.*, 2019).

This information indicates that the main aim was public engagement followed by scientific research.

Example B

'During the last three decades, India has evolved several rules …. Environmental Protection Act (EPA), 1986 sections on 3,5,6,8,25, Environmental Protection Rules - 1986, Plastics manufacture, sale and usage rules, 1999, Plastic waste management rules, 2011 (Amended in 2016, 2018, 2021, 2022) and section 4 - clause 10 of Coastal Regulation Zone (CRZ) notification, 2019 are enforced from time to time……the SUPs are difficult and economically not viable to recycle….Future beach litter studies will help in monitoring the effectiveness of the ban, and dilation of the ban on other frequently occurring SUPs.' (Mishra *et al.*, 2023)

In this example, in the entire paragraph, the authors report the potential the projects hold in addressing various policies by the government. Thus the information indicates scientific management, i.e., producing data for policymaking.

3.3. Results

- **Evolution of projects based on project initiation years**

As of April 2023, the total recorded number of CS projects in India is 57. The first recorded CS project in India was in 1987. However, when examining project start dates reported in the academic and grey literature (CSP-AL and CSP-GS), it appears that the adoption of CS as a data collection methodology gained prominence in India post-2009 when at least two new CS projects were reported annually. Project initiation numbers peaked between 2016 to 2018 when at least n=6 new projects began per year. However, from 2019 onwards to 2021, the yearly initiation of projects ranged between n=3 to 5.

- **Evolution of publications**

When examining dates of publications related to CS, they first can be traced back to a safe drinking water and women empowerment project which ran in 1995, with the associated article being published in 1998 (Devasia, 1998). Between 1998 and 2015, only 2 publications reported on CS projects and their outcomes (CSP-AL) (Datta-Roy, Ved and Williams, 2009; Bachan *et al.*, 2011) both of which focused on biodiversity conservation and monitoring. However, articles reporting on CS projects (CSP-AL) started gaining momentum in 2015 with regular publications till 2023. The average time between project initiation and reporting is 5.4 years (combining short-term and long-term projects); this observed decline in project initiations and publications in recent years may be attributed to reporting delays, with outputs potentially not yet released.

The first scientific research in India utilising CS data (CS-UD) was conducted on anglers' logbooks of Masheer Fish (*Tor spp.*) between 1998-2012, published in 2015 (Pinder, Raghavan, & Britton, 2015) but no new articles were published in this category from 2015 to 2019. However, post-2019, several publications have emerged that use CS data, out of which 83% (9 out of 11) used CS observations from eBird India (Bird Count India), iNaturalist or GBIF to develop entropy models or to identify distributions of various avian species (Kumar, Sinha and Kanaujia, 2019; Singh and Saran, 2020; Dawn, 2021; Jha and Jha, 2021; Singh, Saran and Kocaman, 2021; Girish and Srinivasan, 2022; Jaiswara *et al.*, 2022; Ramesh *et al.*, 2022; Deomurari *et al.*, 2023). Notably, a 2022 study developed a landslide prediction model using data from the 'Satark' project by the Centre for Citizen Science (CCS), Pune, Maharashtra. (Kulkarni *et al.*, 2022).

The first review on CS in India (CS-R) was published in 2008, which reviewed the discontinued MigrantWatch project (Sharma, 2008). No further reviews were published until 2014 when two studies explored the motivations of citizen scientists (Rotman *et al.*, 2012; Johnson *et al.*, 2014). Reviews became more frequent from 2019 to 2023 (Figure 7), covering diverse topics such as the impact of birding CS, CS mobile applications in participatory disaster monitoring, the role of digital technology in biodiversity conservation during the COVID-19 pandemic, and best practices guidelines for data management (Aiyadurai and Banerjee, 2019; Sukhwani and Shaw, 2020; Dwivedi, 2021; Vattakaven *et al.*, 2022).

Since 2017, 9 records were identified that published innovative and potential citizen science projects (CS-IA). These projects were termed as innovative as simialr CS projects do not exist in India, however the majority of these (7 out of 9) presented new mobile phone-based apps and systems through conceptual papers with a very small-scale pilot project to collect data for environmental monitoring and evaluation projects. However, these projects open up the possibility of harnessing mobile phone applications and internet-based platforms. For instance, a project has been able to develop an app that can utilise smartphone sensors to monitor air quality by estimating turbidity levels through the camera (Middya, Roy and Das, 2021). Project proponents have also designed projects to develop multi-stakeholder interactions in collecting data and contributing to Sustainable Development Goal 6 on clean water and sanitation (Venkatesh and Velkennedy, 2023). Similarly, a geospatial solution has been developed to collect real-time geotagged data on water quality by participants, aiding initiatives like the Clean Ganga Mission (Dwivedi, 2021). Another groundbreaking project introduces India's first energy consumption monitoring tool, the 'Yo!Green' Carbon Calculator, enabling individuals and households to measure their carbon footprint (Nahar and Verma, 2018). In comparison to the global compound annual growth rate (CAGR) of publications between 2006-2017 (16.14%) (Bautista-Puig *et al.*, 2019), publications in India saw a CAGR of 9.05% (2008-2017).

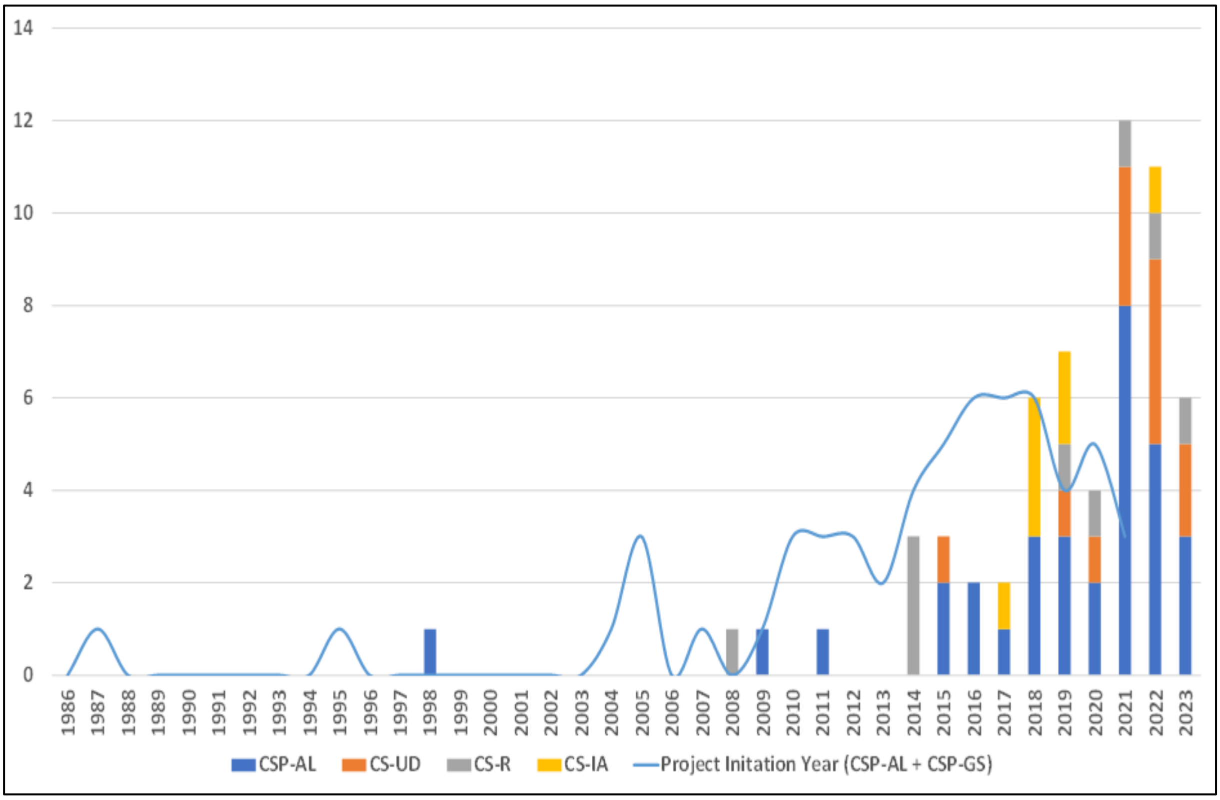

Figure 7 shows the evolution of CS initiatives and publications in India from 1987-2023.

- **Thematic dimension**

The review recorded four types of socio-environmental thematic domains to which CS has contributed to India based on the logic described in Table 5. Biodiversity conservation (BC) projects were the most common projects (n=43) followed by environmental monitoring and evaluation (n=11); disaster monitoring and management (n=3) and transdisciplinary (n=2) projects. The first recorded CS in India was the Asian Waterbird Census project which began in 1987 (Vargiya, Jethva, & Pandya, 2022).

Table 4. Diversity of CS projects identified in India (based on the socio-environmental issues addressed by the projects)

<table>
<tr><th>Logic</th><th>Level 1 Classification</th><th>Level 2 Classification</th></tr>
<tr><td>The project referred to collecting data on biotic factors, i.e. species of flora or fauna, and/or their conservation</td><td>Biodiversity Conservation (BC) n=41</td><td>Class (taxonomy) to which the investigated biotic factor belongs:
Types of projects
<table>
<tr><td>All Taxa</td><td>n=3</td></tr>
<tr><td>Amphibians</td><td>n=2</td></tr>
<tr><td>Arthropod</td><td>n=6</td></tr>
<tr><td>Avian</td><td>n=10</td></tr>
<tr><td>Invasive species</td><td>n=1</td></tr>
<tr><td>Mammals</td><td>n=6</td></tr>
<tr><td>Marine biology</td><td>n=3</td></tr>
<tr><td>Pisces</td><td>n=1</td></tr>
<tr><td>Plants</td><td>n=3</td></tr>
<tr><td>Plants (Invasive species)</td><td>n=1</td></tr>
<tr><td>Reptilia</td><td>n=6</td></tr>
</table></td></tr>
<tr><td>The project referred to collecting data on abiotic factors, i.e. water, air, temperature, humidity, etc.</td><td>Environmental Monitoring & Evaluation (EME) (n=10)</td><td>The abiotic factor under investigation:
Types of projects:
<table>
<tr><td>Air Quality Monitoring</td><td>n=1</td></tr>
<tr><td>Beach litter monitoring</td><td>n=2</td></tr>
<tr><td>Municipal Waste Management</td><td>n=3</td></tr>
<tr><td>Noise Monitoring</td><td>n=1</td></tr>
<tr><td>Sanitation</td><td>n=1</td></tr>
<tr><td>Water Quality & Management</td><td>n=3</td></tr>
</table></td></tr>
<tr><td>The project referred to a disaster induced by a change in environment or climate e.g., landslide, sea-level rise, etc.</td><td>Disaster Monitoring & Management (DMM) (n=2)</td><td>Disaster as referred by project proponents:
Types of projects:
<table>
<tr><td>Climate Adaptation</td><td>n=1</td></tr>
<tr><td>Forest Fire</td><td>n=1</td></tr>
<tr><td>Landslide Prediction</td><td>n=1</td></tr>
</table></td></tr>
<tr><td>The project has referred to more than one level 2 classification listed above e.g., projects monitoring both biodiversity and water quality.</td><td>Transdisciplinary (TDS) (n=2)</td><td>Class, abiotic factor, disaster referred by project proponent
Types of projects:
Avian and Water Quality Monitoring (n=2)</td></tr>
</table>

The biodiversity conservation (BC) theme was further subdivided into 9 sub-level categories based on the phylogenetic Class addressed by the respective projects. Notably, avian CS projects accounted for the highest number (n=10) of BC projects, making these the most prevalent. Growth in the number of BC projects was seen after 2004 following the enactment of the Biological Diversity Act, 2002 (BDA) but whether there was a direct influence of this policy on CS initiation requires further exploration. Out of 41 BC projects, only the India Biodiversity Portal (IBP) project explicitly mentioned its development along the lines of BDA (Vattakaven *et al.*, 2016).

In the case of environmental monitoring and evaluation projects (EME), CS has been used to address issues related to air pollution (Middya, Roy and Das, 2021), beach litter monitoring (Owens *et al.*, 2022; Mishra *et al.*, 2023), municipal waste monitoring and management (Jha *et al.*, 2017; Nagendra, Lakshmisha and Agarwal, 2019; Shipingana, Shivaraju and Yashas, 2022), noise monitoring (Kumar, Mukherjee and Singh, 2017), and water quality and management (Devasia, 1998; Jadeja *et al.*, 2018; Lekshmi *et al.*, 2021). The possible influence of the *Swachh Bharat Mission* (Clean India Mission) 2014 can be seen with the introduction of projects related to municipal waste post-2014. The mission has been an instrumental policy in promoting sanitation and hygiene in India. Jha *et al.*, 2017, stated that their project was developed in line with the *Mission* and the mobile application was launched by government officials to commemorate the Mission in 2016. In the case of both of the beach litter assessment projects, project activities were undertaken as part of International Coastal Clean-up Day (Owens *et al.*, 2022; Mishra *et al.*, 2023).

The first disaster monitoring and management project (DMM) identified was a forest fire monitoring effort by the Jammu & Kashmir Forest Department involving their rangers and citizens (Saran et al., 2020). The second project focused on sea-level change adaptation and used CS as a process of data collection to make informed decisions (Khan, Kumar and Chella, 2022). The latest projects used land-slide data collected by citizen scientists to identify landslide hotspot areas. Both the transdisciplinary projects (TDS) monitored both the biodiversity and water qualities of lakes (Yardi, Bharucha and Girade, 2019; Menon et al., 2021). Overall, compared to BC projects, the number of projects in other thematic areas is very few, especially in the case of DMM, and TDS projects.

- **Geographical distribution of projects across the country**

There was variation in the distribution of socio-environmental CS projects between India's States and UTs. Projects are primarily concentrated in the Western and Southern regions (Figure 8), with Maharashtra having the highest number of projects (n=27), followed by Tamil Nadu (n=23) and Kerala (n=22). In terms of thematic distribution, BC projects were present all over India in different variations, with Maharashtra and Tamil Nadu having the most (n=20 each) in this thematic area. In the case of EME projects, they were present in several states, including Maharashtra, Karnataka, Kerala, Tamil Nadu, West Bengal, Odisha, Punjab, Uttarakhand, Gujarat, and Rajasthan. DMM projects were observed in Maharashtra, Tamil Nadu, and Jammu & Kashmir. Only Kerala and Maharashtra had TDS projects. Notably, Maharashtra featured utilisation of CS in all four thematic areas identified for this study.

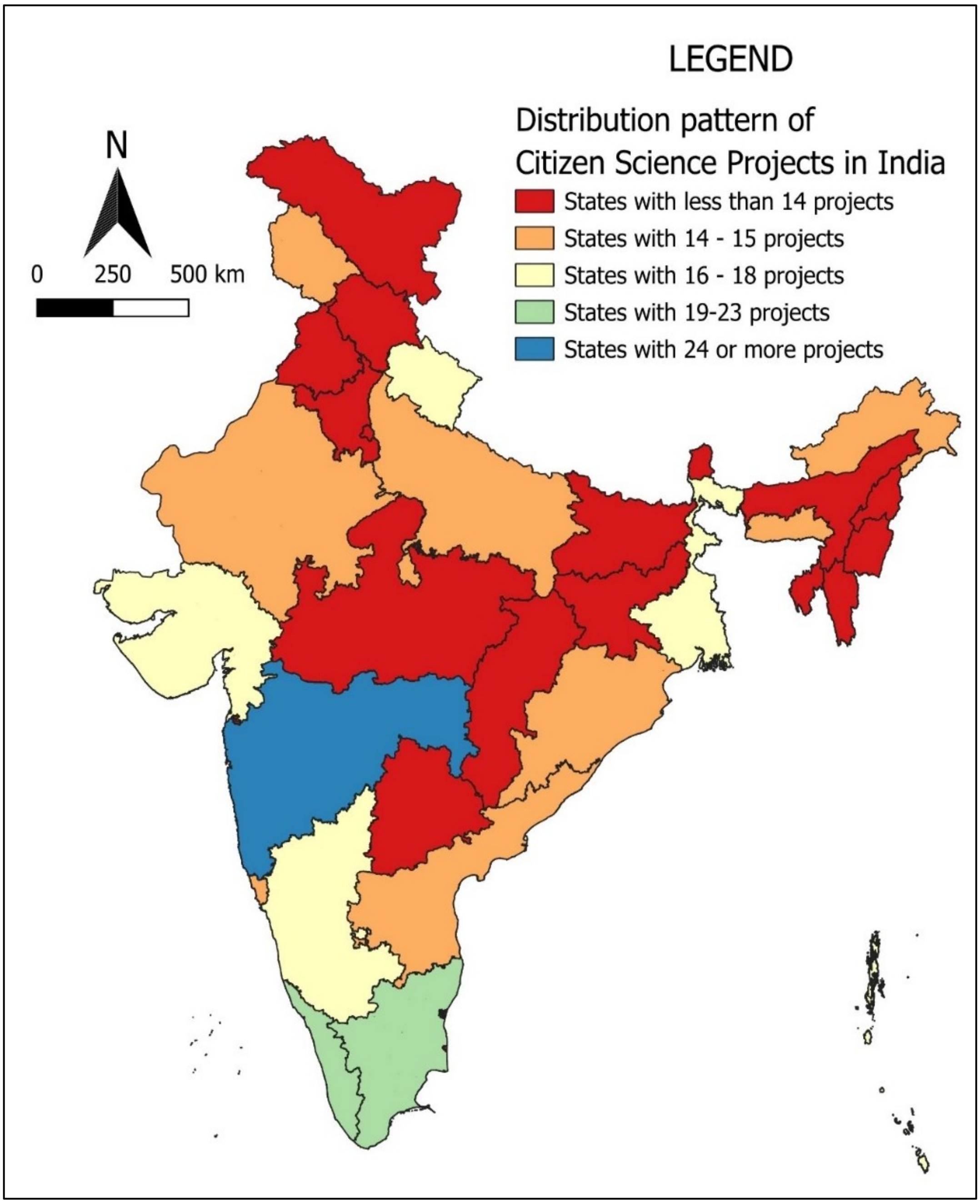

Figure 8: Distribution of CS initiatives across India (including country-wide CS projects)

- **Representation of project across different areas**

In the context of project distribution, a notable pattern emerges where the number of projects is highest in urban areas (Figure 9). Y and Z cities account for 52% of the project, closely followed by X cities at 48%. It has to be noted that the number of X cities is very few compared to Y and Z cities in India. Rural areas have 42% of the projects, indicating a substantial engagement with local and indigenous communities. Additionally, designated forest areas contribute significantly, with approximately 47% of the projects potentially open to collect data from these ecological sites.

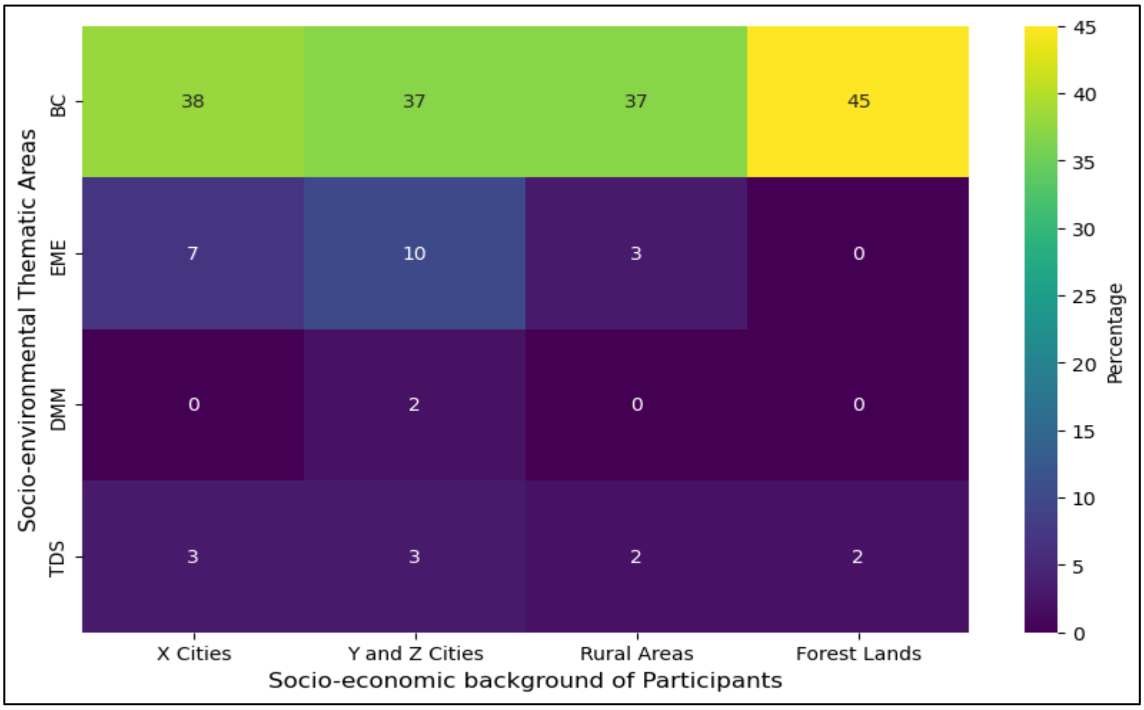

Figure 9: Distribution patterns of project sites of CS projects in India across various socio-environmental thematic areas.

- **Correlation test between the number of projects and socio-economic indicators of Indian States and UTs**

The Spearman's correlation test (Table 6) showed a weak positive correlation between the numbers of CS projects vs. GDP per capita of states (0.323) and CS projects vs. the SDG Index (0.319). The significance level for both economic development and the SDG Index was marginally above the conventional threshold of p-value (0.051 & 0.055 respectively). However, this does not concretely establish the possibility of influence. In the case of CS projects vs. literacy rate and CS projects vs. MPI, no statistically significant correlation was observed.

Table 5. Spearman's Correlation test between the numbers of projects and socio-economic indicators of Indian States and UTs

			Number of CS Projects	Literacy Rate	GDP/Capita	MPI	SDG Index 2018
Spearman's rho	Number of CS Projects	Correlation Coefficient	1.000	.103	.323	-.070	.319
		Sig. (2-tailed)	.	.545	.051	.683	.055
		N	37	37	37	37	37
	Socio-economic conditions of	Correlation Coefficient	.319	1.000	1.000	1.000	1.000
		Sig. (2-tailed)	.055	.	.	.	.

			Number of CS Projects	Literacy Rate	GDP/Capita	MPI	SDG Index 2018
	States and UTs of India	**N**	37	37	37	37	37

- **Representation of participants concerning age and education**

The distribution of various age categories across the different thematic areas is depicted in Figure 10. Notably, 80% of the projects under the biodiversity conservation thematic area actively engaged participants across all age groups (Figure 10). The predominant age range for recruitment encompassed students from colleges and universities (18-25 years) and adults within the 25-65 age bracket. The review underscores the prevalence of university students as the most recruited participants in Indian CS projects.

Almost all BC projects encouraged participants of all ages to join them. School children are generally recruited through schools with the assistance of teachers to lead them (Binoy, Radhakrishna and Kurup, 2017; Schuttler *et al.*, 2019; Ramaswami, Sidhu and Quader, 2021). These projects were directed towards the youth to develop an activity-based education tool or to promote environmental awareness among them. Young adults i.e., undergraduate or post-graduate students including PhD students are generally motivated to join biodiversity CS projects to help their careers (Johnson *et al.*, 2014; Mukherjee *et al.*, 2021). Their specialisation is usually closely related to this theme.

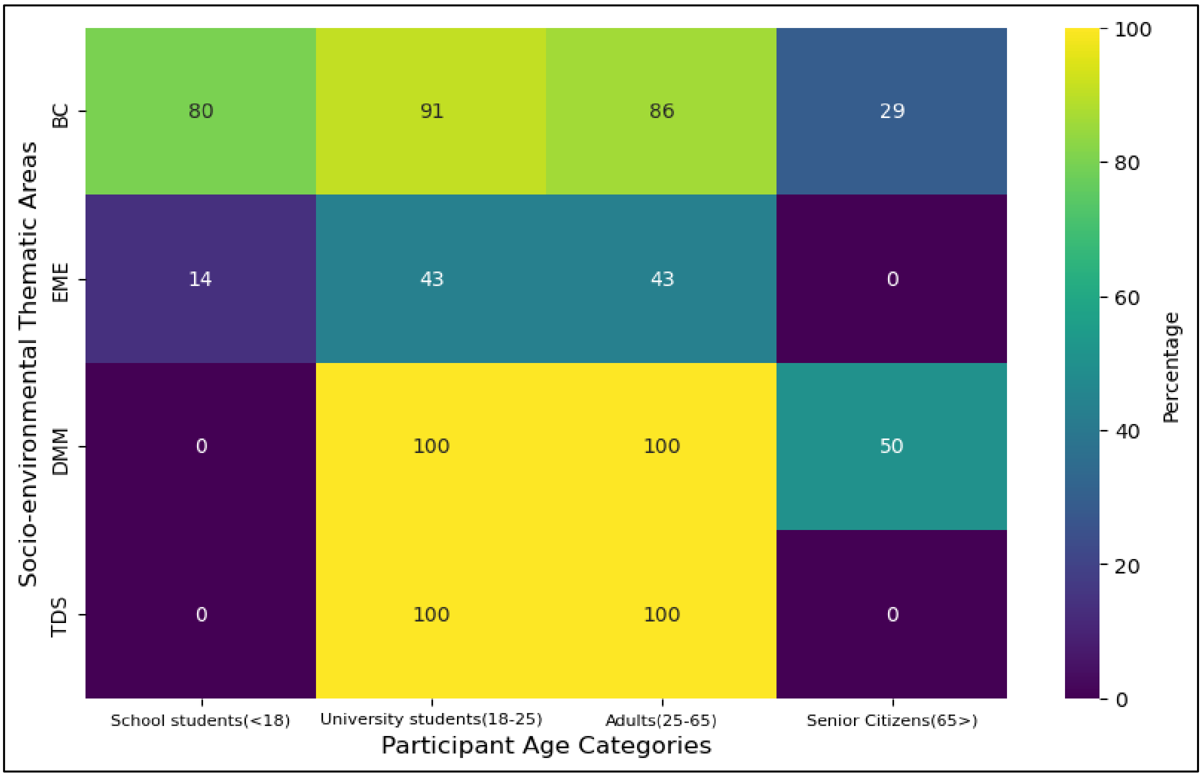

Figure 10: Distribution patterns of the age of participants of CS projects in India across various socio-environmental thematic areas.

- **Representation of projects concerning the number of participants in projects**

The assessment of the number of participants indicated recruitment of volunteers was conducted based on the project requirements. This is because overall there is no clear distribution pattern across the number of participants Figure 11. In terms of thematic areas, the review showed that BC projects usually have participants between 500-1000, while EME projects are usually smaller with less than 50 participants. The study found that a high number of participants i.e., above 1000, was recorded for projects undertaking blitz events (i.e., a large number of participants join a project for a short period) or very long-running projects. Projects with less than 50 participants were usually localised and targeted local socio-environmental issues.

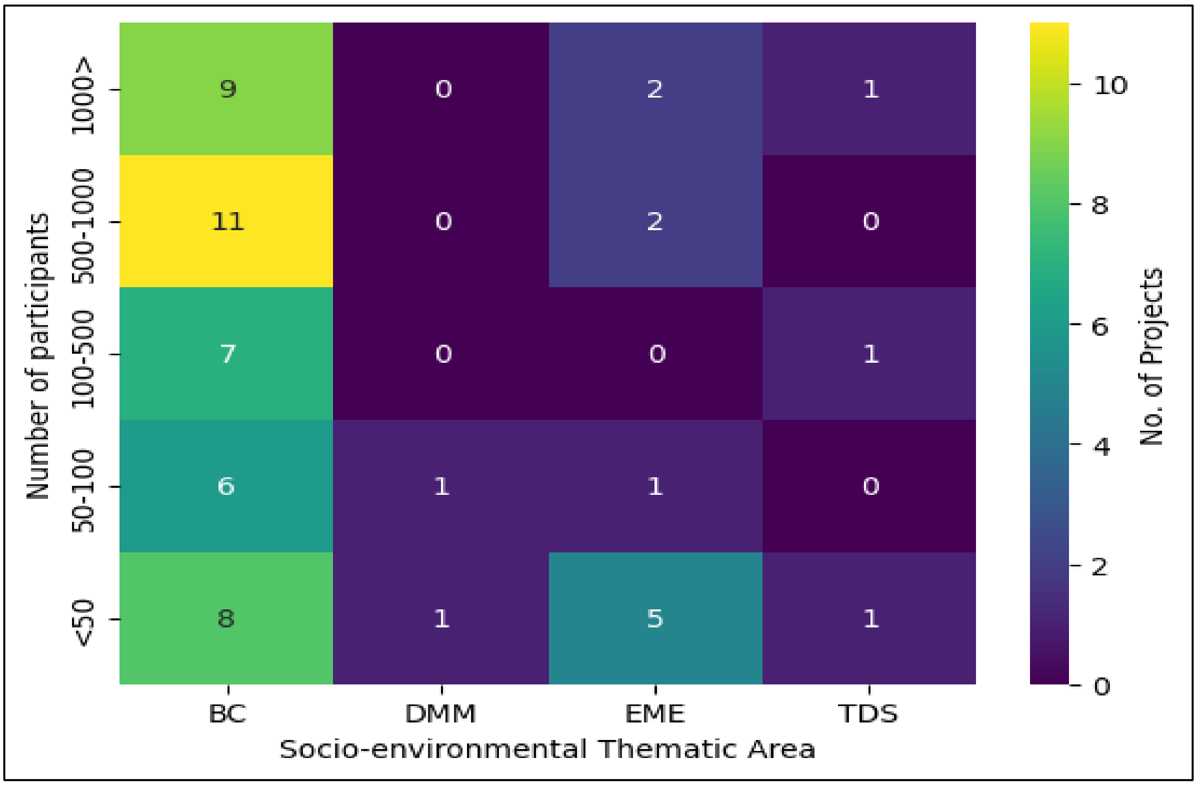

Figure 11: Participation numbers of volunteers of CS projects across different socio-environmental thematic areas.

- **Representation of participants concerning gender**

Only four projects directly reported on gender diversity. Of these 4 projects, 2 projects were related to municipal waste management (Nagendra, Lakshmisha and Agarwal, 2019; Shipingana, Shivaraju and Yashas, 2022). In these projects, the female participation rate was higher; Nagendra, Lakshmisha and Agarwal, 2019 found 52% of their participants to be women (housewives), and Shipingana, Shivaraju and Yashas, 2022 found 63% of their participants were female. In the case of air pollution, the project had 35% female participants and the remaining 65% were male participants (Middya, Roy and Das, 2021). The last project to present gender diversity was the climate adaptation project, which saw 50% attendance from both gender groups.

- **Degree of involvement of participants**

In the context of the level of involvement in CS projects in India, a predominant majority falls under the contributory project category 88% of all projects. Thematic analysis reveals that a substantial number (n=40) of the biodiversity conservation CS initiatives aligned with the contributory model. Furthermore, seven environmental monitoring and evaluation projects also followed a contributory approach (Figure 12). Apart from contributory models, other recorded engagement models included participatory science, collaborative projects, and distributed intelligence.

A thematic examination of the participatory science project reveals that it was adopted by two environmental monitoring and evaluation initiatives and only by one biodiversity conservation project. In the case of the collaborative project category, there was one project each from environmental monitoring and evaluation and biodiversity conservation thematic area. Only one project from the disaster monitoring and management thematic area showed characteristics of distributed intelligence. Notably, none of the EECS projects in India displayed attributes of extreme CS, crowdsourcing, or co-created projects based on the collected data.

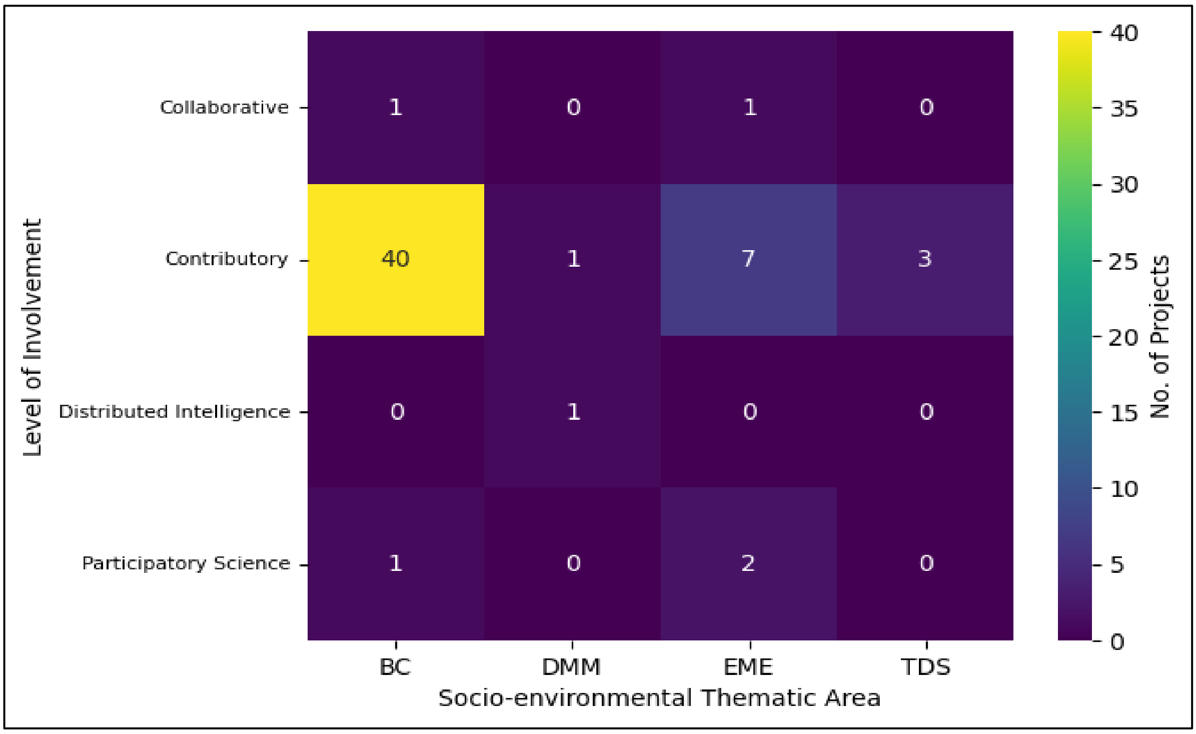

Figure 12: Degree of involvement of participants in different types of CS projects.

- **Training provided to participants:**

Most of the projects (79%) did not mention whether training was provided to participants. Only eleven projects reported providing training to participants. Training was provided through workshops constituting multiple sessions and included data collection through different techniques such as GPS, Mini Secchi disks, etc.

- **Purpose of the project activities**

Scientific research is the main aim of the majority of the projects (81%) followed by policy outcomes (74%) and public engagement in environmental awareness (59%). BC projects concentrated mostly on scientific research, while the majority of EME projects have indicated policy outcome as their leading purpose over scientific research and public engagement (Figure 13).

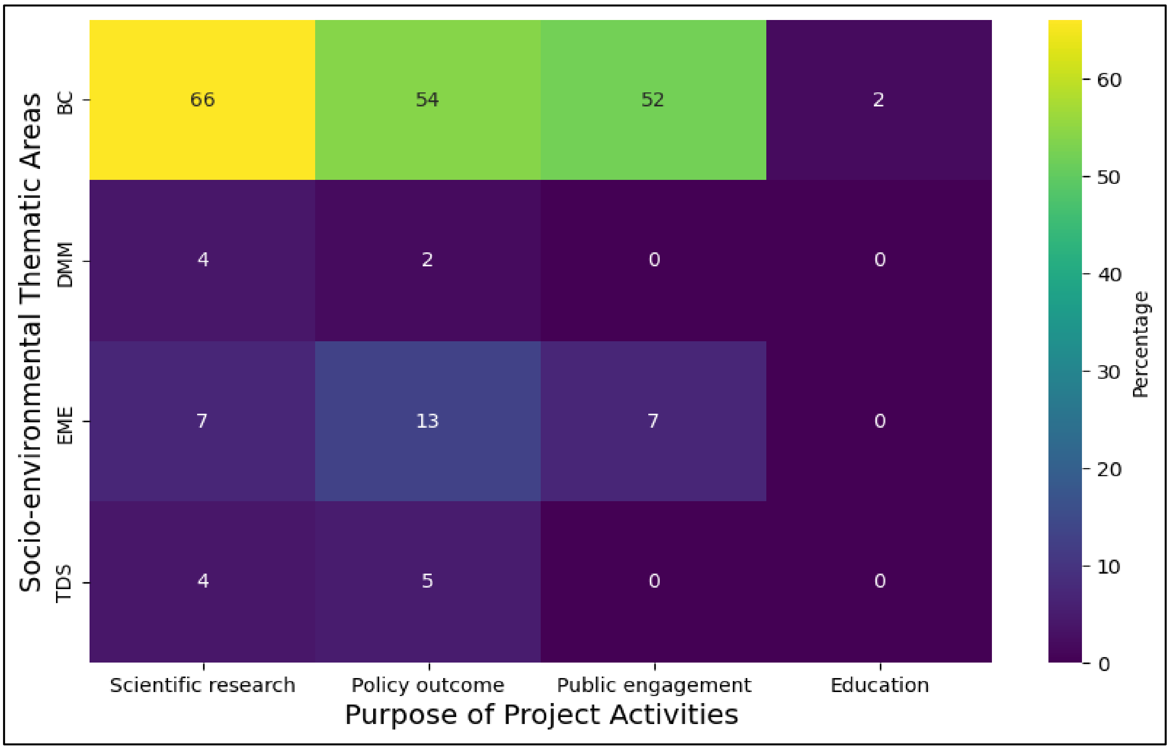

Figure 13: Distribution of purpose of project activities undertaken by various initiatives in different socio-environmental thematic areas

- **Purpose of knowledge generated by the project**

The purpose of the knowledge generated by the projects was for scientific management (81%), followed by scientific discovery (72%). A small percentage (11%) of projects also aimed at sharing the knowledge generated as local knowledge. The study found that no project indicated the knowledge generated by their projects was utilised in personal discovery, developing alternative knowledge or used for commercial applications (Figure 14).

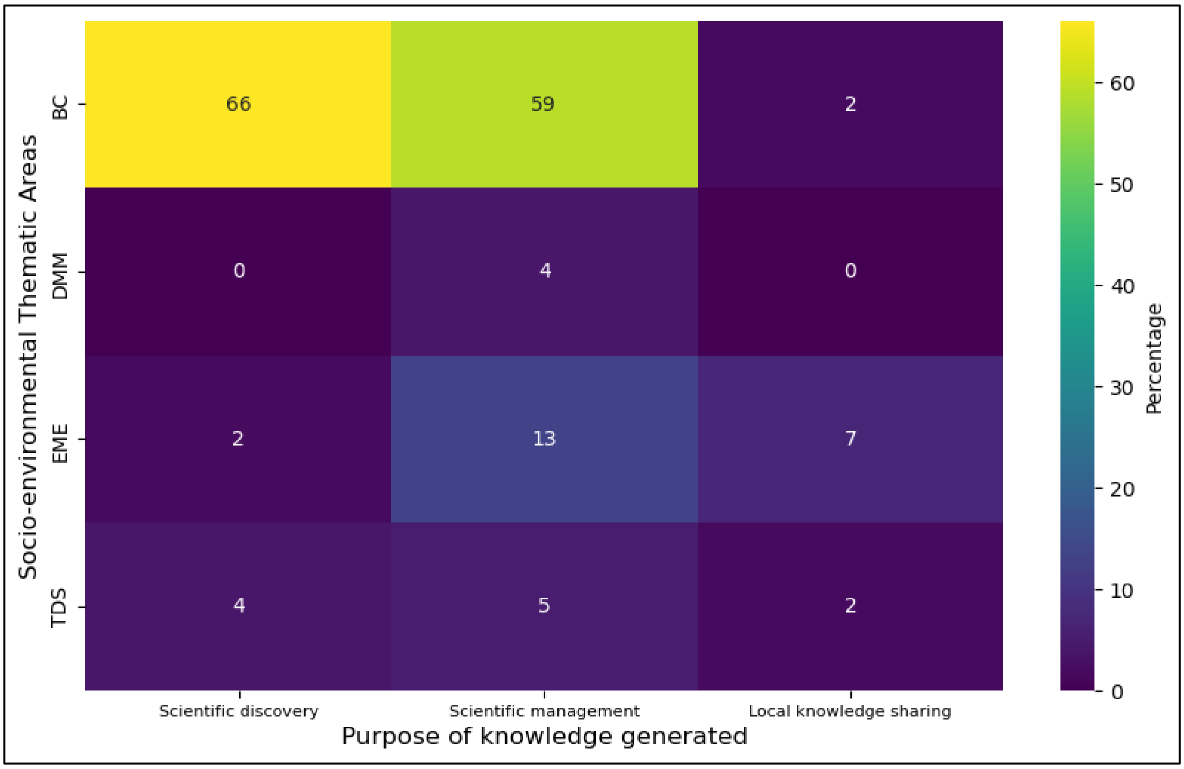

Figure 14: Project outcomes in terms of thematic domains

3.4. Discussion: Key Findings of the Systematic Review

3.4.1. Key findings on the evolution of CS projects in India

Citizen science in India traces its origins to the Asian Waterbird Census in 1987, marking a nascent stage in its development. However, the substantial establishment of CS projects in the country gained momentum only from the mid-2000s, with a prominence surge in publication since 2013. The post-2013 period witnessed a gradual rise in the diversity of publications, suggesting a plausible correlation with the increase in the number of CS projects around the globe (Pelacho *et al.*, 2021). The growing diversity of publications reflects the expansion and maturation of CS initiatives in India. This is reflected by studies undertaken by practitioners to study the needs and requirements of their participants (Johnson et al., 2014; Radhakrishna, Binoy and Kurup, 2014; Mukherjee et al., 2021), thereby contributing to a deeper understanding of CS dynamics.

Moreover, the role of government policies in shaping and fostering the growth of CS in India is evident. A notable shift in the number of biodiversity conservation projects was observed following the enactment of the Biological Diversity Act (BDA) in 2002. This policy appears to have catalyzed steering the trajectory of CS initiatives within the country.

3.4.2. Key findings on the current status of CS projects in India

The review identified a distinctive skewness in the distribution of addressing socio-environmental issues. Biodiversity conservation projects, particularly those related to birding, have dominated the landscape. This trend aligns with the global patterns where biodiversity-related projects hold popularity (Follett and Strezov, 2015; Pocock *et al.*, 2017; Pelacho *et al.*, 2021).

Geographically, the projects are concentrated in Western and Southern India, with Maharashtra, Kerala, and Tamil Nadu, emerging as prominent hubs. The regional distribution indicated imbalances in project presence; however, it did not show correlation patterns of being influenced by socioeconomic conditions.

Next, the study found that project proponents tend to heavily recruit university students, mainly undergraduates and postgraduates who are motivated to contribute to biodiversity conservation projects. Also, the younger generations have a higher probability to participate in these projects in India where the age range is from school children to individuals around the age of 40. This can be due to their accessibility to better education. The rate of accessibility to education in India has been rapidly rising each decade, which means that younger generations have better access to education as compared to their older generation which can motivate them to volunteer (Little, 2010; Honkalaskar *et al.*, 2014; George *et al.*, 2019).

Despite this trend, participants from diverse backgrounds have engaged in CS projects. Citizen scientists in India represented a spectrum encompassing rural communities (farmers, fishermen, tribes) and urban professionals (bankers, engineers, housewives). Although reporting on gender diversity was limited, both the projects that provided data indicated a predominant female presence in waste management projects, which I infer as potentially influenced by cultural roles defining women's involvement in household management (PEW, 2022), however, this requires further investigation.

In terms of level of involvement, the review unveiled a prevailing top-to-bottom structure in CS projects, largely influenced by researchers. Participants are mostly contributing to projects through data collection across all socio-environmental issues. Notably, there is a lack of extreme CS or co-created projects, indicating a predominant influence of researchers and professional scientists in shaping these initiatives.

A key finding was the lack of comprehensive data on participant training. Training is pivotal for understanding data validity, ensuring good quality data and facilitating knowledge transfer to participants. However, projects which included training components usually delivered have demonstrated positive impacts on participants' lives such as empowering them with knowledge and skills through workshops and training (Johnson *et al.*, 2014; Mukherjee *et al.*, 2021; Pradhan and Yonle, 2021).

3.4.3. Key findings of current utilisation and contribution of CS projects in India

The study showed that data and knowledge generated by CS initiatives in India are predominantly utilised for scientific research, aid policy outcomes, and engage the public in creating awareness to address socio-environmental issues. This depicts a multifaceted potential impact of CS on various socio-environmental issues that manifest in India. The review illustrates that socio-environmental issues related to biodiversity conservation were the first to utilise CS and have most extensively used the process to contribute to society and science. Some of the initial projects, for example, the participatory elephant monitoring by the community in 2004, were not just limited to data collection but also helped in tackling the livelihood issues of local communities arising from human-wildlife (elephant) conflict (Datta-Roy, Ved and Williams, 2009).

The biggest contribution of CS initiatives, especially biodiversity conservation projects, in India, has been its role in addressing critical ecological data gaps over the last two decades. This significant role is highlighted by the scientific outputs and contributions by Pinder, Raghavan, and Britton (2015), Mujumdar et al. (2020), Dawn (2021), Ramaswami, Sidhu, and Quader (2021), Jaiswara et al. (2022), Vargiya, Jethva and Pandya, (2022), and Only (2022) towards developing baseline data on various flora fauna, especially birds of India. These initiatives and studies have been instrumental in developing baseline studies and shaping a more comprehensive understanding of India's ecological landscape. For example, the Asian Waterbird Census (AWC) has been able to influence policies such as the National Action Plan for Aquatic Ecosystem Conservation and the National Action Plan for Migratory Birds and their Habitats in the Central Asian Flyway (Vargiya, Jethva and Pandya, 2022).

3.4.4. Key findings on the potential contribution of CS in India

CS projects in India have significant potential to contribute to national policies aimed at addressing socio-environmental issues and challenges. For example, projects have been developed that are aligned on the lines of *Swachh Bharat Abhiyan* (Clean India Mission) and SDGs to collect and generate data relevant to climate change adaptation, mitigation strategies, sanitation practices, etc. (Jha *et al.*, 2017). Innovative and pilot projects since 2017 have shown that there is a scope to expand CS into monitoring air and water quality, noise pollution, and other environmental parameters. These projects provide valuable data for urban planning, infrastructure development, and environmental management strategies. Furthermore, these projects can aid in compliance with pollution monitoring standards set by the Central Pollution Control Board (CPCB) of India or state pollution boards and identification of emission sources of pollutants (Kumar, Mukherjee and Singh, 2017; Ghosh *et al.*, 2019; Middya, Roy and Das, 2021). Thus, from the study it can be inferred that these projects can potentially be used to aid policies such as the National Clean Air Program, Swachh Bharat Abhiyan, Smart Cities Mission, Atal Mission for Rejuvenation and Urban Transformation, Ganga Rejuvenation Plan, etc. to meet their goals

(Ravindra and Mor, 2018; Ghosh *et al.*, 2019; Dwivedi, 2021; Lekshmi *et al.*, 2021; Middya, Roy and Das, 2021; Venkatesh and Velkennedy, 2023).

3.4.5. Comments and interpretation on evolution, current status and utilisation of CS projects in India

The promotion of CS projects in India can be attributed to several factors that are both local and global. Post 2010, the review saw a proliferation of projects and publications, which is most likely to be influenced by global recognition and dissemination of CS initiatives (Cunha *et al.*, 2017). This is evident from publications of special editions on CS by various journals such as *Frontiers in Ecology and the Environment* and *Nature* (Cunha *et al.*, 2017).

Secondly, project proponents in India are aware of the significant role CS play in fostering scientific and accountable environmental regimes and also fulfil the requirement of big data digitally for the country (Sekhsaria and Thayyil, 2019). Thus, the project proponents recorded in this study from India have shown a tendency to adopt CS as a means to connect with the local community and address their local issues. For example, the PAC Waste Tracker project sought to shed light on the need for accountability at local levels, addressing issues like solid waste management through collaboration between citizens and government (Nagendra, Lakshmisha and Agarwal, 2019).

The third reason can be attributed to the rising number of smartphone users in India. More than 180 million people in India bought a smartphone between 2014 and 2017 with evidence of a 72% increase in application downloads from the Google Play Store from 2015 to 2016 (Sukhwani and Shaw, 2020). The development of mobile phone applications in recent times to collect data has encouraged citizens to voice concerns, identify and mitigate risk, and address community-level issues (Oberai *et al.*, 2018; Nagendra, Lakshmisha and Agarwal, 2019; Sukhwani and Shaw, 2020; Menon *et al.*, 2021; Saran *et al.*, 2020). MOBILE

In addition to increasing accessibility to smartphones and mobile phone applications, the internet has played a pivotal role in increasing the popularity of CS in India by enabling the fast aggregation and uploading of data and information (Jha *et al.*, 2017; Saran *et al.*, 2020; Sukhwani and Shaw, 2020; Menon *et al.*, 2021; Middya, Roy and Das, 2021). After the launch of Jio Network in 2015, a budget telecommunication network in India, internet connectivity has become affordable to the majority of the population, thus making information and connectivity available to them (Brogen Project 2019). This coincides with the increasing density of project initiation since 2015. This demonstrates how the internet provided scope for CS projects to reach out to a large number of people in India in recent times.

These technological advancements and conditions have been instrumental in the growth and evolution of CS in India. These technologies used in the projects have helped bring people together on one platform by providing a common space to discuss and exchange information and data (Vattakaven et al., 2016). The Asian Waterbird Census during its initial years struggled to gain attention in the absence of such technologies a couple of decades ago (Sekhsaria and Thayyil, 2019). At current times, eBird India (Bird Count India) has more than a million observations (George *et al.*, 2019)

The support structure provided by the Government of India (GoI) under its Biological Diversity Act, 2002 (BDA) and the preliminary work undertaken by the current members of the Biodiversity Collaborative Group in the country might have led to the skewness in the presence of biodiversity conservation projects over other projects. This review has found continuous growth of biodiversity conservation CS projects initiated in 2004 and continuously increasing till the review was conducted. Furthermore, the Government of India (GoI) since 2020 has further extended its support to biodiversity conservation projects through platforms such as CitSci India. CitSci India started as a national-level conference for biodiversity conservation CS projects and is predominantly supported by Government of India agencies i.e., the Office of the Principal Advisor Scientific to the Government of India and the National Biodiversity Authority, the nodal agency formed under the Biological Diversity Act, 2002 (CitSci India, 2022; MoEFCC, 2022). The key catalysing partner in CitSci India is the Biodiversity Collaborative (CitSci India, 2022).

Another interpretation for this skewness is attributed to the global trend of CS projects where the number of projects related to biodiversity conservation is higher than other projects (Follett and Strezov, 2015; Pocock *et al.*, 2017). The outcomes of these projects might have encouraged similar trends in India.

Based on the evidence seen in this review, projects in India need to diversify their projects. Since 2017, various practitioners have published several innovative approaches that can foster CS in thematic areas beyond biodiversity conservation. These approaches predominantly provided new ideas to initiate environmental monitoring and evaluation projects, which are required in India. Also, the diversification of projects should not be restricted to addressing socio-environmental issues but should involve the participants in more project activities, such as designing research questions and project outcomes.

CS in India does have the potential to address the needs and requirements of policy initiatives that address socio-environmental issues by the Government of India (GoI) (Vattakaven *et al.*, 2016; Jha *et al.*, 2017; Singh *et al.*, 2018; Owens *et al.*, 2022; Mishra *et al.*, 2023). For instance, the Indian Institute of Remote Sensing (IIRS) (a governmental higher educational institute) has designed a project to track solid waste through a mobile app, specially to support the *Swachh Bharat Abhiyan* (Clean India Mission) (Jha *et al.*, 2017). The institute has also developed the species mapping app for the Indian Bioresource Information Network (IBIN), a citizen-driven data-gathering platform under the Digital India initiative by GoI (Singh *et al.*, 2018). This evidence also opens up the question of the role of various stakeholders involved in the process. Studies have indicated that stakeholders, especially research and academic institutions, play an important role in initiating and coordinating projects and disseminating project outcomes (Göbel, Martin and Ramirez-Andreotta, 2017; Skarlatidou *et al.*, 2019).

This is also evident in the unequal distribution of projects across the country. The study did not find clear patterns in terms of the cumulative influence of socio-economic conditions on project numbers; however, strong influence based on GDP per capita, and SDG Index indicates the investment abilities of the states in CS initiatives. Moreover, these states have the premier academic and research institutes in the country. The review indicates that these institutes have actively influenced project activities. For instance, the National Centre of Biological Science (NCBS) and the National Institute of Advanced Studies (NIAS), as well as research organisations such as the Centre for Wildlife Studies (CWS), Nature Conservation Foundation (NCF), and Ashoka Trust for Research in Environment and Ecology (ATREE), have started several biodiversity projects and are located in the southern states. Similar centres of education can be seen in Maharashtra, for example, the Indian Institute of Technology, Mumbai, Centre for Citizen Science, Pune, etc. (Lekshmi *et al.*, 2021; Kulkarni *et al.*, 2022) as well as in West Bengal e.g., Jadavpur University (Middya, Roy and Das, 2021). Thus, in a subsequent chapter (Chapter 6), I shall be identifying and evaluating the influence of the various types of stakeholders, their interactions and their influence on the process of CS projects in India.

Another interpretation of the geographical skewness can be due to the geographical presence of biodiversity hotspots in the Western Ghats of India (Figure 15). Thomas Vattakaven, a CS practitioner from the India Biodiversity Portal (IBP) puts forward the idea that these states are within biodiversity hotspots and thus people are more closely related to nature (Bhuyan, 2020). IBP had reported that the highest participation in their projects comes from Kerela, followed by Northeast India (Bhuyan 2020). From this review, the presence of biodiversity hotspots leading to CS also manifests in Northern West Bengal (Adhurya and Bhandary, 2019; Mujumdar *et al.*, 2020; Dawn, 2021; Pradhan and Yonle, 2021; Pradhan, George and Dewan, 2023). The SeasonWatch project also reported that 87% of their participants are from Kerela (Ramaswami, Sidhu and Quader, 2021).

Thus, this review also points to a probable relationship between culture, educational institutes, and region that might influence the popularity of CS projects drastically in different regions of the country, even though statistical data trends may not suggest otherwise (Devasia, 1998; Maheshwari *et al.*, 2014; Radhakrishna, Binoy and Kurup, 2014; Jadeja *et al.*, 2018). The Centre for Wildlife Studies (CWS) identified that most of their volunteers originated from the western and southern states of India (Figure 16) (Johnson *et al.*, 2014). The statistically low correlation was indicated in this study because many projects were open to participants across the country and did not reflect actual effective participation in those states. However, the study counted those states as part of the projects. Thus limiting the statistical understanding of the study on these influences.

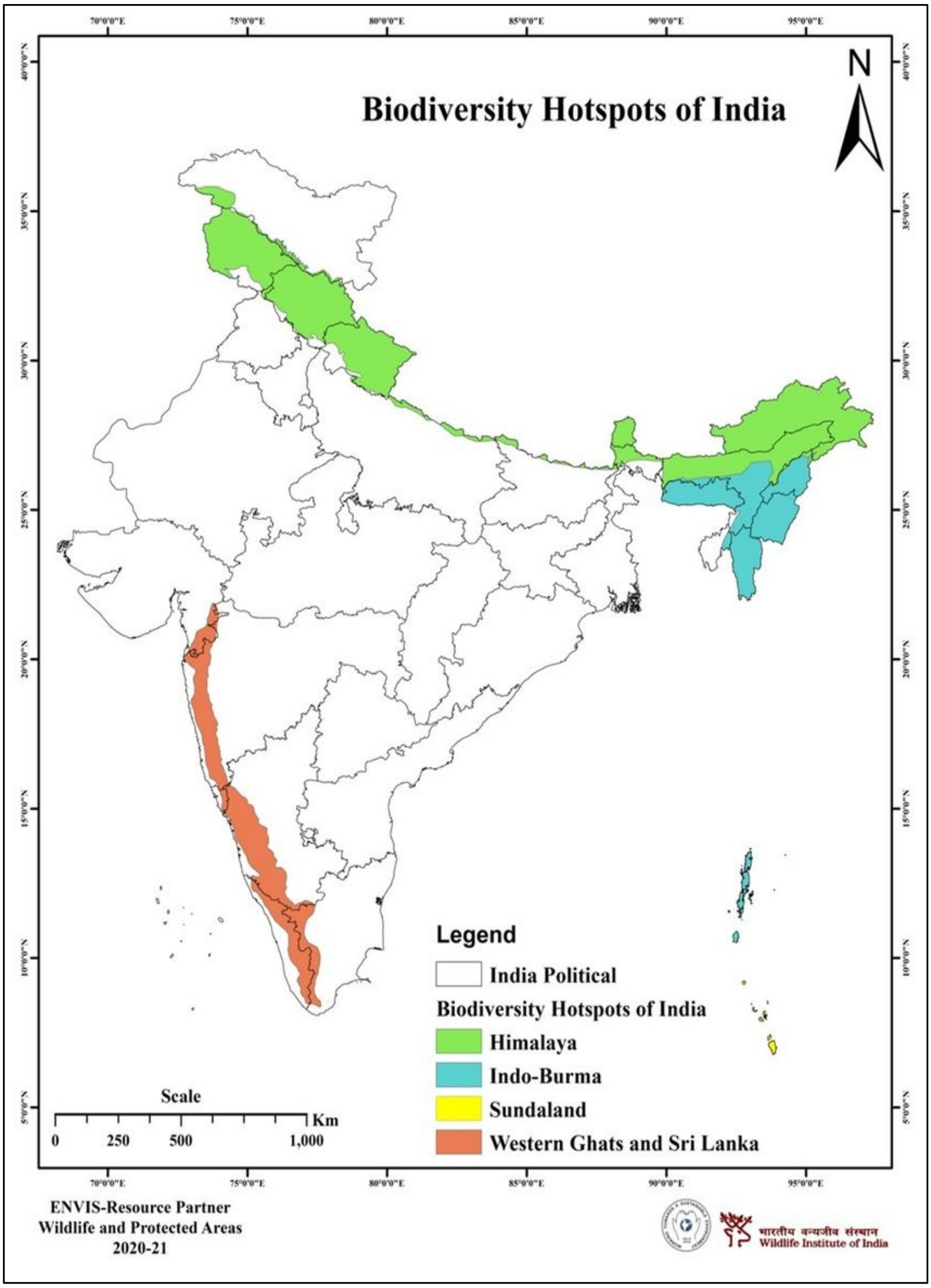

Figure 15: illustrates the biodiversity hotspot regions of India. Most biodiversity conservation projects are spread across the same states that are present on this map. The map has been sourced from the Wildlife Institute of India (Sujithra et al., 2021).

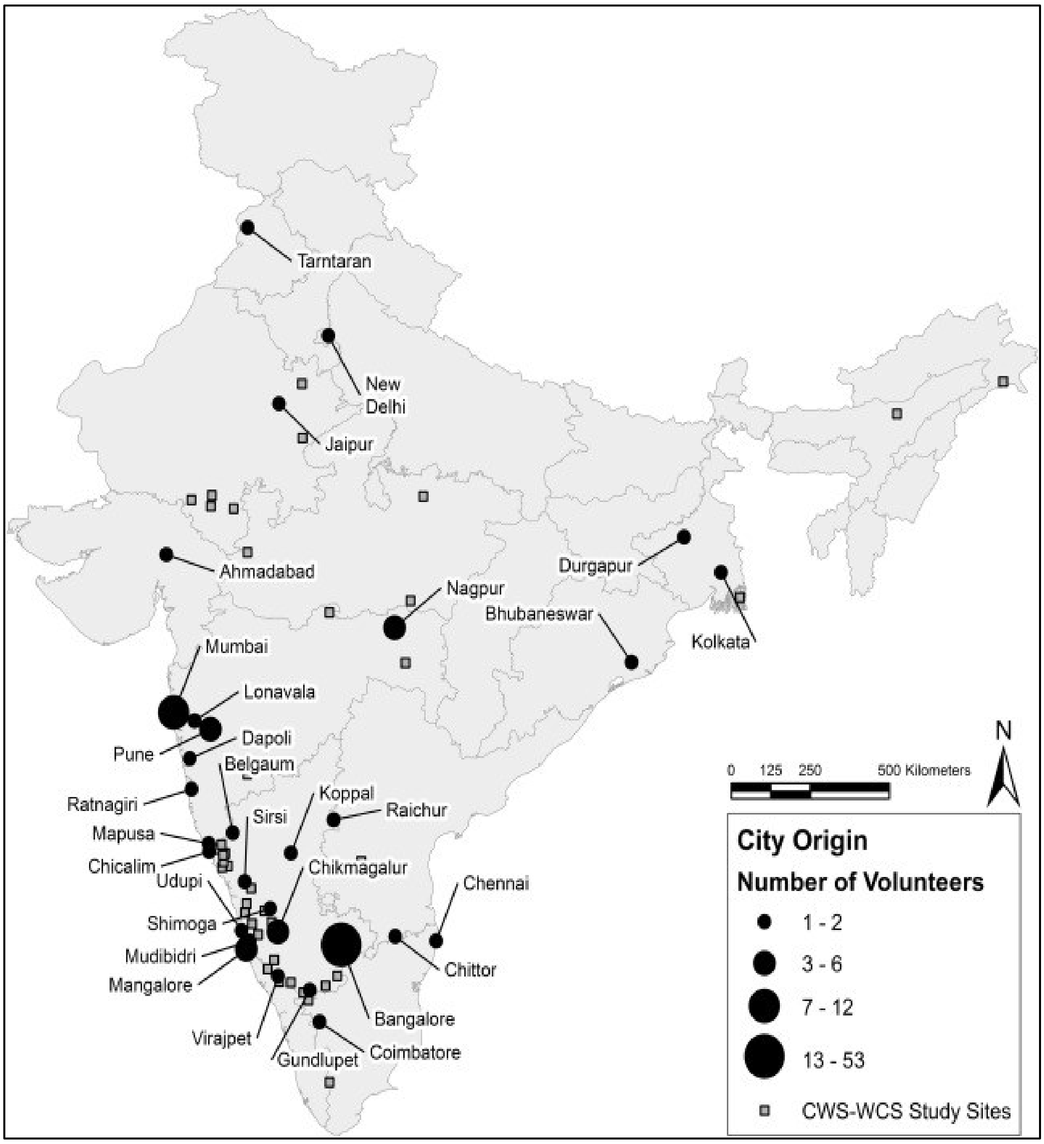

Figure 16: Map of volunteer origins of CWS-WCS and CS project sites. (Source: Johnson et al., 2014.) [N.B.: The state boundaries in this map differ from the currently used map of India due to regime change in 2014]

3.4.6. Limitations of the review

One of the limitations of the study was its inability to find all the scientific outputs from biodiversity conservation CS projects. This is because most of the reports would refer to the eBird database (Bird Count India) or use the term "community-generated data" which was not part of the search terms identified for data collection. Moreover, in these types of articles, the abstracts and names of the articles reflected more on the scientific research over CS. Hence, some of these research papers might have been rejected during the scoping process since their abstracts did not conform with the selection criteria of the study. Bird Count India claims to have supported 41 scientific research papers through their data (*Bird Count India*, 2023).

Another limitation of the study is that it did not consider smaller projects or seasonal projects that are supported by larger projects, such as, Bird Count India supporting Salim Ali Bird Count (*Bird Count India*, 2023). These projects tend to have similar processes as their peers. The difference in these projects solely lies in their names and project coordinators. In some cases, these projects might share their participants. Hence, to reduce further skewness, the study chose to represent Bird Count India as an umbrella project that hosts smaller and seasonal birding CS projects.

3.5. Conclusion

The review revealed that India had an indigenous origin of CS initiatives. Projects such as the Asian Waterbird Census were initiated in 1987, a decade before the first promotion and popularisation of the term in the mid-1990s (Irwin, 1995; Bonney, 1996). However, the growth has been slow as opposed to countries such as the USA, UK, or its neighbour, China, which have recently shown a high number of projects (Pelacho *et al.*, 2021). This review provides an understanding that the distribution of projects ~~in~~ tackling socio-environmental issues is highly skewed towards biodiversity conservation in the country. This comes as a limitation for the process to reach its effective potential.

India currently lacks a support structure or an enabling platform for different types of CS projects. The development of enabling platforms or consortiums in North America (Association for Participatory Science) and citizenscience.gov by the US government) or Europe (EU-Citizen.Science) have shown how they can act as nodal points through which the promotion and exchange of ideas and knowledge can take place (Wagenknecht et al., 2021). In the case of India, biodiversity conservation projects have been supported by platforms like CitSci India. This platform has provided a stage for the exchange of ideas and knowledge for biodiversity projects in India. One of the prominent research outputs from the platform is providing a space for the development of best practice guidelines for data management in India (CitSci India, 2022; Vattakaven *et al.*, 2022). This thesis will further investigate the role of various stakeholders that can enable the promotion and diversification of CS projects in India in Chapter 6.

The reviewer infers that CS in India has been able to make some slow progress. In the last two decades, there might have been several achievements and impacts by CS projects on the environmental, societal, economic, scientific, and governance needs of various communities in India (Wehn *et al.*, 2021). In the next chapter, Chapter 4, I will delve into these achievements and the impacts contributed by CS projects in India. On the other hand, the review also identified the skewness in project diversity, slow growth, etc. and thus would look more into barriers and challenges faced by the projects in India in Chapter 5. This is to understand why the process has taken time to expand in India and in what ways they contribute to the grand challenges of CS (Fritz, See and Grey, 2022).

Chapter 4

4. A systematic assessment of impacts of ecological and environmental citizen science projects in India

"Indeed pleasure can be derived from the most everyday birds in the most everyday surroundings and even the jaded city dwellers can regale their [his] leisure hours without the necessity of going far afield in search of special opportunities."

- **Salim Moizuddin Abdul Ali** [Eminent ornithologist and titled the Birdman of India] (Shekhar, 2020)

4.1. Introduction

In this chapter, I have investigated the impacts and identified the achievements of citizen science (CS) initiatives in India. I have then looked at the pattern of impact distribution across different socio-environmental issues in the country. I aim to identify the achievements by utilising the Citizen Science Impact Assessment Framework (CSIAF) (Wehn *et al.*, 2021; Antonella, Annelli and Katharina, 2022). The identification of the achievements or the lack of them has helped in mapping the strengths and weaknesses required for the SWOT analysis in Chapter 7.

4.1.1. Background and objective of the study

In recent years, CS has emerged as a collaborative approach to research by engaging both the public and professional scientists. As we know, this process facilitates public participation in data collection processes and empowers individuals with scientific knowledge, fostering their involvement in addressing diverse environmental, societal, economic, scientific, and governance challenges (Missingham, 2013; Eitzel et al., 2017; Hecker et al., 2018; Olteanu-Raimond et al., 2018; Turbé et al., 2019; Dowd et al., 2020; Schade et al., 2021; Wehn et al., 2021). Thus, over the years, CS projects have emerged as a powerful tool for generating knowledge by collaborating with a diverse set of stakeholders (Shirk *et al.*, 2012; Bonney *et al.*, 2014; Capdevila *et al.*, 2020). Communities involved with well-designed CS projects have shown to benefit as these projects can inculcate scientific temperament, and improve society's scientific literacy while promoting engagement in local issues and extending the opportunity to trust in science (Shirk *et al.*, 2012; Bonney *et al.*, 2014; Capdevila *et al.*, 2020). Studies have indicated that participants have seen growth in their scientific literacy as they get first-hand experience to hone their observation skills, learn to use new software and instruments, and learn to appreciate the importance of scientific endeavours by associating with scientific enterprises (Cathy C. Conrad and Hilchey, 2011; Bela *et al.*, 2016; Land-Zandstra *et al.*, 2016; Allf *et al.*, 2022).

Professional scientists also stand to gain from CS initiatives, as they provide opportunities to gather and analyse large datasets collected by a multitude of participants (McKinley et al., 2017; Bhuyan, 2020; Walker, Smigaj and Tani, 2021). Engaging with the public through CS projects enables scientists to promote scientific literacy among diverse audiences, thus enabling scientific temper and democratising science by directly providing access to scientific research (Irwin, 1995; Pocock et al., 2014; Bonney et al., 2016; Land-Zandstra et al., 2016; Katapally, 2020). Furthermore, CS can offer unique perspectives and insights derived from local knowledge, which may not be accessible to professional scientists alone (Quinlivan, Chapman and Sullivan, 2020; Roche et al., 2020; Albagli and Iwama, 2022).

Though these are the positive areas of CS, however, evaluation of policy documents reveals that most policies view CS as a tool for data collection and analysis mainly in the field of environment (Hecker *et al.*, 2019). Only a few policies have expanded the understanding of CS as a process to democratise science and emphasise collaboration between the wider community and scientists (Hecker *et al.*, 2019). Previous observations (Chapter 3) from India have shown that CS initiatives aimed to contribute to policy outcomes, public engagement, and scientific research as part of the project activities.

Practitioners of CS around the world have been extensively promoting the idea of using CS as a powerful tool to contribute to the policy process (Hecker *et al.*, 2018; Fritz *et al.*, 2019; Turbé *et al.*, 2019). This has led to uptake of the process by several governments and their agencies, especially by the Annex I countries via initiatives such as *'Horizon 2020 by EU, Citizens' Observatories, Collective Awareness Platforms (CAPs),* etc. or bypassing of legislation such as by USA to support the integration of CS generated data as official sources (Cathy C. Conrad and Hilchey, 2011; Hecker, Garbe and Bonn, 2018; Fraisl, Campbell, See, Wehn, Wardlaw, Gold and Moorthy, 2020; Quinlivan, D. V Chapman and Sullivan, 2020). Furthermore, the funding of projects by governmental agencies in Europe and North America has encouraged the evaluation of impacts generated by CS initiatives. Such evaluation tactics facilitate refining policies and generating reliable data required to implement and evaluate actions based on knowledge generated by CS initiatives while keeping within the values and principles of CS (Hecker, Garbe and Bonn, 2018; Robinson *et al.*, 2018).

This chapter will identify the impacts of CS initiatives in India on society, environment, economy, science and technology and governance to inform the research question, **"What are the achievements and impacts of Citizen Science in India till present time (2023)?"** By measuring the impacts of CS, we will be able to identify the areas of strength or areas of weakness of CS projects in India, which is crucial for developing it as an effective approach to maximise its potential benefits, improve project design and contribute to broader societal and environmental objectives. Overall, it will also help in developing a strong case to support CS and its promotion in India.

To date, no study has attempted to comprehensively assess and identify the impacts of ecological and environmental CS projects in India. Thus, this systematic assessment will address this knowledge gap by qualitatively identifying the impacts and quantitatively assessing the distribution of impacts over different socio-environmental issues using the Citizen Science Impact Assessment Framework (CSIAF). The assessment was conducted by analysing the records collected and identified using the

PRISMA Framework described in Chapter 2. In addition to this, the study also explored pathways for assessing the impacts of CS initiatives and reporting of CS initiatives through systematic reviews.

4.2. The Impact Assessment Framework

Citizen science (CS) projects have shown the capacity to bring changes to environmental management within institutions, which is similar to traditional research endeavours (van Noordwijk *et al.*, 2021). These influences or change can be manifested through change in the identification, adaptation and mitigation strategies of socio-environmental problems (Chandler, Rullman, *et al.*, 2017; Hecker *et al.*, 2018; van Noordwijk *et al.*, 2021). In contrast to regular scientific endeavours, CS has a special principle, i.e., to elevate social problems through scientific activities (Irwin, 1995; Robinson *et al.*, 2018). This principle of CS has helped to establish the process as a space for integrating various stakeholders where they can actively collect and disseminate data (Wehn *et al.*, 2021). This has led to the popularity of the process in jointly addressing common social issues, in this case, socio-environmental issues. Due to this growing popularity of the process, it's important to capture and report on its outcomes, outputs, and impacts. However, until recently, the interventions and changes resulting from CS are often assumed, ignored, or speculated (Wehn *et al.*, 2021).

Over the years, several studies have tried to holistically evaluate and conceptualise the impact of ecological and environmental CS projects (Hecker *et al.*, 2018; Kieslinger *et al.*, 2018; van Noordwijk *et al.*, 2021; Walker, Smigaj and Tani, 2021; Wehn *et al.*, 2021; MICS, no date). 'Holistic' in this case means evaluating impacts from projects such as accounting growth of scientific knowledge within participants; individual development; and broader socio-ecological and economic benefits (Shirk *et al.*, 2012; Kieslinger *et al.*, 2018). Each of these evaluating frameworks has highlighted more or less similar domains or areas of impact from CS after successive systematic reviews. Thus, I have chosen the Citizen Science Impact Framework (CSIAF), the state-of-the-art framework, which has consolidated the previous theories and concepts with which impacts of CS initiatives can be captured (Wehn *et al.*, 2021). It offers an impact assessment guideline for CS initiatives across five interlinked domains: Society, Economy, Environment, Science and Technology, and Governance (Wehn *et al.*, 2021). According to the results of the systematic review undertaken to develop CSIAF, publications on impact assessments considered one or more of these impact domains when assessing CS initiatives (Wehn *et al.*, 2021). Their results show that most publications referred to assessing impacts on Society followed by Science and Technology, Governance, Environment and Economy.

One of the main aims of this framework was to provide consistency, comparability, and a multi-dimensional view of impacts across different CS initiatives and reduce variability while reporting and assessing project impacts (Wehn *et al.*, 2021). This is because previously attempted frameworks or studies lacked a methodological approach required to standardise impact reporting or they did not cover all the identified domains. Thus, these holistic approaches have been able to provide a platform to record and analyse the impacts of CS projects by developing concrete approaches to successfully assess each of the impact domains.

The framework also aligns with my theoretical basis for undertaking the study, i.e., promoting ecological and environmental CS in India. The CSIAF framework has tried to incorporate the interlinked domain of sustainable development, i.e., Environment, Society and Economy, which has been accepted as essential pillars of future sustainable growth and development (Wehn *et al.*, 2021, p. 1685). This is important for my study as CS projects dealing with sustainability or sustainable development are an integral part of my research focus area. The framework incorporated the Science and Technology domain due to CS's alignment with promoting the use of the scientific process, scientific paradigms and technology; and Governance domain was added as CS initiatives usually contribute to monitoring, such as environmental monitoring, and the data generated can be used for management and decision-making (Wehn *et al.*, 2021, p. 1685). This multi-dimensional visualisation of the impact domain also aligns with my critical understanding of CS based on the 'Ten Principles of Citizen Science' (Robinson *et al.*, 2018). These principles have been the guidelines in selecting the records for this study related to CS initiatives and thus the CSIAF framework provides a platform to evaluate and identify impacts in India.

Using the framework, I have tried to describe the identified major impacts across the impact domains as achievements of CS in India. This means impacts that are commonly seen across the majority of the projects are an achievement of CS. The evidence of impact depending upon the project objectives and outcomes in lower numbers or for small-scale projects was taken as potential achievements.

Then I integrated the indicators of the impacts from the ACTION (Assessing Community Transformation Impact on Our Nation) impact assessment framework by Measuring the Impacts of CS (MICS) (Antonella, Annelli and Katharina, 2022) into the CSIAF framework. MICS is technically a project that helps CS initiatives to comprehensively measure and assess their impacts across the five impact domains by providing standardised indicator methodologies (MICS, no date). The MICS framework provides a step-by-step process to map the impacts of a CS project through a series of questions that help in setting up key issues to address, and the research questions. It has a repository of 200 predefined questions that can be tailored to the specific needs of project proponents. It has also prescribed a set of quantifiable parameters, similar to the Likert scale, to assess the impacts using the indicators. These indicators are types of instances, evidence or areas of impact for CS projects, based on evidence gathered by CSIAF to define the impact domains (Wehn *et al.*, 2021). It is important to note that the evidence for these indicators often overlap and have cross-domain interlinkages (Somerwill and Wehn, 2022).

Thus in my study, the CSIAF framework has been taken as the theoretical basis of the impact assessment framework while MICS has provided indicators to identify what the impacts can be. The following impact domains and indicators identified by these two literatures were used to guide the identification of the impacts and achievements of CS initiatives in India (Figure 17).

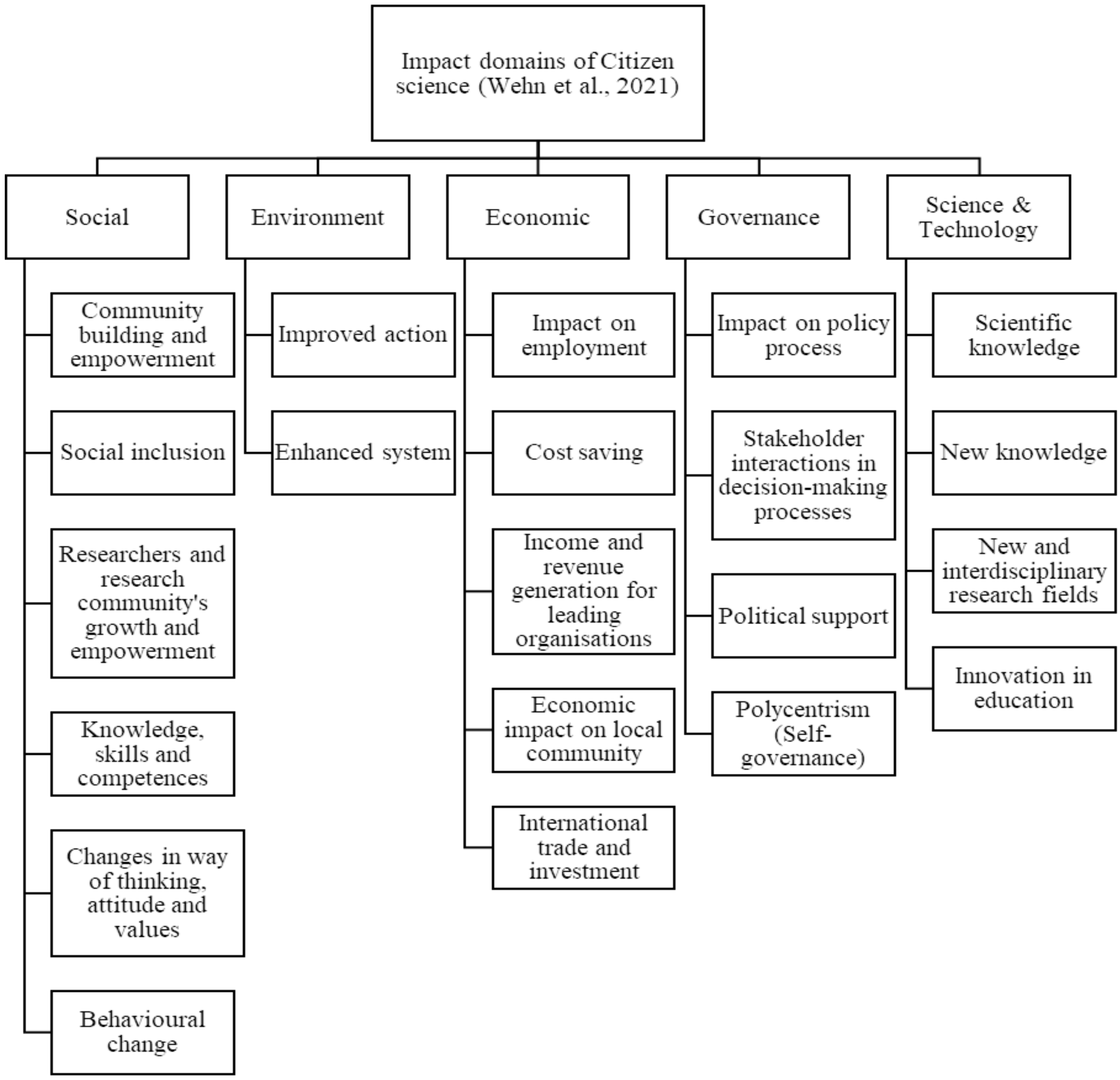

Figure 17: Indicators of CS project impacts across various impact domains identified by Wehn et al., 2021.

4.2.1. Society

The impact on society and individuals is one of the core principles of CS that defines it (Irwin, 1995; Robinson *et al.*, 2018). Impacts on society can be in various forms and their indicators may overlap each other (Somerwill and Wehn, 2022). The social domain also includes individuals' personal development by participating in the process (Kieslinger *et al.*, 2018). This includes aspects such as gaining scientific knowledge and skills, as well as in terms of behavioural change (Phillips et al. 2014). The majority of the Global literature on ecological and environmental projects indicated that at least one of their aim was to influence the knowledge of environmental behaviour as an impact dimension on society (van Noordwijk *et al.*, 2021). These changes or impacts are indicated through processes such as stewardship and civic action (Kieslinger *et al.*, 2018). Overall, literature until now has identified two types of categories of indicators to assess social impacts. Firstly, individual and collective level outcomes, and secondly, alterations in knowledge, attitudes, and behaviours (Wehn *et al.*, 2021). The framework has identified the following as indicators of Society Domain.

1. Community building and empowerment
2. Social inclusion
3. Researchers and research community's growth and empowerment
4. Knowledge, skills and competencies
5. Changes in way of thinking, attitude and values
6. Behavioural change

4.2.2. Science and technology

The impact of CS on science and technology is usually traced through scientific processes or methods that help in producing outputs such as data collection, or technological artefacts such as sensors, mobile apps and standards (Wehn *et al.*, 2021). The impact on science and technology within the process is indicated by features such as projects being required to have clearly defined research questions based on the project activities and their relevance to society and scientific curiosity (Kieslinger *et al.*, 2018). Kieslinger et al., 2018, recommend that evaluation standards should match those of traditional academic standards. This entails upholding the rigorousness of the scientific activities involved, generation of genuine scientific knowledge, possibly captured in publications and development of new technology, multidisciplinary approaches and projects. Indication for scientific and technological impacts can be traced from new and scientific knowledge generated by the data gathered by project activities, developing interdisciplinary research areas to address local issues and developing new technologies to address them. The following indicators have been selected to guide the identification of impacts:

1. Scientific knowledge
2. New knowledge
3. New and interdisciplinary research fields
4. Innovation in education
5. New technology

4.2.3. Economy

In the economic domain, one of the core impacts of CS is reducing the cost of data collection. Currently, studies have postulated areas of impact; however, the evidence for the generation of economic and entrepreneurial activities is low (Wehn *et al.*, 2021). Literature has shown indicators of economic impacts to be job creation in local communities, and positive changes to the growth of organisations, fostering new business models and entrepreneurs (Kieslinger *et al.*, 2018; Wehn *et al.*, 2021). The following indicators were indicators of the economic domain.

1. Impact on employment
2. Cost saving (Cost-benefit)
3. Income and revenue generation for leading organisations
4. Economic impact on the local community
5. International trade and investment

4.2.4. Governance

Governance or political impacts are made through both formal and informal processes, i.e., developing public policy or developing collaboration and relationships with various stakeholders. Collaborations with civic society organisations help in enhancing visibility and impact by facilitating broader societal engagement. Moreover, the data generated by CS can be used for governance as it can provide policymakers with scientifically reliable information necessary for policy formulation, implementation, and evaluation. For example, the European Union has integrated CS data into legislation, like the Environmental Acquis Communautaire to fulfil its mandatory monitoring and reporting requirements. Further contributions of impacts cover areas such as policy cycle, policy changes, multi-level interactions among actors, communication, relationships, and trust. The following indicators were selected to identify the impacts of CS in India.

1. Impact on the policy process
2. Stakeholder interactions in decision-making processes
3. Political support
4. Polycentrism (Self-governance)

4.2.5. Environment

Finally, as part of all ecological and environmental CS projects, CS initiatives have shown significant impacts on the environment by focusing on the status of environmental resources, conservation efforts, ecosystem functions, services, and resilience. Impacts on environments and ecology are indicated by better conservation efforts and outcomes as a result of data collected on biodiversity. The data collected on the physical environment helps in enhancing our natural habitats and ecosystems by monitoring abiotic factors such as water quality and air pollution. Finally, these projects help in developing resilience by monitoring and detecting environmental changes and disturbances. This is usually achieved by adaptive strategies, such as early warning systems which can help communities withstand and recover from natural and human-induced challenges. Overall, CS initiatives contribute significantly to environmental stewardship by improving conservation efforts, enhancing ecosystem services, and promoting resilience. Indicators identified to assess these impacts are:

1. Improved action better ecosystem function, service and resilience
2. Enhanced system services and resilience

4.3. Methodology

To assess the impacts of CS initiatives on the five domains in India, I selected records from three types of sources of evidence that were collected during the systematic search in Chapter 2. The sources of evidence were:

a. Records describing CS projects and extracted from academic databases (CSP-AL) (n=33)
b. Records referring to innovative approaches in CS (CS-IA) (n=6)
c. Records referring to evidence of utilisation of data, generated by CS for scientific research (CS-UD) (n=12)

CSP-AL and CS-IA records were selected as they contained data indicating both accomplished and potential achievements, impacts and results of the CS projects in India. CS-UD records supplemented evidence, especially in determining the scientific impacts of Bird Count India (eBird). Thus, a total of 54 records were chosen for this study.

Data from records extracted from Google search (CSP-GS) were not utilised in the analysis because the details required would mean expanding the data outside those collected through the PRISMA Framework, which can deter the reproducibility of the study in the future. In the case of records reviewing CS projects in India (CS-R); some of the projects referred to in these records were already part of CSP-AL. The second reason was that at times these records referred to more than two projects, which created uncertainty in documenting evidence. Thus, both these types of records were dropped from the quantitative analysis.

To investigate the impacts and identify the achievements of CS in India, I undertook a qualitative analysis by identifying and coding relevant text segments from the identified records to suitable impact domains (codes) and indicators (sub-codes). The qualitative analysis was conducted in NVivo. NVivo is a software package that helps in conducting qualitative analysis by coding text segments of text documents, PDFs, etc. Foremostly, it helps in organising the data under different labels known as codes and sub-codes. I transported the selected records from Rayyan AI to NVivo as .XML files for coding into the impact framework selected for this study (discussed in Section 4.2). Thus, a deductive process was undertaken to identify the impacts of CS in India using the preidentified impact domains and indicators from the CSIAF framework. In deductive coding, the coding process utilises existing themes, theories, or codes proposed by the researcher (Fereday and Muir-Cochrane, 2006; Proudfoot, 2023). I then calculated the distribution percentage of records that mentioned evidence on the impacts to summarise and visualise the distribution of impacts and domains that need further focus.

In Box 5, I have provided an example of how the coding was conducted. The paragraph in the box illustrates the evidence of developing new technology and creation of new knowledge i.e., the development of the Forest Fire Reporting app. Thus, this paragraph was coded under Science & Technology (code: an impact domain) and New Technology (sub-codes: an indicator).

Box 5: Example of a text segment to illustrate the indicator identification and coding.

> *"The Forest Fire reporting (FFR) mobile app (Figure 5) is a participatory sensing-based smartphone application that is specifically designed and developed in consultation with the participant's objectives and their goals to tackle forest fire incidents at the preliminary stage. Using this mobile app, geotagging of incident-prone sites is possible. Users can also record (photograph) the incident, fill in basic fields relevant to the fire, and send all the collected information to a web application server (Figure 3). This mobile app is not only designed as a reporting tool for its users but also as a means to visualize tagging patterns for monitoring sites, to make it transparent to the users as much as possible. Besides, this application includes a feature of offline storage when the network (or data) is not available. The FFR mobile application was originally designed and developed using HTML5 and JavaScript and built using the Apache Cordova framework to run on mobile devices, specifically on the Android operating system. This mobile app sends data to the remote application server through the AJAX, which is then stored in the database and shows the corresponding information in the map panel of the dashboard"* (Saran *et al.*, 2020).

The collected text segments were then assessed to determine if the evidence provided in the records was a strong indicator of impact. This is because not all records reported evidence of equal quality, that is, measured the impacts of the CS process in detail as the focus of reporting varied among the records. To guide me through the evaluation of the strength of evidence, I modified the CSIAF to identify strong and weak evidence of impacts (an extension of Wehn et al., 2021). In the modified framework, I collated and provided reasoning on "What is strong and measurable evidence of impact?" Then I identified currently recommended best practices for measuring the impacts of CS to identify measurable impacts from the selected records using the Wehn et al., 2021 framework. This is because MICS concentrates on impacts and impact pathways of CS projects from a project proponent or assessor viewpoint of a single project. Thus using the MICS scale to evaluate academic records is not possible in this particular study unless reported by the authors (Antonella, Annelli and Katharina, 2022). The first limitation arose as most records did not report on change or impacts from project initiation to the project end (or a reporting period for long-term projects) and thus it became difficult to follow the methodology recommended by MICS. Secondly, the focus of reporting also varied among records. Thus, this modification helped to identify and measure the strength of evidence that indicates the impacts of CS when using systematic reviews.

In Table 7, I have mapped out the best possible features to identify strong evidence and what I considered weak evidence for each impact domain. To identify features of "strong evidence" I used the argument that "strong evidence is indicated by measurable impacts or change" (Kieslinger *et al.*, 2018; Schaefer *et al.*, 2021; van Noordwijk *et al.*, 2021; Wehn *et al.*, 2021; Somerwill and Wehn, 2022). In the case of indicators that had impact-measuring frameworks, features of strong evidence were referred to from these impact-measuring frameworks (Table 7). However, there are still gaps in actually measuring the impacts of CS as many indicators currently do not have well-defined impact measuring frameworks (Somerwill and Wehn 2022) and are still being explored. In cases where there was no properly identified impact measuring framework, I have used the basic condition "strong evidence is indicated by measurable impacts or change," and developed my understanding from the coded text segments of articles from India to fill these gaps. There are scope and gaps in identifying features that measure impacts for the identified impact domains, and these options were briefly explored (Wehn et al., 2021). I also assigned 'no evidence' when there was no specific reference to one of the indicators in the records. Consequently, the exercise added to the idea of identifying evidence of impacts using systematic review, adding value to the CS impact assessment framework (Wehn et al., 2021).

Table 6. explains the features of strong evidence for each indicator and impact domain. In cases where there are no features to identify strong evidence based on an impact measuring framework, I have identified them with the (+) symbol. The symbol refers to the statement, "Currently there are no well-defined and recommended quantitative methods to measure the impacts on community building and empowerment by CS initiatives. A systematic study or methodological study is required to be undertaken. These systematic studies or methodological studies were not conducted as part of this chapter as it is beyond the scope of the thesis objectives."

Impact Domains	**Strength of Evidence**		**Features of strong evidence for impact indicators**
	Strong evidence	**Weak evidence**	
Social			
Community building and empowerment (S1)	Indicated by a measurable change in social structure due to project activities such as the availability of local groundwater data to the local community; quantified representation of women within the decision-making process; etc.	Non-measured and probable empowerment due to project activities observed by authors.	(+)

Impact Domains	Strength of Evidence		Features of strong evidence for impact indicators
	Strong evidence	**Weak evidence**	
Social inclusion (S2)	Indicated by measurable change in social structure and decision-making process due to inclusion and representation of marginalised groups such as using Social Impact Assessment techniques, psychometric analysis, etc.	Actions leading to a probable mass change in social structure due to project activities, or inclusion of a marginalised community under project aim such as engaging a forest dwelling community in a biodiversity conservation CS project due to their affinity to the project area. This is weak evidence as it does not portray inclusion within a diverse group of participants to determine the inclusion of the targeted groups.	(+) **Note:** There are several social inclusion measuring frameworks across various domains which can be used to measure the impacts of social inclusion, but there is a lack of established methods to measure social inclusion to cross-refer from (Cordier *et al.*, 2017) Systematic reviews on social inclusion recommend the use of psychometric tests to determine the inclusion of targeted groups. Theories in social inclusion are complex topics and scholars have argued the importance of exploring social exclusions to measure the accomplishment of social inclusion, e.g., relative social exclusion in terms of spatial, temporal and cultural contexts, or intergenerational patterns of exclusion (Cordier *et al.*, 2017).
Researchers and research community's growth and empowerment (S3)	High-medium impact factor (IF ≥ 2) and peer-reviewed journals including journals under Declaration on Research Assessment (DORA) and Open Access journals.	Low impact factor (IF ≤ 2) and peer-reviewed journals	The impact factor (IF) of journals denotes the outreach of a particular journal to a research community. This is an important indicator for researchers as IF journals show higher outreach of the knowledge generated. Moreover, at certain times publication in high IF becomes essential for the career growth of researchers. IF as an indicator to determine impacts on researchers, scientific output was used by Chandler et al., 2017 to evaluate EarthWatch projects. Based on Margolius and Salasfky, 1998 They classified the impact scheme: **Low:** Low impact factor (IF ≤ 2) journals.

Impact Domains	Strength of Evidence		Features of strong evidence for impact indicators
	Strong evidence	**Weak evidence**	
			Medium: medium impact factor (IF 2–4) journals. **High:** high impact factor (IF ≥ 4) In this case, if an open-access journal provides its impact factor, then the impact factor score preceded the fact the journal is open-access in categorising the strong or weak evidence. However, this is a condition created only for this study and needs further discussion. **Note:** However, scholars have argued on the effects of journal IF as a measure of researchers' empowerment. Thus in cases where journals prescribe DORA were also taken as the measure of impact. DORA supports open science, and open access can be an alternative to evaluate the impacts of researchers and their scientific outputs DORA aims to promote responsible and comprehensive research assessment practices over matrices such as the Journal Impact Factor. It helps to evaluate the scholarly outputs and researchers. Thus it can measure and evaluate the impacts on researchers and the research community's growth and empowerment (DORA, 2023).
Knowledge, skills and competencies (S4) Changes in way of thinking,	The project reported the use of a methodology to compare the change in participants' pre and post-project	The authors reported they observed change in participants without quantified comparison.	To measure the changes in attitudes, behaviour, and knowledge in CS projects, Somerwill and Wehn 2022 conducted a systematic literature review in environmental psychology

Impact Domains	Strength of Evidence		Features of strong evidence for impact indicators
	Strong evidence	**Weak evidence**	
attitude and values (S5)	activities, e.g., NEP		and identified five validated approaches that can be applied to measure these indicators.
Behavioural change (S6)			
Economic			
Impact on employmen t (E1)	Quantifies the number of livelihoods generated or employed as a result of project activities against the total population in project area and unemployment rate of the project area	Number of people employed, or livelihoods created without a comparison against the total population in the project area and unemployment rate of the project area.	(+)
Cost saving (Cost-benefit) (E2)	Indicated by a cost-benefit analysis of the project.	Authors indicate that CS was chosen as a method of data collection due to its reputation as a cost-effective process.	There are a few studies which have proposed different methods to measure cost saving or benefit impacts of CS (Michele Ferri et al., 2020). The following aspects are recommended to analyse • time invested by researchers in engaging and training citizens (Thornhill et al., 2016) • cost per observation (Davids et al., 2019) • staff costs and any other costs (Blaney et al., 2016)
Income and revenue generation for leading organisation s (E3)	Quantified indication of revenue generated due to actions related to the project over a fiscal period due to project activities including funding and grants.	Indication of financial growth of the leading organisation or probable financial growth.	(+).
Economic impact on the local community (E4)	Quantified indication of economic upliftment such as no. of new business started, no. of livelihood	Probable economic upliftment that has/might take place due to current project activities as observed by the authors.	(+) **Note:** The impact can be measured for scientific benefits, public engagement benefits and the benefits of strengthened

Impact Domains	Strength of Evidence		Features of strong evidence for impact indicators
	Strong evidence	**Weak evidence**	
	generated, the economy generated by ecosystem services, etc. as well as future economic trajectories		capacity of participants (Blaney *et al.*, 2016)
International trade and investment (E5)	Indicated by the quantity of goods and/or the total amount of transaction and/or knowledge	Mention of international cooperation, international author collaboration and/or funding by an international grant agency	(+)
Environment			
Improved Action better ecosystem function, service and resilience (EN1)	Quantified or authentic evidence of actions undertaken, e.g., using the IUCN Review Protocol for Biodiversity Net Gain to report	Project actions leading to probable improved action	(+)
Enhanced ecosystem services and resilience (EN2)	Quantified or authentic evidence of actions undertaken that resulted in enhanced ecosystem services.	Project actions leading to probable ecosystem services	(+)
Science & Technology			
Scientific knowledge (ST1)	Indicated by measures such as number of species recorded, quality of water, air, or waste characterisation, etc. and publication and dissemination of scientific research based on the data generated by CS.	Report of probable knowledge generation or	(+)
New knowledge (ST2)	Indicated by measurable generation of new scientific and		(+)

Impact Domains	Strength of Evidence		Features of strong evidence for impact indicators
	Strong evidence	**Weak evidence**	
	technical knowledge, such as the identification of a new species in an area where it was previously unknown. It also includes new knowledge generated from the project activities for the benefit and understanding of issues related to society, economy, environment and governance.		
New and interdisciplinary research fields (ST3)	Authenticated reporting of the emergence of new research leading from project activities which were not part of the project research initially.	A single project initiative undertaking research in more than one thematic area.	(+)
Innovation in education (ST4)	Utilising CS to develop activity-based learnings for schools and colleges to measure outcomes.	Knowledge generated by CS has brought innovation in education as reported by authors.	(+)
New Technology (ST5)	Indication of development of apps, sensors, etc. for the project including the process or design of the technology.	The utilisation of an app made by a third party e.g., eBird to collect data	(+)
Governance			
Impact on the policy process (G1)	Indicated by authentic contributions to management plans and policies, i.e., use of data and research outputs in policy development or	Probable and potential use of data and research outputs for policy development as mentioned by authors	Chandler et al., 2017 recommend measuring the number of high-level contributions to management plans, policies, conventions, treaties or the creation of protected areas. The measuring idea is similar to S3 explained above.

Impact Domains	Strength of Evidence		Features of strong evidence for impact indicators
	Strong evidence	**Weak evidence**	
	management plans by identifying the policy(s) or management plan(s) a project contributed to.		
Stakeholder interactions in decision-making processes (G2)	Indicated by a detail of the interaction process during and/or post-project activities	Indicated only through the mention of training and feedback	(+)
Political support (G3)	Support indicated by active involvement of governmental agencies, such as a platform for working, promotion of the initiative, co-designing of projects and integration of project outcomes in decision-making	Only funding by government agencies and organisations, or authors indicating that data has been shared with governmental bodies.	(+) The current evidence indication is drawn from Chandler 2017 based on the argument given above (G1, S3).
Polycentrism (Self-governance) (G4)	Indicated by authentic reporting on the integration of project outcomes in the decision-making of local bodies by local authorities leading to local-level changes.	Indicated that the data has been shared with local bodies without indication of integration.	(+) The current evidence indication is drawn from Chandler 2017 based on the argument given above (G1, S3).

4.4. Results

4.4.1. An overview of the impacts of ecological and environmental citizen science projects in India

The overall distribution of evidence of impacts based on the selected records showed that 71% of them referred to impacting Society; 67% referred to impacting Scientific & Technology domains; 53% referred to impacting Governance; 26% referred to impacting the Economy and 82% referred to impacting the Environment (Figure 18) (Table 8). This high value for the Environmental domain reflects concentrating only on ecological and environmental CS in my thesis (Chapter 2).

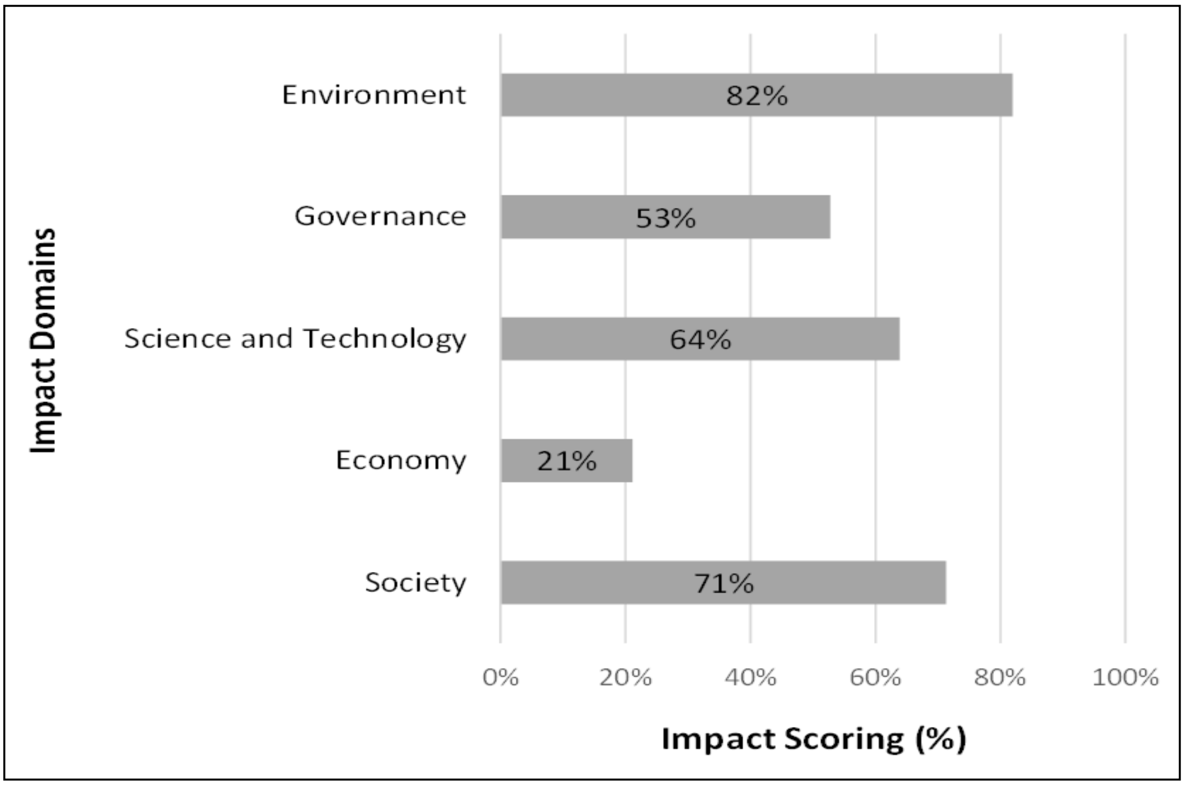

Figure 18: Overall distribution of evidence of impacts across identified CS impact domains based on the academic records identified through the systematic review.

Table 7. The table provides the codes used in NVivo and the number of records that referred to each of the codes (impact domain) and sub-codes (indicators).

Impact Domains (Codes)	Indicators (Sub-codes)	Records
Social	Community building and empowerment (S1)	29
	Social inclusion (S2)	21
	Researchers and research community's growth and empowerment (S3)	58
	Knowledge, skills and competencies (S4)	28
	Changes in way of thinking, attitude and values (S5)	23
	Behavioural change (S6)	20
Economic	Impact on employment (E1)	9

	Cost saving (E2)	19
	Income and revenue generation for leading organisations (E3)	0
	Economic impact on the local community (E4)	17
	International trade and investment (E5)	3
Environment	Improved action (EN1)	33
	Enhanced system (EN2)	32
Science & Technology	Scientific knowledge (ST1)	43
	New knowledge (ST2)	41
	New and interdisciplinary research fields (ST3)	15
	New Technology (ST4)	14
	Innovation in education (ST5)	11
Governance	Impact on policy process (G1)	26
	Stakeholder interactions in decision-making processes (G2)	29
	Political support (G3)	15
	Polycentrism (Self-governance) (G4)	9

4.4.2. Strength of Evidence

In terms of overall distribution *Researchers and the research community's growth and empowerment* (S3) (Figure 19) have been able to show the highest number of strong evidence of impacts from CS projects. This high reflection of strong evidence for this indicator is due to the quantifiable option of using the Impact Factor (IF) to define the strength of evidence. There was a lack of strong evidence in most cases unless the article (record) focused on reporting on an indicator of a particular impact domain. After R*esearchers and the research community's growth and empowerment* S3, *Scientific knowledge* (ST1), *New knowledge* (ST2) and *New Technology* (ST4) showed the highest number of strong evidence. It was interesting to note that there was no indication of evidence towards *Income and revenue generation for leading organisations* (E3). The review showed that most of the reporting on impacts by the authors focused on particular aspects, such as scientific and conservation outcomes, scientific knowledge, social benefits of participants or local community and contribution to policy development for enhanced ecosystem.

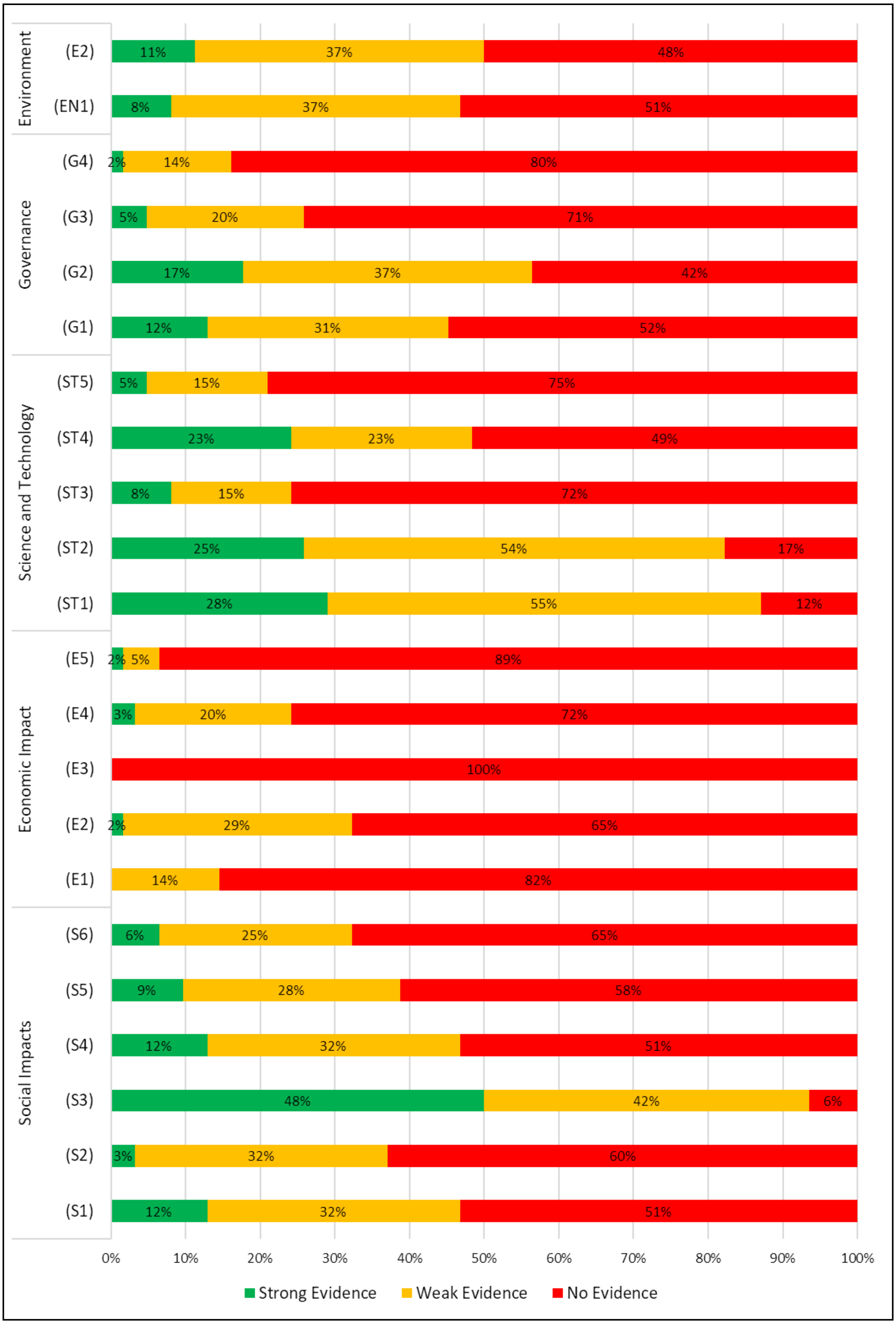

Figure 19: Strength distribution of evidence of impacts concerning the impact indicators identified for this study. It is segmented into Strong Evidence (green), Weak Evidence (yellow), and No Evidence (red). The y-axis showcases the percentage breakdown of the evidence types. The x-axis represents the percentage scale from 0 to 100%.

4.4.3. Qualitative data analysis

In this section, I have synthesised and systematically presented notable evidence of impacts collected using NVivo to identify the achievements, strengths and weaknesses of CS in India. The systematic qualitative analysis is presented using the CSIAF framework. In this analysis, I have tried to focus on impacts which are unique to India while noting common impacts found in CS initiatives (Walker, Smigaj and Tani, 2021). The idea is to identify impacts which can address India's indigenous issues, which will make a strong case for promoting CS initiatives.

4.4.3.1. Impacts on Society

CS initiatives in India have demonstrated their potential to impact local communities through knowledge sharing and capacity building. EM&E projects showed strong evidence of engaging and empowering local communities as the projects were targeted to address local issues and sustainable resource management by fostering cooperation among the locals. This is evident in projects such as MARVI, Safe Drinking Water, and Vembanad Lake Water Quality Monitoring which directly recruited local participants to engage them in local issues (Devasia, 1998; Maheshwari *et al.*, 2014; Jadeja *et al.*, 2018; George *et al.*, 2019; Lekshmi *et al.*, 2021; Menon *et al.*, 2021). By leveraging community interactions, these projects empowered marginalised groups, such as rural women, to actively participate in scientific research and decision-making processes related to biodiversity conservation, groundwater management, and environmental monitoring. For example, Safe Drinking Water and MARVI have shown that CS projects can provide a space to rural women whose voices are rarely represented within the family as well as in the village-level decision-making spectrum in India.

The review found strong evidence that CS activities had successfully led to awareness creation of local biodiversity, especially in rural areas and among marginalised communities (Bachan *et al.*, 2011; Binoy, Radhakrishna and Kurup, 2017; Schuttler *et al.*, 2019; Pradhan and Yonle, 2021; Pradhan, George and Dewan, 2023). One of the notable impacts was from the Hornbill conservation project (Bachan *et al.*, 2011). The project involved participants from the Kadar tribe of the Annamalai forest. Their participation and involvement led to conservation efforts and fostered a sense of ownership and stewardship over local biodiversity. The project also involved 6 ex-poachers from the Kadar Tribe, which indicated that CS can be used as a space for rehabilitation and utilise their knowledge of the area to collect data and conserve biodiversity instead of poaching. Similarly, the Squamate project has shown the potential to transform attitudes and values towards wildlife conservation by fostering awareness of participants on their local reptilians (Pradhan and Yonle, 2021). A pre-activity survey of the participants in the projects showed that 83% of them believed that all squamates are poisonous as they directly relate them to snakes, and 52% suggested that they would kill squamates. However, the project was able to push towards a behavioural change among the participants on their notion of squamates through workshops.

It was interesting to note that in two cases, evidence showed that by providing guardianship and ownership of local socio-environmental issues, project proponents were able to bring behavioural change, promotion of awareness and community empowerment. For example, in the MARVI project, volunteers were given a title or position called *Bhujal Jankaars (BJs),* meaning 'g*roundwater informants.*' The authors described that this special distinction instilled a sense of ownership of the issue and pride as the champions of their community who monitor, manage, and disseminate knowledge on water quality for the village (Maheshwari *et al.*, 2014; Jadeja *et al.*, 2018). Secondly, the Bugun community from Arunachal Pradesh made the bird Bugun liocichla (*Liocichla bugunorum*) their local mascot (Aiyadurai and Banerjee, 2019). The tribe was honoured by naming the bird in their name for their participation and role in strengthening conservation efforts.

In terms of empowerment and awareness creation, studies have indicated that the training and workshops provided to participants have helped them acquire new knowledge, skills, and competencies in various scientific disciplines, such as conducting water quality monitoring with 3D printed Secchi discs, analysing cat-scat litter, or using GPS for monitoring (Johnson *et al.*, 2014; George *et al.*, 2019; Mukherjee, 2019). Other studies did not provide measurable impacts; however, they suggested that their trainings and workshops were able to develop knowledge and awareness among participants on the research topic as well as provide skills that can help in career or livelihood development.

4.4.3.2. Impacts on the Economy

Only one record conducted a cost-benefit analysis (George *et al.*, 2019) however three other records have acknowledged CS as a cost-effective tool for data collection (Mujumdar *et al.*, 2020; Singh, Saran and Kocaman, 2021; Mishra *et al.*, 2023). The Vembanad Lake project compared the cost per data point between citizen scientists who collected data and professionals, which demonstrated the cost-effectiveness of the process (George *et al.*, 2019).

CS Projects in India have shown only one strong evidence in creating job opportunities and economic empowerment, especially among rural communities and marginalised communities. Evidence from the MARVI project indicated that the *Bhujal Jankaars* were recruited from the local communities and employed under the *"Mahatma Gandhi National Rural Employment Guarantee Act"* (MNREGA) (Maheshwari *et al.*, 2014). They argued that groundwater monitoring in rural India can be conducted by employing locals under this scheme and developing a "*durable asset base"* for data collection. Other evidence indicated the involvement of local graduates as field assistants and project coordinators (Devasia, 1998; Rane and Datta, 2015; Jadeja *et al.*, 2018; Khan, Kumar and Chella, 2022). Thus closely tying the involvement of representatives from the local communities within the project.

Furthermore, EM&E projects focused on improving livelihoods; however, the evidence did not indicate measurable impacts in their reports. For example, all four projects monitoring lake ecosystems argued that activities undertaken by their CS initiative helped in managing the lake ecosystems and supporting local ecotourism (Yardi, Bharucha and Girade, 2019; Mujumdar *et al.*, 2020; Lekshmi *et al.*, 2021; Menon *et al.*, 2021). The MARVI project helped in managing and rejuvenating groundwater aquifers required for consumption and agriculture in rural Gujarat, Madhya Pradesh and Rajasthan (Maheshwari *et al.*, 2014; Jadeja *et al.*, 2018). Economic development and livelihood generation can be by-products of CS activities. This was demonstrated by the development of ecotourism and related livelihoods in West Kameng, Arunachal Pradesh, where birders from across India would visit to collect data on migratory species every year (Aiyadurai and Banerjee, 2019).

International trade and investment through CS can be observed through the exchange of design for the fabrication of the 3D printed Mini Secchi Disk from a high school in the UK and the development of the mobile application for water quality from India (George *et al.*, 2019; Menon *et al.*, 2021). Another international trade can be attributed to the development of biodiversity platforms in Bhutan using the codebase of the India Biodiversity Portal (IBP) (Vattakaven *et al.*, 2016). These trades identified in this study, as understood from the articles, did not entail monetary transactions but were an exchange of ideas and information. Strong evidence of international trading was indicated by Schuttler *et al.,* 2019, who shipped camera traps from the USA to India. Funding from international and foreign country agencies was taken as weak evidence of international investments.

4.4.3.3. Impacts of Citizen Science on Science & Technology

CS initiatives have shown overwhelming impacts on the generation of scientific knowledge. Contribution to scientific research involved the identification of new species, water quality monitoring for investigating purposes, or the development of new tools or applications for sensing the physical environment.

The knowledge generated by BC projects has been extensively used for understanding human-wildlife conflict (Datta-Roy, Ved and Williams, 2009), to developing climate change simulations models associated with distribution and migratory patterns of birds (Singh and Saran, 2020; Girish and Srinivasan, 2022; Deomurari *et al.*, 2023), or seasonal patterns of trees (Ramaswami, Sidhu and Quader, 2021). Furthermore, projects were able to establish distribution patterns of different avian species which were previously unknown to certain locations and habitats (Adhurya and Bhandary, 2019; Kumar, Sinha and Kanaujia, 2019). Another knowledge generation and its impact are evident from the 11 records which conducted scientific research using CS-generated data.

Besides that, 13 projects also indicated the generation of new knowledge by developing indigenous technologies such as mobile phone apps to monitor air quality, noise quality, water quality, and beach litter. The study notes that mobile phone applications were the most commonly developed technologies to aid participants in collecting data. In addition to monitoring, mobile phone applications were used for continuous interactions with participants to inform them of local socio-environmental issues. Both the India Biodiversity Portal and PAC Waste Collection mobile application reported developing their platforms for interactions among participants and with project proponents to encourage discussions on issues of interest (Vattakaven *et al.*, 2016; Nagendra, Lakshmisha and Agarwal, 2019).

Two initiatives showed strong indications of using CS as an innovation in education through activity-based learning in the school curriculum (Binoy, Radhakrishna and Kurup, 2017; Schuttler *et al.*, 2019). For example, the integration of eMammal software and lesson plans in schools encouraged students to conduct scientific studies using camera traps, thereby getting hands-on learning experiences (Schuttler *et al.*, 2019). The second example is the Student Scientist Project, which tried to inculcate CS activities to promote inquiry-based learning (Binoy, Radhakrishna and Kurup, 2017). Other projects showed weak evidence of the inclusion of school and college students in their projects; however, this was not their main motive (Lekshmi *et al.*, 2021; Menon *et al.*, 2021; Ramaswami, Sidhu and Quader, 2021). It is important to note that there are barriers to realise the full potential of the impacts as observed by Binoy, Radhakrishna and Kurup, 2017.

In terms of new and interdisciplinary studies, CS-generated data have been used to understand climate change, monitor lake ecosystems and develop software technologies to integrate mass participation (Yardi, Bharucha and Girade, 2019; Ramaswami, Sidhu and Quader, 2021). However, there is very little indication of transdisciplinary approaches in India and thus the review could not establish with strong evidence if there is a real impact of CS initiatives in establishing new and interdisciplinary research.

4.4.3.4. Impacts of Citizen Science on Governance

The impact of CS on governance is best seen in the policy process. More than 20 articles reported that their data can be potentially used for policy-making in India; however, only one project strongly indicated that their data has been used in developing national action policies on biodiversity (Vargiya, Jethva and Pandya, 2022). Other projects such as the IBIN and IBP were developed to collect data on bioresources in India; however, the current record does not show how successfully the data had been integrated (Vattakaven *et al.*, 2016; Singh *et al.*, 2018). In the case of BC projects, half of the projects reported that the data collected by them has the potential (weak evidence) to contribute to policy development in India.

In the case of EM&E projects, the potential contribution was indicated by the PAC Waste Tracker, which involved various local-level stakeholders including the Bangalore municipal corporation (*Bruhat Bengaluru Mahanagara Palike*). The project proponents mentioned that they shared their data with local authorities to develop an evidence-based policy for waste management in Bangalore (Nagendra, Lakshmisha and Agarwal, 2019). This was observed as a possible endorsement by the local authorities in developing policies. Another example is Pashan Lake; in this case, the Pune Municipal Corporation allocated funding to monitor the lake conditions using CS. Thus establishing a potential route for local governmental bodies to support CS projects addressing local socio-environmental problems (Yardi, Bharucha and Girade, 2019). Moreover, the mention of the involvement of local officials in advocacy seminars, training sessions, and workshops in various projects (n=11) indicates institutional recognition of CS as a valuable tool for informing policy development and the decision-making process.

Political support or endorsement by government agencies can be observed, especially from the forest department. A considerable number (n=9) of the projects were carried out with funding provided by the Ministry of Environment, Forest and Climate Change (MoEFCC) and Department of Forest (Rane and Datta, 2015; Singh *et al.*, 2018; Saran *et al.*, 2020; Dawn, 2021; Mukherjee *et al.*, 2021; Only, 2022; Vargiya, Jethva and Pandya, 2022; Gole *et al.*, 2023; Pradhan, George and Dewan, 2023). Other organisations, such as the Department of Science and Technology (DST), Ministry of Earth Sciences (MoES) and the Department of Biotechnology (DBT), among others, also played a catalysing role in supporting projects. Other political endorsement was seen in accepting data generated by the Asian Waterbird Census by MoEFCC to develop National Action Plans on Migratory Birds (Vargiya, Jethva and Pandya, 2022).

4.4.3.5. Impacts of Citizen Science on the Environment

The impact of CS on the environment was very much evident from all the records, as the study concentrated on CS initiatives addressing ecological and environmental issues in India. Thus the results are biased when looked at in terms of the distribution of evidence, but it has aided in identifying and recording the impacts achieved by CS projects in improving action, better ecosystem function, service and resilience, and enhanced ecosystem services and resilience in India.

The review found extensive evidence that CS initiatives aided in the conservation of biodiversity and ecosystems. More than 400 species of fauna had been recorded using CS through the various records that were evaluated, including the identification of 5 new species of birds that were not previously recorded in the project area (Pinder, Raghavan and Britton, 2015; Adhurya and Bhandary, 2019; Aiyadurai and Banerjee, 2019; Schuttler *et al.*, 2019; Dawn, 2021; Jaiswara *et al.*, 2022; Only, 2022; Rana, Rayal and Uniyal, 2022; Thaker *et al.*, 2022; Vargiya, Jethva and Pandya, 2022; Gole *et al.*, 2023). The main contribution to conservation was aiding the development of baseline data on biodiversity in India. This is not strong evidence of improved actions; however, over time, the data collected can enhance ecosystem services and their resilience when shared with policymakers.

In the case of EM&E projects, CS initiatives have shown strong evidence of improved quality of lake ecosystems, and probable or weak evidence of improved waste collections due to project activities (George *et al.*, 2019; Nagendra, Lakshmisha and Agarwal, 2019; Yardi, Bharucha and Girade, 2019; Mujumdar *et al.*, 2020; Lekshmi *et al.*, 2021). However, some of the projects dealing with air quality, pharmaceutical waste, and noise did not report strong evidence of improved actions after the project (Kumar, Mukherjee and Singh, 2017; Ghosh *et al.*, 2019; Middya, Roy and Das, 2021; Shipingana, Shivaraju and Yashas, 2022).

Strong evidence of improved ecosystem was also inferred from Khan, Kumar and Chella, 2022, who developed a model to communicate the sea-level rise risk and build capacities of artisanal fishing communities as adaptive measures to develop resilience against sea-level rise.

4.5. Discussion

The study aimed to find the impacts and the achievement of CS in India. However, while conducting the systematic review using the CSIAF, new opportunities for the framework were identified. I have divided the discussion into two sections. In the first section, I have discussed the strengths and weaknesses of CS in India identified through the impacts. In the second section, I have discussed the opportunities and limitations of the modified CSIAF in conducting rapid systematic reviews.

4.5.1. Strengths and Weaknesses of CS in India

The key findings of the study indicate that CS has been able to establish itself as a valid scientific process among professional scientists and researchers. The impact on science and technology has been the highest through generation of academic research, scientific knowledge, new knowledge, and new technology. The main achievement under this impact domain is the contribution of CS to developing baseline ecological data. This is an essential achievement as conservationists in India often highlight the mismatch in priorities given to conservation sites as a result of insufficient data or coverage in terms of biodiversity associated with it (Srivathsa *et al.*, 2023). Data generated by CS has been able to cover this gap, which is a significant achievement within the Indian context.

The study did not find evidence to suggest that CS data is popularly used; however, the integration of data and insights from several projects in National Action Plans such as the *National Action Plan for Aquatic Ecosystem Conservation,* and *the National Action Plan for Migratory Birds and their Habitats in the Central Asian Flyway* suggest that GoI does value the process (Vargiya, Jethva and Pandya, 2022). Many projects also aligned themselves so that they could contribute to national and international policies such as IBP aligned themselves with the *Biological Diversity Act (BDA), 2002* (Vattakaven *et al.*, 2016). Projects were also developed to contribute to the Sustainable Development Goals (Lekshmi *et al.*, 2021; Menon *et al.*, 2021; Venkatesh and Velkennedy, 2023). Thus indicating that government agencies are aware of its potential use. This acknowledgement comes as a strength for further integration of CS in the policy-making process.

Within this domain, CS has not been able to show much impact in addressing interdisciplinary issues as well as in bringing innovation to education. This gap was also observed by Phartyal and Yadav, 2022; who argue that integration of CS is very limited even within Higher Education Institute (HEI) set-ups in India. This comes as a weakness, as CS can be incorporated into the curriculum as an innovative educational technique that can help students focus on projects relevant to their lives as well as aid their neighbourhood (Phartyal and Yadav, 2022). At the current time, there is a probability that only a small percentage of people, even those at higher education levels, had the chance to participate in CS initiatives. A survey across various academic and research organisations in India revealed that 74% of the respondents lacked hands-on experience with CS, even though 80% of them had a prior idea about it. More importantly, 30-40% of the respondents were familiar only with biodiversity projects (Phartyal and Yadav, 2022). Another weakness is the limited development of technology. Only mobile applications have been developed in India for CS, which has reduced the variety in innovation as opposed to developing low-cost technologies to monitor such as Secchi Disk, or air quality monitor.

Next to science & technology, CS had evident impacts on society; in some cases, projects were specially designed to address the requirements of the community, especially in the case of EM&E projects, which focused on improving the livelihood of the participants. This characteristic is found in many Non-Annex I countries especially those understanding water resources (Walker, Smigaj and Tani, 2021). The project proponents utilised the process to conduct their scientific studies while attempting to connect with the public and contribute to it. However, it should be noted that the impacts of CS in India were not shared by the majority of the participants and were localised to the project area. From Chapter 3, we can also draw on the fact that the impacts were not equally distributed across the country. Thus, these impacts cannot be described as major impacts as they have not been able to bring about a change on a large scale. However, they can be viewed as potential achievements at a small-scale level, which can be strengthened.

The achievements in bringing social change though limited in scale, proved that CS can empower the local rural communities by integrating rural women, forest dependent tribes, etc. in scientific and decision-making processes; and engage local communities in monitoring and stewardship activities. This is an essential achievement for a country like India where economic disparity and caste system are evident in everyday social structure. For example, the MARVI project observed that there were limitations in engaging women initially and also participants hesitated to monitor water from areas belonging to upper-caste communities (Jadeja *et al.*, 2018). Within the traditional systems, there are accessibility restrictions, depending on the level of caste a person belongs to. In modern India, though the constitutional norms have defined such traditions as social evils, these traditions are practised in certain places, especially in rural areas (Sahgal *et al.*, 2021). Through this project, we can see CS projects can help in breaking social evils by bringing a variety of stakeholders to a common platform to discuss their issues and develop awareness and knowledge.

Another interesting achievement was the rehabilitation of poachers into participants, and involving them in conservation through CS. Though there was single evidence; however, significant impact can be achieved if such projects can be scaled. As observed in the review, poachers belonged to traditional forest-dependent communities usually termed as indigenous communities in India (Bachan *et al.*, 2011). There are several such communities in India whose livelihood, food security and sacred cultural practices are intertwined with their local forests (Hamilton, 2023). Though there are policies to safeguard their rights; however, these communities remain among the most marginalised groups in the country. Their involvement in CS activities can help rejuvenate their education and provide them with skills to help them with their livelihood.

Other measures of community empowerment can be linked to the impact on employment under the economic domain. The review found that the impact on the economy through employment generation can be direct or indirect. The review showed that employment can be impacted by directly employing locals as part of the project management team, or by providing incentives. For example, the compensation given to participants as groundwater informants in the MARVI project shows that there is a possibility of leveraging CS initiatives to generate part-time livelihoods in rural India. This is especially essential when looking at the current massive unemployment crisis in India (CMIE, 2024). On the other hand, indirect employment refers to livelihood generated due to the outcomes of CS projects. For example, the Vembanad Lake project that monitored the ecosystem of the lake led to its restoration of biodiversity, and water quality (George *et al.*, 2019; Menon *et al.*, 2021). This helped in developing ecotourism and related livelihoods due to the restoration of the lake. These cases also reflect the interlinkage of the domain feature of CSIAF (Wehn *et al.*, 2021). Again, such evidence was very limited in numbers in India and requires further scrutiny. Providing incentives is often not considered part of volunteerism and might have a philosophical conflict with volunteerism in CS (West and Pateman, 2016; Guerrini *et al.*, 2018). However, in projects in Non-Annex I countries, participants might seek some kind of incentive for the time spent on project activities (Requier *et al.*, 2020; Walker, Smigaj and Tani, 2021; Pasgaard *et al.*, 2023).

The study found there were shortcomings in reporting impacts, especially those related to polycentrism or self-governance and, the direct involvement of participants in the actual policymaking process. Moreover, the review did not show impacts on the health and well-being of participants. In addition to that, the utilisation of various features of CS in India is limited, and thus the impacts are limited, as indicated by this review. This is evident from the skewed distribution of impacts across various domains as well as within domains.

Overall evidence in the review suggests that the CS process has shown potential strength in changing the current socio-environmental issues in India; however, the main weakness of CS lies in the number of projects and its scale in reaching out to participants. At its current rate, it is yet to reach even 1% of the population in the country, given the maximum number of participants including irregular volunteers of the largest CS project i.e., eBird India is only 12000, while other projects have fewer than 1000 participants. Hence, the potency of the process has not been realised fully. Increasing the number of projects can be one of the pathways to achieving major impacts as more participants join the process, especially those dealing with EM&E, DMM, and TDS projects. This raises further questions, such as what are the barriers and challenges of CS in India to achieving its full potential and what opportunities lie in promoting it. Thus, in the next chapter, Chapter 5, I have traced these questions to understand the shortcomings of the process and the features that hinder its uptake.

The review was not able to find any reporting on the negative impacts of CS. The last global assessment that captured water-related CS initiatives showed that 70% of the articles did not capture any negative impacts (Walker, Smigaj and Tani, 2021), thus it was unsurprising to see a lack of reporting of negative outcomes in this study as well. The study categorised the identified negative impacts into three main categories (Walker, Smigaj and Tani, 2021, pp. 15–19): livelihood impacts, disempowerment, and demotivational impacts. Livelihood can be impacted if participation in CS initiatives adds to the regular struggle of the participants, something potentially seen in participants from Non-Annex I countries. Other negative impacts on livelihood can be through health and safety issues, decreased self-reliance, and increased sensitisation towards hazards. The review did not show any such evidence.

Disempowerment can be through the exclusion of certain groups or sections of society, which can lead to biased representation of data or exclusion through technology. Scholars in India have pointed out that participants' representations are higher in urban areas than in rural areas (Urfi, 2012; Phartyal and Yadav, 2022). Thus, there is a high probability that a large number of potential participants were not recruited in India due to the digital divide stemming from socio-economic conditions and accessibility to technology. Other negative impacts are decentralisation of monitoring and risk delegating important responsibilities to the public, and conflict of interests, e.g., certain groups can put forward their interests and try to discredit the data generated or create conflicts (Walker, Smigaj and Tani, 2021).

Lastly, demotivational impacts can arise from time-consuming, boring or difficult tasks, non-alignment of participants' interests and data goals, or lack of impacts and erosion of confidence and trust. Devasia, 1998, observed that when these impacts are shared on individual and collective levels, they motivate stakeholders, especially the marginalised communities (rural women in this case) to gain their trust in the process. Initially, the project had a slow participation rate; however, as the benefits were seen in the community and discussed, the participation rate increased.

4.5.2. Opportunities and limitations of using the modified CSIAF for systematic reviews of CS initiatives

This study provided a platform to discuss how impacts from CS initiatives can be measured through systematic reviews using CSIAF. Using the methodology, researchers and policymakers can conduct rapid systematic reviews to identify impacts from any set of CS initiatives, for example, reviewing impacts of EM&E CS initiatives on a particular region, nation or province in the world; or solely concentrating only on impacts of water quality or air pollution CS projects over a certain period. Using the impacts measured over large temporal or spatial resolutions, policymakers and funding agencies can track how effectively CS has been able to impact and develop informed decisions for further support.

However, there are a few limitations to the current status of the modified CSIAF framework. Currently, my framework has been able to identify the strength of the quality of evidence-based reporting. Thus the recognition of impacts is directly dependent on the reporting of authors. Secondly, there are several gaps in the overall literature to understand what can be defined as strong evidence of impact by CS and the methodology of their measurement. For instance, in this study, I have suggested to use of impact factors to quantify the impacts on Researcher and research community empowerment (S3). However, Impact factors can vary depending on the topic of research and the research audience. Moreover, to keep with the principles of CS, open and accessible research is important but currently with the techniques available the study could not measure the openness, accessibility and outreach of these articles.

This study recommends that further examination is required to define strong impacts for those indicators which currently lack them, and the definition can enhance the framework. For example, there are possible frameworks similar to the New Environment Paradigm (NEP) which was recommended to identify behavioural or attitude change among participants. Next, the study has not been able to quantify the impacts generated as suggested by MICS (Antonella, Annelli and Katharina, 2022). One of the recommendations is to adjust a scoring system which can accommodate the categorisation of the strength of evidence in a quantifiable manner. Walker, Smigaj and Tani, 2021 used a categorising system to determine mentions of impacts in their systematic review. It would be interesting to examine if their scale can be theoretically integrated into CSIAF to further enhance the quantitative assessment of impacts.

4.5.3. Limitation of the current study

One of the limitations of the current study is that it did not trace the impact journey of the project from its initial period to its current status. This is because secondary sources limited to academic literature (records) were considered for this study. This increased the possibility that not all impacts in India have been captured. However, the study has been able to give a clear picture of what impacts CS has been able to accomplish within each of the impact domains in India. It has also been able to demonstrate the potential and scope of CS to address socio-environmental issues in India. Moreover, the information generated here would help in determining the strengths and weaknesses required to undertake the SWOT analysis in Chapter 7 for the determination of a roadmap.

4.6. Conclusion

In conclusion, CS initiatives in India have made localised impacts in the Society domain by engaging and empowering local communities, especially marginalised groups. By involving them directly and providing them with local data, these initiatives have fostered cooperation and sustainable resource management within communities. In the Science and Technology domain, CS has impacted significantly the generation of new knowledge and the development of indigenous technologies for environmental monitoring. Economically CS has shown potential to generate livelihood options in India as well and it has established itself as a cost-effective data collection method with the vigour of traditional and academic scientific endeavours within the Indian scientific community. However, challenges such as limited project coverage, low participation or lack of project continuation can hinder the widespread impact of CS in India. Further efforts are required to understand and overcome the barriers to ensure that CS can maximise its potential in India. The evidence gathered in this study can be used to develop a case for CS in India to promote it as it showcases the potential impacts.

Chapter 5

5. Barriers, opportunities and challenges for environmental and ecological citizen science in India

"It is science alone that can solve the problems of hunger and poverty, of insanitation and illiteracy, of superstition and deadening custom and tradition, of vast resources running to waste, or a rich country inhabited by starving people... Who indeed could afford to ignore science today? At every turn we have to seek its aid... The future belongs to science and those who make friends with science."

— Jawaharlal Nehru (Freedom fighter and 1st Prime Minister of India) (Khan, 2018)

5.1. Introduction

In this chapter, I seek to systematically identify barriers, and challenges evident in CS projects in India as well as opportunities to facilitate sustained and impactful outcomes of CS initiatives. The study in this chapter comprises two phases of work First, I conceptualised a framework based on available literature on what are 'barriers' and 'opportunities' (B&O) of CS projects, what 'influencing factors' (IFs) lead to 'barriers' and 'opportunities' and how 'challenges' manifest through 'interactions of barriers' at a larger scale for CS. The idea to develop this framework arose from my observations and understanding of existing literature on CS which indicates that there are clear and useful distinctions between IFs, B&Os and challenges (Section 5.2). The second phase of the study was to use resources identified in the systematic review to map 'barriers' and 'opportunities' of CS in India using the conceptualised framework developed in the first phase. The conceptualised framework enabled me to identify B&Os that are indigenous to India and those which are similar across the globe. At the same time, it also aided me to identify key challenges that require attention for the effective promotion of CS initiatives in India which contributed towards the SWOT analysis and roadmap development in Chapter 7. The study was guided by the following research question **"What are the barriers and opportunities of CS in India and the challenges it currently faces?"** The study also demonstrates the practical utilisation of the conceptual framework I developed, using India as a case study.

5.2. Development of a framework of influencing factors for citizen science

To understand factors that influence the success and failure of CS projects I undertook a literature review through a generic search in Google Scholar. The search was undertaken in October 2021 using the terms: ("Barriers" AND "Challenges" AND "Opportunities") AND "Citizen Science." As this study concentrated on EECS, articles were restricted to those considering EECS projects. After reviewing abstracts of the first 50 results from a Google Scholar search, 25 articles were selected to understand factors influencing the extent of success of CS projects. Out of the 25 articles, 3 systematic reviews discussing IFs and B&O of EECS projects were taken as core articles which developed the base of my B&O understanding and later became central to the conceptual framework idea. Later, Fraisl *et al.,* (2022) were identified as being highly relevant and added to the list of core articles.

While reading through the selected literature, it became apparent that a variety of terms were used in the context of understanding factors affecting the success or failure of CS. These included 'influencing factors', 'barriers', 'opportunities' and 'challenges' of CS. These terms are overlapping and open used to mean the same thing. For example, the terms 'Barriers' and 'Challenges' are often used interchangeably while discussing project impediments and limitations across different literature. In some cases, articles reported on influencing factors leading to barriers; or discussed barriers directly, creating diverse viewpoints in understanding. Thus, to bring distinction across the terminology and to bring uniformity in understanding, I propose a 'conceptual idea' which distinguishes between and links influencing factors, barriers, opportunities and challenges of CS.

5.2.1. The conceptual idea for the framework

The framework which is postulated in this study has three levels of logical conceptualisation based on my understanding of existing literature:

1) The <u>first level</u> of logic is that the success or failure of a CS project and the extent to which it can succeed in its aims is due to a multitude of factors. These I term them as **'influencing factors'** (IF) of CS projects.
2) The <u>second level</u> of logic is that when these IFs negatively influence CS projects, they create **'Barriers'** meaning obstacles or limitations that bar progress and outcomes or prevent access to a CS project. **'Opportunities'** on the other hand mean the positive IFs which lead to success, growth and promotion of CS projects.
3) The <u>third level</u> of the logic is that **'Challenges'** are formed when various 'Barriers' and 'Opportunities' (B&O) interact with each other. The interaction of 'Barriers' leads to 'Challenges' similarly, the interaction of 'Opportunities' leads to solutions to challenges.

5.2.1.1. Understanding the terminologies introduced above

1. **Influencing Factors (IFs)** can be one of the multitude of factors such as age of participants, culture of participants, data quality, political and legal impediments, or training, etc. which affect the outcomes of a CS project (Blake, Rhanor and Pajic, 2020; MacPhail and Colla, 2020; Lotfian, Ingensand and Brovelli, 2021; Wu, Washbourne and Haklay, 2022).
    a. **Barriers (B): Negative outcomes of IF** that can introduce obstacles that may impede the successful implementation of a project. For example, attributes such as 'age of participants', 'awareness about projects by participants', 'gender', 'availability of time', etc. when negatively influenced can create barriers to recruiting and retaining participants (Pateman, Dyke and West, 2021; Wu, Washbourne and Haklay, 2022; Terenzini, Safaya

and Falkenberg, 2023) and/or risk interacting with each to introduce new barriers such as biases in participation, and barriers to scientific and social impacts (Capdevila *et al.*, 2020; Chesser, Porter and Tuckett, 2020; Cooper *et al.*, 2021; Fraisl *et al.*, 2022).

   b. **Opportunities (O): Positive outcomes of IFs** that help in the success, growth, and promotion, of a project. For example, facilitating policies, data sharing and management frameworks, and funding opportunities help in overcoming barriers such as data quality, and political and institutional acceptance of CS-generated data (Sen. Coons, 2015; Wilkinson *et al.*, 2016; de Sherbinin *et al.*, 2021; Walker, Smigaj and Tani, 2021; Fritz, See and Grey, 2022).

2. **Challenges** in the context of CS can be seen as the interaction of barriers that affect the majority of CS projects. Challenges affect the overall robustness of the CS process and can be considered as milestones that 'need to be overcome' to make the CS process more robust and impactful. For example, Fritz et al., 2022 highlighted that the use of CS environmental data by governments, local authorities and NSOs for policymaking is still a challenge. CS has shown the potential to contribute to national and international developmental agendas such as the SDGs or developing policies for agriculture (Ryan et al., 2018; Fritz et al., 2019). However, barriers such as 'political and institutional acceptance', 'funding' and 'data collection and management' can create challenges in using CS-generated data for policymaking when institutional stakeholders such as academic and research organisations, and government agencies do not accept its validity. This is a challenge that can be overcome through 'opportunities' such as awareness creation among institutional stakeholders, developing good practices for data collection and management, etc.

Table 8. Characteristics of Barriers & Opportunities and Challenges to differentiate them and to utilise it for evidence gathering.

Characteristics of B&O	Characteristics of Challenges
B&O originates from Influencing Factors (IF).	Challenges manifest when a range of barriers affect a majority of CS projects within a collective set of CS projects instead of a singular CS project, such as within a region, domain, etc.
One or more B&O together form a challenge or solution.	Challenges can be seen as goals that need to be achieved for a robust CS process in a region, domain, etc.
B&O can manifest in individual projects, and such may not be prevalent in other CS projects in the same set of CS projects, such as within a region, domain, etc.	Challenges are time-dependent, i.e., over time challenges may change, emerge or be solved.

B&O is time-independent, i.e., they tend to exist for all CS projects and can manifest at different stages of a CS project.	

In summary, IF influences create B&O and interactions of B&O lead to challenges. For example, IF such as age, time and interest in the research topic can deter participants from joining projects. Age and Time can influence the availability to participate in projects. The age of participants in CS projects tends to vary depending on projects making some projects popular for certain age groups (Strasser *et al.*, 2023; Thompson *et al.*, 2023). The availability of time to participate also influences the outcomes (Land-Zandstra, Agnello and Gültekin, 2021; Terenzini, Safaya and Falkenberg, 2023). Similarly, interest in the topic of research is an important IF which can motivate or demotivate participants to join projects (West and Pateman, 2016; Land-Zandstra, Agnello and Gültekin, 2021; Thompson *et al.*, 2023). Drawing on these examples, age and time can create barriers to participation while interest can create barriers to motivation. These barriers can lead to challenges in recruiting and retaining participants in CS projects.

5.2.2. Developing the B&O framework

The conceptual idea explained above has shown the distinctions and connections between the terminologies used by the core articles selected to develop the B&O framework. The 4 articles selected to be the core articles systematically analysed and reported on IFs and B&O of EECS projects.

1) Cunha et al. (2017) systematically analysed 126 articles relating to CS projects worldwide and identified seven key IFs that contribute to the success and longevity of projects. The study highlighted factors such as geography, disciplinary areas, project proponents, project goals, local priorities, participant profiles, funding, etc as key IFs. This literature demonstrates the variability and range of concepts that can be taken as IFs.
2) Capdevila et al. (2020) critically examined 56 projects focusing on water quality monitoring and identified nine IFs divided into three groups, which are attributed to citizens, institutions and process mechanisms. This article helped to develop the idea of the positive and negative effects of IFs which the authors propose create successes and failures.
3) MacPhail and Colla, (2020) identified 13 B&Os associated with CS projects after reviewing 300 papers. The article describes them as challenges; however, on closer examination, the challenges they propose fit the characteristics of ‘barriers’ as defined in my framework. For example, poor experimental design, insufficient funding, political impediments, etc. are barriers that can affect any CS project in the absence of good practices.
4) Fraisl et al., (2022) highlighted various limitations and recommendations at different stages of EECS projects. The article provides an overview of EECS illustrating the range of key issues that

CS faces. The limitations and recommendations of the article showed similarities with the developed B&O framework.

5.2.2.1. Types of B&O

The core articles showed common themes around IFs and B&O they referred to, but their presentation varied as they presented their ideas from different viewpoints. Thus, to bring uniformity, I categorised the different themes of IFs and B&O into 'Types of B&O.' For example, both Cunha et al., (2017) and Capdevila et al., (2020) identified different Institutional Stakeholders as major IFs. Cunha *et al.*, (2017), termed this '*Project Proponents*' i.e. the main institutions or group of people who are responsible for the initiation and management of projects; Capdevila et al., 2020, referred to it as a '*Type of organisation*.' MacPhail and Colla, (2020) highlight those barriers such as economic and social controversies; and political and legal impediments, which are influenced by institutional stakeholders. A common theme of "Political and institutional acceptance" of CS as a tool for research and policymaking can be traced among the terminology used to describe the B&O and can be attributed to institutional stakeholders. Thus, this particular B&O is associated with institutional stakeholders and their acceptance of CS as a legitimate process.

Table 9. Mapping of different types of IFs and B&Os identified by the core articles. The column on the extreme left are the different types of B&O categorised by my study. The last two columns on the right are characteristics of B&O through which evidence is examined.

B&O types	**Terminologies used by the core selected articles to describe their IFS and B&O.**				**Characteristics of evidence to identify B&O**	
	(Cunha *et al.*, 2017) **(IF)**	(Capdevila *et al.*, 2020) **(IF)**	(MacPhail and Colla, 2020) **(B&O)**	(Fraisl *et al.*, 2022) **(B&O)**	**Characteristics of barriers**	**Characteristics of opportunities**
Political and institutional acceptance	Project proponents	Type of organisation	Economic and social controversies	Risks related to data collection, from visiting locations that are remote or unsafe, political risks, and so on	Evidence of restrictive political dynamics and legislation (MacPhail and Colla, 2020; Paul et al., 2020). For example, restrictive policies such as the 'China Statistics Law' prohibit unauthorised data collection and permit only government-sanctioned individuals to gather information (Wu, Washbourne and Haklay, 2022).	Evidence of uptake of CS by government agencies and policymakers for policy making such as utilisation of CS data by city officials of Lagoas; and uptake of CS by National Statistical Organisations of Kenya and Ghana (de Sherbinin et al., 2021).
			Political and legal impediments			
			Lack of awareness of data among professionals		Evidence of lack of interest and lack of trust in the CS process by institutional stakeholders leading to lack of funding, under-representation of participants from diverse communities leading to failure of achieving project goals (Cunha et al., 2017; Pocock et al., 2019; Queiroz-Souza et al., 2023; Capdevila et al., 2020; MacPhail and Colla, 2020; Schacher et al., 2023).	Evidence of CS projects by Non-Governmental Organisations and other institutional stakeholders for creating awareness and engaging local communities, researching, monitoring and evaluation (Capdevila et al., 2020).
			Results not always accepted.			

B&O types	Terminologies used by the core selected articles to describe their IFS and B&O.				Characteristics of evidence to identify B&O	
	(Cunha *et al.*, 2017) **(IF)**	(Capdevila *et al.*, 2020) **(IF)**	(MacPhail and Colla, 2020) **(B&O)**	(Fraisl *et al.*, 2022) **(B&O)**	**Characteristics of barriers**	**Characteristics of opportunities**
Motivation of project proponent		Motivation of project proponent	Reduction in researcher productivity			
Funding	Funding sources	Consistent and adequate funding	Insufficient funding		Evidence of financial unsustainability of CS projects is a major concern usually influenced by institutional stakeholders and creating barriers such as project longevity, scaling-up, transportation of participants, etc. (Weeser et al., 2018; Capdevila et al., 2020; Vohland et al., 2021; Pateman, Tuhkanen, and Cinderby, 2021).	Evidence of support by dedicated funding programs like Horizon 2020 by the European Commission's Science with and for Society Program (SwafS) leading to new CS projects (Trojan *et al.*, 2019; Wuebben, Romero-Luis and Gertrudix, 2020; Pelacho *et al.*, 2021).
Data management and collection	Scientific methods	Supporting structures (e.g., training, data management)	Delays in data analyses, sharing results	Temporal biases, such as the daytime and weekend bias	Evidence of negative effects on data influenced by data access, data infrastructure, licenses, lack of training and documentation leading to	Ensuring data quality by using robust principles such as the FAIR Principles or through other good practices including multiple

B&O types	**Terminologies used by the core selected articles to describe their IFS and B&O.**				**Characteristics of evidence to identify B&O**	
	(Cunha *et al.*, 2017) **(IF)**	(Capdevila *et al.*, 2020) **(IF)**	(MacPhail and Colla, 2020) **(B&O)**	(Fraisl *et al.*, 2022) **(B&O)**	**Characteristics of barriers**	**Characteristics of opportunities**
			No Standardized assessment methods	Risks related to data collection, such as loss of smartphones, visiting locations that are remote or unsafe.	barriers related to data quality, data ownership, bad project design, etc. (Ganzevoort *et al.*, 2017; de Sherbinin *et al.*, 2021, 2021)	observations, random sampling sites, consortium development, and reliable sensors (Dickinson, Zuckerberg, and Bonter, 2010; Wilkinson et al., 2016; Capdevila et al., 2020; Requier et al., 2020; Fritz, See, and Grey, 2022).
				Varying data protection laws in different countries		

B&O types	Terminologies used by the core selected articles to describe their IFS and B&O.				Characteristics of evidence to identify B&O	
	(Cunha *et al.*, 2017) **(IF)**	(Capdevila *et al.*, 2020) **(IF)**	(MacPhail and Colla, 2020) **(B&O)**	(Fraisl *et al.*, 2022) **(B&O)**	**Characteristics of barriers**	**Characteristics of opportunities**
Technology and equipment	Scientific methods	Supporting structures (e.g., training, data management)	Lack of Specialized equipment	Quality of sensors used	Evidence of limited access to acquiring and maintaining required technologies including low-cost sensors especially in underdeveloped areas due to lack of funding (Benyei *et al.*, 2023) (Geoghegan *et al.*, 2016; Constant and Hughes, 2023). Lack of required technologies can also affect data collection, and observations as well as prevent certain groups from participating due to the digital divide (Burgess et al., 2017; Benyei et al., 2023).	Evidence of the development and integration of low-cost sensors including DIY systems and mobile phone apps that can be easily accessed by citizen scientists allows them to build their own devices and expand their skills (Mazumdar *et al.*, 2018). Mobile phone apps and smartphones have enabled a large number of participants to join and cover large geographic scales (Newman et al., 2012).

B&O types	**Terminologies used by the core selected articles to describe their IFS and B&O.**				**Characteristics of evidence to identify B&O**	
	(Cunha *et al.*, 2017) **(IF)**	(Capdevila *et al.*, 2020) **(IF)**	(MacPhail and Colla, 2020) **(B&O)**	(Fraisl *et al.*, 2022) **(B&O)**	**Characteristics of barriers**	**Characteristics of opportunities**
Training and feedback	Scientific methods		Poor experimental design	Bias related to the quality of non-professional contributions, with subsequent risk of citizen science not being recognized as a legitimate source of knowledge in decision-making	Evidence of labour-intensive collection methodologies, complicated recording forms and barriers due to communication techniques such as language and technical jargon (Pocock *et al.*, 2019; MacPhail and Colla, 2020; Heinisch, 2021; Paleco *et al.*, 2021). This also includes evidence of the lack of technical literacy of the facilitator.	Evidence of good practices such as regular communication and feedback helps in identifying and addressing gaps in understanding and skills.
	Communication and engagement	Communication and Feedback Culture	Specialised expertise required	Bias related to the extent of participant contributions		
				Requires a wide range of skills outside the research subject		

B&O types	Terminologies used by the core selected articles to describe their IFS and B&O.				Characteristics of evidence to identify B&O	
	(Cunha *et al.*, 2017) **(IF)**	(Capdevila *et al.*, 2020) **(IF)**	(MacPhail and Colla, 2020) **(B&O)**	(Fraisl *et al.*, 2022) **(B&O)**	**Characteristics of barriers**	**Characteristics of opportunities**
Scientific and social impact		Knowledge and experience			Evidence of lack of awareness from institutional stakeholders regarding the CS process or lack of scientific knowledge, educational qualifications, or accessibility to technology by/of participants (Burgess et al., 2017; Pocock et al., 2019; Roche et al., 2020; Fritz, See and Grey, 2022; Lewis, 2022).	Evidence of participants and other stakeholders being exposed to new knowledge and skills through training, social media and interactions to make collective judgements (Peltola and Arpin, 2018).
Demography of Participants	Volunteer profiles	Socio-economic background		Bias in the profile of participants	Evidence of biasness due to demographic influencing factors such as age, ethnicity, socioeconomic status, gender and sexual orientation. Projects when failing to align with the needs of participants can lead to skewed	Evidence of collaborative efforts, stakeholder workshops, and action plans to foster inclusivity (Pandya, 2012; Paleco et al., 2021). For example, Youth engagement through social media presents an

B&O types	**Terminologies used by the core selected articles to describe their IFS and B&O.**				**Characteristics of evidence to identify B&O**	
	(Cunha *et al.*, 2017) **(IF)**	(Capdevila *et al.*, 2020) **(IF)**	(MacPhail and Colla, 2020) **(B&O)**	(Fraisl *et al.*, 2022) **(B&O)**	**Characteristics of barriers**	**Characteristics of opportunities**
		Awareness of environmental issues		Bias related to human population density	representation of beneficiary communities as well as of data. For example, projects in countries like the UK often see more participants belonging to the 55-64 age group, middle-class, white participants in the UK; or underrepresentation of African American and Native American groups (Chesser et al., 2020; Paleco et al., 2021; Geoghegan et al., 2016; Ganzevoort et al., 2017; Pateman, Dyke, and West, 2021).	opportunity for recruitment, emphasising the need for understanding participant age dynamics (Capdevila et al., 2020).

B&O types	Terminologies used by the core selected articles to describe their IFS and B&O.				Characteristics of evidence to identify B&O	
	(Cunha *et al.*, 2017) **(IF)**	(Capdevila *et al.*, 2020) **(IF)**	(MacPhail and Colla, 2020) **(B&O)**	(Fraisl *et al.*, 2022) **(B&O)**	**Characteristics of barriers**	**Characteristics of opportunities**
Motivation of participants	Volunteer commitment	Motivation of Citizen	Barriers to participation	Lack of participant engagement and lack of diversity among participants	Evidence of high turnover rates or dropout rates of projects indicates non-alignment of motivations of participants with the project (West and Pateman, 2016; Rotman et al., 2012). However, motivation can change over time and country or be influenced by childhood experiences, age, education, and socioeconomic background (Kam, Haklay and Lorke, 2021). For example, minority ethnic groups show distinct motivations related to personal development and career enhancement (West et al., 2021).	Leveraging intrinsic motivators like personal interest in environmental science and the desire to contribute to societal well-being (Capdevila et al., 2020). This can be done by designing projects that align with participants' values and needs to foster a sense of purpose and promote continued engagement (Larson et al., 2020). Frameworks such as those proposed by West and Pateman (2016) and Lotfian et al. (2020) are good practice examples to enhance participation by examining the motivations of participants.

B&O types	Terminologies used by the core selected articles to describe their IFS and B&O.				Characteristics of evidence to identify B&O	
	(Cunha *et al.*, 2017) **(IF)**	(Capdevila *et al.*, 2020) **(IF)**	(MacPhail and Colla, 2020) **(B&O)**	(Fraisl *et al.*, 2022) **(B&O)**	**Characteristics of barriers**	**Characteristics of opportunities**
Recruitment of participants	Citizen scientist responsibilities		Volunteer coordination	Lack of participant engagement and lack of diversity among participants	Evidence of low initial numbers, high turnover or dropout rates of participants indicates barriers to recruitment and retaining participants (West and Pateman, 2016; MacPhail and Colla, 2020; Fritz, See and Grey, 2022). Evidence can be indicated by both motivational reasons mentioned above, lack of awareness of opportunities, and/or commitments that do not align with the project (West and Pateman, 2016; Cunha et al., 2017; Capdevila et al., 2020). Long-term engagement is essential as it leads to improved data quality and quantity as participants gain familiarity with protocols, improve research skills, and increase their effectiveness as data collectors (Cunha et al., 2017).	Evidence of good practices for sustaining participation is indicated by constant feedback, acknowledgement, and outreach (West and Pateman, 2016; Nelms et al., 2022). Secondly, projects demonstrate impacts by connecting participants with broader impacts on socio-environmental issues to motivate them to join CS initiatives (Kam, Haklay and Lorke, 2021; Fritz, See and Grey, 2022).

5.3. Application of Barriers and Opportunities Framework to the case-study of India

5.3.1. Selection and inclusion of relevant literature

To identify B&Os of CS which have been reported in India, records of CS projects and related articles were extracted from the dataset identified through the PRISMA Framework presented in Chapter 2 (Figure 2). The PRISMA *(Preferred Reporting Items for Systematic Reviews and Meta-Analyses)* framework provides a comprehensive search strategy to identify and appraise relevant articles required for this particular study (Moher et al., 2009; Tawfik et al, 2019). These records were then analysed using qualitative analysis in NVivo to identify B&O in India.

5.3.2. Analysis of relevant literature to identify B&O using a hybrid 2-step method

For this study, all n=63 records identified by the PRISMA framework were selected. To identify B&Os discussed in these records, I used both inductive and deductive qualitative coding methods. The combination facilitates triangulation and comprehensive identification of different themes, in this case, 'Types of B&O' and the emergence of new B&O in India (Proudfoot, 2023). This method of thematic analysis is used across multiple domains such as health science, psychology, etc., to systematically code and identify emerging themes and ideas (Xu and Zammit, 2020). The steps of the analysis are described below, explaining the combination of using both 'inductive coding' and 'deductive coding' to identify B&O in NVivo.

5.3.2.1. Steps to data coding for the combined qualitative analysis in NVivo

Step 1: Generation of initial codes using inductive coding

Inductive coding helps with the familiarisation of data. Articles were first read to gain familiarisation with the data for meaningful interpretation. Text segments referring to different barriers or opportunities of a project were then coded in NVivo. New codes were created when the need arose (Fereday and Muir-Cochrane, 2006; Proudfoot, 2023). Using inductive coding helped in identifying barriers and opportunities which were influenced by local Indian factors.

1) **Identification of Barriers:** identified text segments in the collected data referring to obstacles and limitations such as prevention of access to projects, difficulty in running projects and problems with recruiting participants.
2) **Identification of Opportunities:** identified text segments referring to successes or enablers.

Step 2*:* Searching for themes through deductive coding

The codes generated by the inductive coding were then grouped in the B&O framework codes. This step can be called deductive coding as it utilises the B&O framework to code (Fereday and Muir-Cochrane, 2006;

Proudfoot, 2023). The Types of B&O were coded into NVivo, and the inductive codes were converted to sub-codes of relevant Types of B&O as presented in Table 11.

Table 10. presents the number of records that had significant text segments discussing B&Os of CS projects from India. The records were collected using the systematic review detailed in Chapter 2.

Deductive codes (Types of B&O)	**Inductive Codes**	**Total record under each type of B&O**
Political and institutional acceptance	Policies and suggestive policies	11
	Institutional Support	12
Data management and collection	Data Analysis	33
	Data Collection	33
	Data Standardisation	7
Funding of projects	Funded	29
	Non-Funded	27
Demography of participants	Gender	4
	Religion	1
	Education and profession	10
	Rural and rural adjacent areas	10
	Urban	12
Motivation of participants	Motivation	13
	Demotivation Factors	3
	Acknowledgement	18
	Incentives	1
Recruitment of participants	Blitz Events	5
	Direct Recruitment	18
	Social Media	7
Scientific awareness and growth	Scientific Achievements	15
	Social Impact	11
Technology & equipment		13
Training & feedback	Awareness Through Training	5
	Data Collection Training	27
	Teacher’s Training	5
	Trust Building	1

Step 3: Reviewing code connection

The reliability of the inductive codes and their connection to the B&O framework was established by comparing notes on characteristics of B&O identified from inductive coding (Fereday and Muir-Cochrane, 2006; Proudfoot, 2023).

Step 4: Synthesis of results

The B&O presented in the results section is a synthesis of observations made from the text segments of the selected literature. It provides a high-level understanding of the B&O present in India and highlights important gaps in evidence of some B&O.

5.3.3. Challenges of CS

Using the results of this analysis and the concept that challenges are created through B&O, I discuss the challenges CS in India using the framework identified by Fritz *et al.*, (2022). Using Table 12 I have mapped the 'Types of B&O' identified in my framework to the 'challenges' postulated by Fritz *et al.,* (2022).

Table 11. demonstrates the mapping of challenges of CS postulated by Fritz et al., 2022 from the identified themes of B&O in this study.

<table>
<tr><th>Types of B&O</th><th>Challenges of CS (Fritz et al., 2022)</th></tr>
<tr><td>Data management and collection</td><td rowspan="3">Data Quality</td></tr>
<tr><td>Technology and equipment</td></tr>
<tr><td>Training and feedback</td></tr>
<tr><td>Political and institutional acceptance</td><td rowspan="2">Potential use of CS environmental data by governments, local authorities and NSOs</td></tr>
<tr><td>Funding of projects</td></tr>
<tr><td>Motivation of participants</td><td rowspan="3">Engagement, motivation, and retention of participants</td></tr>
<tr><td>Recruitment of participants</td></tr>
<tr><td>Demography of participants</td></tr>
<tr><td>Data management and collection</td><td>Data sharing and ownership.</td></tr>
<tr><td>Demography of participants</td><td rowspan="2">Digital opportunities and the digital divide</td></tr>
<tr><td>Scientific and social awareness and growth</td></tr>
<tr><td>Scientific and social awareness and growth</td><td>The contribution of CS to address big global challenges</td></tr>
</table>

5.4. Results: Barriers and opportunities of CS in India

The results presented here are a synthesis of the observations on B&O of India identified under each 'Type of B&O' in the framework. A total of 21 key barriers and 20 key opportunities were identified for India. This consists of 'limited incorporation of CS generated data', 'funding inadequacies', several issues with 'data management and collection', 'motivation, etc.' However, the review was not able to identify barriers influenced by training, scientific and social awareness and growth, age, ethnicity and race. This unavailability of evidence does not indicate the non-existence of these barriers. In the following sub-sections I have highlighted the key barriers and opportunities of CS in India inferred from the synthesis.

5.4.1. Political and institutional acceptance

- **Barriers to political and institutional acceptance in India**

The review showed limited evidence of the incorporation of CS data in policy in India. Only 3 projects indicated the use of CS data in policymaking, primarily limited to Biodiversity Conservation projects, especially birds (SoIB, 2020; Only, 2022; Vargiya, Jethva and Pandya, 2022). Practitioners in other thematic areas mentioned the potential contribution of the data generated by their projects to national policies but did not show evidence of real contribution (Jha *et al.*, 2017; Kumar, Mukherjee and Singh, 2017; Nagendra, Lakshmisha and Agarwal, 2019; Menon *et al.*, 2021; Kulkarni *et al.*, 2022; Owens *et al.*, 2022; Mishra *et al.*, 2023; Pradhan, George and Dewan, 2023).

Lack of awareness of CS-generated data among professionals was not frequently reported as a barrier within the records. Only 2 records raised the point that local governing authorities are not aware of the potential usability of CS data even after practitioners have shared data and outcomes with them (R. Shah, 2015; Nagendra, Lakshmisha and Agarwal, 2019).

- **Opportunities for political and institutional acceptance in India**

Government agencies recognise the potential of CS-generated data for national policies, especially in biodiversity conservation. The government has integrated CS-generated data from the Asian Waterbird Census in the National Biodiversity Action Plan 2012-2018 (Vargiya, Jethva and Pandya, 2022); and the development of State of India's Birds (SoIB, 2020) and Kerala Bird Atlas (Only, 2022) indicates conservation effort and report generation through CS. Currently, researchers see potential in filling gaps in ecological and environmental data such as species distribution, climate pattern changes, etc. which India historically lacked before independence (Barath, 2014; Kumar, Mukherjee and Singh, 2017; Malhotra, 2018; Dawn 2021; Adhurya and Bhandary, 2019; Kumar et al., 2019; Singh and Saran, 2020).

5.4.2. Data management and collection

- **Barriers to data collection and management in India**

Due to the historical lack of data in India, data quality remains a concern as the quality could not be measured (Vattakaven *et al.*, 2016). However recent CS projects have improved the baseline, especially for bird conservation however it is yet to cover certain areas of environmental monitoring and evaluation (EME) (Kumar, Mukherjee and Singh, 2017; Schuttler *et al.*, 2019; SoIB, 2020; Ramaswami, Sidhu and Quader, 2021; Only, 2022).

There is a lack of a standardised data collection system at the national level for data collection and management across various thematic domains, especially water quality and air pollution, etc. Practitioners often refer to protocols from other countries to address these issues, (this can be seen as an opportunity to gain recognition globally) (George *et al.*, 2019; Mishra *et al.*, 2023). Overall, the review found limited evidence within collected resources which have addressed the issues of data quality and data standardisation however, authors have acknowledged the necessity of developing robustness in data quality. One observed reason by Sekhsaria and Thayyil, 2019, is that many projects are currently focusing on raising awareness then influencing policy or producing scientific research.

Three review articles discussed that risk persists over data ownership and intellectual property rights of CS-generated data in the absence of concrete data protection policies in the country (Sekhsaria and Thayyil, 2019; Namdeo and Koley, 2021; Vattakaven *et al.*, 2022).

In certain cases, poachers have been shown to leverage project portals to identify sensitive species (Dwivedi, 2021). This emerges as a substantial barrier to the free sharing of data. The review found the critical need for robust mechanisms to address the delicate balance between data sharing and preventing malicious use of CS-generated data in India (Singh *et al.*, 2018; Sekhsaria and Thayyil, 2019; Vattakaven *et al.*, 2022).

- **Opportunities in data collection and management in India**

Projects have integrated various strategies and methods into their platforms for data quality management, data collection and validation. They use local coordinators to verify data or group new participants with experienced volunteers or scientists to ensure data quality (Devasia, 1998; Datta-Roy, Ved and Williams, 2009; Rane and Datta, 2015; Jadeja *et al.*, 2018; Nagendra, Lakshmisha and Agarwal, 2019; Menon *et al.*, 2021; Mukherjee *et al.*, 2021; Owens *et al.*, 2022; Mishra *et al.*, 2023). Secondly, projects also employed technological processes such as employing a multilayer checks and review system, incorporating filters and providing checklists to participants (Sekhsaria and Thayyil, 2019; Only, 2022). They also employed other alternative methods, such as comparing CS-generated data with expert data or databases such as Global Biodiversity Information Facility (GBIF) (Vattakaven *et al.*, 2016; Jadeja *et al.*, 2018; Singh *et al.*, 2018; Adhurya and Bhandary, 2019; Aiyadurai and Banerjee, 2019; Schuttler *et al.*, 2019; Menon *et al.*, 2021). Lastly, some of the mobile apps used for data collection had in-built security functions such as restricting GPS, real-time data upload, etc. (Oberai *et al.*, 2018; Sekhsaria and Thayyil, 2019; Middya, Roy and Das, 2021).

New projects in India employ well-established and international protocols and training for their participants. For example, Biodiversity Conservation projects in India can follow a set of best practice guidelines for managing data quality (Vattakaven et al., 2022). Currently, there is no evidence of utilising Artificial Intelligence (AI) for data collection and quality control in India.

5.4.3. Funding

- **Barriers to funding of CS in India in India**

Only three records discussed funding as a major barrier to financial sustainability, technological accessibility and expansion of CS projects in India (Schuttler *et al.*, 2019; Sekhsaria and Thayyil, 2019; Mishra *et al.*, 2023). The review also observed that the predominant funding model is short-term financial support received through research grants. These grants typically originate from Government of India (GoI) agencies and foreign donor institutions and organisations. However, these funding opportunities were not explicitly earmarked for CS initiatives in India.

- **Opportunities in the funding of CS in India in India**

Government of India (GoI) agencies directed funds toward academic and research organisations involved in CS projects (Singh *et al.*, 2018; Sekhsaria and Thayyil, 2019; Middya, Roy and Das, 2021; Jaiswara *et al.*, 2022; Gole *et al.*, 2023; Mishra *et al.*, 2023; Pradhan, George and Dewan, 2023). Prominent GoI agencies involved in funding are the Ministry of Environment, Forest & Climate Change, Ministry of Earth Sciences, Department of Science and Technology (DST), Department of Biotechnology University Grants Commission (UGC), and the Social Science Research Council (SSRC) (Sekhsaria and Thayyil, 2019; Menon *et al.*, 2021; Vargiya, Jethva and Pandya, 2022; Gole *et al.*, 2023; Mishra *et al.*, 2023; Pradhan, George and Dewan, 2023). Currently, they are the key and potential agencies for playing crucial roles in catalysing CS initiatives in India (Sekhsaria and Thayyil, 2019).

Funding collaboration with international funding agencies, such as the Natural Environment Research Council (NERC-UKRI), German Academic Exchange Service (DAAD), and the U.S. National Science Foundation, have opened further opportunities for financial support to CS projects in India (Singh, Eldho and Prinz, 2002; George *et al.*, 2019; Schuttler *et al.*, 2019; Menon *et al.*, 2021).

India has shown opportunities for community funding where participating communities arrange funds independently for the maintenance of management and monitoring activities or support CS projects acquire equipment and other project-related costs (Devasia, 1998; Maheshwari *et al.*, 2014; Rane and Datta, 2015; Jadeja *et al.*, 2018).

5.4.4. Demography of participants

- **Barriers due to demographic factors of participants in India**

The review could not find evidence of barriers due to age, ethnicity and race barriers due to the lack of such reporting. The review indicated barriers can be created due to caste of participants, religion, language and education.

Caste influences accessibility to certain areas required for data collection; for example, participants in the MARVI projects who belonged to lower caste were restricted from collecting data from areas that belonged to higher caste (Jadeja *et al.*, 2018). While religious beliefs may restrict participation in certain topics such as recording canid species by followers of Islam (Binoy, Radhakrishna and Kurup, 2017).

Language acted as a barrier, especially in projects with a large geographical extent due to India's linguistic diversity (Ramaswami, Sidhu and Quader, 2021). To overcome the language barriers, practitioners in India try to collect data using local languages (Datta-Roy, Ved and Williams, 2009; Bachan *et al.*, 2011; Maheshwari *et al.*, 2014; Jadeja *et al.*, 2018; Pradhan and Yonle, 2021; Only, 2022)

Though education is not a prerequisite it can act as a barrier to directly participating in the co-creation of projects. Project initiators for projects in rural areas prefer at least university graduates to coordinate the project at the community level (Devasia, 1998; Rane and Datta, 2015). However, George *et al.*, (2019) have observed that educational background does not impact or ensure better data collection quality.

Radhakrishna, Binoy and Kurup, (2014) noted during their initial phase, school students were reluctant to pursue a project if the project did not provide any incentives to their annual academic results, e.g. extra marks. The authors believed this might have stemmed from the Indian educational culture that prefers regular syllabus-based educational curricula over activities-based learning. Often the teachers themselves were reluctant or provided lower priority to project activities than the regular educational curriculum as a result of this cultural notion. Thus it can affect the long-term participation of students as well as the viability of the project.

Gender can play an important role in influencing participation that varies between urban and rural areas. Projects related to urban household activities such as monitoring municipal solid waste or wastewater saw higher female participation in projects than those which required travelling in rural areas (Maheshwari *et al.*, 2014; Jadeja *et al.*, 2018; Nagendra, Lakshmisha and Agarwal, 2019; Shipingana, Shivaraju and Yashas, 2022).

- **Opportunities from demographic factors of participants in India**

Project proponents while developing projects targeted or aimed at beneficial outcomes of local communities by recruiting them, solving rural socio-environmental issues, impacting livelihood, etc. (Devasia, 1998; Datta-Roy, Ved and Williams, 2009; Bachan *et al.*, 2011; Rane and Datta, 2015; Jadeja *et al.*, 2018; Lekshmi *et al.*, 2021; Menon *et al.*, 2021; Pradhan and Yonle, 2021; Khan, Kumar and Chella, 2022).

5.4.5. Motivations of participants

- **Barriers to the motivation of participants in India**

Barriers to participation can occur after the initial training and workshops leading to low excitement and participation (Binoy, Radhakrishna and Kurup, 2017; Mishra *et al.*, 2023; Pradhan, George and Dewan, 2023) For example, Binoy, Radhakrishna and Kurup, 2017 saw enthusiasm and excitement from student participants during their initial training workshops that slowly that can recede subsequently. Projects in India can also experience high dropout and low involvement of participants if the research topic does not meet their interest; participants are unfamiliar with the issue; or they do not find it unique enough to pique their interest (Binoy, Radhakrishna and Kurup, 2017; Jadeja *et al.*, 2018).

- **Opportunities to motivate participants in India**

Initial motivation within participants from rural areas was often driven by social incentives, such as solving everyday problems and protecting the environment (Devasia, 1998; Jadeja *et al.*, 2018; Sekhsaria and Thayyil, 2019) which can be channelled through awareness and training programs (Binoy, Radhakrishna and Kurup, 2017; Jadeja *et al.*, 2018; Pradhan and Yonle, 2021; Pradhan, George and Dewan, 2023). Motivations in urban areas include environmental concerns, wildlife conservation, and opportunities to spend time in nature (Johnson *et al.*, 2014). Project proponents usually assess the motivation of participants through continuous evaluation of their requirements, either statistically or through self-observations. Overall, participants were reported to have motivations such as pursuing science and knowledge, adding to scientific knowledge, and desiring to bring accountability within the environmental regulatory regime indicating high-level concerns for environmental outcome and welfare for all (Johnson *et al.*, 2014; Sekhsaria and Thayyil, 2019).

As global studies suggested student participation was mainly to advance their careers by obtaining skills, knowledge and training (Johnson *et al.*, 2014; Mukherjee *et al.*, 2021). Best practice learnings from the review indicate acknowledging the involvement of local communities as guardians or gatekeepers to instil a sense of pride and ownership, both over the issue and project (Devasia, 1998; Jadeja *et al.*, 2018; Aiyadurai and Banerjee, 2019; Dwivedi, 2021; Owens *et al.*, 2022).

5.4.6. Recruitment and engagement of participants

- **Barriers to recruiting and engaging participants in India**

The review indicates that maintaining active participants is a significant challenge in India, particularly for long-term projects while short-term projects face barriers in outreach and recruiting large numbers of participants (Binoy, Radhakrishna and Kurup, 2017; Pradhan, George and Dewan, 2023). Learnings from the review indicate that it is best to seek permission from the village headman if project proponents want to conduct a project or recruit participants from rural areas (Devasia, 1998; Datta-Roy, Ved and Williams, 2009; Honkalaskar *et al.*, 2014; Maheshwari *et al.*, 2014; Rane and Datta, 2015; Ravindra and Mor, 2018; Menon *et al.*, 2021; Owens *et al.*, 2022).

The review observed that participants in India are often limited to data collection roles, which I think lowers the scope of engagement of participants in the co-creative and collaborative process.

- **Opportunities for recruitment and engagement in India**

More than 18 records showed participants recruited directly through formal learning centres (schools and universities) (Binoy, Radhakrishna and Kurup, 2017; Singh *et al.*, 2018; George *et al.*, 2019; Schuttler *et al.*, 2019; Yardi, Bharucha and Girade, 2019; Lekshmi *et al.*, 2021; Middya, Roy and Das, 2021; Mishra *et al.*, 2023). George et al., 2021 found that recruiting university students helped in maintaining the average number of participants and the project network as new students joined through the university each year. This can be seen as an opportunity to overcome the barrier to long-term participation.

Selecting volunteers from within the community through grassroots organisations or non-governmental organisations can help to access participants from different socio-economic backgrounds, education as well and professional communities such as farmers, fishermen, local tribes, forest guards, engineers, housewives, and shopkeepers depending upon the project location, purpose and intentions (Devasia, 1998; Rane and Datta, 2015; Jadeja *et al.*, 2018; Nagendra, Lakshmisha and Agarwal, 2019; Saran *et al.*, 2020; Shipingana, Shivaraju and

Yashas, 2022; Gole *et al.*, 2023; Venkatesh and Velkennedy, 2023). In some cases, where barriers to time and financial conditions affected participation, monetary incentives were provided to the participants to compensate for their time (Jadeja *et al.*, 2018).

Involving employees of private corporate houses such as HSBC India as part of their Corporate Social Responsibility (Yardi, Bharucha and Girade, 2019; Lekshmi *et al.*, 2021). HSBC India in Pune and Powai (Mumbai) encouraged its employees to actively participate in CS projects for the water quality monitoring of Pashan Lake and Powai Lake.

Five projects undertook blitz events to recruit a large number of participants in a short period, usually lasting 3 to 4 days (Jha *et al.*, 2017; Adhurya and Bhandary, 2019; Dawn, 2021; Vargiya, Jethva and Pandya, 2022; Mishra *et al.*, 2023).

Large-scale projects use social media for recruitment, especially in urban areas (Johnson *et al.*, 2014; Ertiö and Bhagwatwar, 2017; George *et al.*, 2019; Sekhsaria and Thayyil, 2019; Sukhwani and Shaw, 2020; Dawn, 2021; Dwivedi, 2021; Mishra *et al.*, 2023). Project proponents have demonstrated both snowballing techniques of recruiting participants through social media, usually seen in urban projects, and targeted recruitments of local communities in rural projects.

5.4.7. Scientific and social awareness and growth

- **Barriers to scientific and social awareness and growth in India**

The review did not identify specific barriers to scientific and social awareness and growth. This might be due to underreporting in the records reviewed.

- **Opportunities for scientific and social awareness and growth in India**

Training and workshops, and sharing of data from projects helped to increase the scientific and social awareness of participants by bringing a positive shift in participants' attitudes (Devasia, 1998; Bachan *et al.*, 2011; Jha *et al.*, 2017; Nahar and Verma, 2018; Pradhan and Yonle, 2021; Khan, Kumar and Chella, 2022).

Communication through mobile applications helped in encouraging sustainable behaviour and contributing to data collection by participants as they can be updated with results (Vattakaven *et al.*, 2016; Nahar and Verma, 2018).

5.4.8. Technology and equipment

- **Barriers to technology and equipment in India**

Some projects indicated limited access to specialised equipment, such as research-grade equipment, or the reliability of data collected using smartphone-based sensors, as phone sensors may not be apt enough (Kumar, Mukherjee and Singh, 2017; Schuttler *et al.*, 2019; Sukhwani and Shaw, 2020)

Barriers arise in developing and maintaining multiple mobile apps across different operating platforms such as iOS and Android. Hybrid apps, while designed to function on both platforms, may suffer from lower performance, restricted access to device features, and a limited user interface compared to native apps (Singh *et al.*, 2018; Sukhwani and Shaw, 2020).

Only a few indigenous mobile applications exist in India with a limited outreach for CS projects (Sukhwani and Shaw, 2020). Thus the barrier lies in the adoption and widespread use of these applications (Vattakaven *et al.*, 2016; Jha *et al.*, 2017; Kumar, Mukherjee and Singh, 2017; Singh *et al.*, 2018). Sometimes participants might lack smartphones due to their financial conditions which can act as a barrier to participation (Pradhan, George and Dewan, 2023).

- **Opportunities for technology and equipment in India**

Transfer of technology and sharing of knowledge on low-cost technologies across various countries or regions as collaborators. For example, low-cost, hand-held technologies like 3D Mini Secchi disks (3DMSD) which were used to monitor the Vembanad Lake were designed in a high school in the UK. The design plans were then transferred to India and the Secchi disks were 3D printed using a single machine making them accessible to participants on a large scale by cheap production (George *et al.*, 2021). This technology was integrated with a smartphone application "TurboAqua" which helped in capturing pictures using the mobile camera and uploading GPS locations and data from 3DMSD to a central database (George *et al.*, 2021).

Leveraging internet-enabled smartphones to efficiently collect data where deploying static sensors is challenging (Sukhwani and Shaw, 2020). The Internet has allowed for fast aggregation of data through various online platforms, including social media groups, thus overcoming the limitations imposed by the lack of these technologies a few decades ago (Sekhsaria and Thayyil, 2019; Sukhwani and Shaw, 2020; Middya, Roy and Das, 2021; Pradhan, George and Dewan, 2023). In case of loss of internet connectivity, the Forest Fire mapping project showed ingenuity by developing offline modes to maintain real-time mapping even with low connectivity (Saran *et al.*, 2020).

5.4.9. Training and feedback

- **Barriers to training and feedback in India**

The review could not identify barriers to training and feedback in depth based on characteristics such as barriers arising due to labour-intensive methodologies, complicated data entry systems, use of Artificial Intelligence or lack of scientific understanding. The review observed that training workshops were usually organised by project proponents to train participants in data collection. Out of the 33 projects reviewed in this study (CSP-AL), 20 projects provided training workshops to their participants. This entailed training for data collection using scientific instruments and awareness of the topic of focus. A skewed reporting may also arise here as projects concentrated more on reporting scientific and social achievements. Communication, feedback, etc, were mostly reported in 'Discussion Sections,' thus limiting the report on barriers faced by project proponents and focusing more on positive outcomes.

- **Opportunities for training and feedback in India**

Long-term projects like MARVI and IBP have developed robust communication and feedback mechanisms using newsletters published in local languages to connect with communities and or through online portals (Maheshwari *et al.*, 2014; Vattakaven *et al.*, 2016).

5.5. Challenges for CS in India

In this section, I draw on the results presented above to discuss the state of CS in India in the context of the challenges for CS identified by Fritz *et al.,* (2022). No new challenges were identified however some challenges manifested differently in the context of India than those discussed by Fritz *et al.,* (2022). These outputs are important contributions to a broader understanding of the challenges of CS.

The first challenge proposed by Fritz et al., (2022) is "*Data Quality".* My study showed that proponents of CS projects in India are aware of the challenges in ensuring data quality and reliability. To ensure the data quality they provided training, workshops and feedback to participants. This helps in communicating the goals of the project, the type of data they are collecting and the equipment they are handling.

Secondly, various data management systems used in the projects are comparable to Annex I countries as project proponents in India standardise their data collection methods as per international standards. This has huge implications for generating high-quality data that can contribute to international developmental agendas such as the Sustainable Development Goals (SDGs) and Biennial Transparency Reports (BTRs) (Fritz *et al.*, 2019; Fraisl, Campbell, See, Wehn, Wardlaw, Gold, Moorthy, *et al.*, 2020). New projects in India can identify the best practices from biodiversity conservation projects which have a higher number of projects and a longer experience period than other thematic domains in India. They have been able to make progress such as developing best practice guidelines for data protection and sharing (Vattakaven *et al.*, 2022). Thus a transferability of knowledge is required among projects from different thematic domains.

Data validation systems in India can be updated by integrating Artificial Intelligence (AI) and Machine Learning (ML) and bringing in policies and funding to develop and manage systems (Lotfian, Ingensand and Brovelli, 2021). These two technologies can be integrated with human interventions for example, ML algorithms can be used for filtering large data sets while humans can intervene in subtle and refined interventions (Fritz, See and Grey, 2022). However, AI requires a huge amount of data to be trained but a country like India lacks several crucial sets of data at the local level. CS itself can help generate large datasets which can be used to train AI. The use of AI is not just limited to data verification, processing and categorisation. Generative AI can now be used for project management and outreach (Fraisl et al., 2024). For example, develop personalised feedback, and training, and engage participants. Generate relevant content for social media posts, videos, stories, visualisations and newsletters.

The third but the most important B&O contributing to this challenge in India is participants' ability to access technology and equipment. Though Fritz et al., (2022) highlight that the cost of sensors, especially low-cost sensors, has decreased dramatically, the cost is still high compared to the spending ability of participants in buying these equipment. For example, a trap camera to capture wildlife can range between US$200-$400 (Schuttler *et al.*, 2019). Looking at the per capita income of India which is US$2,730 annually, leaves limited scope for disposable income of participants (IMF, 2024). India requires knowledge to create low-cost sensor technologies. Mobile phone-based sensors are being developed in the country however factors such as phone models, operating systems, etc. can affect data quality for example, different operating systems of mobile phones require different app development, different phone camera lenses require different calibrations for the app, thus adding expenses to project running cost (Kosmala *et al.*, 2016; Sukhwani and Shaw, 2020). This leads to the barrier of funding required to acquire and develop these technologies (Namdeo and Koley, 2021; Kotzagianni *et al.*, 2023).

To overcome this challenge, CS in India requires dedicated funding and recognition of the CS process by institutional stakeholders like government agencies, academic and research institutions, etc. This review did not find ‘lack of funding’ as an explicit barrier; however, it is an important barrier as most projects are dependent on research grants which can affect their sustainability (Land-Zandstra, Agnello and Gültekin, 2021). Most funding appears to originate from governments, thus high dependence on this single source could create risks. I will be looking into depth on the funding aspects of CS in the next chapter. Secondly, the issue of importing low-cost sensors which are expensive to Indians can be overcome by developing indigenous technologies. This can be aided by STEM aspirants, students and researchers and through *the Make in India* initiative (Namdeo and Koley, 2021).

The second challenge of Fritz et al., (2022), is the “*potential use of citizen science environmental data by governments, local authorities and NSOs*.” The review does not indicate strong support from GoI in incorporating CS-generated data into policymaking, even though they fund CS projects. Only data generated from birding projects have seen inclusion in three different governmental policies, which include only one national policy. CS-generated data from other projects did not see any acceptance for policy and decision-making. To overcome this challenge, India requires a sustained and high number of impactful projects that can generate enough data to develop baseline data and improve the data quality. For example, birding projects are the highest variety of CS projects and have been the first set of popular projects CS projects in India, thus this challenge has been partially overcome by them. As other domains have a very low number of projects, policymakers are less aware of the potential of integrating CS projects into environmental policymaking (Chapter 3). Also, there are possibilities of variable attitudes among different governmental agencies and ministries in adopting CS projects (Capdevila *et al.*, 2020; Schade *et al.*, 2021). The study at this point has observed that the major governmental agency to recognise the potential of CS is the Forest Department under the Ministry of Environment, Forest and Climate Change (MoEFCC). The next chapter will delve further into the roles various stakeholders play in facilitating CS projects in India and if the current observation on stakeholder involvement holds.

Visible incorporation of CS data in policymaking and adaptation by NSOs will be possible if the number of projects, variety of projects and participants increase over time in the country, and this requires funding. The GoI has extended funding support to CS projects through its agencies however there is a barrier to translating it into higher numbers encompassing diverse thematic issues (Chapter 3). India can take the option of establishing a dedicated funding scheme by the government for CS in India and encouraging the establishment of supporting organisations like CitSci India (CitSci India, 2023a). Studies have shown that establishing supporting organisations such as the Association for Advancing Participatory Sciences (North America) or the European Citizen Science Association (Europe) has proved essential in addressing issues with data standardisation, identification of funds, exchange of ideas and knowledge, and outreach participants (Wagenknecht *et al.*, 2021; Fritz, See and Grey, 2022). Such platforms can also facilitate synergistic networking of small and local projects into large endeavours and provide a platform to freely advertise new initiatives where researchers can meet the participants (Liu *et al.*, 2021; Wagenknecht *et al.*, 2021).

The next challenge postulated by Fritz et al., 2022 is the *"engagement, motivation, and retention of participants"* in projects. Projects in India generally did not show high numbers of participants unless they were long-term projects which have been running for over a decade; for example, projects associated with Bird Count India. Participation in most of the reviewed projects was lower than 100 participants. This may be because the projects were pilot projects. Another reason is the lack of sustained funding for the projects which is essential for its continuation and outreach (Land-Zandstra, Agnello and Gültekin, 2021).

Interestingly, India has shown a distinct difference in motivation and participation between rural and urban India. Projects in rural India are generally community-based projects where citizens are data contributors working towards solving a relevant local issue, a feature seen in Non-Annex I (low- and middle-income) countries (Pocock *et al.*, 2019). In urban areas citizens participated due to their willingness to contribute to science or the environment, a feature found more among Annex I (high-income) countries. Thus from the review, it can be understood that project proponents in India can face challenges in recruiting and retaining participants where the motivations, personal interests and attributes of participants are completely different from one another based on their socio-economic conditions and area of habitation.

The review showed instances where culture, gender and religion can play an important role in influencing participation. Besides acknowledgements of contribution, participants in India desire incentives in the form of financial benefits, skills and knowledge, academic marks or recognised stewardship. The limitation of the study is that it was not able to identify if the projects were representative, inclusive and addressed issues of participants from various castes, ages, genders, and socio-economic conditions found in India (Pandya, 2012; Paleco *et al.*, 2021; Pateman, Tuhkanen and Cinderby, 2021). Further studies with primary data are required to understand the influence of these factors.

The fourth challenge postulated by Fritz et al., (2022) is on *"data sharing and ownership."* The review found limited discussion around data sharing and ownership. Thus the review does not explicitly portray it as a major challenge but a record perceived that it can be a challenge when multiple stakeholders are involved (Vattakaven *et al.*, 2022). There is a need for further discussion and research on this challenge in India particularly by engaging both institutional stakeholders and participant stakeholders in the research.

The fifth challenge by Fritz et al., (2022) is on the "*digital opportunities and the digital divide.*" They highlight this challenge in terms of the integration of passive sensors in phones, and wearables into CS projects and the protection of human perception data under strong data protection policies like the General Data Protection Regulation (GDPR). These concerns however are underrepresented as challenges in India and the review did not provide any evidence discussing this challenge.

The increasing popularity of developing mobile phone-based apps to address common and local environmental issues directs to opportunities in reducing the digital divide among the participants. India's improving and cheap internet infrastructure has also increased the recruitment of interested participants. Online forums and platforms such as India Biodiversity Portal are popular as they provide a space to interact among participants and experts (Vattakaven *et al.*, 2016; Liu *et al.*, 2021). The review could not find extensive opportunities to overcome the challenge of digital opportunities and the digital divide in India.

The final challenge of CS as postulated by Fritz et al., (2022) is its ability to "*contribute to global transformational change"* such as contribution to positive change to reduce climate and environmental footprints. The review infers that India's challenge of transformational change lies in the lack of outreach and coverage of CS projects in the country. Though the review has found evidence of CS projects contributing to social transformation but at a very limited area or level. Projects have shown 'potential' contribution to transformational change for the community such as providing livelihood adaptative policies to sea level rise in coastal areas, awareness of human-wildlife conflict, space for women in decision-making, etc. (Devasia, 1998; Maheshwari *et al.*, 2014; Nagendra, Lakshmisha and Agarwal, 2019; Lekshmi *et al.*, 2021; Khan, Kumar and Chella, 2022; Shipingana, Shivaraju and Yashas, 2022). The projects showed an ability to bring changes and create awareness within the local communities, especially those which were targeted to solve their local socio-environmental issues. (Bachan *et al.*, 2011; Pradhan and Yonle, 2021). Thus based on learnings from literature across the globe, targeted outreach of CS projects in Non-Annex I can elevate the ability to engage marginalised communities in projects by capturing their diverse perspectives (Noorashid and Chin, 2021; Benyei *et al.*, 2023; Huang *et al.*, 2024).

5.5.1. Contribution and limitation of the B&O Framework

A key part of this study was the development of a unifying framework which brings together and synthesises previous research into barriers and opportunities in CS. Here I reflect on the contributions of this framework, as well as its limitations.

Contributions:

1) This B&O framework is the first attempt to conceptually understand and characterise 'Influencing Factors', 'Barriers', 'Opportunities' and 'Challenges'; and develop a structured framework to identify 'Barriers' and 'Opportunities' of CS.
2) Through the framework, the study was able to detect the B&O of India and map the progress in overcoming its challenges. Thus the framework can be further developed as an extension of systematic reviews to identify B&O of CS projects from published literature such as journal articles and reports. Periodic reviews of B&O of CS projects at thematic levels, regional levels, national levels, etc., would help in tracking and measuring the progress in overcoming the challenges as well as curating best learning practices from various CS projects.

Limitations:

1) The conceptual idea and the framework idea can seem complex, thus under the three levels of logic presented in the study further systematic studies can be undertaken to comprehensively identify the maximum possible IFs and B&O affecting CS projects. This poses a limitation at the current moment but can be rectified with new and repeated reviews.
2) Secondly, the methodology of the application is complex as it requires both inductive and deductive coding approaches potentially making it more challenging.
3) Another technical limitation of the framework is its dependence on published literature. The accuracy of the results relies on the information provided in published literature, and the lack of utilising grey resources and thus cannot fully visualise the real-life scenario.

5.6. Conclusion

This review has been able to identify the local causes that lead to barriers to CS projects in India and opportunities to overcome some of them. India needs to establish a self-sufficient and sustainable CS ecosystem that can support the growth and development of CS projects. The major IF for the challenges in India is the project numbers. India needs to increase the number of projects in domains other than Biodiversity Conservation to achieve major socio-environmental impacts. Thus the grand challenge of India is increasing the number of CS projects. This in the future will broaden the scope and variety of B&O of CS inherent to India.

To increase the number of projects, it is imperative to understand the supporting structures and relationships that exist among project proponents, funders, and other collaborators of CS projects in India. The study acknowledges the conducive environment provided by the government as well as other organisations such as research and academic institutes, schools and colleges, and non-governmental organisations. In the next chapter, the thesis will explore the relationship among the institutional stakeholders and understand the support network around the CS process in India for its success. The stakeholders of CS in India have an important role to play in further developing the process and increasing the numbers.

Chapter 6

6. A systematic analysis of institutional stakeholders of ecological and environmental citizen science in India

Only a Robinson Crusoe can afford to be all self-sufficient. When a man has done all he can for the satisfaction of his essential requirements he will seek the co-operation of his neighbours for the rest.

- **Mahatma Gandhi** *in Harijan, 31-3-46, p. 59)* (Gandhi, 1968)

6.1. Introduction

In this Chapter, I have identified the different types of stakeholders involved with citizen science (CS) initiatives in India and their roles. I analysed their interest and influence in the CS process, and the actions taken by them to facilitate the process in the country. Conducting a Stakeholder Analysis (SA) is beneficial for the identification of stakeholders and their roles, which in turn can support CS through better allocation of time and funds; addressing ethical issues arising from data generation; facilitation of communication and sharing of information (Haklay, 2015; Skarlatidou *et al.*, 2019); and reducing conflicts (Roy *et al.*, 2012; Alender, 2016; Veeckman *et al.*, 2019). The main aim of this chapter is to understand the collaborative efforts, funding, and other interactions that take place among the stakeholders of the CS process in India. To unravel these interactions, I undertook a Stakeholder Network Analysis (SNA) where I identified various stakeholders involved in the CS process in India. I mapped out their collaboration in Gephi 9.2 and the roles they played in CS initiatives using a qualitative analysis in NVivo. The data from the PRISMA framework were further supplemented with interviewees of stakeholders identified through the SNA. The study provided valuable insights to enhance and foster successful and sustainable CS initiatives in India. This is the first study which tried to investigate the stakeholders of CS in India and understand the ecosystem of collaboration among them.

6.1.1. Background

In participatory research approach projects, numerous groups, organisations, and individuals are directly or indirectly affected by the project and/or can influence the project and other groups involved. These affected or influencing groups are termed **stakeholders** of the project (Freeman, 1984; Schiller *et al.*, 2013; Rahman *et al.*, 2017; Skarlatidou *et al.*, 2019). The stakeholder theory was first established by Edward Freeman, originating from strategic management discourses to understand the critical role of stakeholders in influencing the strategic goals of a business or project (Freeman, 1984). Over the years, various academicians and researchers have used it to understand organisational structures, natural resources management and community-oriented programs (Schiller *et al.*, 2013; Skarlatidou *et al.*, 2019). Defining who qualifies as a stakeholder is a subject of debate; however, the majority of the scholars across various domains of research refer to Freeman's seminal work, which states that *"any group or individual who can affect or is affected by the achievement of the project's objectives"* is a stakeholder (Freeman, 1984).

In initiatives such as CS projects, it is essential to identify stakeholders, especially at the initial stages to understand complex public issues and ensure that critical perspectives are not overlooked by project proponents (Schiller *et al.*, 2013). Studies on CS initiatives have found that different stakeholders involved can contribute and share their experiences, knowledge, and insights to support the project throughout its life cycle (Wiggins and Crowston, 2011; Eitzel *et al.*, 2017; Rahman *et al.*, 2017). Thus, conducting a stakeholder analysis helps capture their inputs to develop more relevant projects to varying needs and requirements (Wiggins and Crowston, 2011; Eitzel *et al.*, 2017; Rahman *et al.*, 2017), and understand conflicts that can arise from distrust among the stakeholder groups due to their actions (Baalbaki *et al.,* 2019: Walker, Smigaj and Tani, 2021).

For example, Zemadim et al., (2014) reported in Ethiopia that their hydrometric sensors were damaged by local people who were unaware of them. Moreover, when they initiated the projects, locals were reluctant to cooperate as they were hesitant of foreign researchers who were misidentified as foreign land investors. Discussions with officials and communities, especially the farmers, on research objectives helped in cooperation. It is important to understand that not all people from a community can be selected for a project and key figures, such as local government and authority, appointed observers or coordinators play an important role in appointing (Zemadim *et al.*, 2014). Thus, conducting and identifying stakeholder analysis helped in better understanding who is (or should be) involved and how communication can be supported among them (Roy et al., 2012; Skarlatidou et al., 2019). Another benefit of stakeholder analysis is that it provides a scope for reaching out to new stakeholders who do not have prior experience in the CS process (Pandya, 2012).

Stakeholder theory has various perspectives to define who is a stakeholder in a business or project. In this study, I have considered that CS has a normative perspective. In simpler terms, the normative perspective holds the view that businesses or projects should be managed concerning the necessities and requirements of all stakeholders and not limited to actors who are involved only for financial profits (Pesqueux and Damak-Ayadi, 2005; Rambaree *et al.*, 2021). Thus, a normative perspective brings the idea of ethical consideration while conducting a business (Mahajan *et al.*, 2023). The other school of thought is the instrumental perspective. The instrumental perspective focuses on the strategic importance of stakeholders based on the financial profit or loss of the business (Pesqueux and Damak-Ayadi, 2005; Mahajan *et al.*, 2023). Hence, in the case of CS, it can be assumed that a normative perspective would be best suited for it based on its characteristics (Robinson *et al.*, 2018).

In CS, only a few comprehensive studies on the stakeholder ecosystem have been conducted. These studies provided insights into stakeholder behaviour and actions (Hecker and Wicke, 2019; Turbé *et al.*, 2019; Queiroz-Souza *et al.*, 2023); and normative perspectives that understand the interests of all stakeholders (Göbel, Martin and Ramirez-Andreotta, 2017; Skarlatidou *et al.*, 2019).

Göbel, Martin and Ramirez-Andreotta (2017) were the first to map the typologies of stakeholders involved in CS projects beyond professional and "non-professional" researchers (Skarlatidou *et al.*, 2019). Their study aimed to understand data-sharing scenarios among various stakeholders in CS projects. The study interviewed representatives associated with 16 projects from Annex I countries, particularly from the USA, Australia, and Western Europe (Spain, Austria, Germany, Hungary, the Netherlands, and Belgium), and comprehensively identified stakeholders and their characteristics. They identified six main stakeholder groups that are involved in CS projects across different levels of engagement. The stakeholders and their characteristics are:

- **Academic and research organisations**: The second group consists of academic and research institutions. The report has identified this group to be highly involved in the process of CS, and they form the largest group of lead organizations or project proponents for projects (Cunha *et al.*, 2017; Göbel, Martin and Ramirez-Andreotta, 2017). Examples can be traced to projects such as eBird led by Cornell Lab of Ornithology (Sullivan *et al.*, 2014).
- **Civil society organisations, informal groups, and community members:** Gobel et al., (2017) bring together formally organised (incorporated) and less formally or informally organised stakeholders from civil society, including activist and advocacy groups, as well as individual community members under this group. This group has been attributed with functions such as support, collection and use of data in governance models, and leading or making decisions in collaborative and co-created projects, which are usually focused on a local or sectoral area with values to local communities (Cunha *et al.*, 2017; Göbel, Martin and Ramirez-Andreotta, 2017; Capdevila *et al.*, 2020).
- **Government agencies and departments:** This group plays a vital role in influencing the outcomes of the projects through governance models and influencing policy outcomes. Compared to the previous two groups of stakeholders, the presence of this third group in the CS projects has been moderate (Göbel, Martin and Ramirez-Andreotta, 2017). Government agencies and departments have been recognised as significantly influential stakeholders. as they have the power to influence the integration of CS into governance models such as in decision and policymaking (Göbel *et al.*, 2019).
- **Formal learning institutions for primary and secondary education:** Gobel et al., 2017 categorised schools and colleges under this group. They found that this group supports contributory and co-created projects (especially for data collection), and used CS data or knowledge from contributory, collaborative, co-created, and collegial projects, primarily for educational purposes.
- **Businesses or industry:** Gobel et al., 2017 found there is a lack of involvement of industry and business in the majority of projects they evaluated. This group was found to be usually involved with co-created projects where they assisted in decision-making, support, and use of data and knowledge. Involvement of businesses and industries can be seen in supporting projects through technology [e.g., providing sensors], funding [e.g., Blue Carbon CS program was funded by HSBC Bank (BCL, 2020)], promotion [e.g., social media companies like Facebook, Instagram help in supporting groups and pages for promotion as well as data collection (Dawn, 2021; Rana, Rayal and Uniyal, 2022)]
- **Individual volunteers:** Globel et al., 2017 categorised members of the community who participated in projects as participants under this group. This excludes individuals who represent institutional stakeholders.

These identified categories of stakeholders are similar to those found in other participatory processes, such as the importance of the involvement of government, CSOs or other community-based organizations, practitioners or professionals, service providers, and private businesses (Schiller *et al.*, 2013; Rambaree *et al.*, 2021).

6.1.2. The two types of Stakeholders in Citizen Science

In my study, I used Göbel et al., (2017) as a template to identify and define the categories of institutional stakeholders, their roles, and potential functions. However, I consider that in the CS process, the stakeholders can be further divided into two mega-categories or types based on the idea that CS has both "top-down" and "bottom-up" approaches (Cooper and Lewenstein, 2016; Geoghegan *et al.*, 2016; Woolley *et al.*, 2016; Capdevila *et al.*, 2020). The first mega-category reflects participants (termed as *'individual volunteers'* by Göbel, Martin and Ramirez-Andreotta, 2017), who democratise the process of CS by participating in projects, i.e., Irwin's viewing of CS as a bottom-up approach. With a more inclusive approach, this participant category can be extended to accommodate family members of individual participants.

The second mega-category reflects institutional stakeholders, such as professional scientists, policymakers, etc. (including the individual who represents institutional stakeholders), who usually utilise the process to meet their goals, such as data collection or engagement in decision-making, etc., i.e., Bonney's definition of utilising the contributory nature of CS in research pursuits, education, or engagement. This idea reflects both Irwin and Bonney's definitions of CS (Irwin, 1995; Bonney, 1996). The grouping helps to evaluate participants and institutional stakeholders separately as the scope of participation and collaboration of participants and institutional stakeholders differ to large extents.

The idea evolved during the analysis of the previous chapters, where I observed that a single project can sometimes attract participants from distinct members of communities. For example, the PAC waste tracker project saw that the majority of their participants identified themselves as housewives, followed by shopkeepers (Nagendra, Lakshmisha and Agarwal, 2019). Another example that was seen was the engagement of different sets of participants such as fishermen, scuba divers, as well as the Indian Navy and Coast Guard, in the Dugong Monitoring Project (Gole *et al.*, 2023). These examples illustrate the diversity of individual volunteers who can construct different sets of stakeholders with diverse requirements and backgrounds that individual projects have to accommodate (Cunha *et al.*, 2017). Hence, it becomes essential to understand individual volunteers separately from other stakeholders who have institutional structures and separate goals.

On the other hand, in CS, institutional stakeholders or actors are represented by *a) Academic and Research organisations; b) Governmental Agencies; c) Civil Society Organisations; d) Businesses or industries; and e) Formal learning institutions for primary and secondary education* (Göbel, Martin and Ramirez-Andreotta, 2017). These stakeholders play a spectrum of roles, from establishing, leading and managing projects as project leaders, supporters, and/or users of the data or knowledge to funding CS projects (Göbel, Martin and Ramirez-Andreotta, 2017a; Skarlatidou *et al.*, 2019, Capdevila *et al.*, 2020). They may exhibit varying degrees of participation, from high involvement to low involvement, depending upon their type and contributions (Göbel, Martin and Ramirez-Andreotta, 2017a).

A comparative example to visualise the relations between these two separate stakeholder groups can be drawn from business and corporates where they treat "*business to business (B2B)*" relationships separately from *"business to customer (B2C)"* relationships (OED, 2024). It is one of the fundamental concepts of marketing, which highlights the difference between communication approaches and dynamics between business and other businesses compared to those between businesses and individual customers. In the case of the CS process, I have drawn parallels from management studies and have visualised that there exist "institutional stakeholders to institutional stakeholders" (I2I) relationships and "institutional stakeholders to participant" (I2P) relationships (Figure 20). In this study, I have focused on the I2I relationships of institutional stakeholders of CS initiatives in India and their influence over the process (area within the red box in Figure 20).

Understanding how institutional stakeholders are involved with each other, such as sharing of roles within a project helps us to identify barriers and opportunities that these relationships create. For example, government agencies and departments play an influential role in integrating CS into decision and policymaking. Thus, they have the potential to provide political legitimacy and stability to a CS project, influencing its political sphere. Their influence also extends to funding which is crucial for longer engagement and outreach of the projects (Skarlatidou *et al.*, 2019; Reynolds *et al.*, 2021).

Secondly, these relationships influence funding, which is essential for CS initiatives to be sustained. For example, the lack of or difficulties in obtaining mainstream science funding for CS research might impact the quality of the research (Reynolds *et al.*, 2021). CS projects are usually funded by grants from government agencies or research councils and third-sector organisations like NGOs and charities (Fradera *et al.*, 2015). Göbel et al, 2017 have not identified any specific stakeholders as funders but all the identified stakeholders theoretically can fund any CS project; however, practically it depends upon individual organisations.

Thirdly, CS projects handle data collected by the public and can be sensitive, e.g., the location of endangered species (Vattakaven *et al.*, 2016). These issues give rise to challenges, such as the 'ethical use of data' and 'data ownership' (Resnik, Elliott and Miller, 2015). In these cases, stakeholders play an important role in safeguarding them, especially in countries where there is a lack of strong data protection legislation (Fritz, See and Grey, 2022). Usually, multiple proponents group together, such as academic and research institutes that collaborate with civil society organizations and sometimes government agencies collaborate with CSOs and academic and research organizations. Cunha et al., 2017 found that these kinds of partnerships or collaborations made up 65% of projects at that time. Collaboration preferences are usually inclined towards projects led by NGOs or academic institutions rather than private or government agencies, although many academic-led projects receive funding from national governments (Turbé et al., 2019). It is seen that *civil society organisations, informal groups, and community members* are more frequently involved in CS project design and implementation, while *businesses or industries* (the last group) are least involved (Skarlatidou *et al.*, 2019). Hence, identifying funders, researchers, and other collaborators through network analysis opens up avenues for better project management, such as quality control, reaching out to new stakeholders and participants and establishing new projects or sustaining existing ones.

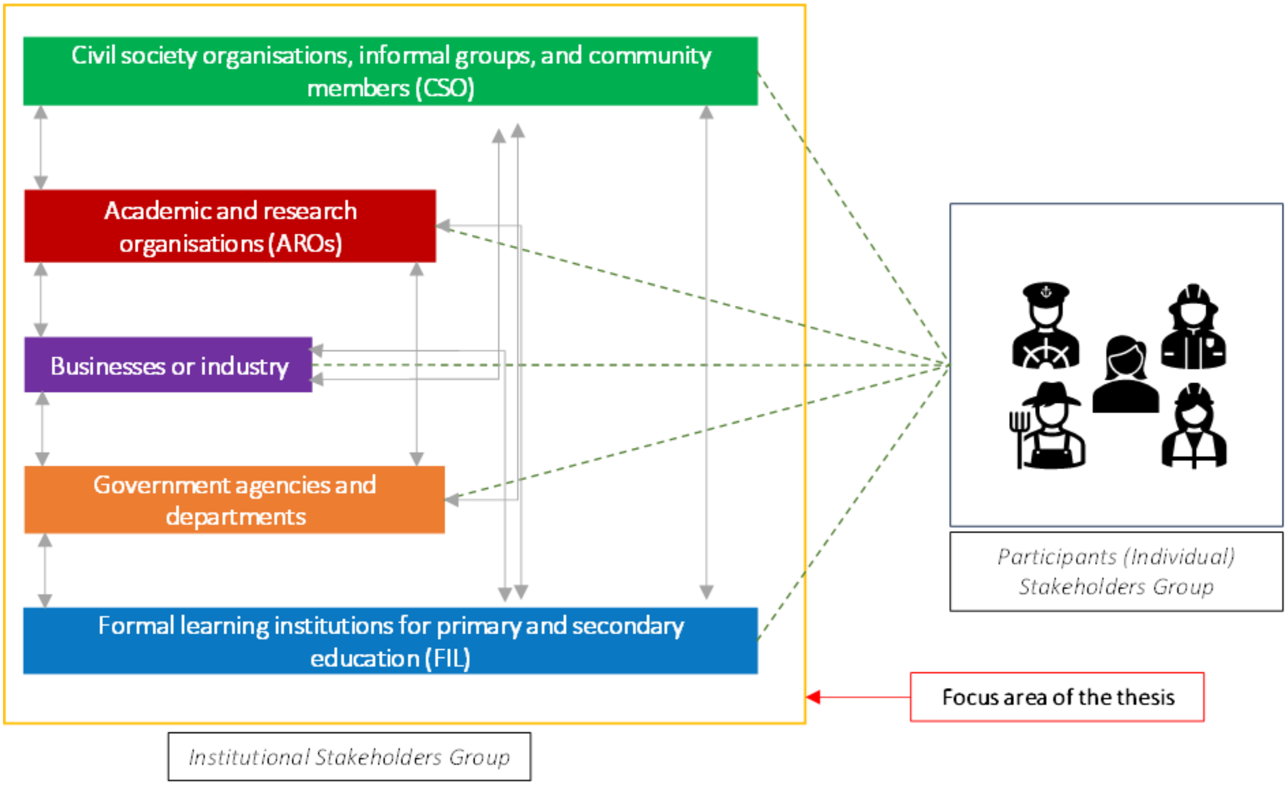

Figure 20: Relationship between institutional stakeholders and participant stakeholders

6.1.3. Objective of the study

In this chapter, I have identified the different institutional stakeholders and the roles they play in the CS process in India. Studying them would enable us to comprehend the dynamics of how CS initiatives are conducted in India, and the potential to broaden its scope. Currently, there are no studies which have tried to map the interactions of institutional stakeholders in India.

Thus, this study has explored the roles of institutional stakeholders to understand their ecosystem and collaboration via three components. Firstly, the identification of stakeholders and visualising the ecosystem through a Network Analysis using selected records collected in Chapter 2, followed by a qualitative assessment of the roles of institutional stakeholders using selected records and interviews of representatives of stakeholders. This was followed by an interest and influence analysis of various types of stakeholders as perceived by the interviewees. Through this, the study aimed to provide information to existing stakeholders for new connections and roles, and new stakeholders can use the information to involve themselves in CS initiatives in India. Moreover, it would provide a chance for international cooperation and partnerships for stakeholders from around the world (GCSP). The study has formulated the following research questions as a guide to better understand the institutional stakeholders of CS in India.

a. Who constitutes the diverse array of institutional stakeholders involved in the execution of CS initiatives in India?
b. What are the various roles and contributions these stakeholders assume that impact CS initiatives?

6.2. Methodology

6.2.1. Data Collection

6.2.1.1. Stakeholder Identification

The first step was to identify the stakeholders. The data utilised in this were sourced from the academic records collected using the PRISMA Framework (Chapter 2). All the records from the following four sources of evidence were selected:

1. records describing CS initiatives (CSP-AL) (n=33)
2. records which used data generated by CS for scientific research (CS-UD) (n=12)
3. records describing participants and stakeholder experience in CS initiatives in India (CS-R) (n=8)
4. records describing CS pilot projects (CS-IA) (n=6)

These articles contained information on various stakeholders involved in the project such as the names of organisations and institutions engaged in a CS project. Information was extracted from the methodology, authors' section information, acknowledgement and funding sections of each academic record. The institutional stakeholders were identified using the stakeholder theory, which states that stakeholders are *any group or individual who can affect or is affected by the achievement of the project's objectives*. The names of the institutional stakeholders were then coded in NVivo software into one of the stakeholder categories described below. The software helped to manage data on the identities of stakeholders under the identified stakeholder categories (section 6.2.1.2.) (which were termed stakeholder category codes). The data was summarised using a percentage-based distribution.

- **Academic and research organisations (AROs):** The following types of academic and research institutes were considered under this category; Government Aided Institutes; Private Indian Institutes, and Research Organisations and Thinktanks. The review also found that in several projects, foreign academic and research organisations (AROs) and were categorised as foreign AROs.
- **Civil society organisations, informal groups, and community members (CSOs):** In India, CSOs and NGOs are organisations that registered themselves under the Indian Trusts Act, 1882 and Societies Registration Act, 1860. Both these legal acts help individuals or groups to establish charities, foundations, and CSOs including grassroots organisations depending on the requirements of the organisations. The following types of CSOs are usually found in India: Grassroots Organisations, Registered Societies and Trusts working at both state and national levels, and International Non-governmental organisations.
- **Government agencies and departments:** Government agencies and departments refer to organisations

under the management of the Government of India and other governments. The study identified ministries, departments and agencies e.g., pollution control boards, museums, etc., under this category.

- **Formal learning institutions for primary and secondary education:** In terms of India, schools refer to formal education of 12 years (until the age of 18) and colleges refer to institutions teaching undergraduate courses. The identification of schools and colleges when mentioned were confirmed using Google search.
- **Businesses or industry:** Businesses and industries in India usually undertake environmental-related activities through their corporate social responsibility or corporate environment responsibility divisions. In India, businesses and industries usually launch foundations or trusts, which are registered as CSOs. In case, a business or industry stakeholder was involved through foundations, I have recorded them under business and industries to understand the contribution of their parent organisation.
- **Collaborative platforms:** Collaborative platforms were a new category that was introduced for this study. This category refers to a) big projects or databases such as eBird and iNaturalist, and b) collaborative networks and informal groups of individuals and organisations, or a mixture of both. This category was introduced as projects such as eBird played an important role as an enabling platform for smaller projects. The second category was to accommodate sets of loosely and informally connected individuals and/or organisations.

The following steps were undertaken to verify the categorisation of stakeholders into the above-mentioned categories.

Step 1: Self-identification of an organisation by itself. The information was extracted from the website of the organisation after a web search.

Step 2: Legal identification of an organisation. In case smaller organisations (organisations with low financial turnover especially in the case of CSOs) do not have a website, their identity has been confirmed using NGO Darpan. NGO Darpan is an online portal maintained by NITI Aayog, India and it serves as a platform for Voluntary Organisations (VOs) and Non-Governmental Organizations (NGOs) to register centrally. This portal aims to create a comprehensive repository of information about VOs and NGOs, categorized by sector and state. It provides these organizations with a system-generated Unique ID, which has become mandatory for NGOs, NPOs, CSOs, and other entities.

Step 3: Authors identification. If no identification was available online, I assigned one based on the activities undertaken by the organisation as reported in the article. For example, *Van Suraksha Samhiti* (Forest Protection Committee), helped in recruiting participants. It was categorised under CSO (Grassroots) but it cannot be ascertained.

6.2.1.2. Roles of Stakeholders

The second analysis consisted of identifying the roles of the stakeholders. The records mentioned above were selected for this process. The roles were identified based on the actions reported in the article, such as authors of the article whose role can be extended to publicity and reporting of the project; or funders of projects (extracted from the Acknowledgement section). The categorisation of roles was identified using an inductive process. The text segments in records that reflected the actions of one of the roles described below were coded into NVivo as ***role codes***. For example, the funding action of a stakeholder reflects its role as a Funder. Box 6.

- Authors, i.e., stakeholders who contributed towards publications. In this case, the institutions to which the authors belonged were recorded as the stakeholders.
- Project proponents, i.e., institutions or organisations leading the CS initiatives.
- Collaborators, i.e., institutions and organisations aided in project activities along with central stakeholders such as by recruiting participants or providing researchers, etc.
- Funders, i.e. institutions and organisations that have funded CS initiatives.

Box 6: Example of identification of roles undertaken by stakeholders. In this example, I have coded the following segments of texts to funding.

Source: (Menon *et al.,* 2021)

FUNDING

This work was funded by REVIVAL; grant numbers NE/R003521/1 and DST/TM/INDO-UK/2K17/64 C&G.

ACKNOWLEDGMENTS

This paper is part of the Department of Science and Technology, India-funded project REVIVAL (under the Indo-UK water quality programme), under which regular water quality assessment of Vembanad Lake has been done since April 2018.

A single stakeholder can have multiple roles within a project, such as they can be both 'Authors' and 'Project Proponents.' However, the limitation arose when articles did not mention specifically distinguished roles among the stakeholders involved, such as coordinators, managers, etc. If their involvement was briefly mentioned in the methodology section of an article along with their names, stakeholders were termed as 'collaborators'.

This analysis of roles helped in understanding stakeholder contributions and a certain degree of influence on the process from the information reported and later informing the PESTELE analysis in Chapter 7. It also informed the diversity and interaction of institutional stakeholders involved in the CS process in India while conducting the Stakeholder Network Analysis (SNA) (Section 6.2.2.1). However, as substantial evidence and information could not be extracted from the selected records about stakeholder roles, interactions, and conflicts, semi-structured interviews of project proponents were carried out to supplement this analysis. Interviews are highly recommended for in-depth insights into stakeholder analysis (Reed *et al.*, 2009; Göbel, Martin and Ramirez-Andreotta, 2017; Queiroz-Souza *et al.*, 2023).

To collect data through semi-structured interviews, initially, twenty-two stakeholders identified from the resources were contacted, representing different categories of stakeholders. However, only nine interviewees agreed to take part in the interview, represented by the CSO group (n=6) and Academic and Research groups (n=3) (Table 13). All of the interviewees have represented organisations which have led CS projects as project proponents. This became a limitation of the study. The initial aim was to understand diverse institutional stakeholder perspectives. The interviews were conducted over Zoom (except for one instance where it was done in person to accommodate the schedule) between December 12th, 2022, and March 20^{th,} 2023. Each interview lasted for 45-60 minutes. During the recording in Zoom, the closed caption (cc) option was 'on' which helped in retrieving the recordings' transcripts. The transcripts that were generated were not 100% accurate; hence, a manual round of correction was undertaken by listening to video recordings. The transcripts were then imported as a .docx file to be processed in NVivo under the same role categories described above.

The interview was guided by a set of questionnaires (Annexure 6) which aimed to gather information about the motivations of the project proponents to initiate the project; barriers in conducting the projects; support network around the project; involvement of government agencies, CSOs, business and industries, etc.; funding and its opportunities and barriers. The following points were referred to while conducting the interview:

- Interviewees' organisation's motivation to associate with CS projects
- Barriers to outreach and network development
- Involvement with the other institutional actors e.g., local government, grassroots organisations, and other organisations.
- Influence of government agencies in funding and their outlook towards CS to tackle environmental and climate change issues.
- Influence of business and industries.
- The potential of Crowdfunding for CS in India
- Sustainability of projects and other funding avenues

Table 12 List of interviewees and their stakeholder category. (+): Projects identified from GSP.

S No.	Name of Stakeholder	Acronym	Stakeholder categories
I1	Ashoka Trust for Research in Environment and Ecology	ATREE	Research Organisations and Think tank
I2	Bihu Bird Count, Assam Bird Monitoring Network*	Bihu Bird Count	Collaborative Platform
I3	SeasonWatch, Nature Conservation Foundation	SeasonWatch	Research Organisations and Think tank
I4	Wild Canids-India Project*	Wild Canids	Collaborative Platform

I5	Confederation of Indian Industries*	CII	Civil Society Organisations
I6	Keystone Foundation	KF	Civil Society Organisations
I7	CitSci India	CitSci India	Collaborative Platform
I8	National Institute of Advanced Studies Bengaluru (Bangalore)	NIAS	Government Aided Indian Institute
I9	Peer Water Exchange	PWX	Civil Society Organisations

6.2.1.3. Interest and Influence

To understand the relative interest and influence of different stakeholders within the CS process in India, a matrix-based analysis (also known as the Mendelow Matrix) was conducted. This matrix helps in understanding the power dynamics and possible stakeholder prioritisation based on perception (Reed *et al.*, 2009; Skarlatidou *et al.*, 2019). The data on influence and interest matrix was collected post-interview as an activity for the interviewees. The interviewees were asked to mark how they perceived the influence and interest of different categories of stakeholders through their general experience of engaging in CS projects in the matrix represented in Figure 21.

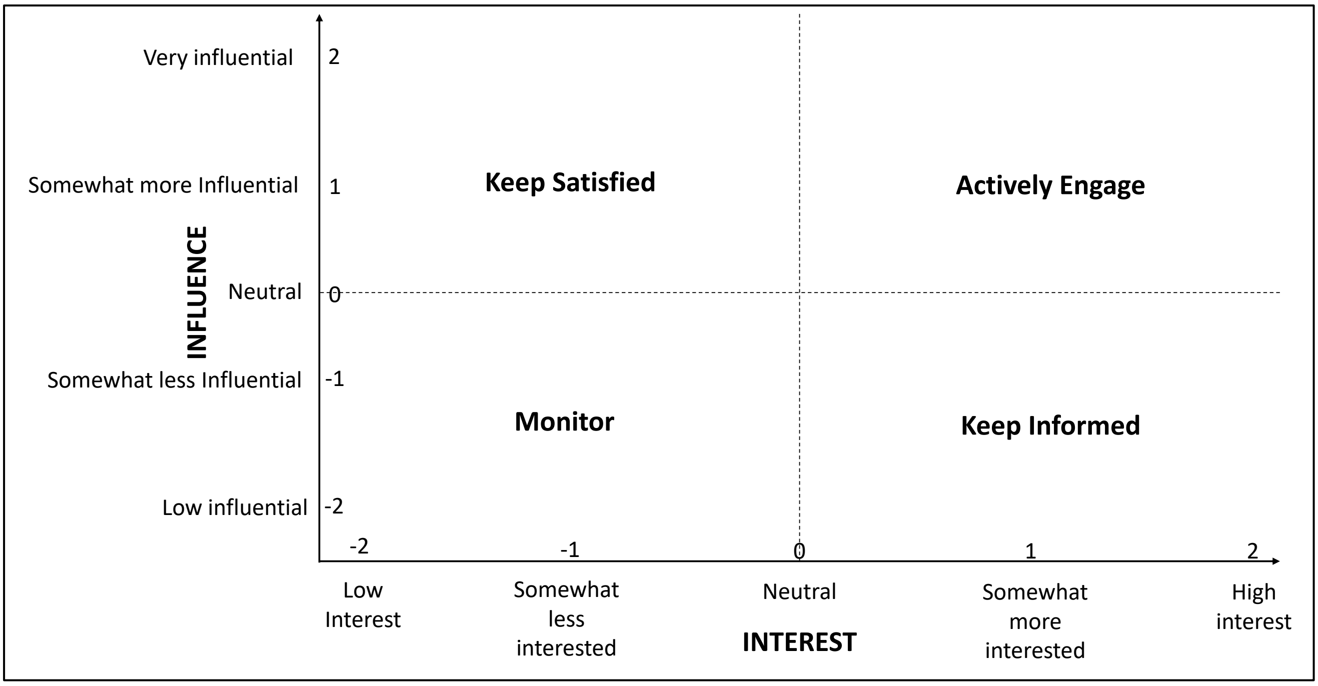

Figure 21: Sample of Mendelow Matrix used to collect data on interest and influence of different stakeholder categories.

6.2.2. Data analysis

6.2.2.1. Stakeholder Analysis

Nine different methods for stakeholder analysis can be conducted in the context of projects related to natural resources management (Reeds et al., 2009). Since my thesis deals with environmental and ecological CS initiatives, the different methods discussed by Reeds et al., 2009 were best suited for this study. These methods have their strengths and weaknesses, and their utilisation depends upon resources, time, and objectives (Reed et al., 2009; Schneider, 2014). For this study, three methods were selected out of the nine methods, due to limited financial resources and time. Methods were chosen such that it required the lowest finance and time to collect the maximum data. However, the assessment using all nine methods portrays a better picture. The selected methods were undertaken in the following stepwise manner to understand and visualise the stakeholder ecosystem:

Data visualisation and stakeholder ecosystem mapping using Stakeholder Network Analysis (SNA)

The SNA is a visualisation technique to study and visualise the connections and interconnectedness of various stakeholders to understand their ecosystem and identify influential and peripheral stakeholders (Reed *et al.*, 2009; Rambaree *et al., 2021).* As various stakeholders work in collaboration in CS initiatives, this would help us to identify groups that work together and the extent of their collaborative networks.

To visualise the distribution of stakeholders and their roles, MS Excel and Gephi 9.2 were used. The institutional stakeholders (**stakeholder category codes**) identified from the academic records using NVivo were extracted to an MS Excel sheet and given a unique identification number (ID No.). Similarly, the data from **role codes** were extracted as the number of times (frequency) a stakeholder undertook a particular role. The frequency was counted against the particular **role code** which helped in measuring the frequency of active engagement of a single stakeholder. The frequency of active engagement was measured for overall participation and each category of roles. This helped in identifying potential funders and partners for future project collaboration. This data was transferred to MS Excel for further analysis of the SNA using Gephi 9.2. Data visualisation in MS Excel helped in picturing the diversity of the stakeholders in percentage and their contribution to each role. Gephi 9.2 was used to find actively engaged institutional stakeholders and to map their connectedness through their roles in CS initiatives.

Data visualisation in Gephi 9.2

- **Creating Nodes:** In SNA, nodes serve as the fundamental elements representing individual actors or entities. They can encompass various attributes, including self-properties like weight, size, and position, as well as network-based characteristics such as degree (indicating the number of connections), cluster membership, and centrality measures. In this study, individual institutional stakeholders represent individual nodes. For example, ATREE, an Academic and Research stakeholder, represents one node on the entire stakeholder network. The characteristics of the nodes in this study are:

a. category of stakeholders (cluster membership)
b. frequency of active engagement (a node might have the sum of frequency arising from all the roles a particular stakeholder played across various projects)

- **Creating Edges:** Edges in SNA are relationships (or meaningful connections) between nodes illustrated as lines in a network graph. Edges provide a flexible means of representing various relationship types within the network. In this case, I used the thematic areas of CS initiatives (Chapter 3) to represent the relationship between two nodes (individual institutional stakeholders). This facilitated the identification of the flow of connections (usually termed as flow of information) between the stakeholders.
- **Data Visualisation:** For visualisation of the stakeholder ecosystem in Gephi 9.2, an MS Excel sheet was created as input data. This Excel sheet contained information on **Nodes** (individual institutional stakeholders). The information entailed the unique ID No. which signified a single node, categories of institutional stakeholders they belonged to, and their frequency of active engagement in each role. Another Excel sheet was created with data on relationships between two nodes, i.e., roles that connected two stakeholders. This was used to visualise **Edges**. For the visualisation of stakeholders across different categories, the following colour scheme was adopted and the frequency of active participation by each stakeholder was visualised by node size, the larger the node the greater its frequency of participation.

Box 7: Colour codes used for graphical representation of stakeholder categories (including SNA)

Academia and Research	(red)	Collaborative platforms	(yellow)
Businesses and Industries	(purple)	Formal Learning Institute	(blue)
Civil Societies	(green)	Government Agency	(orange)

Stakeholder Network Analysis (SNA)

The network analysis (SNA) used the statistical algorithms provided by the Gephi software following the steps given in *"Mastering Gephi Network Visualization"* by Cherven (2015). The following tests from Gephi were considered to understand the network system of stakeholders of CS in India:

- **Average Path Length, Network Diameter and Radius Calculation:** The average path length measures the average number of steps along the shortest paths for all possible pairs of network nodes. The analysis provides a measure of how efficiently the nodes are connected and the influence that can spread through the network. Networks with shorter average path lengths tend to be more cohesive, with nodes being more closely connected.

  The Network Diameter and Radius Calculation test provides insight into the network's overall size and reachability. The diameter of a network is the longest-shortest path between two nodes. The radius indicates the minimum eccentricity of a node, i.e., the distance between the central node to the furthest node.
- **Clustering Coefficient Calculation using the Triangle Method:** The test calculates the clustering of nodes (clustering coefficient) using the Triangle Method. Triangles are a key indicator of local clustering and the presence of cohesive sub-groups within a network. The method measured the extent to which nodes

in the network tend to cluster together by considering the presence of triangles (sets of three mutually connected nodes).

- **Modularity Analysis:** The test helped to identify clusters within the network. It measured the strength of the division of a network into communities. High modularity values indicate a more well-defined community structure.

These tests collectively provided valuable insights into the structure, connectivity, and groupings of the network. This allowed for a comprehensive analysis of the characteristics of how institutional stakeholders interact with each other. To carry out these tests, the following parameters for the network were considered:

- The network flow of information was taken as "undirected" as the review could not determine the directionality of influence; hence, the connections were inherently considered bidirectional.
- Next, I kept the weight of the "edges off", which meant that edge weights were not considered, and the analysis focused solely on the presence or absence of edges, regardless of their weights. Though weights were not provided to edges in this study, this step was considered to reduce possible interferences arising from the software's calculations.
- Third, I kept the modularity resolution at 1. It is the standard resolution setting which helps to keep a balance in the granularity of the detected communities. A resolution of 1 helps to detect both smaller and larger communities.
- Fourth, I randomised the modularity calculation to avoid local interference and provide a more robust cluster detection. Gephi shuffles the node orders and reruns the algorithm multiple times. This ensured that the detected community structure was less likely to be influenced by the initial configuration of the network.
- In the case of network diameter, the centralities were normalised. Normalising the centralities helped in interpreting the results, whose range was standardised between 0 and 1.

These parameters provide a range for conducting a comprehensive analysis of the network. They determine the nature of the network, the methods used for measuring key metrics such as clustering coefficient and modularity, and other factors that influence the analysis and interpretation of the network's structure and properties.

Finally, to create a benchmark, a random graph was generated. In a random graph the nodes are distributed randomly but follow the same distribution pattern as the graph in analysis, i.e., it contains the same number of nodes as the graph in analysis but without defining the relationships among them. Thus it represents a random condition under which the nodes are made to connect. The benchmark helps in establishing if the structure of the graph in analysis has features that are not random or by chance.

6.2.2.2. Qualitative data analysis using text segments and semi-structured interviews

For qualitative data analysis, the roles of stakeholders were considered to understand how the ecosystem works. Relevant text segments from both records and interviews were coded into the roles identified earlier in NVivo using an inductive method (Section 6.2.1.2). The qualitative analysis supplemented the results of the quantitative analysis with further details.

6.2.2.3. Interest-Influence Matrices

The representatives of the organisations (interviewees) in Table 12 were individuals who led CS projects as project coordinators, managers, or principal investigators of research projects. Moreover, they represented stakeholders only from Academic and Research Organisations, Civil Society Organisations and collaborative platforms. Thus, due to the skewness in the representation of institutional stakeholders in the interviews, the influence and interest matrix was analysed as a perception of project proponents or central stakeholders on other categories of institutional stakeholders. The influence-interest matrix was plotted using cartesian coordinates (X-Y plots). The overall perception of interviewees on each stakeholder was represented using 'Mode' The mode represented how the majority of interviewees perceived the influence and interest of each category of institutional stakeholders.

6.3. Results

6.3.1. Overview of institutional stakeholders in India and their network analysis

The stakeholder identification and stakeholder network analysis identified a total of 224 stakeholders from the n=59 academic records. The review found that academic and research organisations (AROs) are the most prominent stakeholders (51%), followed by civil society organisations (CSOs) (20.09%), government agencies (13.39%), formal learning institutes (FLI) (8.48%), collaborative platforms (7.14%), and businesses (2%). It is to be noted that not all records explicitly referred to their project proponent or central stakeholder. In the case of CSP-AL records, only 6% of the records did not explicitly mention their central stakeholder. For CS-UD, 50% did not explicitly mention their central stakeholder as they utilised data from existing databases. In the case of CS-R, in 37% of the records and CS-IA, 25% did not explicitly identify stakeholders.

Table 13. Types of stakeholders of CS in India and their distribution

Stakeholder Categories	Sub-categories	No. of stakeholders
Academia and Research Organisations (AROs)		**108**
	Foreign Institutes/Universities	35
	Government Aided Institutes	44
	Private Indian Institute	12
	Research Organisations and Thinktank	17
Business and Industries		**4**
Civil Societies (CSOs)		**43**
	Collaborative Network	4
	Grassroots	5
	IGO	12
	Registered Society	15
	Trust	7
Collaborative Platforms	Database	**16**

Formal Learning Institute (FLI)	Colleges	**19**
Government Agency		**30**
	Foreign Government Agency	6
	Government Department	17
	Local Government	3
	Ministry	4

6.3.1.1. Stakeholder Network Analysis Interpretation

The stakeholder network analysis of CS initiatives in India exhibits a complex network system of 224 stakeholders (nodes) (Table 14) (Figure 22). It currently exhibits a highly modular, locally clustered but overall fragmented network system. The average path length is 4.248 and a diameter of 9, exhibiting moderate cohesion as compared to the Random Graph of comparable size that exhibits an average path length of 2.49, and a diameter of 4. The network density was low (0.013) with 15 weakly connected components indicating distant and disconnected segments. The network showed fewer total triangles compared to the Random Graph, however, the clustering coefficient was high (0.1051) compared to the Random Graph (0.0496) and average node clustering was 0.320 vs. 0.050. The stronger local cohesion and triangle formation in the network than in the Random Graph suggested that stakeholders are closely knitted together but with a restricted flow of information in the entire network structure. Stakeholders collaborate within their known connections, which is shown by a high modularity score of 0.801.

Table 14. Test results of the stakeholder network analysis (SNA).

Test	Test Results	Random Graph Results	Inference
Average Path Length, Network Diameter and Radius Calculation.	Average Path Length (APL): 4.248	Average Path Length: 2.492	With respect to the Random Graph, the network APL is higher suggesting distinct communities exists and are separated, meaning the network has low efficiency in the flow of information.
	Diameter: 9	Diameter: 4	The diameter of 9 over 4 (Random Graph) show greater dispersion of nodes. It also indicates fragmentation of the network,
	Radius: 0	Radius: 3	This suggests there is at least one node that is not connected. This indicates the presence of isolated nodes or clusters while the Random Graph with 3 means it is fully connected.
	Network Density: 0.013	Network Density: 0.051	This means only 13% of all possible edges between nodes are present indicating a sparse network. Under random conditions the density is near about 50%. This means most nodes are not being directly connected and supports the idea of fragmentation.
Clustering Coefficient Calculation	Total Triangles: 80	Total Triangles: 239	There are 80 sets of three nodes, where one node is connected to the other two.

using the Triangle Method	Number of Paths of Length 2: 2284	Number of Paths of Length 2: 14,441	The result suggests that there were 14,441 opportunities for triangle formation but formed only 2284. The rest of the paths were not closed to form triangles suggesting that the nodes are not connected.
	Clustering Coefficient of the overall network: 0.1051	Clustering Coefficient of the overall network: 0.0496	In this case, the network showed a higher clustering coefficient over the Random Graph. The results indicates that though the triangle formation is low, triangles that were formed were relatively close to each other.
	Average Clustering Coefficient of nodes: 0.320	Average Clustering Coefficient of nodes: 0.05	It indicates that 32% of a node's neighbours are connected and since the percentage is higher than the Random Graph, it indicates that these are meaningful local connections leading to cluster formation.
Modularity Analysis	Modularity: 0.801	Modularity: 0.248	The test indicates high modularity which means the network is divided into distinct communities with dense internal connections among nodes and sparse connections between communities whereas the Random Graph represents homogeneity benchmark.
	Number of Communities: 24	Number of Communities: 10	This indicates that the network is divided into 24 distinct communities and a high level of segmentation. This also indicates the presence of multiple sub-groups with strong internal cohesion.
	Number of Weakly Connected Components: 15	Number of Weakly Connected Components: 1	This indicates that the network comprises 15 weakly connected communities (or sub-graphs which are internally well connected but disconnected from others) given the Random Graph is one fully connected graph.

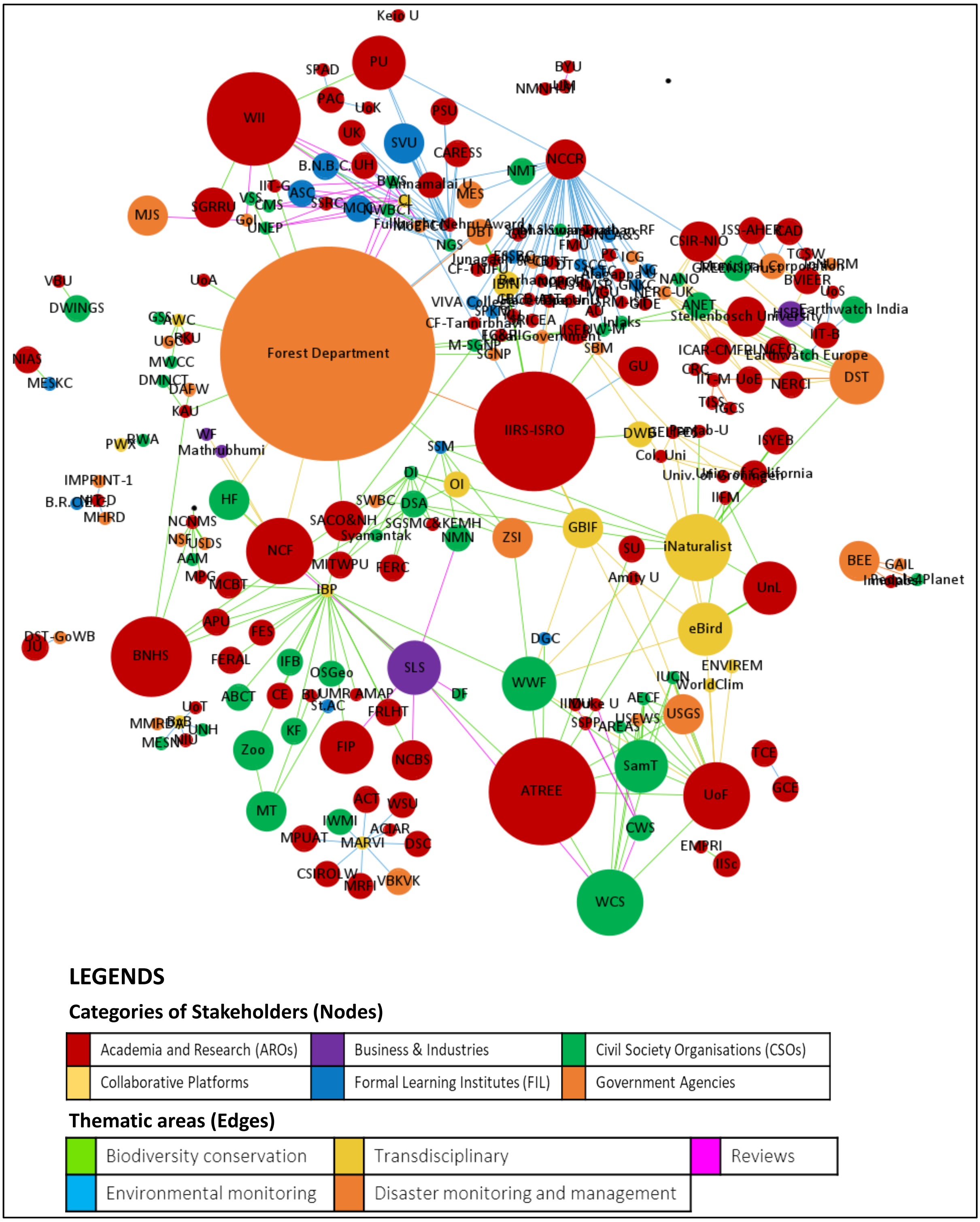

Figure 22: Collaboration network visualisation of stakeholders involved in the CS in India (SNA). The size of the nodes indicates their active engagement level. i.e., a larger node size indicates a more active stakeholder.

6.3.2. Overview of roles institutional stakeholders in India

In this section, I have presented the distribution of stakeholders undertaking the identified roles (SNA) and their methods of engagement in CS initiatives (qualitative analysis in NVivo). Figure 23 presents the distribution of institutional stakeholders across various roles.

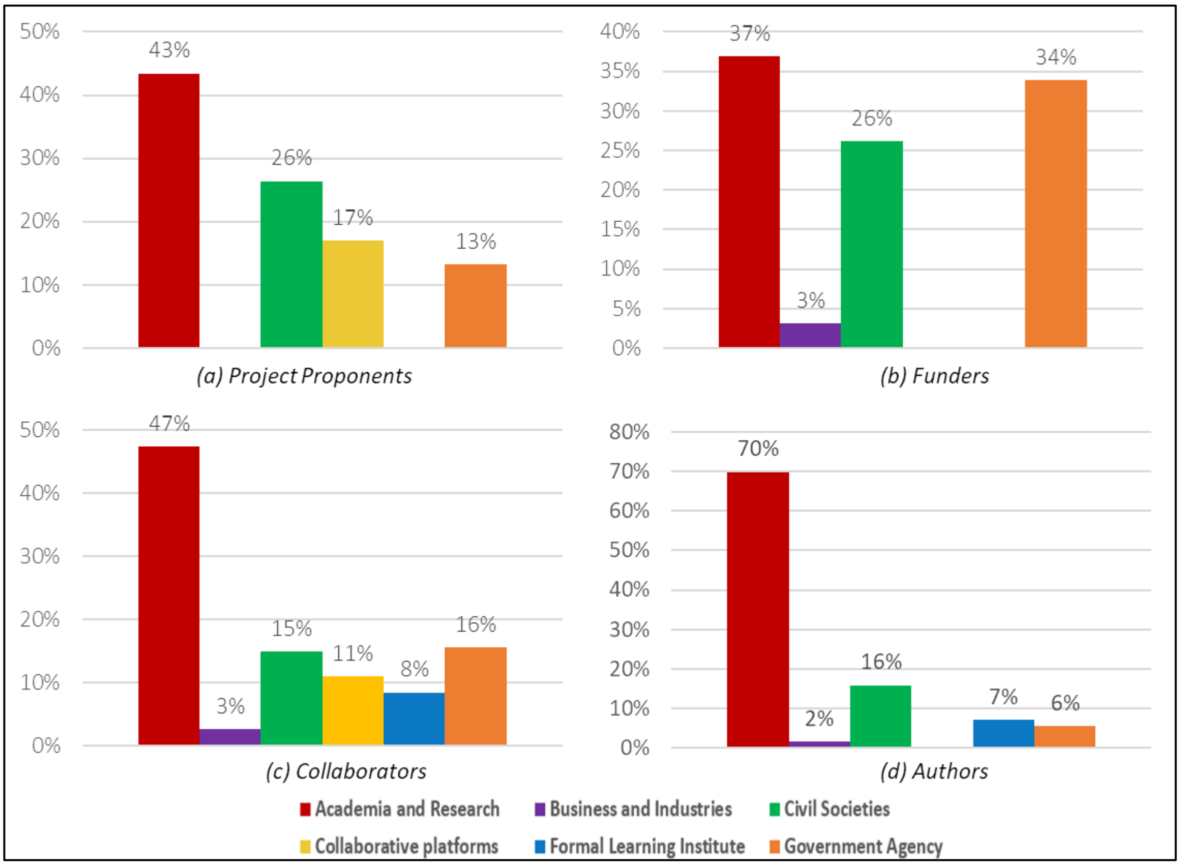

Figure 23: Distribution of different categories of institutional stakeholders in the identified roles

6.3.2.1. Project Proponents

A total of 52 stakeholders were identified as project proponents, i.e., stakeholders leading a CS initiative. AROs were the most prominent group of project proponents (43%), followed by CSOs (26%), collaborative platforms (17%) and government agencies (15%). Businesses and formal learning institutes did not initiate any projects in India (Figure 24). Table 16 presents the distribution of project proponents of CS initiatives in India. Figure 25 visualises the activity level of different stakeholders as project proponents.

Table 15. Different categories of stakeholders engaged as project proponents of CS in India.

Categories and sub-categories of stakeholders	Active engagement as a project proponent
Academia and Research	**22**
Foreign Institutes/Universities	4
Indian Government-Aided Institutes	10
Private Indian Institutes	2

Research Organisations and Think Tanks	6
Civil Societies	**14**
Collaborative Network	2
Grassroots	2
Registered Society	7
Trust	3
Collaborative platforms	**11**
Government Agency	**6**
Foreign Government Agency	1
Government Department	4
Ministry	2

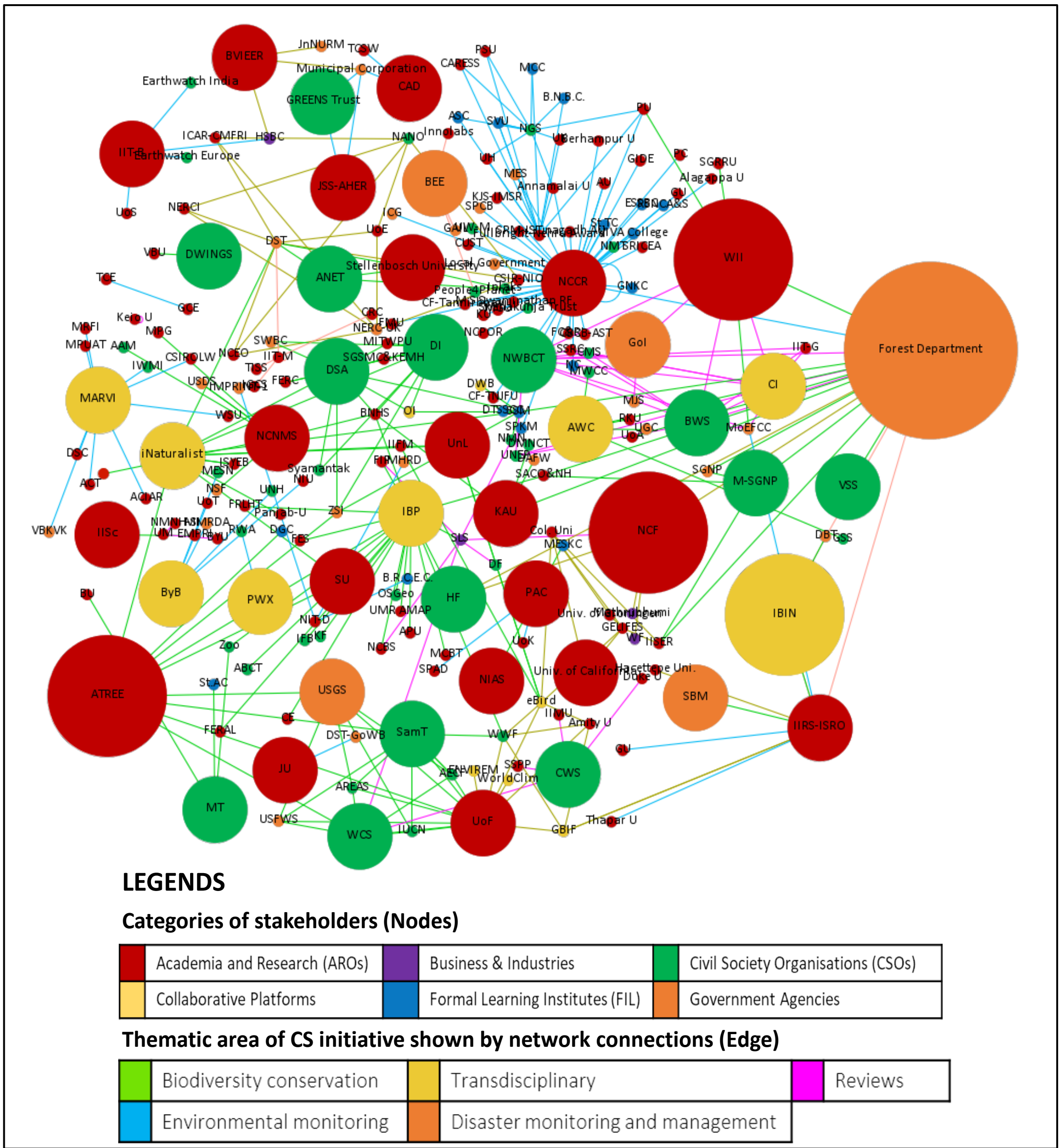

Figure 24: Stakeholder network highlighting project proponents. The size of the node indicates the level of engagement.

6.3.2.2. Funders

A total of 64 funding agencies were identified that funded CS initiatives in India. AROs were the biggest contributors (37%), followed by government agencies (34%), and CSOs (26%). A very small percentage of initiatives were also funded by businesses and industries (2%). Collaborative platforms and FLI did not contribute as funders in India. Figure 25 visualises the prominent stakeholders based on their activity level as funders. Table 17 presents the distribution of CS initiative funders and the different categories they belong.

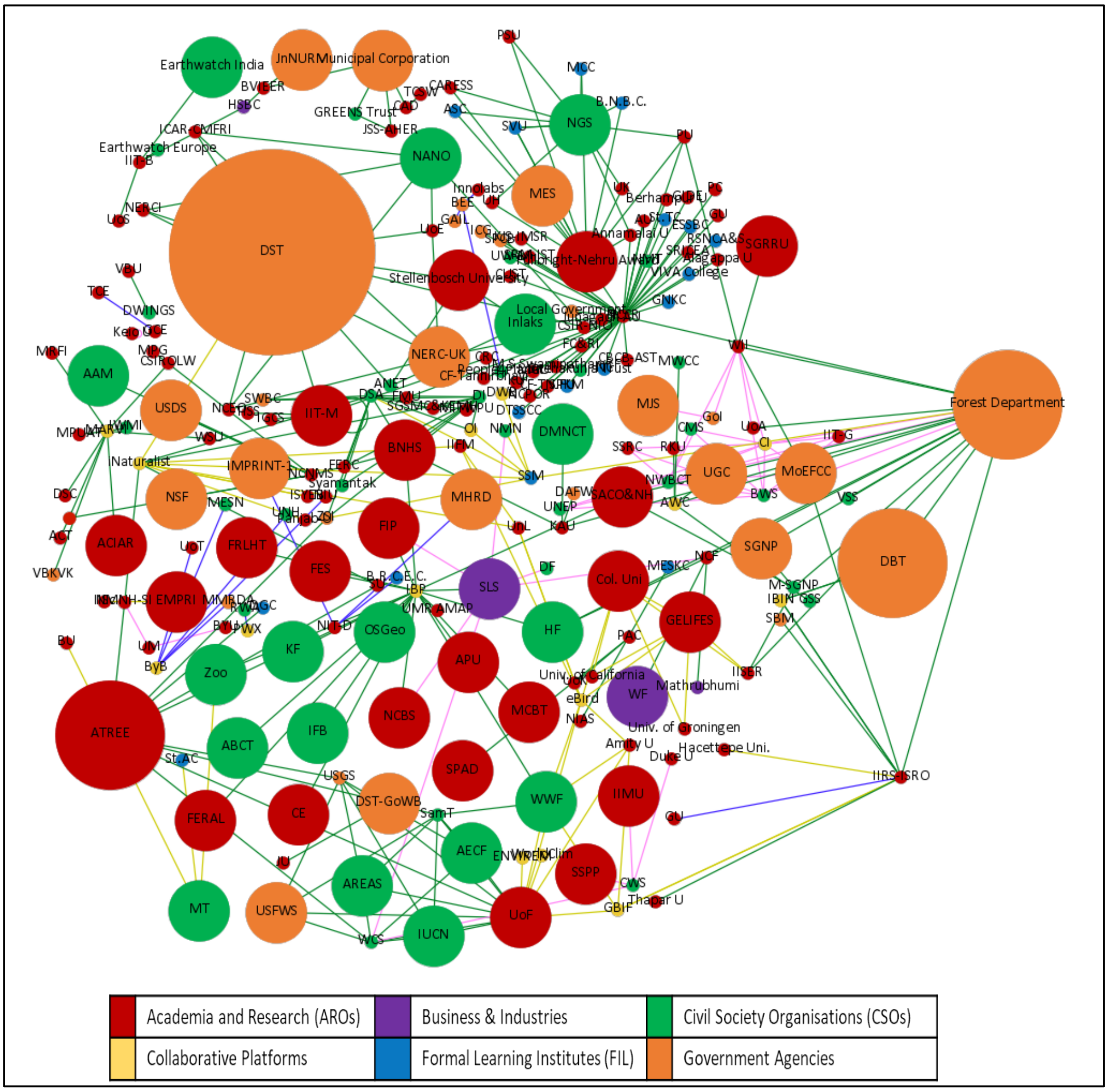

Figure 25: Stakeholder network highlighting funders of CS initiatives in India. The size of the node indicates the level of engagement.

Table 16. Different categories of stakeholders contributing as funders of CS initiatives in India

Categories and sub-categories of stakeholders	Active engagement as funders
Academia and Research	**26**
Foreign Institutes or Universities	9
Indian Government-Aided Institutes	4

Private Indian Institutes	2
Research Organisations and Thinktanks	11
Businesses and Industries	**2**
Civil Societies	**15**
International Governmental Organisations (IGOs)	6
Registered Societies	6
Trusts	3
Government Agency	**21**
Foreign Government Agencies	7
Indian Government Departments	14
Indian Government Ministries	3
Local Governments	1

6.3.2.3. Collaborators

A total of 154 stakeholders were identified who were associated with CS initiatives, who were not project proponents, funders or authors. AROs were the most prominent group (47%) as multiple institutes collaborated. They were followed by government agencies (16%) and CSOs (15%) whose role entailed coordination, grassroots engagements and promotion of initiatives. Collaborative platforms (11%) collaborated by providing a platform for data management of projects. Formal learning institutes (8%) and businesses and industries (3%) collaborated by volunteering their students and employees respectively as citizen scientists. Table 18 presents the distribution of collaborators who participated in CS initiatives in India. Figure 26 visualises the activity level of different institutional stakeholders as collaborators.

Table 17. Different categories of stakeholders who collaborated in CS initiatives in India.

Categories and sub-categories of stakeholders	Active engagement of collaborators
Academia and Research	**73**
Foreign Institutes/Universities	13
Government Aided Institutes	33
Government Departments	1
Private Indian Institutes	6
Research Organisations and Thinktanks	16
Business and Industries	**4**
Civil Societies	**23**
Grassroots	3
IGO	6
Registered Society	8
Trust	4
Collaborative platforms	**17**
Database	**15**
Collaborative network	**2**
Formal Learning Institute	**13**
Government Agency	**24**
Foreign Government Agency	1
Government Department	16
Local Government	1

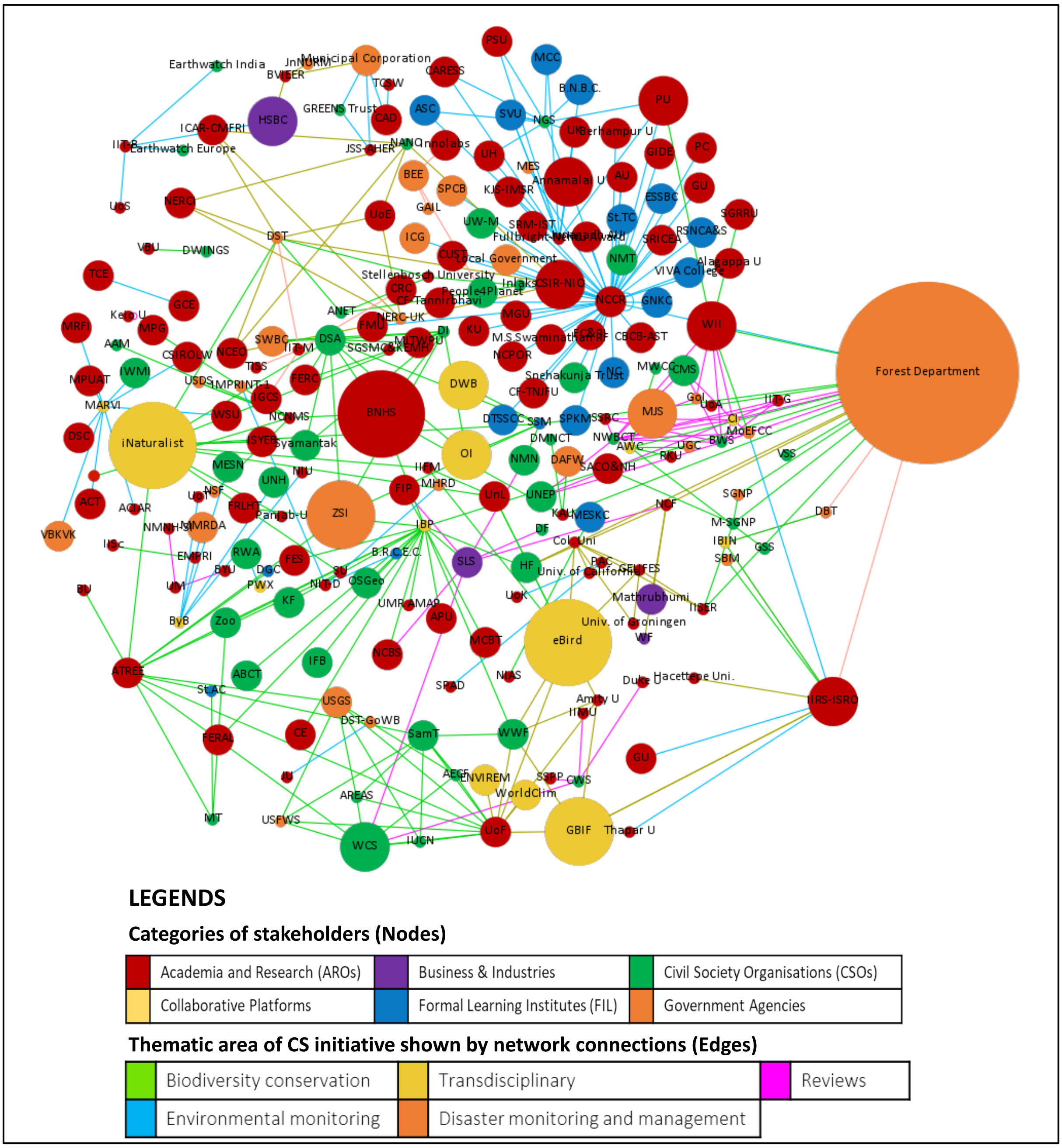

Figure 26: Stakeholder network highlighting collaborators, i.e., stakeholders who were involved in various activities besides funding or leading CS initiatives. The size of the node indicates the level of engagement.

6.3.2.4. Authors

A total of 126 stakeholders contributed as authors. Authors were predominantly from AROs (70%), with a small percentage from CSOs (16%), FLI (7%), Government (6%), and businesses and industries (2%). This skewness can be due to the selection of academic records for this study. Table 19 presents the distribution of authors who reported on CS initiatives in India. Figure 27 visualises the activity level of different institutional stakeholders as authors.

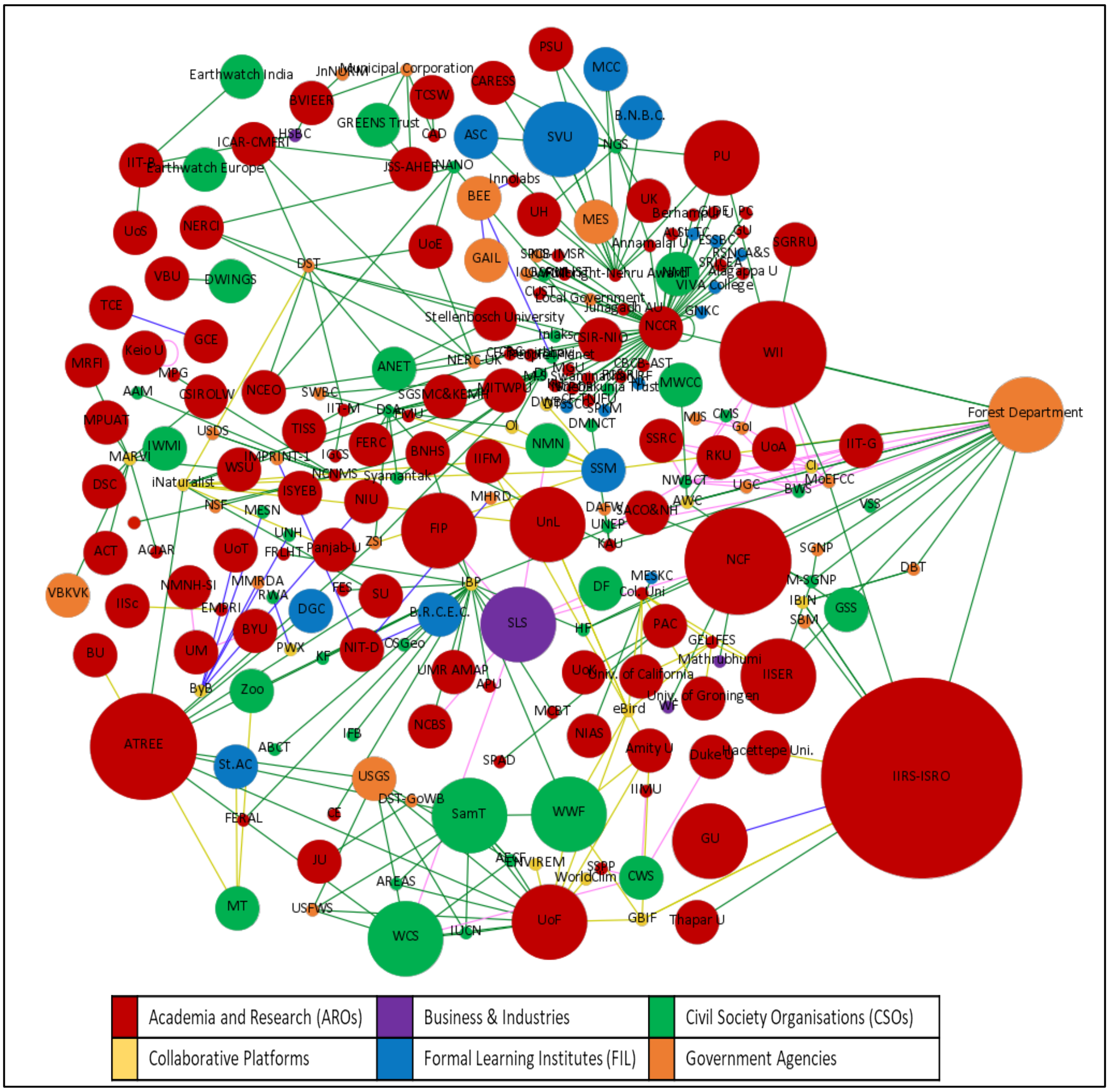

Figure 27: Stakeholder network highlighting authors involved in reporting on CS initiatives. The size of the node indicates the level of engagement.

Table 18. Different categories of stakeholders authored academic records of CS initiatives in India.

Categories and sub-categories of stakeholders	**Active engagement Authors**
Academia and Research	**80**
Foreign Institutes or Universities	29
Government Aided Institute	32
Private Indian Institute	7
Research Organisations and Think Tanks	12
Businesses and Industries	**2**
Civil Societies	**20**
Grassroots	2
International Governmental Organisation (IGO)	5
Registered Society	9
Trust	4
Formal Learning Institute	**12**

Government Agency	**7**
Foreign Government Agency	1
Government Department	5
Ministry	1

6.3.3. Roles undertaken by stakeholders of CS in India.

In this section, I have presented the qualitative assessment of the roles of institutional stakeholders in India. The results have been drawn from the text segments coded from the selected academic records and interviews with the stakeholders mentioned in Table 13.

6.3.3.1. Academic and Research Organisations (AROs)

AROs were the most prominent stakeholder category involved in all four identified roles: project proponents, collaborators, funders, and authors. As project proponents, AROs play a critical role in designing, implementing, reviewing, and promoting CS initiatives. This involvement was evident across all CSP-AL records. For instance, scientists from the National Centre for Coastal Research (NCCR), Chennai, supervised participation and coordination among local government bodies, CSOs, other AROs, and FLIs, and developed protocols for beach litter collection, segregation, and safety measures (Mishra et al., 2023). Besides these functions, the interview records reflected that AROs played an important role in providing infrastructure and facilities to undertake project activities. For example, the representative of the Bihu Bird Count project expressed the support received from Cotton University, Assam, in its initial phase for setting up venue and physical systems in 2022.

"Whatever money was invested partly from our pocket and partly from crowdfunding where we took money from small start-ups, like someone who has opened a restaurant and wants to advertise it. We gave them space, like digital space where their logo could be on our posters, and they gave us a small amount. And that was helpful for us because we didn't have any budget. One, the infrastructure we got from Cotton University, we partnered with Cotton University and got the entire set-up, the hall, the physical system, and the food."(Bihu Bird Count)

AROs' involvement in CS initiatives strengthens the scientific process by involving professional researchers. This is indicated by meticulous presentations of sampling techniques, data collection and management, and the working principles of mobile applications in each record. For example, biodiversity conservation projects often had coordinators with doctorates in conservation, highlighting the role of trained researchers in enhancing scientific rigour (Sekhsaria and Thayyil, 2019). AROs also developed new technologies, particularly mobile applications for data collection and management in areas like air pollution, noise pollution, and sanitation. Sekhsaria and Thayyil, 2019 reported that all the biodiversity conservation projects they surveyed were initiated by AROs supported by Government agencies or CSOs which have ecological science or conservation as their primary mandate.

As collaborators, AROs improve scientific rigour by aiding CS initiatives in developing robust data management plans and providing platforms for ethics committee approvals and technical capacities (Ravindra and Mor, 2018; Aiyadurai and Banerjee, 2019; Mohanty and Measey, 2019; Menon et al., 2021; Thaker et al., 2022). Indian AROs such as IISc and IITs, along with foreign institutions like Stellenbosch University, arranged technical experts and committees for these initiatives. AROs also provided training and knowledge to participants, enhancing data management skills and imparting new skills and knowledge. For instance, participants in projects from the Centre for Wildlife Studies (CWS) were trained by the National Centre for Biological Sciences (NCBS), acquiring skills in GPS mapping, scat collection, wildlife population monitoring, transect design, and conducting social surveys in rural areas (Johnson et al., 2014).

Moreover, AROs showed potential for collaboration with foreign institutions, paving the way for increased North-South and South-South cooperation through CS in India. Fourteen records indicated collaborations with foreign AROs as authors or collaborators.

As funders, AROs facilitated the use of research grants for CS initiatives. Institutions like the Indian Institutes of Technology (IITs), the National Institute of Advanced Studies (NIAS), and centres under the Council of Scientific and Industrial Research (CSIR) have conducted research using government-provided funds. This funding role helps explain why CS projects are often initiated by academicians and researchers (Sekhsaria and Thayyil, 2019).

Other interviewees mentioned focusing on training local youths in identification and documentation to enable them to participate actively in data collection (Keystone Foundation, CitSci India, and NIAS).

"…in Nagaland for example, I know I'm forgetting the name of the village, but one of my colleagues was involved in going in helping change some of the local youth, and to use either to document birds or then to be trained, as also naturalists, who can guide tourists, I think, in Dibang in our natural as well…" (CitSci India)

Other interviews provided a similar perspective on the roles of AROs as those identified through the systematic review.

6.3.3.2. Civil Society Organisations (CSOs) and allies

CSOs were the second most active category of institutional stakeholders, who were actively engaged in all four roles. In India, they usually partnered with AROs to undertake CS activities that addressed local socio-environmental problems. Projects such as Public Affairs Centre (PAC) Waste Collection and Peer Water eXchange (PWX) were initiated solely by CSOs to address Bengaluru's (Bangalore) waste and water quality issues with support from government agencies (R. V. Shah, 2015; Nagendra, Lakshmisha and Agarwal, 2019).

Representatives of Bihu Bird Count and CII commented that CSOs play an instrumental role in facilitating partnerships and actively engaging with local communities and stakeholders for CS initiatives.

"The first thing that we do is organize meetings in local meetings in communities. So definitely, we take support from the local NGOs, who are active in those regions. For the rural areas, it could be cooperative societies, which are, you know, our touch points, basically for to gain access to and to connect with the people there." (CII)

Representatives from ATREE, SeasonWatch, CII, and Keystone Foundation reinforced the fact that CSOs, NGOs, and grassroots organizations had been essential in creating support systems and structures at the ground level for CS initiatives. Partnerships with CSOs contributed to reaching diverse audiences, including farmers, tribal communities, urban enthusiasts, and schools (SeasonWatch).

Literature indicates that CSOs, especially grassroots organisations such as Resident Welfare Organisations (RWAs), Village Forest Management groups played an important role in connecting with participants (R. V. Shah, 2015; Aiyadurai and Banerjee, 2019; George *et al.*, 2019; Nagendra, Lakshmisha and Agarwal, 2019; Yardi, Bharucha and Girade, 2019).

Lastly, they have the potential to engage community and local leaders and promote the active involvement of progressive citizens (CII). CitSci India cited examples of where local communities and stakeholders took up ownership of CS projects, which led to the development of a few projects. These types of engagement portray that CSOs have an influential role to sustain and promote CS initiatives in India.

" You know, Marine Life of Mumbai, I think, started by not a set of scientists, but people who are just very keen on marine life, and using the I-naturalist platform as a way to facilitate their project. Let's all get together, and let's better document the marine life or the Kerala Bird Atlas which was a ground-up kind of effort, thought about by this group of bird watchers in Kerala, saying that, can we document the birds of our State not the simulated by some kind of top-down, some research in some university or institution, saying, you know this is what we should be doing. Let's all join together. So, they came up with it. and so..." (CitSci India)

International (non-) governmental organisations (IGOs), such as World Wildlife Fund (WWF), EarthWatch, and IUCN, etc. funded projects for smaller local CSOs and AROs to carry out CS activities (Goswami *et al.*, 2015; Vattakaven *et al.*, 2016; Lekshmi *et al.*, 2021). CSOs showed similar roles to AROs however their representation is lower than AROs.

6.3.3.3. Government agencies

The systematic review analysis indicated that the role of Government agencies was mostly as funders; however, there are instances where government agencies have shown engagement in a low percentage in other roles as well. The Forest Department, which is part of the Ministry of Environment, Forest and Climate Change (MoEFCC), was the most active stakeholder. The results showed high activity for this stakeholder as the activities were usually undertaken by regional offices independently, and the review summed them together under one umbrella node.

Funding from governmental agencies came from both national and foreign governments. Indian government agencies and departments such as Forest Department, Department of Science and Technology (DST), Department of Biotechnology (DBT) and University Grants Commission (UGC), etc. were the forerunner and entailed research grants to AROs and CSOs, such as Nature Conservation Foundation (NCF); Indian Institute of Remote Sensing (IIRS-ISRO); Wildlife Institute of India (WII); etc., to undertake projects focusing on community participation. The other stakeholders in turn undertook CS initiatives as part of their research projects or engagement activities, for example, DST funded a CS initiative that facilitated risk communication and capacity-building for artisanal fishing communities against sea-level rise (Khan, Kumar and Chella, 2022). However, the systematic review was not able to establish a connection if the fundings from the government were particularly targeted for promoting CS (or participatory approaches as a whole). CitSci India representative feels that the government has not seriously taken steps to fund citizen science initiatives.

"The traditional science funding in India, I don't think, have taken it seriously. Or maybe they will take it seriously unless there is a specified channel for citizen science. It's possible that the other agencies whose primary goal is not funding like MoEF… may fund some of this as part of some larger work. But they are evaluating, you know, proposals not necessarily on for scientific novelty alone. They would be thinking of other kinds of potential" (CitSci India)

Some CS initiatives were funded by foreign governmental agencies such as the Natural Environment Research Council (NERC-UKRI) (UK), the German Academic Exchange Service (DAAD), Germany, and the National Science Foundation (NSF), USA. Some of these funds were part of collaborations between the national governments (Indian government and governments of other countries) (Singh, Eldho and Prinz, 2002; George et al, 2019: Schuttler et al., 2019; Menon et al., 2021). Through this, the review also observed the development of collaborative activities between foreign AROs and Indian AROs due to these grants.

As authors, government officials mostly co-authored projects along with AROs with the particular exception of an innovative carbon emission auditing application (Nahar and Verma, 2018). As collaborators, government agencies have at times facilitated promotion and outreach, granted permissions to access protected forest areas to undertake project activities, as well as infrastructural facilities such as buildings to conduct training and workshops. Mukherjee *et al.*, 2021 observed that conducting training and workshops in Forest Rest Houses or Forest Bungalows motivated participants to join activities that were provided by the forest department for the initiative. As project proponents, Government agencies, such as the forest department and MoEFCC were directly involved in the development of the Forest Fire App and IBIN along with IIRS-ISRO (Singh *et al.*, 2018; Saran *et al.*, 2020). These projects were developed by the agencies in collaboration with AROs to integrate national-level data collection and monitoring for policymaking, under the Digital India initiative.

The interviewees had varied opinions on the support from government agencies. Interviewees from biodiversity conservation project backgrounds perceived that governmental officials and agencies understand the importance of CS initiatives, especially as a process of data collection for the country. They indicated projects have received varying degrees of support from different government levels. For instance, local governments in Kerala have shown interest and provided funding for initiatives like student-led CS projects (NIAS). Additionally, the State Council for Science, Technology, and Environment in Meghalaya collaborated with schools to promote CS (SeasonWatch).

CitSci India indicated that from 2020-2022, the top scientific organisation of the country i.e., the Office of Principal Scientific Adviser to the Government of India arranged grants for CS work as part of broader preparatory efforts for national biodiversity missions. This grant was used to establish CitSci India, a platform for collaboration for CS Initiatives. However, CitSci India also mentioned that despite the interest from key offices, there is limited awareness and interest from overall governmental agencies. Comparing the interview segments among ATREE, SeasonWatch, Bihu Bird Count, and NIAS, it was inferred that it is easier for government-aided institutes to receive grants from funders like DST than CSOs.

"I haven't tried any CSR funding for citizen science yet because my funding mainly came from government agencies" (NIAS)

"No, we have not received any funding from any government agencies for any of our projects, nor have we received any funding from any private agencies." (Bihu Bird Count)

"I think governments hopefully will take notice now from now on in India. But till now we have had support only from NGOs and the Education wing of the government like that. And funding we are supported entirely by the WIPRO CSR." (SeasonWatch)

PWX expressed that as a CSO, they mostly got funding for pilot projects which was not enough to sustain projects in the long-term. ATREE and SeasonWatch indicated that they relied on businesses and industries for funding. Government agencies often prefer to fund larger, established platforms like the India Biodiversity Portal (IBP) or iNaturalist over smaller, species-specific CS projects (Wild Canids – India). This preference stemmed from the perception of broader impact and efficiency in data aggregation and management (Wild Canids – India).

When impacts could be shown through projects, government agencies were proactive in adopting projects. For example, NIAS mentioned that the success of their project in phase one helped them to receive grants from the Kerela state government. Another example was the incorporation of CS activities by the Tamil Nadu Forest Department to address issues like invasive species and ecological restoration (ATREE). Government agencies can play an important role in integrating CS-based educational activities into the school curriculum (Keystone Foundation and NIAS). For example, the Education Department, have shown acceptance by integrating projects like the Climate Smart School into school curriculums (Keystone Foundation). Integrating CS activities as part of the curriculum helped in motivating students to participate in project activities (Keystone Foundation, NIAS). Thus, the evidence gathered from the systematic review and interviews suggests that the government has a very influential role; however, the interests vary depending upon the officials and ministries.

6.3.3.4. Businesses and Industries

From the review, it was evident that the engagement of businesses and industries in CS projects is multifaceted. The review found that HSBC Bank's involvement in CS initiatives was notable, with instances of employee participation as citizen scientists in water quality data collection (Yardi, Bharucha and Girade, 2019; Lekshmi *et al.*, 2021).

Additionally, there were documented instances of financial support provided by HSBC for projects such as the India Bird Race, as corroborated by sources (Yardi, Bharucha and Girade, 2019). The interview findings underscore the significant contributions of businesses, industries, and small start-ups in providing substantial funding and sponsorships. The interviewees expressed that they have sought financial assistance in organising events, acquiring necessary equipment such as low-cost sensors, and facilitating outreach efforts by sponsoring posters, digital spaces, and event sponsorships. Corporate Social Responsibility (CSR) funding has played a vital role in funding several initiatives in the organisations represented by ATREE, SeasonWatch, CII, and Keystone Foundation. This, potentially proves that grants, sponsorships, and engagement given through CSR can facilitate the sustainability and growth of CS initiatives as observed in the systematic review above. Keystone Foundation mentioned that they would appraise the businesses and industries on their use of participatory approaches; however, CII representative expressed that the funders in their case were not concerned with the methodology of data collection as long as impacts could be seen through their funding. Namdeo and Koley, 2021 highlight the potentially important role businesses and industries can play as funders, especially through their Corporate Social Responsibility (CSR) initiatives.

Media, as a business category on its own, has been instrumental in driving outreach and awareness about CS activities and recruiting, as emphasised during the interviews. Project proponents highlighted the use of social media such as Facebook, WhatsApp, etc. to reach and recruit participants. Interestingly, newspapers and radio channels were relied on as ways to connect with participants in the pre-social media era (and are still used sometimes) (ATREE). Mathrubhumi, a media agency was involved in project outreach efforts, while Wipro Foundation funded the SeasonWatch project (Ramaswami, Sidhu and Quader, 2021). With the advent of social media, outreach activities have been conducted mostly through Facebook, WhatsApp, Instagram, and Twitter. The interviewees expressed that it has now become easier to reach specific sets of participants as per the requirements of the projects through these social media platforms.

The representative from SeasonWatch observed that businesses and industries also played a crucial role in providing technological and infrastructural support, such as digital platforms, sensor installations, and data analysis tools. The evolution of the Information Technology (IT) sector has notably enhanced the accessibility to participants, website development, integration of technology into CS initiatives, and the facilitation of data collection and analysis capabilities (I1, I3 and I7). Notably, members of Strand Life Sciences (SLS), which identifies it as businesses and industries, collaborated in the design, implementation and curation of the India

Biodiversity Portal (IBP) as well as in developing the first best practices guidelines for data management in biodiversity conservation CS in India (Vattakaven *et al.*, 2016, 2022).

6.3.3.5. Formal Learning Institutes (FLI) [Schools and Colleges]

Formal learning institutes (FLI) collaborated mostly by engaging their students in data collection activities. In India, the majority of the FLIs were colleges; however, there were three instances where school students were also involved in CS projects. Names of schools were generally not mentioned, except in one case (Schuttler *et al.*, 2019). Moreover, schools and undergraduate colleges were not acknowledged as part of the project team if the students volunteered only for data collection. They were rather seen as participating stakeholders and were acknowledged as such. On the other hand, the interviews highlighted the instrumental role played by FLI in reaching a wider section of society. They were perceived to be extremely effective partners in engaging and recruiting participants by tapping into their networks that went beyond students, and to their parents or other family members (I1, I3, I6 & I8).

Secondly, teachers of FLIs played an important role in supporting and integrating CS activities into the school curriculum. Moreover, the motivations of students who were participants were also influenced by their teachers. They were centres and acted as potential mediums to connect trained and professional scientists with school students and undergraduates. Early participation in school and college has been able to foster sustained interest in scientific inquiry and environmental stewardship (I3, I6, & I8). FLIs can act as a network for knowledge transfer between school and university students through the medium of CS activities, e.g., the Student Scientist Project (Binoy, Radhakrishna and Kurup, 2017).

6.3.3.6. Collaborative platforms

The review found that the role of the collaborative platforms as databases (e.g., Bird Count India, iNaturalist) mostly entailed supporting smaller projects as databases and as such aided in data management. They also provided data to academic and research institutes to conduct scientific research from CS-generated data, which helped in producing scientific knowledge.

The collaborative networks such as DragonflySouthAsia (DSA) and Diversity India (DI) were active as project proponents (Dawn, 2021). The review found that collaborative networks played an important role in the outreach and recruitment of participants, especially through blitz events which helped to recruit a large number of participants for very short project data collection activity (Ertiö and Bhagwatwar, 2017; Mujumdar *et al.*, 2020; Dawn, 2021). For example, DSA helped to recruit participants from the entire Southeast Asia region for a three-day event.

The interview records showed further involvement of collaborative networks. I2, I4 and I7 represented stakeholders who identified themselves as an informal group of researchers with an interest in the environment. The collaborative network can act as lobbies for funding. For example, the Biodiversity Collaborative was essential to persuade grants for the initiation of CitSci India from the government of India (I7). Today, CitSci

India is an important enabling platform that provides a space for interaction, and exchange of knowledge among stakeholders and curate initiatives. Interview records indicate that collaborative platforms can bring together environmental and conservation enthusiasts (I2, I4, I5 & I7). I2 expressed that they received mentorship and support from members of Bird Count India and Biodiversity Collaborative when they sought to initiate their Bihu Bird Count project.

Collaborative networks can also act as filters to limit participants and collaborators as per the needs and requirements of a project. For example, they helped to identify highly interested and trained participants who could contribute to data collection with less training. I4 expressed that it helped in maintaining data quality as they focused on developing a high-quality database for scientific and policy requirements and preferred experienced participants. The review was able to identify an important feature of these collaborative networks. Another benefit in India as a collaborative group helps in reducing administrative workload (a feature of registered organisations) which gives them time to focus on research (I2 and I4). However, since these groups are not registered, they might have fewer chances of receiving funds from funding agencies, as experienced by I4.

6.3.4. Stakeholder Influence and Interest Matrix

In this section, I have presented the results of the Mendelow matrix. The following graphs (Figures 29-34) present how each of the interviewees (n=9) generally perceived the interest and influence of various stakeholders over the CS process in India. Figure 28 depicts the generalised perception of the interviewees on the stakeholder category 'Academic and Research Organisations (AROs)'. Most of the interviewees perceived AROs to have some interest to high interest. However, four stakeholders had a different view. Keystone Foundation and CII perceived that currently, AROs have a neutral position regarding CS in India. Interestingly, the interviewees of CitSci India and SeasonWatch have been associated with CS in India for more than one decade perceived that AROs have less interest however they differed in their perception of influence. The overall perception (mode) indicated that AROs have high interest but have a neutral ability to influence the CS process. Thus, this category currently requires more power and influence so that they can actively engage in the processes.

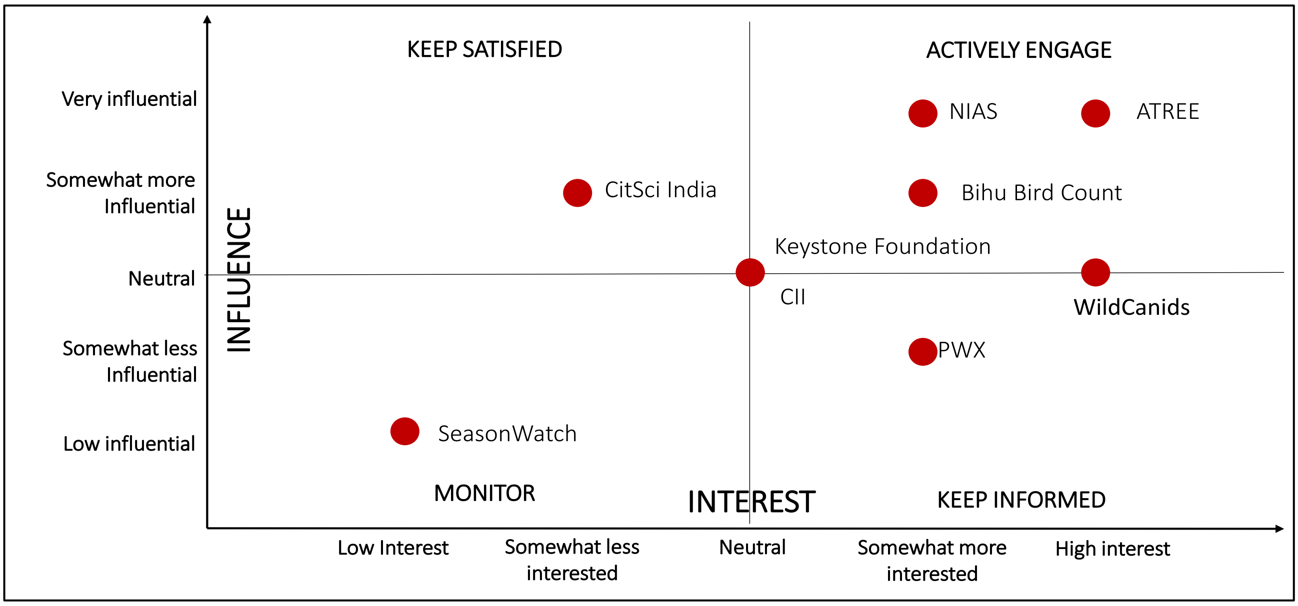

Figure 28: Generalised perception of power and influence of Academic and Research Organisations (AROs) by the 9 interviewees.

Figure 29 depicts the interest and influence of CSOs. Again, the majority of the interviewees perceived CSOs as having good interest levels. However, three interviewees, ATREE, Keystone Foundation, and BBC, perceived CSOs to have neutral interest and influence. Interestingly, these stakeholders initiated as CSOs (legally still registered under various Acts for CSOs in India). This can indicate that their peers are not as motivated to undertake CS activities as they perceived. On the other hand, PWX perceived CSOs to have very low influence in the process. Overall, the mode results indicated that CSOs have high interest and are somewhat influential in the process. Currently, they need to be managed and actively engaged to keep the current status quo, which may lead to very high interest and very high influence.

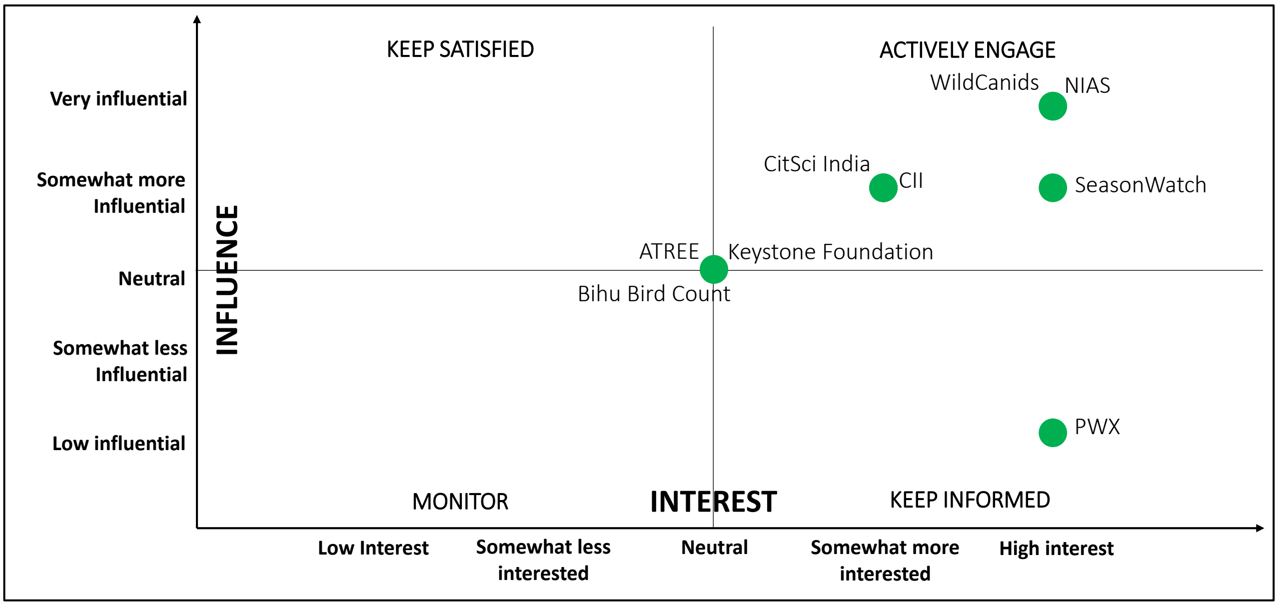

Figure 29: Generalised perception of power and influence of Civil Society Organisations (CSOs)by the 9 interviewees.

Figure 30 depicts a diverse perception of the interest and influence of Governmental agencies. It was interesting to observe that WildCanids and SeasonWatch perceived very little interest and influence from Government agencies. The variety of responses is interesting, as it indicates more of an experience these stakeholders had with government agencies while undertaking some of their projects. Both NIAS and Keystone Foundation expressed the support they received from the Kerela government and the Tamil Nadu Forest Department respectively. The overall assessment indicated that Government agencies in India have high influencing power but have somewhat low interest in the process; thus, they need to remain satisfied, especially with the outcomes and impacts.

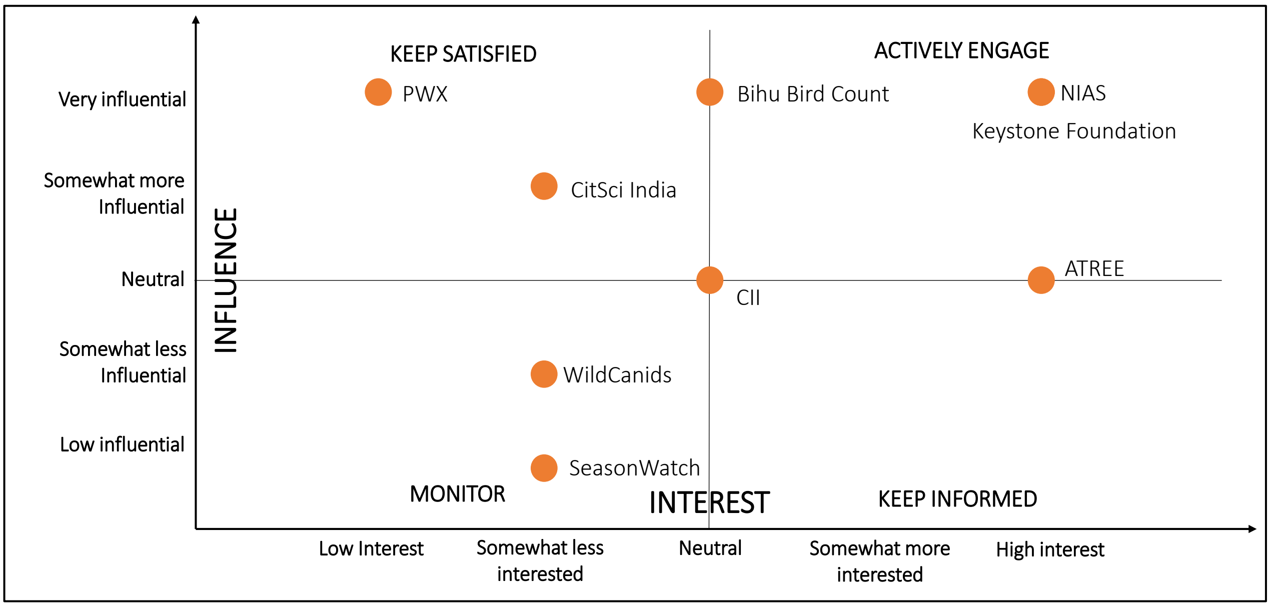

Figure 30: Generalised perception of power and influence of Government Agencies by the 9 interviewees.

Figure 31 presents the perception of businesses and industries. The interviewees had varied perceptions of this category of stakeholders. However, overall they are somewhat interested but the influence is neutral. They need to be more informed about the possibilities and benefits of integrating CS into their CSR activities.

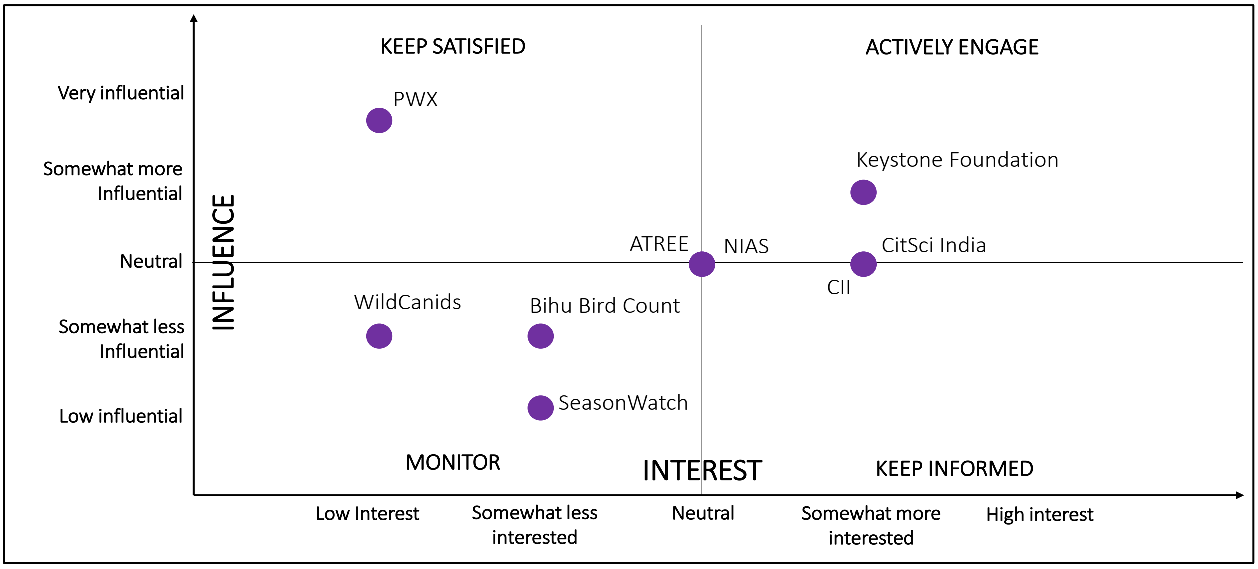

Figure 31: Generalised perception of power and influence of Business and Industries by the 9 interviewees.

Figure 32 depicts the perception that collaborative networks are influential and have an interest in promoting CS. However, it has to be noted that these interviewees themselves have worked collaboratively with various stakeholders for CS projects. Thus, their perception indicates that collaborations and collaborative platforms have a very important role and are actively engaged in the process of CS in India.

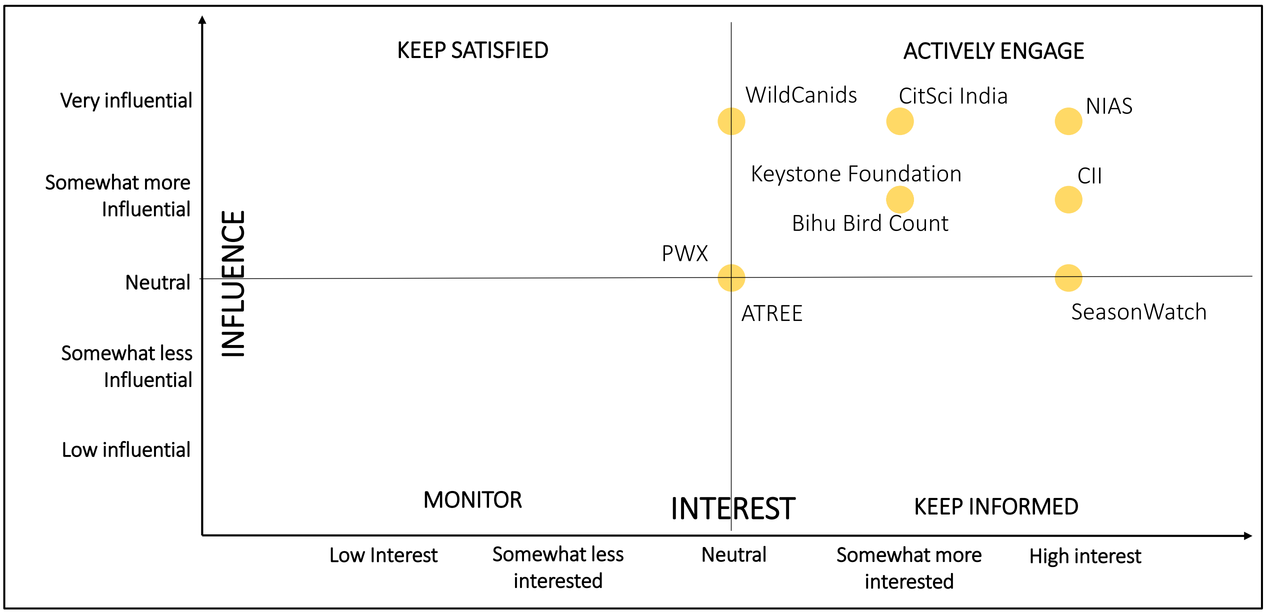

Figure 32: Generalised perception of power and influence of Collaborative Platforms and Networks by the 9 interviewees.

Figure 33 indicates that FLIs were actively engaged in the process with high interest and influence. This is contradictory to the findings in section 6.3.2., which showed that there is low representation. Overall perception indicates that there is a huge potential for this category and requires continuous active engagement.

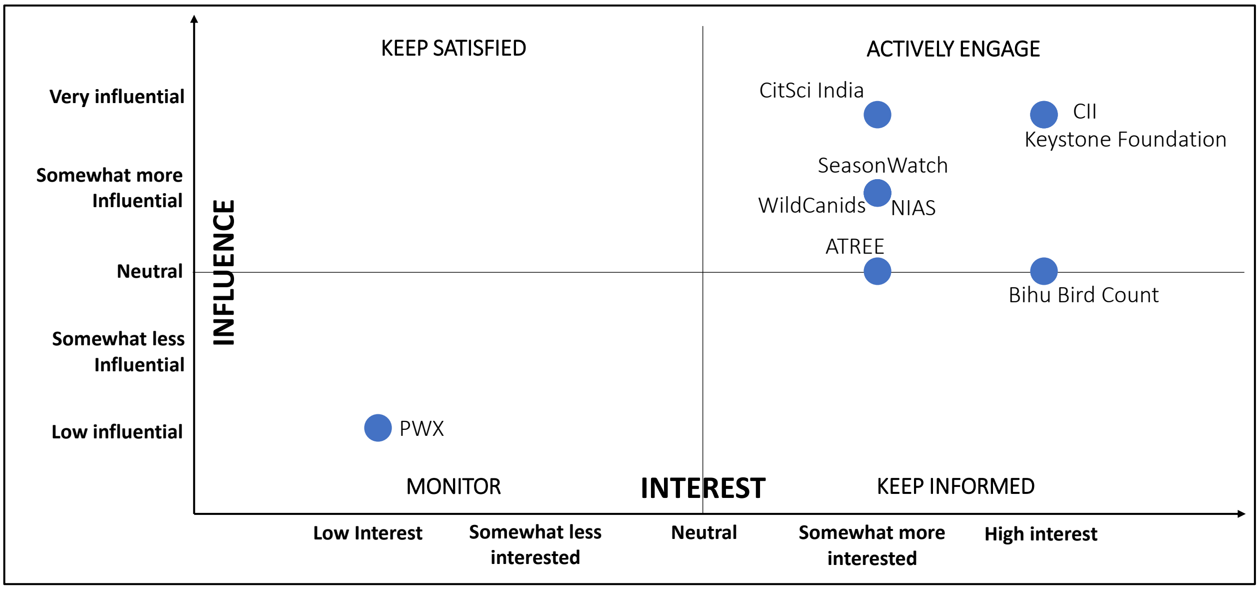

Figure 33: Generalised perception of power and influence of Formal Learning Institutes (Schools and Colleges) by the 9 interviewees.

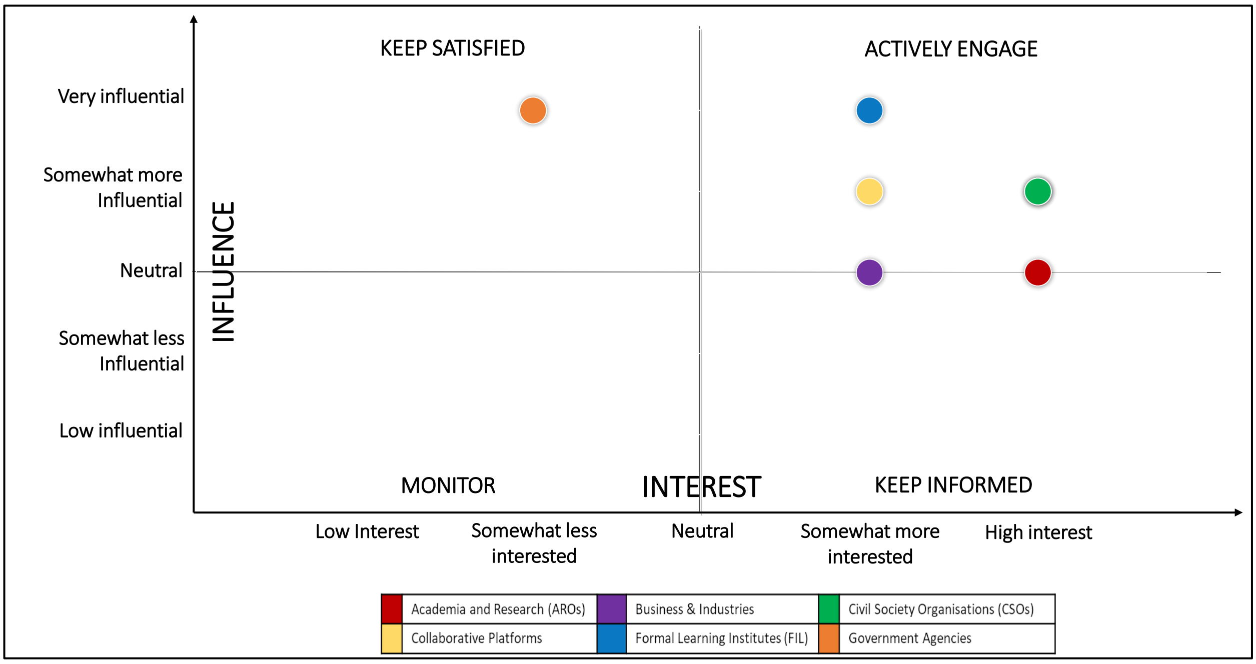

Figure 34: Overall generalised perception of interest and influence of the 9 interviewees on various institutional stakeholders of CS in India. Overall perception is indicated by the mode, i.e., the majority of interviewees' perception rating on a stakeholder category was taken

6.4. Discussion: The Stakeholder Ecosystem in India

The purpose of this study was to identify the institutional stakeholders and to investigate their various roles and contributions to CS initiatives in India. The study identified that Academic and Research Organizations (AROs), Civil Society Organizations (CSOs), Government Agencies, Businesses and Industries, Formal Learning Institutes (FLIs), and Collaborative Platforms, play significant but distinct roles in the development and implementation of CS initiatives in India. The result of the analysis of this study has helped us to understand the crucial roles and contributions of these stakeholders.

The study found that AROs are pivotal in CS initiatives, acting as project proponents, collaborators, funders, and authors, based on their level of engagement. A previous systematic review on identifying stakeholders at a worldwide scale has shown similar findings, where AROs were the most prominent category of stakeholders. AROs represented 35% of stakeholders globally, while in the case of India, they were almost 51% (Cunha *et al.*, 2017). ARO involvement has been crucial in bringing scientific rigorousness to the process; developing new technologies, such as mobile applications for data collection and management; and engaging other institutional stakeholders in the CS process in India. Other studies indicate these as fundamental roles and functions of AROs when they engage in CS initiatives (Göbel, Martin and Ramirez-Andreotta, 2017; Gouraguine *et al.*, 2019; Mofokeng *et al.*, 2024). Two probable reasons for the higher indication of AROs in India by this study are: firstly, the study utilised academic records to map the stakeholders, and such AROs can have a higher representation and secondly, the involvement of AROs directly in scientific research, which is seldom carried out by other institutional stakeholders.

In the case of CSOs, the global representation was 11% while in India it was 20% (Cunha *et al.*, 2017). Previous studies from around the globe have observed that in CS initiatives, NGOs, CSOs, and similar concerned citizen groups would collaborate with professional scientists, a trend that was also observed in the case of India (Cunha *et al.*, 2017; Göbel, Martin and Ramirez-Andreotta, 2017; Skarlatidou *et al.*, 2019). In India, CSOs played a crucial role in connecting with local communities, recruiting participants, and providing financial support, and mentorships to new project proponents. These are in addition to the crucial roles played by them as technical experts (where they are involved in knowledge production); as project proponents, and as advocates and campaigners (promoters) for bridging research and application (Göbel, Ottolini and Schulze, 2021; Espinosa and Rangel, 2022). The lack of representation of CSOs even with their potential to contribute to major project activities can be due to the lack of sustained funding. They were perceived to be highly interested and influential in promoting CS activities in the country. As not-for-profit organisations, they require funding not only to sustain the initiatives but also for themselves. Thus, only IGOs were prevalent as funders within the CSO category in India.

The role of government agencies is currently seen to be extremely essential, as they have been identified as the core funders of CS initiatives, providing necessary financial support, permissions to undertake projects in protected areas, and integrating CS activities into national programs. Government agencies accounted for 13% of the stakeholders identified in India, even though as per the interviewees government's interest is low. Global literature has shown moderate involvement of this category of stakeholders who would usually collaborate with AROs and CSOs (Cunha *et al.*, 2017; Göbel, Martin and Ramirez-Andreotta, 2017). Through programs like Digital India, the Government of India (GoI) aims to transform the country into a digitally empowered society and knowledge economy by focusing on digital literacy, digital resources, and collaborative digital platforms

(MeitY, 2024). Under this scheme, the government has developed several databases (Collaborative Platforms) such as the Indian Bioresource Information Network (IBIN), India Disaster Resource Network (IDRN), and National Database for Emergency Management (NDEM), which utilise citizen-generated data for policy and decision-making (Singh *et al.*, 2018; Sukhwani and Shaw, 2020). Cunha et al., 2017 reported similar findings where governmental agencies often facilitated projects and benefited from improved information flows and public awareness. The government of India too has supported projects that align with its missions and policies. These policies and missions can be utilised as potential pathways for scaling up CS initiatives.

In terms of financial support, though the results show slightly higher contributions by AROs as funders than Government Agencies, in these instances government-aided AROs have redistributed and channelised the funds from the Ministry of Education or its agencies such as the University Grants Commission (UGC). Thus, government agencies can be deemed as the core funders of the country, while AROs are the leaders in promoting and organising projects. The country as such does not have a dedicated funding system for CS, and thus the lack of sustainable funding can be a reason for slow growth in the country. Global studies, too, have highlighted the lack of sustainable funding as an important issue as it can influence participation, access to equipment, and outreach; and as a result, it can influence the quality of the data collection by participants (Land-Zandstra et al, 2021). Thus, funding becomes an important part of project management and science communication as it impacts tangible outcomes and their presentation to the general public, without which participants might hesitate to participate (Requier *et al.*, 2020; Kapono, Kane and Burns, 2023).

The acuteness of inadequate funding varies, depending on the type of stakeholder and the impacts shown by the initiatives. The review found that impactful and well-designed projects were often supported by government agencies in India if they met their agenda, as expressed by the interviewees. However, governmental support varied across different levels, departments, and regions as well as being dependent upon the project proponent's background. AROs preferred to be funded more by government agencies through research grants over CSOs, thus enabling them to initiate a greater number of pilot projects than other stakeholders. Interview records also suggest state governments of Kerela and Tamil Nadu have shown proactive involvement and funding for CS initiatives. This was reflected by a higher number of projects in these states (Chapter 3).

Currently, the need for financial support can be potentially filled by Businesses and Industries through their CSR initiatives (Namdeo and Koley, 2021). Currently, the role of Businesses and Industries is extremely limited in India and global trends show similar results of limited presence in CS projects (Göbel, Martin and Ramirez-Andreotta, 2017). Moreover, potential challenges can arise when corporate houses are involved in CS projects. Scholars have termed the involvement of businesses and industries as *public relations CS (PRCS),* where corporations use CS as a pathway to add a sustainable image to themselves to cover their core policies (Blacker, Kimura and Kinchy, 2021). Other challenges associated with this category of stakeholder can arise when CS initiated or controlled by businesses and industries, especially in the case of biomedical research, can use the data generated for commercial purposes (Blacker, Kimura and Kinchy, 2021). Since currently India lacks an enforceable data protection law, it becomes important to discuss the integration of businesses and industries in the CS process in the country and identify further challenges that may entail. Countries in Europe tend to protect the participant's interest through General Data Protection and Regulation (GDPR) policies.

Formal Learning Institutes (FLIs) were instrumental in recruiting participants, particularly students, and integrating CS activities into the school and college curriculum. The scope of involvement of participating students was usually limited to data collection, a common characteristic of involvement of school students globally (87% of evaluated projects) (Solé, Couso and Hernández, 2023). Solé, Couso and Hernández, 2023 highlight practical reasons for containing students' participation in the data collection phase, such as the necessity to collect repetitive data required for reliable estimations. However, they indicated that it may directly hamper the realisation of the ten principles of CS as the interaction of students and researchers would be limited to assistance and providing advice respectively (Robinson *et al.*, 2018; Garrison *et al.*, 2021). Thus, students might lose their motivation, which is usually reflected by medium levels of student involvement (Solé, Couso and Hernández, 2023).

The low involvement of FLIs, especially by schools, can be because there at certain times exists a power dynamic between the interactions of professional scientists and schoolteachers (Atias *et al.*, 2023). School teachers often tend to visualise professional researchers (from AROs) as a source of knowledge with a unilateral flow of information from researchers to teachers. Literature from around the globe indicates that school teachers may not be aware of their potential contribution and may believe that researchers' expertise is superior to their own and thus a *'hierarchical power relation'* might develop (Atias *et al.*, 2023). This can be one of the reasons why FLIs were more prominent as data contributors than within the project management team. However, projects were and can be consciously initiated to establish mutual learning and contributions to initiatives by schoolteachers and professional researchers.

The databases of the Collaborative Platform category played a crucial role in supporting smaller projects, however, this role was limited only to biodiversity conservation projects. These platforms, even though limited, showed they can bring people together by providing a common space to discuss and exchange information and data (Vattakaven *et al.*, 2016; Pocock *et al.*, 2018). In terms of graphical representation, it was indicated by the fragmentation of the network (unlinked nodes) and a large number of weakly linked components in the SNA. This indicates that there are barriers to the flow of information among the identified stakeholders, which indicates a lack of collaboration (the flow of information) between biodiversity conservation projects and other projects, as the collaboration was mostly limited among stakeholders of biodiversity conservation projects. The real-world manifestation of the stakeholder network around biodiversity is reflected by the members associated with the Biodiversity Collaborative (collaborative network) (Biodiversity Collaborative, 2021).

Building Collaborative Networks has the added advantage of reaching out and involving various stakeholders through local networks and providing a space for interested participants to join and interact (Vattakaven *et al.*, 2016; Pocock *et al.*, 2018; Requier *et al.*, 2020; Queiroz-Souza *et al.*, 2023). For example, the EU-Citizen.Science has become a central enabling platform to exchange experiences, gather information, and network around CS (Wagenknecht *et al.*, 2021). In India, CitSci India, a national-level conference, stands out as an enabling platform organised by a consortium of 10 partners such as the Office of the Principal Advisor Scientific to the Government of India (CitSci India), National Biodiversity Authority (NBA) and the Biodiversity Collaborative (CitSci India, 2022). Their collaborative efforts have led to the development of best practices guidelines for data management in CS projects in India, and currently, the members are working on developing guidelines for diversity and inclusion in projects (CitSci India) (at the time of writing) (CitSci India, 2022; Vattakaven *et al.*, 2022). Though currently CitSci India engages only in biodiversity conservation projects, the platform can potentially grow to accommodate projects from other thematic areas for the exchange of ideas and knowledge. In Europe, these platforms exist as commercial platforms for CS, platforms for specific types of projects, platforms for specific topics of research, national platforms for CS and regional-level CS platforms (Liu *et al.*, 2021). These networks often act as catalysts, which can help in aggregating diverse sets and widespread initiatives, appealing to a broad target audience, providing a space for reflection, and developing goals and strategies to meet national and international needs (Fritz *et al.*, 2019; Liu *et al.*, 2021; Pateman, Tuhkanen and Cinderby, 2021).

The study can have a wider application for identifying potential partners to collaborate in India by interested and potential stakeholders, such as the members of CS Global Partnership or CitizenScience.Asia. The names of all the identified stakeholders are provided in Annexure 7. Usually, stakeholder analysis is conducted to aid in the decision-making of projects (Skarlatidou *et al.*, 2019); however, this analysis has been able to identify stakeholders and their roles in India, which will help in informing the PESTELE Analysis in Chapter 7. The current political influence is limited to Government agencies, as many projects are dependent on their funding, with few representations of Indian charities in terms of funders, and most of them were on the receiving end of the finances. This indicates an absence of awareness among Indian funders and policymakers, resulting in a lack of political autonomy for the other institutional stakeholders. In the next chapter, I will be discussing the influence of stakeholders on the Political, Economic, Social, Technological, Environment, Legal and Ethical aspects of the CS process and their strengths and weaknesses in each of these PESTELE dimensions (D'Alonzo *et al.*, 2022).

6.4.1. Limitation of the Study

While this study provided a comprehensive idea of the roles of institutional stakeholders of CS in India, there are several limitations. Firstly, the scope of the stakeholder analysis was not fully utilised, as recommended by Reed *et al.*, 2009. The article recommends carrying out the nine different pathways to analysis to get a clearer understanding of the ecosystem. However, not all nine analyses were carried out due to a lack of time and finances. This limitation could affect the breadth and depth of insights obtained from the study. Secondly, the study was unable to interview representatives from all categories of institutional stakeholders. This gap might have led to an incomplete understanding of the diverse perspectives and roles within the stakeholder ecosystem. Thirdly, the study was limited only to academic records. This can give skewed and biased interpretations regarding the representation of various stakeholders and their categories.

6.5. Conclusion

The stakeholder analysis of CS in India underscores the multifaceted roles of AROs, CSOs, government agencies, businesses and industries, FLIs, and Collaborative Platforms. It highlights the need for further collaboration, sustainable funding, and thematic expansion to enhance the CS ecosystem in India, especially when cross-thematic interactions are important. This analysis provides valuable insights into the diverse stakeholder ecosystem of CS in India, offering a foundation for strategic enhancements and broader engagement in the field. The findings of this study will be utilised in the next chapter to draw on the PESTELE Analysis.

Chapter 7

7. Developing a roadmap for Ecological and Environmental Citizen Science in India

7.1. Introduction

In this chapter, I draw on the key findings of my previous chapters to devise a roadmap to promote ecological and environmental citizen science projects (EECS) in India. A roadmap, in the traditional sense of strategic planning and management, is used to organise activities that need to be accounted for to deliver progress over a period of time (Kappel, 2001; Kerr and Phaal, 2022). Roadmaps help in determining what is possible or likely to happen and articulate a plan for a course of action. In strategic planning, roadmaps are developed to set targets for an organisation or product; set expectations for positioning an organisation or product; align an organisation or product with trends; or schedule a product for introduction (Kappel, 2001). In this case, I have created a roadmap to scale up the use of CS as a tool for addressing socio-environmental issues in India.

The period for the roadmap was decided as 2025-2030 as it aligns with the global discussion around integrating CS-generated data to monitor and evaluate the 17 Sustainable Development Goals (SDGs) which are to be achieved by 2030 (Fritz *et al.*, 2019; Fraisl *et al.*, 2020), thereby providing a growth period to learn and understand pathways to integrating CS into policy and decision making especially post-2030. Secondly, the period overlaps with the office period of the current government regime of India which has initiated policies such as Digital India and Data for Development (D4D). Through these policies, the government aims to enhance digital governance and citizen participation (Sarma and Sarkar, 2023; Digital India, 2024). The Government of India (GoI) can utilise this roadmap as a policy framework to integrate CS into the policies initiated by them. Thus, there is a possible 'political will' with which the agenda to promote CS in India can be pushed forward.

In this chapter, I first present the key contributions of my thesis, chapter-wise, followed by key findings, and key limitations of the thesis. Then I have presented the strengths, weaknesses, opportunities and threats of CS across political, economic, social, science & technology, legal and ethical dimensions. Followed by a roadmap as a conclusion to my thesis.

7.2. Summaries of key contributions, findings and limitations of the thesis

7.2.1. Key contributions

The main contributions of the study are:

1. **Chapter 3:** Developing a baseline study to catalogue and document the development of CS in India. This is the first study conducted for India which has systematically catalogued the different types of Ecological and Environmental CS (EECS) in the country, its diversity in addressing a range of socio-environmental

issues, its distribution across the country and the involvement of participants in the process. The main contribution of the study is its ability to provide an overview of the characteristics of CS projects in India.

2. **Chapter 4:** In this chapter, I systematically reviewed the impacts of identified EECS in the country. Along with the identification of impacts, I took the opportunity to modify the existing Citizen Science Impact Assessment Framework (CSIAF) to accommodate systematic reviews and meta-analyses. The modified analysis can be now used by third-party evaluators to assess the impacts of projects based on the characteristics of evidence discussed in the chapter. It can also be used by funders and policymakers to assess the performance of CS projects they are funding or supporting. Thus the two main contributions of this chapter are the identification of impacts of CS in India and the modification of CSIAF to undertake systematic reviews of impacts of CS projects.
3. **Chapter 5:** In this chapter, I undertook the first investigation into the barriers and opportunities (B&O) of CS in India. For this investigation, I also developed a framework to identify the characteristics of barriers and opportunities of CS through a literature review. The discussions on characteristics of barriers, opportunities and challenges also make it the first study which has elaborately tried to describe the difference in these terms when dealing with CS. Thus, the chapter has two main contributions, firstly the identification of B&O of India will aid CS practitioners in India in identifying possible limitations that their projects can face and the pathways to avoid them.
4. **Chapter 6:** Finally, I undertook the first study of the roles of institutional stakeholders involved in CS projects in India. I conducted three analyses to triangulate stakeholders, their roles, and their influence and interest in the CS process in India. This study contributes to bringing an understanding of how the CS institutional stakeholder ecosystem works in India.

7.2.2. Key findings of the thesis in each research chapter (Chapters 3-6)

The key finding from Chapter 3 indicates a highly uneven distribution of CS projects in India both geographically and thematically. Birding projects dominate the landscape, accounting for 73% of all CS projects. Geographically, projects are concentrated in southern and western India, particularly Maharashtra, Kerala and Tamil Nadu leading in terms of project numbers. Participation demographics are largely skewed toward university students and adults aged 18-64. Most CS projects in India follow a contributory model where participants are involved in data collection but have involvement in project design or management. This potentially reduces participants' chances of being directly involved in co-designing and managing the research process. Involvement beyond data collection such as in analysis, research design, and project management is crucial for fostering a sense of ownership, integrating local knowledge, and piquing interest in science. These are often cited by CS practitioners as key co-benefits of the process.

The benefits of deeper involvement of participants in the CS project process can help elevate local social issues such as empowering the marginalised groups. For example, findings from Chapter 4 indicate that CS has been impactful in bringing social changes such as women and rural communities' empowerment at local levels, rehabilitating poachers, generation of direct and indirect employment, and supporting livelihoods, especially in rural India. The process also helps in providing accessibility to local ecological data for local communities which are usually maintained by government agencies and inaccessible to the public.

Besides bringing social changes, the review from Chapter 4 also indicates that CS is gaining legitimacy as a scientific method, its use in India remains largely instrumental, primarily supporting data collection, the development of baseline ecological datasets, and the discovery of new species along with some technological innovations in developing mobile phone apps for data collection.

However, the key findings from Chapter 5 suggest that the CS process in India still faces limitations such as limited influence on local governance; lack of evidence of broader transformational change; and low engagement of policymakers with CS, partly due to a lack of awareness and the small number of projects; and the absence of standardised guidelines for domains beyond biodiversity. Opportunities can be found in adopting international standards for data collection that can contribute to international developmental agendas such as the Sustainable Development Goals, etc.

Funding remains a significant barrier, with most CS projects reliant on short-term grants from government or international donors. Promising examples of crowdsourced funding exist (e.g., Hornbill Nest Adoption Program, MARVI), but are rare. Chapter 5 indicated a few instances where cultural, religious, caste, gender, and local political dynamics also influence participation (Devasia, 1998; Bachan *et al.*, 2011; Binoy, Radhakrishna and Kurup, 2017; Jadeja *et al.*, 2018; Nagendra, Lakshmisha and Agarwal, 2019; Shipingana, Shivaraju and Yashas, 2022). The examples showed that religion can hamper species selection while conducting biodiversity assessments (Binoy, Radhakrishna and Kurup, 2017), caste can restrict access to geographical areas (Jadeja *et al.*, 2018) while gender can play both a promoter and restrictor of participation depending on research topic and movement requirements by participants (Jadeja *et al.*, 2018; Nagendra, Lakshmisha and Agarwal, 2019; Shipingana, Shivaraju and Yashas, 2022). Opportunities for recruiting participants lie in incentivising participation through monetary, livelihood, or social benefits especially in rural areas where engagement is low.

Chapter 6 identified Academic and Research Organisations (AROs) as the most influential institutional stakeholders, accounting for 51% above the global average. They typically initiate, manage, and promote CS projects, and often secure funding. Civil Society Organisations (CSOs) play a vital role in community engagement and recruitment, while International NGOs and government agencies are primary funders. However, government support often depends on political alignment and varies regionally.

Businesses and Industries showed some promise in supporting CS through CSR initiatives or employee participation, though engagement is currently minimal. A lack of strong data protection policies raises concerns over data ownership and potential commercial exploitation when Business and Industries funds projects. Since currently India lacks an enforceable data protection law, it becomes important to discuss how the integration of B&I in the CS process in India can create further challenges. Countries in Europe tend to protect the participant's interest through General Data Protection and Regulation (GDPR) policies.

Formal Learning Institutes (FLIs) particularly colleges and universities are important for participant recruitment but contribute minimally to other aspects of the research. Finally, collaborative platforms like India Biodiversity Portal (IBP) and Bird Count India (BCI) play a critical enabling role by supporting smaller projects, facilitating collaboration, and providing open data infrastructure.

7.2.3. Key limitations of the study

The key limitation of the study was its reliance on data from online resources, predominantly academic records. Interviews were incorporated only in the later stage of the study in Chapter 6 to overcome the knowledge gap posed by online data. Though the study was able to identify more CS projects in India (57) than previous reviews, using a systematic review can overlook CS projects which may not have published or reported their outcomes as they might still be collecting data, or their goals may not be producing scientific and academic research. This can result in the skewed interpretation of data, possibly overlooking impacts, barriers and opportunities that were not captured in academic literature. For example, due to inadequate funding for CS projects, project proponents may not establish a website and instead conduct recruitment and outreach through free social media platforms such as Facebook, WhatsApp, X (formerly Twitter) and Instagram. Thus, there is a high possibility of not accounting for these projects using the systematic review as the systematic search was limited to academic databases and Google web searches.

After the search was undertaken and reviewed, eBird India published a list of more than 40 research articles which were published using their data. These articles were overlooked as the keywords and abstract did not indicate the term ‘citizen science’ or any other allied search term used in Chapter 2. Thus there is a limitation of the process if the same terms are not used both by reviewers and authors of records.

Secondly, the study has included several smaller and seasonal projects under a larger project which supported them. This was done under all seasonal and small birding projects supported by BCI (n=17) thus reducing the apparent number of birding projects in India. This exclusion might have led to an underrepresentation of the diversity and nuances in birding CS projects even though the grouping was done to reduce the skewness.

Thirdly, the study did not fully trace the impact journeys of CS projects from inception to current status as it relied on secondary resources and captured only impacts that have been reported by the authors of the academic records. This may have led to underestimating or overestimating the impacts of CS projects in India. Moreover, the modified Citizen Science Impact Assessment Framework (CSIAF) used in the study needs further scrutiny and research to develop it as a protocol for meta-analysis of the impacts of CS projects. Each of the indicators identified and discussed in the modified CSIAF can have an impact on measuring standards, which can be developed through further studies. In addition, systematic reviews and surveys can be undertaken to identify new indicators to strengthen the impacts of CS projects. Thus they can be used as crucial guiding points for designing effective and impactful CS projects.

Similarly, the barriers and opportunities (B&O) framework developed for this study is a novel approach and it requires further refinement by undertaking additional systematic reviews to identify more influencing factors (IFs) and potential B&Os. The current framework was not developed using systematic reviews and meta-analysis and thus does not yet provide an exhaustive list of IFs and B&O. Moreover, though the B&O framework established that challenges in CS are both region and time-dependent, the framework's current design does not fully account for this variability across different regions and periods, particularly in comparing India with Annex I countries. Furthermore, the accuracy of the evidence of B&O for India is dependent on available English academic published literature, which may not fully represent real-life scenarios. The interviews were not integrated into the B&O assessment as its requirements were felt later. The interviews shall be incorporated into the B&O assessment at a paper stage. Thus, a triangulated assessment could have been done if the interviews had been incorporated into the assessment.

Lastly, the stakeholder analysis did not fully utilise all recommended pathways to identify stakeholders as suggested by Reed *et al.*, (2009) due to time and financial constraints. This limitation could affect the comprehensiveness of the insights into the stakeholder ecosystem. In the case of stakeholder interviews, the study was unable to interview representatives from all categories of identified institutional stakeholders, especially government agencies. This can potentially lead to an incomplete understanding of the diverse perspectives and roles within the stakeholder ecosystem. However, there is a scope for undertaking a comprehensive stakeholder analysis and mapping if the research can be supported through finances and a bigger team.

7.3. Mapping the findings of the thesis into SWOT and PESTELE analysis framework for identifying the goals and objectives of promoting CS in India

In this section, the study discusses the overall strengths, weaknesses, opportunities and threats (SWOT) of the PESTELE dimensions for CS in India. Findings from Chapter 3 give us a glimpse of the current inherent characteristics of the product i.e., EECS in India. The strengths and weaknesses of its inherent characteristics were identified by reviewing the impacts of CS projects in India in Chapter 4 using the modified CSIAF. The findings were then used to draw inferences to understand its impacts on the political, economic, sociocultural, technological, environmental, legal, and ethical dimensions (PESTELE) of CS in India.

Similarly, from Chapter 5, the study identified the external conditions that provided opportunities and barriers to CS projects in India using the B&O framework. The external conditions identified from the barriers and opportunities from Chapter 5 have been presented as Opportunities and Threats. Threats were interpreted as Barriers and Challenges. The findings were first categorised as Strengths, Weaknesses, Opportunities and Threats and then recategorized under the PESTELE dimensions. Thus for each PESTELE dimension, there is a list of Strengths, Weaknesses, Opportunities and Threats illustrated in the following sections below.

7.3.1. Dimension: POLITICAL

Strengths (Internal Factors):

- Acceptance by both national and state-level governments, especially for the use of data from BC projects, shows governmental interest in CS as a source and instrument for policymaking. Data from the Asian Waterbird Census, for example, has been used to develop national action policies while Pune Municipal Corporation supported the water quality and fauna monitoring of Pashan Lake to develop the site (Section 4.4.3.4).

Weaknesses (Internal Factors):

- Though 20 records in the systematic review reported that their CS-generated data could be used for policymaking in India, only one project demonstrated strong evidence of its data being used in developing national action policies on biodiversity. Thus indicating limited integration of data in policymaking in the country (Section 4.4.3.4).
- No opportunities or threats were identified from my study for this dimension. However, I have listed down opportunities from external sources.

No Opportunities and Threats were identified from the political dimension in my study.

7.3.2. Dimension: ECONOMIC

Strengths (Internal factors):

- CS projects have the potential to generate livelihood opportunities by (Section 4.4.3.2):
    a. Advancing careers.
    b. Providing useful scientific skills to participants.
    c. Generating indirect livelihoods through ecotourism.
    d. Creating part-time livelihood opportunities in rural areas.

Weaknesses (Internal Factors):

- CS projects in India are mostly dependent on government and government-aided Academic and Research Organisations (AROs) funding, making them vulnerable to shifts in political priorities or funding availability (Section 4.4.3.2; Section 6.3.2.2).
- Although some CS projects have shown potential economic benefits, there is generally weak evidence of measurable impacts on job creation and economic development in most projects (Section 4.4.3.2).

Opportunities (External Factors):

- The Mahatma Gandhi National Rural Employment Guarantee Act (MNREGA) can be integrated into CS projects to generate employment for rural participants, as exemplified by the MARVI Project (Section 5.4.6)
- Businesses can channel their CSR (Corporate Social Responsibility) funds to develop CS projects with measurable outcomes (Section 5.4.3; Section 6.3.2.2).

Threats (External Factors):

- Inadequate and short-term funding models negatively affect the financial sustainability of CS projects (Section 5.4.3).

7.3.3. Dimension: SOCIAL

Strengths (Internal Factors):

- CS projects can empower and provide opportunities to marginalised groups, including rural women and disadvantaged caste communities, by providing them with opportunities to actively participate in scientific research and decision-making processes (Section 4.4.3.1). For example, the CS initiatives in India demonstrated the effectiveness of engaging local communities, especially marginalised groups in data collection and resource management, fostering cooperation, and sustainable resource management within communities, thus bridging science, policy, and community.
- Projects showed the potential to transform attitudes and values towards wildlife conservation by raising awareness among participants and fostering behavioural changes (Section 4.4.3.1).
- Projects have shown the impacts of developing and promoting awareness of local socio-environmental problems and developing scientific temperament, especially among the rural population such as awareness regarding reptiles, protection of hornbills, reasons for human-elephant conflict, etc. Training programs and workshops can enhance participants' skills and understanding, contributing to higher-quality data collection and greater engagement (Section 4.4.3.1).

Weaknesses (Internal Factors):

- Projects have inconsistent data reporting on these factors. There is a lack of measurable impacts to quantify the extent of societal benefits and the long-term effectiveness of CS initiatives (Section 4.5 pages 104-105).

Opportunities (External Factors):

- Opportunities for partnerships and collaborations among local universities, NGOs, schools, and government agencies to facilitate projects. Businesses and industries can use CS to complement their CSR activities, e.g., HSBC Bank (Section 5.4.6).

Threats (External Factors):

- CS manifests differently in urban and rural landscapes in India. Participation in rural areas can be affected by (Section 5.4.5):

a. Local leaders and village councils (panchayat).
b. Women's participation can be restricted due to cultural patriarchy, safety concerns, etc.
c. Other cultural practices such as the caste system.

Projects can also be affected by:

a. Language inaccessibility.
b. Students may be deterred from participation if there are no incentives in their annual marks.

7.3.4. Dimension: TECHNOLOGICAL

Strengths (Internal Factors):

- CS in India has shown strong evidence as a method for scientific discoveries such as discovering unknown species, distribution patterns of various species, and the effect of climate change on them (Section 4.4.3.3).
- It has shown strong potential to be adopted as a method for monitoring, evaluating, and researching air quality, noise, sanitation, waste management, and water quality (Section 4.3.3.3). For example, evidence of the development of indigenous mobile phone apps for monitoring air quality, noise quality, water quality, sanitation, and waste management.

Weaknesses (Internal Factors):

- The development of technology for CS in India is limited, with only mobile applications being developed, thus reducing the variety and innovation potential of CS projects (Section 4.5 Page 103).

Opportunities (External Factors):

- The use of mobile technology and digital platforms facilitates data collection and sharing, connecting participants across diverse geographies. This can enhance the data collection efficiency of the country as well as fill gaps in the current data and knowledge system (Section 5.4.6).

No Threats were identified by my study for the Technological dimension.

7.3.1. Dimension: Environmental

Strengths (Internal Factors):

- Contributed to biodiversity conservation with documentation of over 400 species of fauna, with the discovery of 5 new species of birds (Section 4.3.5).
- Evidence of improved local ecosystem quality after project implementation (Section 4.3.5).
- CS has helped build local capacities, such as in coastal communities adapting to sea-level rise in India (Section 4.3.5).

Weaknesses (Internal Factors)

- While biodiversity and lake ecosystems show strong outcomes, air quality, pharmaceutical waste, and noise pollution projects have weak or no evidence of improved actions (Section 4.3.5).
- The effectiveness of CS projects varies widely depending on the issue, region, and implementation model, leading to inconsistent results (Section 4.3.5).

Opportunities (External Factors)

- Integration and designing projects that can aid National Policies such as Swachh Bharat Mission, International Costal Day, etc. through data collection, monitoring and evaluation, etc. (Section 5.4.2)

Threats (External Factors):

- Misuse of data by non-beneficiaries, for example, poachers identifying the location of endangered species (5.4.2)

7.3.2. Dimension: LEGAL

Strengths (Internal Factors):

- Several EM&E projects collaborated with local governments such as municipalities to monitor and evaluate water quality, noise pollution, waste management, and sanitation in project areas. Thus, there is an opportunity through which CS can aid as a scientific, legal, and regulatory pathway for local governments to monitor the local environment in India (Section 4.4.3.4).

Threats (External Factors):

- Though some projects have shared data with local authorities, there is weak evidence for strong, consistent endorsement and use of CS data by these authorities. This is because there is a lack of standardised legal mechanisms for integrating CS data into official decision-making processes (Section 4.4.3.4).

No Weaknesses and Opportunities were identified for the Legal dimension in my study.

7.3.3. Dimension: ETHICAL

Strengths (Internal Factors):

- All researchers and practitioners in the collected records acknowledged the participants' involvement with the projects. The reviews showed that they are extremely conscious about being accountable towards their participants (Section 5.4.4; Section 5.4.9).

Weaknesses (Internal Factors):

- There is limited discussion around data ownership and the protection of participants' intellectual property rights (Section 5.4.2). Navigating legal and regulatory barriers can be complex, particularly for project proponents when dealing with data privacy, ownership, and use (Section 5.4.2).
- Currently, there is very little discussion around inclusive participation, i.e., addressing issues of representation, inclusivity, and diversity. This includes ensuring that projects are accessible to participants from various castes, ages, genders, and socio-economic backgrounds (Section 5.4.6).

Opportunities (External Factors):

- Practitioners can use open licensing systems, such as Creative Commons and Open Data Commons, and follow best practice guidelines for data management can ensure the appropriate use and sharing of CS data such as following Vattakaven *et al*, (2022) or international standards like the FAIR Data Principles (Wilkinson et al., 2016) (Section 5.4.2).

Threats (External Factors):

- The lack of legal protection of participants' intellectual property rights and the safe sharing of data are critical challenges in India as they can lead to misuse and legal disputes (Section 5.4.2). The current

"Digital Personal Data Protection Bill (2022)" does not cover CS-generated data (Vattakaven *et al.,* 2022). The lack of such protection can be exploited by projects which have been funded by business and industry stakeholders (Section 5.4.2).

7.4. Recommended points for a Roadmap to promote CS in India (2025-2030)

In this section, I am proposing a few points that can be undertaken to initiate the roadmap for promoting CS in India. The actual roadmap may differ from the recommended points I have put forward. However, these particular points would help in devising the roadmap at a macro level. A limitation of the points I have drawn for the roadmap is that they are based on my understanding of the findings frrom my study.

I have hypothetically proposed that the timeline of the roadmap to promote CS in India from 2025 to 2030 due to several enabling policies and support that coincide to support the claim for promotion such as GoI India's National Action Policies on Clean Air, Sanitation and Hygiene (Swachh Bharat Mission), etc., Reporting to UNFCCC on achieving targets of Sustainable Development Goals, reporting for Biennial Transparency Report (BTR), etc. The change of regime and international goals post-2030 shall lead to a different ecosystem that can support CS. Since no information is available on the post-2030 policy scenario, the roadmap was limited to 2030. The recommended strategic approach has a multi-phase approach with the discussion of key activities.

Phase 1: Convening and Co-designing the roadmap (December 2025-December 2027)

The first phase of the road map entails the proposal for developing a road map at India's annual CS conference, CitSci India that takes place in the last week of November or the first week of December. The CitSci India conference offers a platform to discuss these recommendations and communicate with governmental agencies such as the Office of the Principal Scientific Advisor to the Government of India (PSA) and, the Ministry of Environment, Forest & Climate Change (MoEFCC) (CitSci India, 2022, 2023a). The main objective in this phase is to co-develop and co-design the roadmap for CS promotion in India.

The roadmap starts with the presentation of findings from this thesis at the CitSci India conference so that a variety of stakeholders and practitioners can be informed about the work and seek collaboration with various institutional stakeholders nationally. The idea is to facilitate stakeholder consultation through CitSci India with government agencies and departments, AROs, CSOs and Businesses and Industries (Queiroz-Souza *et al.*, 2023).

Nudging various government agencies can aid in formulating clear policies for integrating CS data into already existing environmental policies such as the Swachh Bharat Mission and National Clean Air Program; national statistical organisations and databases such as the National Information Centre (NIC), National Data Analytics Platform (NDAP) and Open Government Data (OGD) platforms; and accept CS-generated data as one of the official sources by the State and Central Pollution Control Boards. The uptake of CS by the pollution control boards would also help in diversifying the thematic areas of CS projects in India as these boards monitor several aspects of the abiotic (physical) environment.

My study has shown that the GoI has some interest in funding and using CS-generated data, thus a formal policy would help in legitimising CS-generated data for use, a major weakness and threat for CS in India. State and Union Territories governments can contribute to the promotion by establishing centres like the *Centre for Citizen Science and Biodiversity Informatics* (CCSBI), Kerela and *Centre for Citizen Science, Pune* (CCS), Maharashtra across other states in the country to promote the uptake of CS (Kulkarni *et al.*, 2022; Kerela Forest Research Institute, 2025). Literature has shown that the establishment of such centres and research groups has highly influenced the uptake of CS across the globe (Liu *et al.,* 2021). Since the establishment of Indian CS centres is a recent event, its effectiveness in India is yet to be ascertained. Chapter 3 has demonstrated that both Maharashtra and Kerala which have the above-mentioned centres are the leading in the numbers of CS projects as well as diversity in addressing socio-environmental issues.

Various government agencies can also integrate CS projects with national employment schemes like MNRGA to mobilise participants, particularly in rural areas and the National Skill Development schemes to build skills among participants (Jadeja *et al.*, 2018). The training programs and workshops enhance community engagement, community knowledge, scientific literacy, and skills of participants, particularly in rural areas for future career options along with local data collection efforts. However, this point raises a philosophical debate if the participants of a CS project should be paid. Literature has shown that to engage participants, especially in Non-Annex I countries, certain monetary incentives are required to compensate for the time spent by participants (Pocock *et al.*, 2019; Sekhsaria and Thayyil, 2019; Walker, Smigaj and Tani, 2021).

Additionally, in this phase, CitSci India (which is also the national-level forum on CS) can be transformed into a multi-stakeholder platform to guide CS in India. Under their banner, strategies and projects can be developed through co-designing workshops to identify priority socio-environmental issues that can be addressed by CS, e.g., air quality, water quality, sanitation, etc. in India. The workshops can also help to define the ethical, legal, and data standards of CS in India collaboratively. Various stakeholders should be invited to take part in the workshops which should be conducted both at national and state levels. By the end of this phase, a handful of CS projects can be co-designed with diverse characteristics, to test effectiveness and build frameworks to enhance project sustainability. Findings from Chapter 5, indicate that blitz events help in recruiting participants, thus collaborative networks that would evolve through the workshops would aid in promoting the EECS projects, and the blitz events on various thematic areas can help in catering to the needs of a variety of participants. The list of stakeholders (Annexure 7) identified in Chapter 6 can be a starting point for building collaboration among the institutional stakeholders in India.

Phase 2: Development and Expansion (December 2027 – December 2028)

In the next phase, the objective is to scale up the efforts and develop a robust infrastructure to support training and partnerships. At the same time projects can be ensured that they align with national priorities and information gathered by the National Statistical Organisations (NSO) of India (Fritz *et al.*, 2019; Proden, Fraisl and See, 2023).

The first step in this phase is to develop standardised protocols and methodologies to ensure consistency and reliability in the data collected across various projects as well as maintaining ethics and inclusivity of participants. For example, standardising data collection methods according to international standards can enhance the credibility and usability of CS data globally, contributing to national international developmental and sustainable agendas like the Swachh Bharat Mission (SBM), National Clean Air Program (NCAP), Mission LiFE, Sustainable Development Goals (SDGs), Biennial Transparency Reports (BTRs), etc. Ensuring the quality and reliability of data collected by non-experts is still a significant challenge. Without standardised data collection methods and adequate training, the credibility and usability of CS data may be compromised.

Current protocols that are being used in the identified CS projects in India can be evaluated and nationally adopted for reporting. At the same time, efforts can be made to recruit participants, including citizens, students, local political leaders and community groups and train them on the protocols and standards. For example, Bird Count India provides training to fill out its eBird checklist (Adhurya and Bhandary, 2019; *Bird Count India*, 2023). With the lessons learnt from these projects, best practices for CS can be recorded and establish the necessary infrastructure, such as digital platforms and data management systems, that will support the ongoing activities.

The second step is to develop indigenous tools and technologies that can be used in CS projects such as low-cost sensors. The current weakness of CS in India in terms of technology is its limited innovation in developing only mobile apps. India can take this opportunity to train STEM aspirants, students and researchers through the *Make in India* initiative to develop indigenous technologies (Namdeo and Koley, 2021; Koley and Bharadwaj, 2024). Furthermore, with the advancement of AI, India can look forward to involving AI to help categorise data, and analyse them and at the same time generative AI can be used in developing outreach and communication materials for participants that can be uploaded to social media (Fraisl *et al.*, 2025). Another weakness is procuring sensors from abroad. Though it opens up trade and cooperation, the cost of these sensors is high when valued against Indian purchasing parity. Thus indigenous development of low-cost sensors can be promoted under the *Make in India* policy. This would open up avenues for both financial investments and self-reliance on indigenously developed products.

The third step is to involve a diverse set of stakeholders to fund and reach participants. My study indicates that several funding opportunities can be availed by project proponents such as Corporate Social Responsibility (CSR) funds, international grants, and crowdfunding to reduce dependency on government funding and ensure the long-term sustainability of CS projects. However, to achieve this project proponents need to strengthen their partnerships among local AROs, grassroots CSOs, local government agencies, and regional and national businesses and industries to develop collaborative networks with a high flow of information through which they can avail fundings. My study showed that though there are collaborative networks, the collaboration is limited to the same set of stakeholders, usually concentrating on biodiversity conservation projects with a lack of flow of information to new stakeholders who want to adopt CS in other thematic areas.

Phase 3: Consolidation and Institutionalisation (December 2028-December 2030)

In this phase, the objective is to embed CS into the national data collection system, under the National Informatics Centre (NIC), the technological department of India that helps the Government of India and State Governments to undertake data-driven decision-making; and the adoption into National Education Policy 2020 for promoting its activity-based-learning and sustainability agenda. As the CS projects are piloted (in Phase 2), collaborative stakeholders can co-design assessment frameworks, protocols, data standards, etc. At the same time, stakeholders will be able to identify issues and pathways to ensure data protection and accountability of various CS projects which India currently lacks. The exercises during this period would entail developing various frameworks and guidelines with the collaborative efforts of the stakeholders to standardise data, evaluate the inclusivity and diversity of participants, etc. This phase would also concentrate on ensuring the sustainability of projects through long-term strategies such as securing permanent funding sources; formalising CS as one of the standard scientific inquiry in India; and establishing formal CS centres across states and regions for recruiting and connecting the public with projects and extend scope of collaboration; and embedding CS into future policy structures.

The first step is to integrate CS into the school and university curriculum. AROs and FLIs can get involved in the process through the Scientific Social Responsibility (SSR) Policy (DST, 2022). This GoI policy calls for the integration of the public directly within the scientific research process. This would help in broadening the scope and impact of both the SSR policy and CS in India The policy aims to inculcate moral responsibility in the scientific community to engage with the general public to enhance awareness about the scientific processes and how they benefit society. In addition, the new National Education Policy (NEP) 2020 has specifically highlighted the requirements of education institutes, especially AROs to contribute to sustainable learning, research and training (MHRD, 2020). The NEP 2020 and U75 policies of the Government of India also cite the use of participatory approaches for research, training and learning purposes of the students. The positive impact of these policies is that AROs and FLIs are evaluated by the Education Ministry of India. Thus a formal integration circular from the Education Ministry would help in boosting the acceptance of EECS in the country. This formality is important because Phartyal and Yadav, (2022) in their study found that though 73% of students have heard about EECS in their institutes and colleges but only less than 26% of the interviewed students had actual hands-on experience on CS. AROs and FLIs can leverage these policies to integrate CS into their curriculum, provide students with beneficial skills through activity-based learning and also extend it beyond the educational campus to accommodate local communities in their activities.

The second step is that various EECS stakeholders should collaboratively evaluate and design ethical and legal frameworks such as data protection, Intellectual Property Rights (IPR), and open licensing protocols for accessibility of data by the beneficiary while at the same time providing protection from the maligned public such as hiding location of endangered from poachers (Chapter 5). Additionally, standardising data collection, protocols, and storage through stakeholder consultation and engagement would help in validating the CS process to be incorporated into national database systems such as those maintained by NIC. A collection of best practices and facilitative guidelines for the design and implementation of EECS projects would help in addressing issues of data collection, data analysis, data quality, organisational structure, volunteer guidance, data ownership and data privacy under the legal provisions. This can be achieved by increasing the number of projects. To develop these protocols Indian stakeholders can refer to FAIR Data Principles and CARE Principles (Wilkinson *et al.*, 2016; Carroll *et al.*, 2020). Integrating these two principles while developing the protocols would help ensure that data is usable and impactful so that it can be used justly and ethically, for example, ensuring representation across caste, gender, geography, and socio-economic status. This will help in supporting CS-generated data as it can enhance public trust in the data, provide equitable access to data benefits and protect the rights of the beneficiaries, especially the public.

The third step in this phase is to develop institutional support such as through formal CS centres in every region (states and UTs of India). This step would help in recognising EECS as a valid method of research accepted by GoI and thus opening up the possibility of integration of CS-generated data into National Policy frameworks.

The final step is establishing a fund to support CS projects and research that can be handled by CitSci India at the national level or by regional CS centres. The fund can generate funding by collaborating with various institutional stakeholders. Figure 35 depicts the milestones of the roadmap to promote CS in India by 2030.

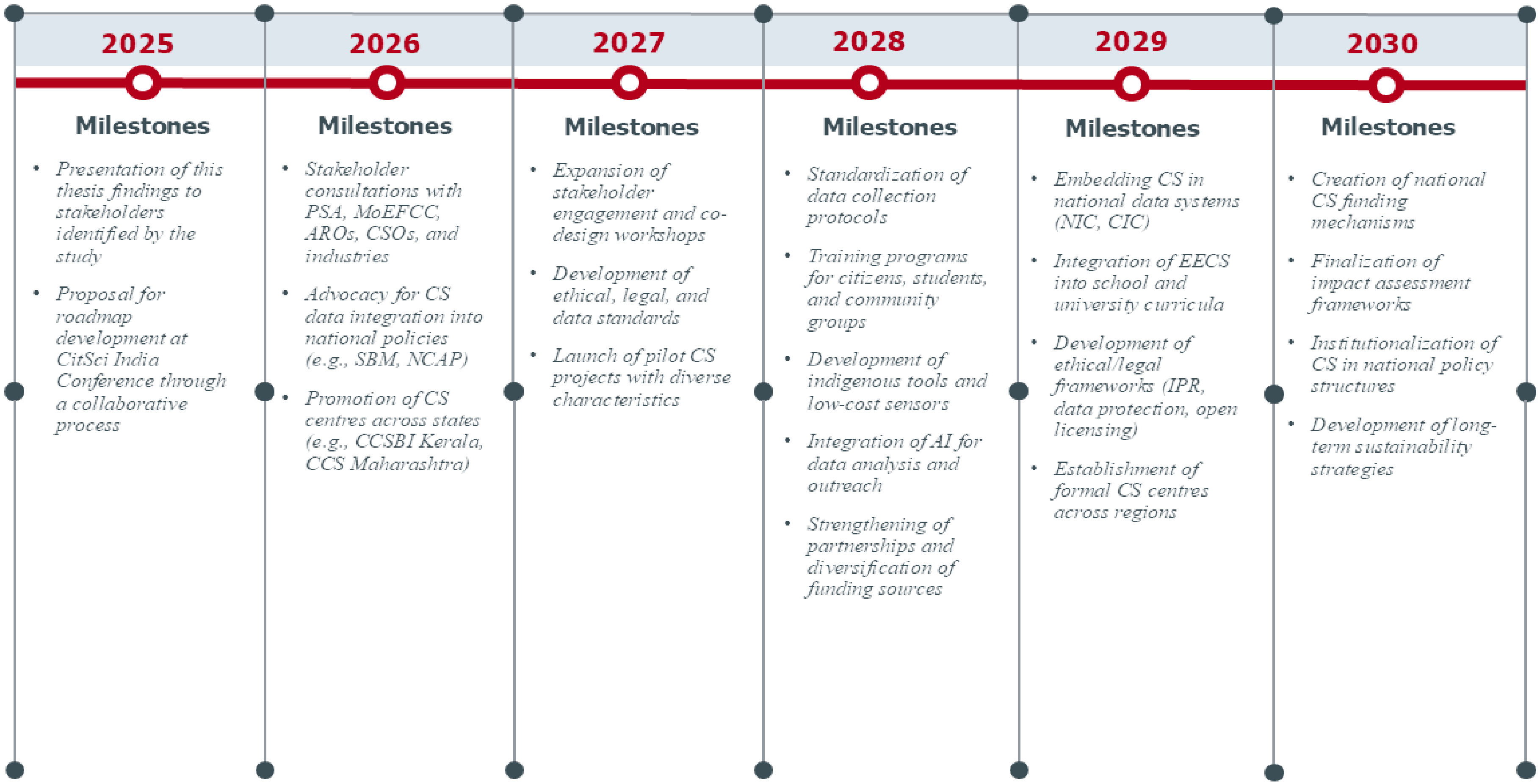

Figure 35: The roadmap to promote CS in India from 2025-2030

7.5. Future research

The study has been able to open several pathways for future research. It can be divided into two types; ‘undertaking research to further understand CS in India’ and ‘intensifying the robustness of the frameworks described in the thesis.’

Under the first type, future research can be undertaken with a ‘participant perspective’ which tries to understand the CS process and highlights the views of participants of CS projects in India. The current study has provided a top-down approach which has essentially failed to address questions about participants such as motivations, inclusivity, diversity, etc. which is essential for the development of the roadmap, especially during the Capacity Building phase (Figure 36), thus making it a priority research area. The scope of this research was initially part of the thesis. However, due to a lack of time to continuously pursue project proponents to share the survey with their participants, this part of the research was omitted with a view to undertaking it in the future. Thus with more finances and time, this particular study can be undertaken.

Secondly, immediate research is required on developing best practices to enhance the quality and outreach of CS projects, especially, the role of media which has been underrepresented in the records collected by the study thus a low inference on their role in CS. This research would help in reaching out to participants. Thirdly, new research can be conducted to understand the influence of Residents' Welfare Associations (RWAs). These societies are run by residents of an area to highlight local issues and development and have a high stake in developing urban local areas in India as per government mandate. Thus immediate research involving them as part of the urban CS process can help in addressing the needs of urban environmental and sustainability problems and increasing the number of non-biodiversity conservation projects.

Under the second type, future research can be undertaken to enhance the current methodologies. The modified CSIAF framework can be enhanced by conducting studies on what can be taken as strong or weak evidence for the indicators proposed in the study. Several systematic reviews similar to Somerwill and Wehn (2022) can be undertaken to understand these indicators. This exercise would also help streamline the reporting of the impacts of CS. Such systematic reviews can also be undertaken to identify, categorise and create a database of various influencing factors (IF) of CS. This can aid in bringing robustness into the B&O framework. Finally, while assembling the key findings of the thesis into the PESTELE analysis, it was realised that a systematic review can be undertaken to develop a set of sub-domains for PESTELE analysis, especially for CS. This will help projects in the future to assess the influence on various PESTELE dimensions.

7.6. Conclusion of the thesis

The main aim of this research was to develop a roadmap to promote CS in India, especially its uptake for environmental science and monitoring. To develop the roadmap the study undertook four investigations to systematically identify CS projects in India, the impacts they have been able to generate and the barriers and opportunities they have in India. The thesis also has a wide range of applications, both in terms of India and at a global scale.

7.6.1. Conclusion on CS in India

CS in India is still in the nascent stage even though its origin can be traced back to 1987, the growth has been slow and limited. India has a limited range in undertaking CS projects, mostly limited to biodiversity conservation, a trend seen globally. The number of CS projects for abiotic environmental factors such as water quality, air pollution, noise pollution, sanitation, etc. needs to be promoted to create more impact on society, economy, environment, governance, science and technology.

CS projects in India are usually undertaken by researchers and academicians to conduct scientific assessments along with traditional scientific endeavours. The inclusion of socio-environmental benefits including livelihood benefits is a common 'add-on' characteristic of projects that involve the rural population, especially those that deal with abiotic factors. Thus Indian project proponents especially researchers consider benefits for society beyond conducting scientific research. But from the study it is evident that these impacts can only be scaled up by increasing the number of CS projects in India; expanding the reach of successful projects, both in terms of participants and geographically; and promoting social impact as an integral part of projects.

For the acceptance of CS in India as a policymaking tool, AROs and CSOs need to create awareness among government agencies, especially at state and local levels both by demonstrating project impacts and conducting seminars and workshops. Established evidence of CS as a tool to fill ecological and environmental data gaps can be highlighted to grow the interest of government agencies in CS projects. The slow uptake of CS in India highlighted several barriers to its promotion.

The fundamental barrier is to channel long-term and sustainable funding opportunities. Most projects are dependent on short-term research grants thus leading to financial uncertainty of project, accessibility to technology, outreach and recruiting participants. Other cultural barriers related to religion, caste, gender and education can restrict participation. Currently, the study was not able to estimate the influence of these influencing factors and suggest further research to analyse their influence in the Indian context.

Though there are barriers to CS in India, several opportunities are also available. India's leading AROs have accepted it as a scientific process to collect data and conduct scientific research using them. Short-term funding opportunities are also available which can aid in initiating pilot projects. Moreover, as information technology grows using social media will help in scaling the projects.

The final research chapter on understanding the institutional stakeholder ecosystem of CS in India has been able to highlight significant contributions by them. The study can be used to identify new partners and collaborators to initiate projects as well as funding opportunities besides the development of the roadmap. However, there have been several drawbacks in the analysis and would require further studies supported by more manpower and finance to overcome them. Overall, the current analysis provided a foundational understanding of the stakeholder ecosystem in India which can be further expanded.

Thus using the information from the results of these four chapters, the study was able to draw on a foundational roadmap to promote CS in India. The drawback of this roadmap is that there was no consultation with the stakeholders on developing it, thus the period used overlooks the practical implementation of the roadmap. Secondly, the roadmap does not consider the quality of existing infrastructure to promote CS and only recognises the existence of the resources and infrastructure. Thirdly, roadmaps are subjected to personal inputs from their authors and can depend on how authors want to develop a plan. Thus other reviewers might have a different perspective from the one presented in this study, leaving scope for improvement.

7.6.2. Global relevance of the study

The systematic review conducted for this thesis can be repeated at the end of the proposed roadmap period to evaluate the progress of CS in India. Moreover, the data collected for the study can be treated as baseline data of CS from 2023 and thus the systematic search can be undertaken periodically to update the project list. Various studies across different countries can be undertaken in line with the methodology proposed by the thesis. Secondly, the modified CSIAF is another significant contribution to the future assessment of CS projects using literature by external assessors. Though the framework requires further modification to strengthen the methodology, it has established a pathway to guide the impact assessment of several projects together such as the impacts of CS projects over a domain, nation or region. The B&O framework developed to identify the barriers and opportunities is an important step towards formulating a matrix to develop best practices before initiating a project. While reviewing the literature to systematically identify barriers and opportunities, the study was able to bring in the concept of influencing factors and their influence on the barriers and opportunities of CS.

Appendices

Appendix 1: Appraisal of records from PRISMA

Source of Evidence: Records describing CS projects (CSP-AL)

ID	Name of Records	Short Name	Appraisal of Record	Authors
P1	Assessment of national beach litter composition, sources, and management along the Indian coast - a CS approach	International Coastal Clean-up day	The projects assess beach litter characteristics of 33 beaches from 2019-2021 across India. Beach litter characteristics included density, weight, composition, and sources. The project was part of the International Coastal Clean-up Day effort by India. More than 2000 citizen scientists and practitioners participated in the project.	(Mishra *et al.*, 2023)
P2	Bridging Educational Institutions for a CS Project: A Case Study from Malappuram District, Kerala, India	Student Scientists	This CS project demonstrates the strategic collaboration of diverse institutions, including schools, colleges, NGOs, youth clubs, and individuals, forming a network for effective grassroots data collection and scientific knowledge dissemination. Focused on the Valanchery region in Kerala, India, the project establishes a 'student network' connecting schools and colleges to monitor local mammalian diversity, highlighting the potential of participatory research in engaging multi-stakeholder communities.	(Binoy, Radhakrishna and Kurup, 2017)
P3	CS in Schools: Students Collect Valuable Mammal Data for Science, Conservation, and Community Engagement	Citizen Science in School	This CS project successfully engaged children as young as 9 years old in collecting valuable mammal monitoring data using camera traps. Students from India, Kenya, Mexico, and the United States, following scientific protocols, detected 13–37 mammal species near their schools, including five endangered species. The project not only demonstrated the potential of children to contribute valid scientific data but also had broader community impacts, involving local politicians, community members, and the media, highlighting the effectiveness of CS in conservation and research.	(Schuttler *et al.*, 2019)
P4	CS Tools Reveal Changes in Estuarine Water Quality Following Demolition of Buildings	Vembanad Lake project	This CS project utilises a low-cost, 3D-printed Mini Secchi disk (3DMSD) with a Forel-Ule colour scale sticker, coupled with the 'TurbAqua' mobile app, to engage laymen in assessing water quality post-demolition of buildings on the shores of Vembanad Lake in southern India. Over a five-week	(Menon *et al.*, 2021)

ID	Name of Records	Short Name	Appraisal of Record	Authors
			period, the project tracked variations in Secchi depth, water colour, and other water quality parameters, revealing short-lived impacts of demolition waste on the lake. The study demonstrates the effectiveness of CS tools in monitoring water resources, aligning with Sustainable Development Goals related to health, water quality, and marine life.	
P5	Citizen-centric tool for near real-time mapping of active forest fires	Forest Fire Monitoring	This CS project introduces a mobile app designed for citizen-centric geospatial recording of real-time forest fire incidents. The app fetches accurate geographical coordinates, captures images, and records pertinent details such as the cause of fire, fire type, and affected species. It operates in both online and offline modes, with an evaluation of its robustness and a case study demonstrating its potential as a participatory sensing-based geospatial tool for forest fire monitoring.	(Saran *et al.*, 2020)
P6	Documenting butterflies with the help of CS in Darjeeling-Sikkim Himalaya, India	Butterflies Conservation	This CS project in the Darjeeling-Sikkim Himalaya utilized both CS and researcher-survey approach to document butterfly biodiversity. The collaborative effort resulted in the identification of 407 species, the highest recorded in the region. The study demonstrates the efficacy of CS as a supplementary tool for biodiversity documentation, providing valuable data on diverse, rare, seasonal, and nationally protected species. The outreach strategy employed underscores the importance of engaging local communities to enhance CS project participation and success.	(Pradhan, George and Dewan, 2023)
P7	Empowering Local Practitioners to Collect and Report on Anthropogenic Riverine and Marine Debris Using Inexpensive Methods in India	Coastal Clean up	This CS project in India focused on marine debris, employing a replicable and cost-effective collection method introduced through a 2019 workshop. The initiative involved local-led collections in three states and two Union Territories, resulting in 33,474 pieces of debris weighing 599.15 kg from 8 beaches and 2 riversides. Plastic, constituting 45% to 89% of items, was the predominant material. The study establishes baseline data with debris density ranging from 0.38 to 3.86 items/m2, employing the Clean Coast Index for site rankings. The research sheds light on the	(Owens *et al.*, 2022)

ID	Name of Records	Short Name	Appraisal of Record	Authors
			pervasive issue of plastic debris originating mainly from residential activities in India.	
P8	Firefly survey: adopting CS approach to record the status of flashing beetles	FireFly Watch	This CS project, conducted on World Firefly Day (3–4 July 2021), engaged participants from 14 states across India. Utilizing an online platform, the survey aimed to assess firefly abundance through flash counts, involving citizens in recording observations. The study received significant participation, collecting data on firefly occurrence from Uttar Pradesh, Uttarakhand, Rajasthan, Gujarat, Maharashtra, Madhya Pradesh, Odisha, Andhra Pradesh, Tamil Nadu, Kerala, Karnataka, West Bengal, Assam, and Ladakh. Over 26,000 fireflies were observed, showcasing the potential of CS for broader ecological studies and public education.	(Rana, Rayal and Uniyal, 2022)
P9	Herd Size Dynamics and Observations on the Natural History of Dugongs (Dugong dugon) in the Andaman Islands, India	Dugong Monitoring Program	This long-term CS project, spanning from 2017 to 2022, monitored dugong aggregations in the Andaman Islands. Employing an inclusive, collaborative approach, the project engaged sea-faring stakeholders, including fishers, SCUBA divers, the forest department, and defence bodies. The study recorded 63 herd sightings, with fishers contributing the majority (73.01%) of reports. The findings revealed changes in the aggregating behaviour of dugongs, emphasizing the effectiveness of involving multiple stakeholders for cost-effective monitoring and conservation efforts in extensive seascapes like the Andaman and Nicobar Islands.	(Gole *et al.*, 2023)
P10	Identification of wetlands of international importance in Porbandar, Gujarat, western India during 2015–2021	Asian Waterbird Census	The Asian Waterbird Census (AWC), running since 1987, conducted extensive CS monitoring in Porbandar District, India. Covering 23 wetlands annually from 2015 to 2021, the project assessed the importance of ghed-facilitated inundation for waterbirds. Results revealed over 100,000 waterbirds at Mokarsagar Wetland Complex, with the highest annual total of 496,620 birds in 2016. Notably, 36 species exceeded 1% of the total population, including globally threatened and Near Threatened species, emphasizing the significance of these	(Vargiya, Jethva and Pandya, 2022)

ID	Name of Records	Short Name	Appraisal of Record	Authors
			wetlands for avian biodiversity despite facing various threats.	
P11	Kerala Bird Atlas 2015-20: features, outcomes and implications of a citizen-science project	Kerela Bird Atlas	The recently completed Kerala Bird Atlas (KBA), the largest in Asia concerning geographical scope, sampling effort, and species coverage, systematically surveyed the entire state of Kerala biannually from 2015 to 2020. With over 0.3 million records from 25,000 checklists, the dataset underwent rigorous filtering, enabling the estimation of various metrics.	(Only, 2022)
P12	Managing aquifer recharge and sustaining groundwater use: developing a capacity building program for creating local groundwater champions	MARVI Project	The MARVI project, focusing on participatory groundwater management, demonstrates the effectiveness of grassroots engagement in monitoring, recharging, and sustainably managing groundwater as a common pool resource. Collaborating with local villagers in 11 villages across Rajasthan and Gujarat, researchers and development facilitators initiated participatory groundwater monitoring. Through an extensive capacity-building program, villagers became "Bhujal Jaankars" (BJs), meaning 'groundwater informed.' These trained BJs conducted geo-hydrological evaluations, monitored groundwater, and shared their insights with the community. The project revealed that, with proper training and ongoing support, BJs play a crucial role in monitoring water table depth, estimating groundwater recharge, and fostering sustainable groundwater use, acting as local champions for groundwater management. While successful, challenges include securing long-term funding for BJs, gaining broader acceptance from scientific communities and policymakers, and integrating BJs into government-led natural resource management programs in India.	(Jadeja *et al.*, 2018)

ID	Name of Records	Short Name	Appraisal of Record	Authors
P13	Mechanistic understanding of human–wildlife conflict through a novel application of dynamic occupancy models	HWC Participatory modelling	This CS project on human-elephant conflict utilized dynamic occupancy models to analyse elephant crop depredation data in India from 2005 to 2011. By considering imperfect detection, the study identified spatiotemporal drivers of conflicts. Detection probability, influenced by factors like distance to roads and elevation gradient, ranged from 0.08 to 0.56. Crop depredation occurrence, influenced by variables such as distance to forests and rainfall patterns, varied from 0.29 to 0.96. The study provides a nuanced understanding of conflict dynamics, emphasizing factors like crop accessibility and availability, essential for predicting and managing human-wildlife conflicts in regions of increasing interactions.	(Goswami *et al.*, 2015)
P14	Mobile application in municipal waste tracking: a pilot study of "PAC waste tracker" in Bangalore city, India	PAC Waste Traker	The PAC Waste Tracker app, a CS initiative in Bangalore, addresses the city's solid-waste management crisis. Utilizing visual mapping and citizen inputs, the app identified issues in waste collection, such as irregular pickups, non-segregation, and inconveniences during collection. The study, conducted over nine months in four wards, facilitated informed policy implementation by presenting findings to local authorities, service providers, and municipal bodies, contributing to resolving the challenges in waste management through a bottom-up approach.	(Nagendra, Lakshmisha and Agarwal, 2019)
P15	Participatory Conservation And Monitoring Of Great Hornbills And Malabar Pied Hornbills With The Involvement Of Endemic Kadar Tribe In The Anamalai Hills Of Southern Western Ghats, India	Hornbill Conservation in Annamalai	The participatory monitoring and conservation program in the Anamalai landscape of the Western Ghats, India, focuses on hornbills threatened by traditional hunting. Initiated in the Vazhachal division, the project engaged the Kadar tribal community through community groups (VSS) in monitoring hornbill nesting during the breeding season. Trained tribal guards patrolled and protected nesting trees, resulting in the discovery of 57 Great Hornbill and four Malabar Pied Hornbill nests. The program not only contributes to hornbill conservation but also aligns with the tribe's traditional forest-dwelling practices, showcasing the importance of continuous community involvement in conservation efforts.	(Bachan *et al.*, 2011)

ID	Name of Records	Short Name	Appraisal of Record	Authors
P16	Participatory elephant monitoring in South Garo Hills: efficacy and utility in a human-animal conflict scenario	Elephant Monitoring in Garo Hills	The community-based elephant monitoring program in South Garo Hills, Meghalaya, aims to comprehend the roaming and habitat utilization patterns of free-ranging Asian elephants in areas prone to human-elephant conflicts. Utilizing participatory wildlife monitoring techniques modified for the region, the study recorded 201 elephant visits from six clan villages heavily affected by human-elephant conflict. The findings highlight seasonality in elephant visits, with peaks during main harvesting periods, emphasizing the efficacy of participatory monitoring for understanding complex elephant ranging dynamics in human interspersed habitats.	(Datta-Roy, Ved and Williams, 2009)
P17	Post-restoration monitoring of water quality and avifaunal diversity of Pashan Lake, Pune, India using a CS approach	Pashan Lake restoration	The CS project at Pashan Lake in Pune, India, focuses on the long-term assessment of an integrated restoration project initiated in 2005. Volunteers from the local community and schools were trained to monitor water quality using standardized methods. The study reveals that bird species richness and abundance increased following restoration, and nutrient concentrations decreased. The CS approach, involving water-quality tests and bird surveys, provided valuable insights into the effectiveness of restoration activities and enhanced community advocacy.	(Yardi, Bharucha and Girade, 2019)
P18	Protecting a hornbill haven: a community-based conservation initiative in Arunachal Pradesh, northeast India	Hornbill Conservation in Arunachal Pradesh	The Hornbill Nest Adoption Program in the Pakke Tiger Reserve (PTR) and its surrounding forests in Arunachal Pradesh addresses the threats of deforestation and hunting to hornbill populations. Despite protection efforts, deforestation in the adjoining Papum Reserved Forest poses a risk to hornbills. To involve the local community in conservation, the 'Hornbill Nest Adoption Program' was initiated in partnership with the Ghora-Aabhe Society, the Arunachal Pradesh Forest Department, and the Nature Conservation Foundation. This program employs a shared parenting concept, with local guardians protecting nests and urban citizens providing financial support. The initiative has successfully located and protected hornbill nests,	(Rane and Datta, 2015)

ID	Name of Records	Short Name	Appraisal of Record	Authors
			ensuring the long-term conservation of these species.	
P19	Quantitative assessment of pharmaceutical drugs in a municipal wastewater and overview of associated risks	Pharmaceutical waste monitoring	This CS project in Mysuru, India, investigates pharmaceutical compounds (paracetamol, diclofenac, salbutamol, ceftriaxone) in wastewater, particularly from healthcare establishments and a municipal wastewater treatment plant. Results showed the omnipresence of diclofenac, while salbutamol and ceftriaxone were found in various concentrations. Paracetamol was detected at the MWWTP inlet. The study engaged CS to gather information on the disposal of unused medications, revealing contributions from hospitals and community disposal to pharmaceutical compound incidence in the local environment. The findings emphasize the need for safe drug management practices.	(Shipingana, Shivaraju and Yashas, 2022)
P20	Rapid Multi-Taxa Assessment Around Dhamapur Lake (Sindhudurg, Maharashtra, India) Using CS Reveals Significant Odonate Records	Multi-taxa assessment at Dharampur Lake	This CS project conducted a four-day rapid survey around Dhamapur Lake and freshwater habitats in Maharashtra's Sindhudurg District. The study engaged public participation and documented 61 odonates, 51 butterflies, 17 amphibians and reptiles, 90 birds, and four mammals. The observations underscore the value of CS in swiftly documenting local biodiversity, with citizens contributing significantly to the recovery of important odonates records for the state.	(Mujumdar *et al.*, 2020)
P21	Report of five interesting avian species from Durgapur ecoregion, West Bengal, India by CS effort	Bird conservation in Durgapur	This study, conducted in the Durgapur ecoregion of West Bengal, India, aimed to report on lesser-known avian species in the area. Despite anthropogenic pressure, the region exhibited high avian diversity, with 257 species from 59 families recorded through CS efforts spanning	(Adhurya and Bhandary, 2019)

ID	Name of Records	Short Name	Appraisal of Record	Authors
			over five years (2013–present). The study highlighted five species, Hume's Lark and Graceful Prinia from riverine habitats, and Lesser Racket-tailed Drongo, White-rumped Shama, and Indian Blue-Robin from woodland habitats. The involvement of citizen scientists in further explorations is emphasized to enhance our understanding of bird diversity, migration patterns, and distribution in the region.	
P22	Risk communication and capacity-building: A case study on framing CBA strategies of artisanal fishing communities to sea-level rise using BASIEC	Adaptation program to sea level rise	This study focuses on addressing the risk of rising sea levels and building the capacity of artisanal fishing communities in the Ennore region of Chennai, India. The research investigates the necessary sea-level rise risk information, effective communication methods, and the efficient utilization of climate services to enhance community capacities. The study employs the BASIEC coastal climate service framework methodology, incorporating sea-level rise risk campaigns and adaptation workshops as platforms for climate services. Utilizing participatory techniques like CS and pair-wise ranking methods, the research identifies and prioritizes community-based adaptation strategies. The case study offers a valuable model for communicating sea-level rise risks and empowering artisanal fishing communities in making informed adaptation decisions, providing an approach that can be extended to empower coastal communities globally.	(Khan, Kumar and Chella, 2022)
P23	Safe Drinking Water and its Acquisition: Rural Women's Participation in Water Management in Maharashtra, India	Safe Drinking Water in Maharashtra	This study explores the active participation of women in 10 villages facing chronic issues of safe and sufficient drinking water in the arid region of Vidarbha, Maharashtra, India. Through participatory research involving discussions and dialogues with both men and women in rural communities, the study unveils how the quest for clean water empowered women not only economically but also in challenging oppression, exploitation, and human rights violations. The women's initiatives, including street plays, protests, and campaigns for water management, led to heightened community awareness. Their efforts resulted in	(Devasia, 1998)

ID	Name of Records	Short Name	Appraisal of Record	Authors
			sufficient safe drinking water in seven villages during the summer months of 1997, marking a significant shift in these communities and their relationship with water resources.	
P24	Science & Technology Agenda for Blue-Green Spaces Inspired by CS: Case for Rejuvenation of Powai Lake	Powai Lake project	This study focuses on Powai Lake, an urban water body in Metropolitan Mumbai, facing challenges of development and pollution. Over a two-year monitoring period involving citizen scientists and environmental researchers, the study identified seasonal and spatial pollution dynamics. The findings informed a three-phase rejuvenation plan, acknowledging Powai Lake as a complex system. This holistic approach aims to restore ecological balance and ensure sustainable delivery of ecosystem services, providing valuable insights for urban decision-makers in managing and rejuvenating urban lakes facing similar pressures.	(Lekshmi *et al.*, 2021)
P25	Scientific contributions and learning experiences of citizen volunteers with a small cat project in Sanjay Gandhi National Park, Mumbai, India	Small Cat Conservation in SGN Park	This project, conducted from 2017 to 2019 in Sanjay Gandhi National Park near Mumbai, involved 35 citizen volunteers in studying small wild cats. Volunteers underwent training, collected scat samples, set up camera traps, and participated in data analysis. A feedback survey from 19 participants revealed an increase in their knowledge of wildlife research, conservation issues, and small wild cats. The study highlights the value of research projects that actively involve citizens, allowing them to acquire semi-technical skills while contributing to scientific endeavours.	(Mukherjee *et al.*, 2021)

ID	Name of Records	Short Name	Appraisal of Record	Authors
P26	Socio-ecological assessment of squamate reptiles in a human-modified ecosystem of Darjeeling, Eastern Himalaya	Squamate Reptiles	This study, conducted in Darjeeling, Eastern Himalaya, aimed to assess the conservation potential of squamate reptiles in a human-modified ecosystem. The research integrated ecological and social methods, including time-constrained visual encounter surveys for ecological diversity and key informant interviews to understand community perceptions about reptiles. Results showed that respondents underestimated local reptilian diversity but recognized their habitats and phenology. A significant proportion believed squamates are poisonous, and some expressed a willingness to kill them. The study suggests that knowledge-building programs, CS initiatives, and identification of venomous squamates could contribute to their conservation in the region.	(Pradhan and Yonle, 2021)
P27	Spatiotemporal variability analysis of air pollution data from IoT based participatory sensing	Air Pollution through IoT	This study addresses the challenge of understanding the spatiotemporal variability of air pollution by utilizing IoT-based participatory sensing and data science. The proposed technique, Multiview Data Fusion model (MVDF), is designed to estimate air pollution considering both spatial and temporal dependencies. The evaluation, based on real-world air pollution data collected over a year in Kolkata, shows that MVDF outperforms several baselines. Additionally, the paper incorporates visual analysis using state-of-the-art visualization techniques to explore spatiotemporal variability at different granularities in the estimated pollution levels of MVDF.	(Middya, Roy and Das, 2021)
P28	Total Turnkey Solution For Swachh Bharat Abhiyan (SBA): A Citizen Centric Approach For Governance	SBA App	This study emphasizes the significance of geospatial technology, including remote sensing, GIS, and GNSS, in managing natural resources and addressing environmental challenges in mountain regions. It highlights the potential of CS as a valuable method for collecting scientific data rapidly, especially in disaster management scenarios. The study notes the role of citizens as "sensors," leveraging their capabilities through geotagged data, including photos, audio, and videos, collected using smartphones and other technologies. Notable examples	(Jha *et al.*, 2017)

ID	Name of Records	Short Name	Appraisal of Record	Authors
			of CS initiatives mentioned include Wikipedia and OpenStreetMap, showcasing the collaborative power of volunteers in contributing to global datasets.	
P29	Traffic noise mapping of Indian roads through smartphone user community participation	Traffic Noise Mapping	This study introduces a novel approach to monitoring road traffic noise pollution by engaging a smartphone user community. The system utilizes a client application on smartphones to record noise, process information, and communicate with a server, sharing noise level data on Google Maps. The study proposes a fuzzy logic-based classification of noise. Results from residential, commercial, and industrial areas in northern India indicate that noise levels often exceed prescribed standards. The research highlights the significant potential of involving a user community in actively monitoring and addressing noise pollution.	(Kumar, Mukherjee and Singh, 2017)
P30	Reconstructing biological invasions using public surveys: a new approach to retrospectively assess spatio-temporal changes in invasive spread	Biological species invasion monitoring	This study introduces a retrospective approach to understanding the patterns of introduction, establishment, dispersal, and spread in biological invasions. Using the case study of the ongoing invasion of the Indian bullfrog on the Andaman archipelago, the researchers surveyed 91 villages on eight islands. They assessed the occurrence of the bullfrog and reconstructed its invasion history by surveying key informants. The study found that the bullfrog's introduction likely occurred in the early 2000s, with exponential expansion since 2009. Dispersal pathways included contaminants from fish culture trade and intentional releases, with three sites acting as dispersal hubs. This approach demonstrates the efficacy of using public surveys to identify dispersal pathways and hubs in invasive species research.	(Mohanty and Measey, 2019)
P31	Using CS to build baseline data on tropical tree phenology	SeasonWatch	This study highlights SeasonWatch, an India-wide CS initiative, aiming to understand the phenology of widespread tree species in the absence of large-scale and long-term data. Over eight years (2011-2019), contributors increased annually, but consistent contribution remained low. Phenological patterns of four most-observed species (Jackfruit, Mango, Tamarind, and Indian	(Ramaswami, Sidhu and Quader, 2021)

ID	Name of Records	Short Name	Appraisal of Record	Authors
			Laburnum) were described. Kerala, with the maximum contributors, influenced these patterns. Cassia fistula showed potential aberrant phenology, suggesting a shift from historical baselines. Latitudinal patterns in Mangifera indica phenology were observed. The study emphasizes the need for sustained CS efforts to establish baselines for understanding climate change impacts on tropical tree phenology.	
P32	India Biodiversity Portal: An integrated, interactive and participatory biodiversity informatics platform	IBP	The paper introduces the India Biodiversity Portal (IBP), initiated in 2008, serving as a comprehensive platform to consolidate curated biodiversity data in India. The IBP aims to engage both amateurs and experts, facilitating interaction and knowledge exchange. Notably, the portal has experienced significant growth, with over 20,400 species descriptions and 1,280,000 observations covering 30,000 species. With 8,500 registered users, the IBP is poised to be a vital resource for scientists and conservation stakeholders, contributing to effective biodiversity conservation in India, one of the most ecologically diverse countries globally.	(Vattakaven *et al.*, 2016)
P33	Species Mapping Using Citizen Science Approach Through IBIN Portal: Use Case in Foothills of Himalaya	IBIN	The paper highlights the development of the IBIN mobile app, which integrates citizen science and technology for biodiversity monitoring in India. It provides a platform to collect geographical and taxonomical data using GPS and mobile cameras, with a case study conducted at the foothills of the Himalayas to demonstrate its effectiveness.	(Singh *et al.*, 2018)

Records from Google Search (CSP-GS)

ID No.	Name of Record	Initiation Year	Appraisal of Record	Authors/ Website
P34	Amphibians of India	2017	Amphibians of India is a peer-reviewed biodiversity platform developed by the Indian Foundation for Butterflies. It serves as a CS initiative, engaging ordinary citizens ingathering scientific data on amphibians. The platform aims to disseminate comprehensive information, encourage observation, collect data, and raise awareness about amphibian conservation.	(Kunte, 2024a)

ID No.	Name of Record	Initiation Year	Appraisal of Record	Authors/ Website
P35	Bird Count India (eBird India)	2013	Bird Count India is the representation of eBird in India. It aims to create a repository on avian data in India and hosts 17 sub-projects under it.	(BCI, 2024)
P36	Biodiversity of Chennai	2019	Biodiversity of Chennai uses iNaturalist to document all kinds of biodiversity from birds, butterflies, plants, fungi, insects, marine life, etc. around Chennai.	(CitSci India, 2021a)
P37	Butterflies of India	2009	Butterflies of India is a peer-reviewed biodiversity platform that is designed to disseminate comprehensive information on the biology of butterflies, encourage their observation to study natural history, gather population and distributional data in a centralized database, and spread awareness about butterfly conservation. It is developed by the Indian Foundation for Butterflies ("IFoundButterflies"), a group of butterfly biologists and naturalists.	(Kunte, 2024b)
P38	Charotar Crocodile Count	2013	Charotar Crocodile Count monitors Mugger crocodiles in the Charotar region of Gujarat. It engages participants and create awareness on muggers and wetlands.	(CitSci India, 2021b)
P39	Coimbatore City Bird Atlas	2020	Coimbatore City Bird Atlas is localised CS project to map the avian distribution in Coimabtore City	(CitSci India, 2023b)
P40	Community-based fisheries monitoring (CBFM) in the Lakshadweep	2014	The Community-Based Fisheries Management (CBFM) program involves the collection of systematic data on key fishery variables by engaging Lakshadweep's pole and line fishers in a participatory and voluntary manner. Utilizing co-created monitoring logbooks, this approach aims to overcome logistical constraints associated with conventional monitoring, promoting sustainability in the region's fisheries management.	(CitSci India, 2023c)
P41	Croc Watch	2021	Croc Watch is a CS where participants contribute crocodile sightings from across India. The project research on three species of crocodiles found in India	(CitSci India, 2023d)
P42	Freshwater Turtles and Tortoises of India	2016	Freshwater Turtles and Tortoises of India is hosted by the India Biodiversity Portal and the project encourages students, researchers, and biodiversity enthusiasts to contribute observations on freshwater turtles and tortoises. It aims to create a comprehensive database to shed light on these ecologically significant yet often neglected *Chelonia, Testudines* species	(IBP, 2023)
P43	Frogwatch - Mapping the Malabar Tree Toad	2020	This initiative focuses on the conservation of the endangered Western Ghats endemic Malabar Tree Toad (*Pedostibes tuberculosus*). The initiative conducts field-based workshops, awareness programs, and citizen scientist field surveys, to collect information and to create awareness on the	(IBP, 2024)

ID No.	Name of Record	Initiation Year	Appraisal of Record	Authors/ Website
			distribution and ecology of the Malabar Tree Toad. Their data is publicly available.	
P44	Harrier Watch	2016	This is a long term project focusing on monitoring wintering populations of Harriers at their established roosting sites throughout India. The initiative seeks to identify and map new roosts through exploration and comprehending the impact of grassland degradation on specialist species like harriers through citizen participation.	(ATREE, 2024)
P45	Indian Turtle Conservation Action Network	2018	The initiative involves a consortium of citizens, biologists, and turtle enthusiasts dedicated to conserving turtles and tortoises in India. The initiative aims to increase public awareness, engage citizens in real-time scientific data collection through reporting turtle sightings, and contribute to nationwide rescue and triage efforts.	(CitSci India, 2023e)
P46	Mammals of India	2017	The project, developed by the Indian Foundation for Butterflies, engages ordinary citizens in CS to observe, study, and document information on the biology of Indian mammals. It serves as a peer-reviewed biodiversity platform, aiming to gather population and distribution data in a centralized database, disseminate comprehensive information, and raise awareness about mammalian conservation.	(Bayani *et al.*, 2023)
P47	Mapping Invasive Alien Plants	2021	This initiative focuses on mapping the distributions of invasive plant species in India to address the lack of systematic information on their presence. By creating public awareness about invasive alien species and their potential impacts, the project aims to contribute to the management of these species and their ecological and socioeconomic implications.	(CitSci India, 2023f)
P48	Marine Life of Mumbai	2017	The Marine Life of Mumbai (MLOM) project aims to showcase the diverse marine life along Mumbai's shores, encouraging the rediscovery of these natural treasures and promoting awareness about their significance. The project invites collective thinking about the potential losses if these marine spaces, crucial to the city's existence, continue to be overlooked.	(Marine Life of Mumbai, 2024)
P49	Moths of India	2015	Similar to the Mammals of India project, Moths of India is a CS initiative developed by the Indian Foundation for Butterflies. It aims to disseminate comprehensive information on the biology of Indian moths, encourage observation for natural history studies, and gather population and distribution data in a centralized database to promote awareness about moth conservation.	(Kunte, 2024c)
P50	National Moth Week-India Chapter	2011	National Moth Week provides an opportunity for citizen scientists to contribute scientific data about moths. Participants help map moth distribution	(CitSci India, 2023g)

ID No.	Name of Record	Initiation Year	Appraisal of Record	Authors/ Website
			globally, supporting the documentation of this diverse group of insects. The initiative encourages observations and data contributions from individuals worldwide to enhance understanding and conservation of moths.	
P51	Reeflog	2016	Reeflog is a CS program designed for scuba divers to survey marine ecosystems across India. By collaborating with the dive tourism industry, the project tracks key species' populations and behavioural associations, contributing to the continuous monitoring of marine ecosystem health and biodiversity.	(Dakshin, 2024)
P52	Reptiles of India	2017	This CS initiative focuses on Indian reptiles, aiming to provide comprehensive, peer-reviewed, and open resources dedicated to their taxonomy, biology, and conservation. The project encourages observation, gathers population and distribution data, and spreads awareness about the conservation of reptiles in India.	(Kamdar *et al.*, 2023)
P53	UPL Sarus Conservation Project	2015	The United Phosphorus Limited Sarus Conservation Project, initiated in Gujarat, involves awareness programs, volunteer involvement, and the formation of Rural Sarus Protection Groups. Through these efforts, the project aims to document the status of Sarus cranes, identify important sites, and address threats to the species and its habitats, increasing Sarus numbers.	(CitSci India, no date)
P54	Wild Canids- India Project	2018	Focused on under-represented wild canids in India, this project assesses the ecology and conservation status of eight species and sub-species. Targeting dhole, golden jackal, Indian wolf, Tibetan wolf, Indian fox, red fox, desert fox, Tibetan fox, and the striped hyena, the initiative aims to fill research and conservation gaps in understanding these wild canids.	(Srivathsa *et al.*, no date)
P55	Non-Native Trees in India	2023	This Initiative aims to support public research on the impacts and populations of these non-native species in India.	(SciStarter, no date)
P56	Landmark Trees of India	2016	The Landmark Trees of India project is a documentation and monitoring initiative that focuses on famous, remarkable, and heritage trees across the country. The project seeks to highlight the significance of these landmark trees in the broader context of the nation's environment and heritage.	(SciStarter, no date)

Source of evidence: Articles which used data generated by CS for scientific research (CS-UD)

ID	Name of Record	Appraisal of the Record	Authors
UD1	An expanding cityscape and its multi-scale effects on lizard distribution	The study incorporated CS data for evaluating environmental determinants influencing the habitat presence of *Psammophilus dorsalis* (Lizards) in Bengaluru, India. The project acknowledges the instrumental role of CS for its critical contribution	(Thaker *et al.*, 2022)

ID	Name of Record	Appraisal of the Record	Authors
		through public participation in ecological data collection within urban ecosystems.	
UD2	A new species of *Indigryllus* (*Orthoptera, Gryllidae, Eneopterinae, Xenogryllini*) from Kerala, India, with first data on acoustics and natural habitat	CS observations from the website iNaturalist were used to identify *Indigryllus* from Kerala, India, with details on its habitat and acoustic signals.	(Jaiswara *et al.*, 2022)
UD3	Dragonflies and damselflies (Insecta: *Odonata*) of West Bengal, an annotated list of species	Data from web-based CS platforms like iNaturalist, Odonata of India, Dragonflies and Damselflies of West Bengal, DragonflySouthAsia Facebook group etc. were used to develop a list of Odonata species of West Bengal.	(Dawn, 2021)
UD4	Efficacy of angler catch data as a population and conservation monitoring tool for the flagship Mahseer fishes (*Tor spp.*) of Southern India	Data collected by anglers from 1998-2012 (14 years) were recorded through logbooks which were analysed for monitoring or conservation of Mahseer Fish.	(Pinder, Raghavan and Britton, 2015)
UD5	Habitat prediction modelling for vulture conservation in Gangetic-Thar-Deccan region of India	CS data from eBird and iNaturalist was used to fill gaps in data for habitat prediction modelling for vulture conservation.	(Jha and Jha, 2021)
UD6	Maximum Entropy Modelling Using CS: Use Case On Jacobin Cuckoo As An Indicator Of Indian Monsoon	The study developed an entropy modelling using eBird data from India between 2008-2017	(Singh and Saran, 2020)
UD7	Projected Shifts in Bird Distribution in India under Climate Change	The study utilised databases such as eBird and GBIF to find bird species distribution with respective to different climate scenarios (RCPs)	(Deomurari *et al.*, 2023)
UD8	Role of maximum entropy and CS to study habitat suitability of Jacobin Cuckoo in different climate change scenarios	GBIF repository was used to understand the migration patterns of Jacobin Cuckoo to understand climate change	(Singh, Saran and Kocaman, 2021)
UD9	Using CS in assessing the distribution of Sarus Crane (*Grus antigone antigone*) in Uttar Pradesh, India	This study uses eBird database to map the distribution of the Indian Sarus Crane in Uttar Pradesh over the past decade.	(Kumar, Sinha and Kanaujia, 2019)
UD10	Using CS to parse climatic and land cover influences on bird occupancy in a tropical biodiversity hotspot	An occupancy modelling framework was derived from the data collected using eBird checklist across the Nilgiris and Annamalai hill ranges for nine years (2013–2021).	(Ramesh *et al.*, 2022)
U11	"Satark": Landslide Prediction System over Western Ghats of India	The study utilised rainfall and land slide data collected by volunteers of Centre for CS.	(Kulkarni *et al.*, 2022)
U12	Community science data provide evidence for upward	The study utilised eBird data to understand the shift to upward range by eastern Himalayan bird	(Girish and Srinivasan, 2022)

ID	Name of Record	Appraisal of the Record	Authors
	elevational range shifts by Eastern Himalayan birds		

Source of Evidence: Articles reviewing CS in India (CS-R)

ID	Name of Record	Appraisal of the Record	Reference
R1	Network environmentalism: Citizen scientists as agents for environmental advocacy	This research focuses on the motivations and impacts of individual citizen scientists in Bangalore, India. The findings indicate that highly motivated citizen scientists not only raise environmental awareness but also share acquired expertise through social networks, education initiatives, and changes in career paths, contributing to an active environmental advocacy network in India.	(Johnson *et al.*, 2014)
R2	Best practices for data management in CS: an Indian outlook	The article advocates for the adoption of data repositories and data sharing agreements to ensure the enduring preservation and accessibility of data in CS projects. It underscores the significance of data security through encryption and access control measures and proposes guidelines for effective data management in Indian CS initiatives, encompassing standardization of data collection methods, data quality control, data management planning, sharing agreements, and security measures.	(Vattakaven *et al.*, 2022)
R3	Bird conservation from obscurity to popularity: a case study of two bird species from Northeast India	The paper explores the integration of two lesser-known bird species, *Bugun liocichla* and Amur falcon, into global conservation initiatives in Northeast India through community-based efforts and highlights the collaborative efforts of NGOs, governments, and scientists in promoting these species, despite conflicting value systems among various interest groups.	(Aiyadurai and Banerjee, 2019)
R4	CS at work in India	The article discusses MigrantWatch, a CS project in India led by the National Centre for Biological Sciences. Additionally, it highlights similar CS initiatives involving villagers in Meghalaya tracking Asian elephants and volunteers monitoring bats, demonstrating the valuable role of CS in engaging people in scientific research and conservation efforts.	(Sharma, 2008)
R5	Motivations affecting initial and long-term participation in CS projects in three countries	The article comparatively examines the motivations of citizen scientists in the United States, India, and Costa Rica for participating in CS projects. The study identifies factors that affect their initial and long-term participation, including personal interest, social interaction, project design, communication, and feedback.	(Rotman *et al.*, 2014)
R6	Operationalizing crowdsourcing through mobile applications for disaster management in India	The paper addresses the challenge of limited real-time data during disasters in India. It explores the potential of mobile apps for crowdsourcing disaster-related information by systematically analysing 33 freely accessible disaster-related mobile apps in India.	(Sukhwani and Shaw, 2020)
R7	Role of digital technology in freshwater biodiversity monitoring through CS during COVID-19 pandemic	This article discusses how digital technology can be used as a tool for biodiversity monitoring through the cooperation of citizens and scientists during the COVID-19 pandemic. It emphasises on training volunteers to share ecological data,	(Dwivedi, 2021)

ID	Name of Record	Appraisal of the Record	Reference
		photos, and videos of species and disturbances within ecosystems, using various digital platforms.	
R8	The culture of environmental education: Insights from a CS experiment in India	The article explores how culture can impact environmental education. The authors illustrate how cultural beliefs about the purpose of school education and environmental issues presented challenges to recruiting participants during the initial phase of the Student Scientist project (Binoy, Radhakrishna and Kurup, 2017).	(Radhakrishna, Binoy and Kurup, 2014)

Source of Evidence: Articles describing innovative approach (CS-IA)

ID	Name of Record	Appraisal of the Record	Authors
I1	Citizens as planners: Harnessing information and values from the bottom-up	The paper describes the crucial role citizens can play in urban planning and policy issues using mobile applications and internet-based participatory platforms. It highlights the increasing interest and capacity of citizens to engage with these online tools for urban planning and provides policy recommendations to urban planners.	(Ertiö and Bhagwatwar, 2017)
I2	Formulation of CS approach for monitoring Sustainable Development Goal 6: Clean water and sanitation for an Indian city	The article focuses on the contribution to Sustainable Development Goal (SDG) 6, specifically targets 6.1 and 6.2 related to clean water and sanitation in Tirunelveli city municipal corporation, Tamil Nadu, India by using a CS approach. The study proposes involving college students, ward councillors, and community volunteers to collect household data for all 55 wards, aiming to monitor and contribute valuable information for the achievement of SDG 6 in the region.	(Venkatesh and Velkennedy, 2023)
I3	Geospatial based citizen centric water quality measurement solution	This study developed a geospatial solution based on CS to collect geotagged data about water quality. The solution consists of an Android-based mobile app and a web-based dashboard for real-time data visualisation and analysis. The web application allows users to view interpolated geotagged data about water quality over various background maps.	(Oberai *et al.*, 2018)
I4	Shaping public behaviour and green consciousness in India through the 'Yo!Green' Carbon Footprint Calculator	The article presents the 'Yo!Green' Carbon Calculator as India's first certified energy consumption tool, enabling individuals and households to measure their carbon footprint and receive recommendations for mitigation measures. The paper outlines the methodologies, assumptions, and processes involved in developing this carbon footprint measurement system for India.	(Nahar and Verma, 2018)
I5	Visibility monitoring using mobile application	The article presents a smartphone-based visibility monitoring system that assesses air quality using the quantitative measure of turbidity. This approach encourages citizens to approach allows for widespread data collection by the public using the app. This has helped in addressing the current limitations of existing visibility estimation techniques.	(Purohit and Chauhan, 2018)
I6	NoiseProbe: Assessing the Dynamics of Urban Noise Pollution through Participatory Sensing	The innovativeness of the NoiseProbe project lies in its use of participatory sensing and mobile technology to monitor city-scale noise pollution levels in real-time. By incorporating crowd-sensed data from mobile devices, the project can provide a more comprehensive and up-to-date picture of noise pollution in urban areas. This can help policymakers and planners make more informed decisions to improve the quality of life in smart cities. Additionally, by providing users with information on their exposure to noise pollution, the project can raise awareness and encourage individual action to reduce noise pollution.	(Ghosh *et al.*, 2019)

Appendix 2: Assessment for undertaking qualitative analysis

An assessment was carried out to validate the qualitative analysis for its utilisation in the thesis for Chapter 4, 5 & 6 by using the CASP (Critical Appraisal Skills Programme) Checklist[1]. The following steps were carried out:

Checklist	Yes/No	Comments
Section A: Are the results valid?		
1. Was there a clear statement of the aims of the research	Yes	The aim and objectives of the research are clearly stated in sub-section 1.2.
2. Was a qualitative methodology appropriate?	Yes	A qualitative methodology is appropriate as the sample size is very low for quantitative assessment.
3. Was the research design appropriate to address the aims of the research	Yes	The rationale for using the research design as appropriate to the study has been explained in section 2.1.1.
4. Was the recruitment strategy appropriate to the aims of the research?	-	No recruitment was required for the study.
5. Was the data collected in a way that addressed the research issue?	Yes	The process of data collected and synthesised is summarised in Section 4.
6. Has the relationship between the researcher and participants been adequately considered?	-	No participants were recruited.
Section B: What are the results?		
7. Have ethical issues been taken into consideration?	Yes	The data for the study has been collected from publicly available databases. Ethical clearance was given by the Department of Environment & Geography, University of York for semi-structured interviews for representatives of organisations.
8. Was the data analysis sufficiently rigorous?	Yes	Data analysis has been undertaken using various frameworks and an extensive literature review. The methodology of data analysis is further explained in the Methodology section of each data chapter.
9. Is there a clear statement of findings?	Yes	The findings are clearly stated in the Results sections of each data chapter
Section C: How valuable is the research?		
10. How valuable is the research?	Yes	This is the first research to map and understand the current scenario of citizen science in India.

[1] Critical Appraisal Skills Programme Qualitative research checklist

Appendix 3: Data Management Plan

(A Data Management Plan created using DMPonline)

Name of Project: Ecological and Environmental Citizen Science Projects in India

Creators: Sagarmoy Phukan

Affiliation: University of York

Template: York DMP Template for Doctoral Student Research Projects

Project abstract: The project deals with understanding the potential of citizen science in India and the key factors that will contribute to the growth of CS in India. The study will consist of two sets of data from which results will be analysed. The first set of data consists of Journal Articles which will be used for a systematic review of EECS. The data collected are mostly PDF and can be occasionally Word documents. The data has been collected using PRISMA Framework and will be uploaded as a .txt file which will be generated through Rayyan AI. The second set of data consists of interview transcripts of identified institutional stakeholders. The data will be collected through zoom conferences and converted to transcripts to remove personal identities.

ID: 86514
Start date: 01-10-2020
End date: 20-03-2024
Last modified: 23-02-2022

1. Defining your data

1a. What data will you produce?

The research data collected will be to analyse the current scenario of CS in India, its impacts, barriers and challenges, and the roles if stakeholders using data extracted from journal articles collected using the PRISMA Framework and interview transcripts.

Data Production:

PRISMA framework and transcripts of interviews from Zoom by generating their audio files and transcripts only.

1b. What formats and software will you use?

Systematic Review Data: Collection based upon web search which will be stored as. enl as well as .txt files. The first backup of files will be kept in my PhD Google Drive under the folder Systematic Review.

Interviews: Audio recordings of interviews shall be carried out by the university-provided Zoom application. The files will be transcribed, anonymised and uploaded to University Google Drive.

1c. How much data do you expect to generate?

The data generated is expected to be less than 500GB.

1d. Who owns the data you will generate?

According to my studentship agreement, the University owns all data I create, but I retain the copyright on publications based on my data.

2. Looking after your data

2a. Where will you store your data?

I will store my data on the University's centrally managed network, in the University provided filestore (Google Drive) under the university-managed network. Only my supervisor and I will have access to the filestore.

2b. How will you back up your data?

My data will be stored on the University's centrally managed filestore. The filestore is regularly and automatically backed up by IT Services.

2c. Who else has a right to see or use this data during the project?

Only my supervisors shall have access to my data during the project.

2d. How will you structure and name your folders?

I will use the folder structure in the filestore: <Project (Systematic Review/Survey)><source of data (participant survey/project survey/SR articles)><automatic folder generation>

2e. How will you name your files?

I will use the conventions:

- *For Systematic Review:* [SR Selected Files]
- *For Interviews:* [Stakeholder Type_Stakeholder Code)]_[YYYYMMDD], for example, Group 2_01_20220605 is an interview with a Stakeholder belonging to group 2 (Stakeholder code means the sequence of interviews which will correspond to the name of the organization or institution they represent) on 5 June 2022.

2f. How will you manage different versions of your files?

All files shall be uploaded to University Provided Google drive for record and back-ups.

2g. What additional information will be required to understand your data? No additional information is required to understand my data.

3. Archiving your data

3a. What data should be kept or destroyed after the end of your project?

All data can be kept until the end of the 10-year archive period by the university as per its policy.

3b. For how long should data be kept after the end of your project?

In line with the University Research Data Management Policy, the data that will support my published research findings will be kept for 10 years from the date of the last requested access.

3c. Where will the data you keep be archived at the end of the project?

The data supporting my thesis will be provided to the University's Research Data York service for archiving at its institutional repository.

3d. When will you archive your data?

I will provide a copy of the data supporting my thesis to the University for long-term retention when I submit my thesis.

4. Sharing your data at the end of your project

4a. What data should or shouldn't be shared openly and why?

Data from the systematic review can be shared openly. Respondents to my survey will be informed that their responses will be anonymised and archived for data sharing with the UK Data Service. Explicit consent for this will be collected.

4b. Who should have access to the final dataset(s) and under what conditions?

Bonafede researchers including postgraduate researchers from UK and India will be granted access to the data upon request after due consideration by Dr Rachel Pateman or Dr Steve Cinderby.

4c. How will you share your final dataset(s)?

- A copy of the data supporting my thesis will be retained by the University's Research Data York service, and users will be able to download my data from the York Research Database, the University's research portal.
- A copy of the data supporting my thesis/publication will be retained by the University's Research Data York service University, and my supervisor will field any requests for access on my behalf. Data will be made available to the requestor where appropriate.
- My physical data will be retained for the long term by the University's Borthwick Institute for Archives, who will field any requests for access on my behalf.

5. Implementing your plan

5a. Who is responsible for making sure this plan is followed?

I will take responsibility for carrying out the actions required by this plan and report them to my supervisor as appropriate.

5b. How often will this plan be reviewed and updated?

My supervisor and I will review this plan every 6 months and will agree with updates if necessary.

5c. What actions have you identified from the rest of this plan?

- Set up a backup system and periodically test that I can restore from my backup.
- Ensure that I request informed consent from my participants for archiving and sharing their data.

5d. What policies are relevant to your project?

This project is covered by the University of York Research Data Management Policy.

5e. What further information do you need to carry out these actions?

No further information is required.

Appendix 4: Quantitative data extraction from selected records using PRISMA.

Originally Google form was used to extract data. This is the list of entries for data extraction.

1. Title/Name of Project:
2. Year of publication: dd/mm/yyyy
3. Type of Literature
   - Project Article/Project Website
   - Innovative Approach for CS Technology
   - Using CS data to produce scientific research
   - Review of Citizen Science in India

Project Information (CSP-AL; CSP-GS)

4. Abstract:
5. Starting year of the project
6. End year of project
7. Type of subject topic:
   - Air Pollution
   - Biodiversity Conservation
   - Climate Change
   - Noise Pollution
   - Sanitation
   - Adaptation to Climate Change
   - Disaster Management
   - Waste Management
   - Water Quality and Management
8. Number of publications of the project
9. URL
10. Location of the project (State/UT) (Tick all that apply) States and UTs names of India
11. Name of District (if provided)
12. Project Site (Inclusivity across socio-economic dimensions):
    - Metropolitan City
    - Tier 2 and 3 cities
    - Village/Rural areas
    - Designated forest areas
13. Length of project:
    - Short-term (research conducted on a particular topic only once) or Pilot Project

    - Long-term (Continuous projects or repeated more than once)

14. Type of project based on project goals
    - Action: Monitoring and evaluation of environmental changes.
    - Conservation: Ecology or biodiversity protection.
    - Investigation: To answer specific scientific questions.
    - Education: To create engagement and awareness among participants.
    - Other:
15. What is the overall aim of the activity? (Tick all that apply)
    - Research
    - Policy outcome: e.g. environmental management monitoring, action or other policy actions
    - Public engagement
    - Education
    - Game
16. Type of Involvement based on Veeckman *et al.,* 2019
17. Was training provided before the activity? Yes/No
18. Training (skills requirements from the participants)
    - Anyone: no assumption about expertise
    - Self-selected: a barrier to entry or assumptions about prior knowledge
    - Targeted: aiming at a specific set of experts, for activities beyond their work
19. Participant diversity (Tick all that apply)

School students (<18); University students (UG+PG) (18-25); PhD (25-30); Adults (and professionals) (25-65); Senior Citizens (65>); Other

20. Number of participants
21. Describe participation
22. Gender diversity (Give numbers)
23. Technology/scientific technology/App used in the project

For Innovative Applications

1. Describe the innovative process:
2. Type of subject topic: (Same as used in Project Information)

For CS data utilisation

1. How was the CS data utilised?
2. Type of subject topic

For reviews

1. Review Topic (Tick all that apply) Motivation; Review of Techniques; Review on CS in India; Other
2. Describe the review in brief

Appendix 5: Consent form for the stakeholder interview

Interviewee Information

Thank you for considering taking part in my study '*Institutional Actors of Citizen Science in India*'. This is a PhD research project by me, Sagarmoy Phukan, a PhD Candidate at the University of York, with the Stockholm Environment Institute at York.

This interview is designed to evaluate your organization's experiences as a part of citizen science projects, to understand what motivated you to start or aid the project and what can be done to sustain and promote the project and citizen science in India in general. I hope this will help to inform the design of future projects and how citizen science can be supported in India.

Participation in the interview is voluntary and all questions in the interview are also voluntary. If you do not want to answer any of the questions, that is fine. You can also stop the interview at any time and request for your answers not to be recorded without giving a reason. You can also ask to withdraw your interview responses from the analysis by the end of March 2023 at the latest.

The interview should take approximately 45-60 minutes to complete and will be recorded on Zoom (iOS encrypted recordings will only be used if you would like to have the interview in person). Please read the privacy notice under which your data will be protected. Click here to read the policy.

All of the data you provide will be stored securely and access restricted to me, my supervisors, Dr Rachel Pateman and Dr Steve Cinderby from the University of York and potentially my examiners. Summarized findings will be shared through scientific publications and other public outputs as well as mailed to your organization. This may include direct quotes from your responses. Your name will not be included in outputs and you can choose whether your job title and organisation name are also anonymised. Your anonymized responses will be archived with the University institutional repository for a period of 10 years and can be used by other researchers for further studies.

If you have any questions about this interview, or how your data will be processed, then please contact me, Sagarmoy Phukan at (email id). or my supervisors Dr Rachel Pateman (email id) and Dr Steve Cinderby (email id)

Appendix 6: Question guide for semi-structured interview

Questions

Research objective

To better understand the motivations of projects, barriers and challenges and the network of institutional stakeholders of citizen science in India

Background questions

Aim: to put the interviewee at ease and get the conversation started

- Role of the representative and what they do in the project
- How does your organisation links to citizen science projects (E.g. if you are directly involved with the coordination of the project)

Motivation

Aim: to gather information about the motivations of the project

- Motivation to associate with citizen science projects by your organization
- Your impacts
- Public awareness and scientific involvement

Barriers to outreach and network development

Aim: to capture how networks among institutional actors have developed and the barriers to outreach to participants

- What mechanisms are you using to outreach to participants
- What works well and not so well
- Involvement with the other institutional actors e.g., local government, grassroots organizations, and other organisations.

Funding

Aim: to understand central funding avenues for projects

- Influence of government agencies in funding and their outlook towards citizen science to tackle environmental and climate change issues.
- Influence of business and industries.
- Potential of crowdfunding for citizen science in India
- Sustainability of projects and other funding avenues

Activity at the end of the interview

Aim: to understand the interest and influence of stakeholders within the project.

Appendices 7: List of Institutional Stakeholders of CS in India.

The details of their roles are provided in the excel spreadsheet shared with the thesis file.

ID. No.	Names of Institutional Stakeholder	Abbreviation
1	Forest Departments	Forest Department
2	India Bioresource Information Network (IBIN)	IBIN
3	India Biodiversity Portal (IBP)	IBP
4	Public Affair Centre, Bangalore	PAC
5	Vana Samrakshana Samithy of Kadar Tribes	VSS
6	Bharati Vidyapeeth Institute of Environment Education and Research	BVIEER
7	Indian Institute of Technology Bombay	IIT-B
8	Gawand-wadi Vikas Sanstha (Trust)	GVS
9	Bugun Welfare Society (a local NGO)	BWS
10	Conservation India (CI)	CI
11	Nagaland Wildlife and Biodiversity Conservation Trust (NWBCT)	NWBCT
12	National Institute of Advanced Studies (NIAS)	NIAS
13	North Carolina Museum of Natural Sciences	NCNMS
14	Block by Block	ByB
15	Peer Water Exchange	PWX
16	Mahseer Trust	MT
17	Indian Institute of Remote Sensing, ISRO	IIRS-ISRO
18	Department of Computer Science, Gujarat University, Ahmedabad,	GU
19	Gramin Vikas Trust	GVT
20	Managing Aquifer Recharge and Sustainable Groundwater Use through Village-level Intervention (MARVI)	MARVI
21	ICIMOD	ICIMOD
22	University of Florida	UoF
23	Wildlife Conservation Society	WCS
24	Samrakshan Trust, Bolsalgre, Baghmara, Meghalaya	SamT
25	United States Geological Survey, Patuxent Wildlife Research Center, USA	USGS
26	Centre for Wildlife Studies	CWS
28	District Administration	Panchayat/Municipalty
29	Swachh Bharat Mission	SBM
30	DragonflySouthAsia	DSA
31	Diversity India	DI
32	Durgapur Wildlife Information and Nature Guide Society	DWINGS
33	Government of India	GoI
34	Community Action for Development (CAD)	CAD
35	Grassroots organization	GrO
36	Bureau of Energy Efficiency, New Delhi, India	BEE
37	Ashoka Trust for Research in Ecology and the Environment (ATREE)	ATREE
38	University of Lucknow	UnL
40	Undi Centre of Acharya N.G. Ranga Agricultural University (ANGRAU)	ANGRAU

ID. No.	Names of Institutional Stakeholder	Abbreviation
41	Salim Ali Centre for Ornithology and Natural History	SACO&NH
42	Asian Biodiversity Conservation Trust	ABCT
43	Azim Premji University	APU
44	Bombay Natural History Society	BNHS
45	Care Earth	CE
46	Foundation for Ecological Research Advocacy and Learning	FERAL
47	Foundation for Ecological Security	FES
48	Foundation for Revitalisation of Local Health Traditions	FRLHT
49	French Institute of Pondicherry	FIP
50	Hornbill Foundation	HF
51	Indian Foundation for Butterflies	IFB
52	Keystone Foundation	KF
53	Madras Crocodile Bank Trust	MCBT
54	National Centre for Biological Sciences	NCBS
55	OSGeo	OSGeo
56	Strand Life Sciences	SLS
57	WWF India	WWF
58	Zoo Outreach Organisation	Zoo
59	Society for Peoples Action for Development (SPAD)	SPAD
60	Local Schools	Schools
61	HSBC	HSBC
62	Nature Conservation Foundation	NCF
65	Ministry of Environment and Forests (MoEF)	MoEFCC
66	Wildlife Institute of India	WII
67	Convention on Migratory Species Office (CMS)	CMS
68	United Nations Environment Programme (UNEP)	UNEP
69	MES Keveeyam College	MESKC
70	Museo de Paleontologia de Guadalajara, Mexico	MPG
71	UN-Habitat	UNH
72	Mumbai Metropolitan Region Development Authority (MMRDA)	MMRDA
73	Mumbai Environmental and Social Network (MESN)	MESN
74	Resident Welfare Associations	RWA
75	iNaturalist	iNaturalist
76	Odonata of India	OI
77	Damselflies of West Bengal	DWB
78	University Grants Commission	UGC
79	Arid Communities and Technologies (ACT)	ACT
80	Western Sydney University, Penrith, Australia	WSU
81	CSIRO Land & Water, Adelaide, Australia	CSIROLW
82	InternationalWater Management Institute, Colombo, Sri Lanka	IWMI
83	Development Support Centre, Ahmedabad, India	DSC
84	Maharana Pratap University of Agriculture and Technology, Udaipur, India	MPUAT
85	Vidhya Bhawan Krishi Vigyan Kendra, Udaipur, India	VBKVK

ID. No.	Names of Institutional Stakeholder	Abbreviation
86	Mekong Region Futures Institute, Laos	MRFI
87	Foundation for Environment Research and Conservation	FERC
88	MIT World Peace University, Pune	MITWPU
89	Zoological Survey of India	ZSI
90	Syamantak	Syamantak
91	Sindhudurg Wetland Brief Committee	SWBC
92	Ministry of Jal Shakt	MJS
93	People4Planet	People4Planet
94	Innolabs	Innolabs
95	e-bird India	e-Bird
96	Wageningen University and Research Centre	WURC
97	Department of Biotechnology	DBT
98	Municipal Corporation/Bord (PMC)	MB/C
99	Jawarharlal Nehru National Urban Renewal Mission (JnNURM)	JnNURM
100	Department of Science and Technology (India)	DST
101	Natural Environmental Research Council (UK)	NERC-UK
102	NANO (NF-POGO Alumni Network for Oceans)	NANO
103	Google Earth Engine Faculty Grant	GEEFG
104	LGFG Baden-Wuertemburg/ Germany and German Academic Exchange Service (DAAD), Bonn	DAAD
105	Australian Centre for International Agricultural Research, Canberra, Australia.	ACIAR
106	U.S. Fish and Wildlife Service	USFWS
107	Asian Elephant Conservation Fund, WWF	AECF
108	Asian Rhino and Elephant Action Strategy	AREAS
109	Sir Peter Scott Fund (IUCN)	IUCN
110	Indian Institute of Management, Udaipur	IIMU
111	Sanford School of Public Policy	SSPP
112	PGIMER	PGIMER
113	Netherlands Ministry of Agriculture, Nature and Food Quality	NMANFQ
114	University of Kassel, Kassel, Germany	UoK
115	Department of Biology, University of Arkansas	UoA
116	Indian Institute of Technology, Gandhinagar	IIT-G
117	Social Science Research Council (SSRC), New York, USA	SSRC
118	Indian Institute of Science	IISc
119	Nansen Environmental Research Centre India, Amenity Centre, Kerala University of Fisheries and Ocean Sciences	NERCI
120	Fishery Resources Assessment Division, ICAR-Central Marine Fisheries Research Institute	ICAR-CMFRI
121	CSIR-National Institute of Oceanography	CSIR-NIO
122	Centre for Geography and Environmental Science, College of Life and Environmental Sciences, University of Exeter	UoE
123	National Centre for Earth Observation, Plymouth Marine Laboratory, Plymouth	NCEO
124	University of Turku, Finland	UoT
125	Northern Illinois University, USA	NIU

ID. No.	Names of Institutional Stakeholder	Abbreviation
126	Shyampur Siddheswari Mahavidyalaya	SSM
127	National Science Foundation	NSF
128	American Alliance of Museums,	AAM
129	US Department of State, and Bureau of Educational and Cultural Affairs.	USDS
130	Sree Narayana Training College, University of Kerala	SNTC
131	Department of Atmospheric Science, University of Alabama in Huntsville, USA	UoAlabama
132	Faculty of Science and Technology, Bournemouth University, Fern Barrow, Poole, Dorset	BU
133	Conservation Research Group (CRG), St Albert's College, Kochi	St.AC
134	Department of Zoology, Visva-Bharati University	VBU
135	GAIL (India) Ltd. New Delhi, India	GAIL
136	Darjeeling Government College	DGC
137	Tirpude College of Social Work, Nagpur University	TCSW
138	Gujarat Institute of Desert Ecology	GIDE
139	College of Fisheries, Junagadh Agricultural University	Junagadh AU
140	Shree Ramkrishna Institute of Computer Education & Applied Sciences	SRICEA
141	VIVA College, Virar, Vasai	VIVA College
142	United Way Mumbai	UW-M
143	Dhirajlal Talakchand Sankalchand Shah College of commerce	DTSSCC
144	G.N. Khalsa College Mumbai	GNKC
145	K.J. Somaiya Institute of Management Studies and Research	KJS-IMSR
146	Shri Pancham Khemraj Mahavidyalaya	SPKM
147	National Centre for Polar and Ocean Research	NCPOR
148	RSN College of Art & Science	RSNCA&S
149	Karnataka University	KU
150	College of Fisheries-Tannirbhavi	CF-Tannirbhavi
151	Snehakunja Trust, Kasarkod, Honnavar, Karnataka	Snehakunja Trust
152	Nirmalagiri College	NC
153	District Collector Office, Disaster Management, Kozhikode	Local Government
154	Cochin University of Science and Technology	CUST
155	Mahatma Gandhi University	MGU
156	St. Thomas College and S. N. College, Sivagiri, Varkala	St.TC
157	Egra Sarada Shashi Bhusan College	ESSBC
158	Fakir Mohan Univerity	FMU
159	CNCB Academy of Science and Technology	CBCB-AST
160	Berhampur University	Berhampur U
161	Centre for Studies on Bay of Bengal, Andhra University	AU
162	Indian Coast Guard	ICG
163	National Centre for Coastal Research	NCCR
164	Presidency College	PC
165	SRM Institute of Science & Technology	SRM-IST
166	Nammal Mudiyum Trust	NMT
167	Annamalai University, Parangipettai	Annamalai U
168	M.S.Swaminathan Research Foundation	M.S.Swaminathan RF

ID. No.	Names of Institutional Stakeholder	Abbreviation
169	College of Fisheries Engineering, TNJFU	CF-TNJFU
170	Alagappa University	Alagappa U
171	FC&RI	FC&RI
172	Puducherry Pollution Control Committee	SPCB
173	Pondicherry University	PU
174	Ministry of Earth Sciences, Govt. of India	MES
175	Nature Mates Nature Club	NMN
176	Dakshin Foundation	DF
177	Sikkim University	SU
178	Fulbright-Nehru Academic and Professional Excellence Awards program	Fullbright-Nehru Award
179	The National Geographic Society	NGS
180	Department of Politics, Economics, and International Studies, University of Hartford,	UH
181	Department of Environmental Sciences, University of Kerala	UK
182	Toulan School of Urban Studies, Portland State University, Portland	PSU
183	Department of Zoology, Madras Christian College,	MCC
184	Department of Environmental Sciences, All Saints' College, Thiruvananthapuram	ASC
185	Centre for Action Research on Environment Science and Society (CARESS),	CARESS
186	Department of Science and Humanities, K. J. Somaiaya College of Engineering,	SVU
187	Department of Zoology, B.N.N. College, Bhiwandi	B.N.B.C.
188	Department of Zoology, School of Basic & Applied Sciences, Shri Guru Ram Rai University	SGRRU
189	Department of Civil Engineering, Government College of Engineering	GCE
190	Department of Civil Engineering, Thiagarajar College of Engineering, Madurai,	TCE
191	IIFM, Bhopal	IIFM
192	Duleep Matthai Nature Conservation Trust	DMNCT
193	IMPRINT-1	IMPRINT-1
194	Ministry of Human Resources Department (MHRD)	MHRD
195	National Institute of Technology Durgapur	NIT-D
196	Dr. B. C. Roy Engineering College, Durgapur	B.R.C.E.C.
197	GBIF	GBIF
198	eBird	eBird
199	ENVIREM	ENVIREM
200	WorldClim	WorldClim
201	Department of Environmental Sciences, JSS Academy of Higher Education and Research,	JSS-AHER
202	Center for Water, Food and Energy, GREENS Trust,	GREENS Trust
203	Andaman and Nicobar Environment Team, Wandoor	ANET
204	Centre for Invasion Biology, Department of Botany and Zoology, Stellenbosch University, Stellenbosch 7602, South Africa	Stellenbosch University
205	Tata Institute of Social Sciences (TISS)	TISS

ID. No.	Names of Institutional Stakeholder	Abbreviation
206	Coastal Resource Centre	CRC
207	IGCS	IGCS
208	Hacettepe University	Hacettepe Uni.
209	Earthwatch Institute India Trust	Earthwatch India
210	Earthwatch Europe	Earthwatch Europe
211	University of Siena	UoS
212	Mumbaikars for SGNP	M-SGNP
213	Sanjay Gandhi National Park,	SGNP
214	Indian Institute of Science Education and Research	IISER
215	Thapar University	Thapar U
216	Jadavpur University	JU
217	Higher Education, Science and Technology and Biotechnology, Department of Science and Technology, Government of West Bengal, India.	DST-GoWB
218	Wipro Foundation	WF
219	Mathrubhumi	Mathrubhumi
220	Columbia University	Col. Uni
221	Groningen Institute for Evolutionary Life Sciences (GELIFES)	GELIFES
222	Univ. of Groningen	Univ. of Groningen
223	Univ. of California, Los Angeles,	Univ. of California
224	Institut de Systématique, Evolution, Biodiversité	ISYEB
225	Environmental Management and Policy Research Institute	EMPRI
226	Panjab University	Panjab-U
227	Indian Institute of Technology Madras	IIT-M
228	Inlaks Shivdasani Foundation Ravi Sankaran Fellowship Programme	Inlaks
229	Department of Community Medicine, Seth GS Medical College and KEM Hospital	SGSMC&KEMH
230	Amity Institute of Forestry and Wildlife, Amity University	Amity U
231	College of Climate Change and Environmental Science, Kerala Agricultural University	KAU
232	Department of Agriculture and Farmers' Welfare	DAFW
233	University of Maryland	UM
234	National Museum of Natural History, Smithsonian Institution	NMNH-SI
235	Information Technology, Brigham Young University	BYU
236	Duke University, USA	Duke U
237	Graduate School of Media and Governance, Keio University, Japan	Keio U
238	UMR AMAP, IRD, Montpellier, France	UMR AMAP
239	School of Pharmacy, RK University,	RKU
240	Mokarsagar Wetland Conservation Committee	MWCC
241	Green Support Services, Sargasan Circle, Gandhinagar	GSS
242	Asian Waterbird Census (AWC)	AWC
243	Goa University	GU

List of Abbreviations

1. 3DMSD: 3D Mini Secchi Disk
2. AROs: Academia and Research Organisations
3. ATREE: Ashoka Trust for Research in Environment and Ecology
4. B&O: Barriers and Opportunities
5. BC: Biodiversity Conservation
6. BCI: Bird Count India
7. BDA: Biological Diversity Act
8. CAGR: Compound Annual Growth Rate
9. CCS: Centre for Citizen Science
10. CS: Citizen Science
11. CSA: Citizen Science Association
12. CS-IA: Citizen Science – Innovative Approach
13. CSIAF: Citizen Science Impact Assessment Framework
14. CSIR: Council of Scientific and Industrial Research
15. CSOs: Civil Societies
16. CSP-AL: Citizen Science Projects – Academic Literature
17. CSP-GS: Citizen Science Projects – Google Search
18. CS-R: Citizen Science Projects – Review
19. CS-UD: Citizen Science Projects – Utilisation of Data
20. CWS: Centre for Wildlife Studies
21. D4D: Data for Development
22. DAAD: German Academic Exchange Service
23. DBT: Department of Biotechnology
24. DMM: Disaster Monitoring and Management project
25. DORA: Declaration on Research Assessment
26. DSA: DragonflySouthAsia
27. DST: Department of Science and Technology
28. ECSA: European Citizen Science Association
29. EECS: Ecological and Environmental Citizen Science
30. EME: Environmental Monitoring and Evaluation project
31. EU: European Union
32. FLI: Formal Learning Institute
33. GDPR: General Data Protection and Regulation
34. GoI: Government of India
35. HSBC: Hong Kong and Shanghai Banking Corporation
36. IBIN: Indian Bioresource Information Network
37. IBP: India Biodiversity Portal
38. IDRN: India Disaster Resource Network
39. IF: Impact Factor
40. IGOs: International (non-) governmental organisations
41. IIT: Indian Institutes of Technology
42. IUCN: International Union for Conservation of Nature
43. MARVI: Managing Aquifer Recharge and Groundwater Use through Village-level Intervention
44. MeitY: Ministry of Electronics and Information Technology
45. MICS: Measuring the Impact of Citizen Science
46. MoEFCC: Ministry of Environment, Forest and Climate Change
47. NAPCC: National Action Plan for Climate Change
48. NCAP: National Clean Air Program

49. NCBS: National Centre of Biological Science
50. NCF: Nature Conservation Foundation
51. NDEM: National Database for Emergency Management
52. NERC-UKRI: Natural Environment Research Council
53. NGO: Non-governmental Organisation
54. NIAS: National Institute of Advanced Studies
55. NIC: National Information Centre
56. NSF: National Science Foundation
57. OECD: Organization for Economic Co-operation and Development
58. PESTELE: Political, Economic, Social, Technological, Environmental, Legal, and Ethical
59. PR: Participatory Research
60. PRA: Participatory Rural Appraisal
61. PRCS: Public Relations Citizen Science
62. PRISMA: Preferred Reporting Items for Systematic Reviews and Meta-Analyses
63. PWX: Peer Water Exchange
64. SBA: Swachh Bharat Abhiyan *(Clean India Mission)*
65. SCM: Smart Cities Mission
66. SDG: Sustainable Development Goals
67. SNA: Stakeholder Network Analysis
68. SR: Systematic Review
69. SWOT: Strengths, Weaknesses, Opportunities, and Threats
70. TDS: Transdisciplinary projects
71. UGC: University Grants Commission
72. UK: United Kingdom
73. UNFCCC: United Nations Framework Convention on Climate Change
74. USA: United States of America
75. UT: Union Territories
76. WoS: Web of Science
77. WWF: World Wildlife Fund

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