Developing metrics and instruments to evaluate citizen science impacts on the environment and society

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Abstract (for dissemination)	This report presents the draft MICS Citizen Science Impact Assessment framework which constitutes the overarching structure within which novel and appropriate impact assessment methods will be provided for citizen science projects, including the MICS case studies, and which will be implemented via the MICS online platform.
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Acronyms

CBPR	Community-Based Participatory Research
CER	Community-Engaged Research
CLI	Community Level Indicators
CO	Citizen Observatories
CoP	Community of Practice
CS	Citizen Science
CSIA	Citizen Science Impact Assessment
DITOS	Doing It Together Science
EC	European Commission
GT2.0	Ground Truth 2.0
HU	Hungary
IA	Impact Assessment
IMP	Impact Management Project

IRIS	Impact Reporting and Investment Standards
ISE	Informal Science Education
IT	Italy
MoRRI	Monitoring the Evolution and Benefits of Responsible Research and Innovation
MoS	Measures of Success
NGO	Non-Governmental Organisation
RIA	Research and Innovation Action
PPSR	Public Participation in Scientific Research
RO	Romania
RRI	Responsible Research and Innovation
SDGs	Sustainable Development Goals
SMART	Specific, Measurable, Achievable, Realistic, Time-dependent
STEM	Science Technology Engineering Maths
ToC	Theory of Change
UK	United Kingdom
UN	United Nations
UNSTATS	United Nations Statistics Division
WO	WeObserve
WP	Work Package

Executive Summary

The MICS project is tasked with setting up and implementing an Impact Assessment framework for citizen science projects that serves to capture impacts in five distinct domains: society, science, environment, economy and governance. This report is a deliverable of Work Package 2 (WP2) – 'Methods for measuring citizen-science impact' which provides the conceptual insights for the development of MICS approaches and tools to assess citizen-science impacts. The purpose of this report is to present the draft MICS Citizen Science Impact Assessment framework which constitutes the overarching structure within which novel and appropriate impact assessment methods will be provided for citizen science projects and which will be implemented via the MICS online platform.

This report presents the steps involved in constructing (and eventually validating) the MICS Citizen Science Impact Assessment (CSIA) framework. The overall aim of the MICS CSIA framework is to synthesise existing methods and indicators in a coherent structure and to indicate gaps where indicators are still needed. The results from the systematic review of 74 publications in the citizen science literature on impact assessment methodologies, frameworks or approaches and the insights generated from the general impact literature (reported in MICS D2.2, Wehn et al., 2020a) are combined and organised within a holistic intervention logic and using the five MICS impact domains (society, science, economy, environment, governance).

The report presents the draft MICS CS IA framework at three different levels of abstraction: i) the overarching impact domains; ii) the intervention logic; and iii) the identified conceptual and practical approaches within each domain (themes and indicators). Publications are grouped according to the MICS impact domains and, within those, according to themes. Clusters of indicators within each theme will be reviewed and relevant ones selected, based on the strengths and weaknesses reported in the literature review. The details of selected indicators will be entered in the draft MICS CSIA framework in Excel according to a tailored MICS indicator characteristics protocol. For the development of the protocol, the MoRRI (Monitoring the Evolution and Benefits of Responsible Research and Innovation) indicator characteristics were adopted, refined or supplemented with those relevant for the MICS context, resulting in a list of 17 items.

The development of the framework thus far has resulted in distinctly different inputs per MICS impact domain, with the largest number of relevant publications by far in the society impact domain and the lowest in the economy domain. It will, therefore, be necessary to identify missing themes and indicators, drawing on other relevant research areas. With the exception of two publications, each of the reviewed publications considers one or more of the five impact domains, with the majority of the approaches focusing on one or two domains and only two out of the 77 publications referring to all five domains. The analysis of the methodological approaches per impact domain reveals that a mixed methods approach (qualitative and quantitative) is by far the most commonly used for capturing impacts of citizen-science in the different domains. The low percentage of quantitative methods used in all five domains is noteworthy, and perhaps particularly so for the economy domain. Overall, it can be argued that this is indicative of the difficulties (and inappropriateness) with quantifying the impacts of citizen science.

The inputs drawn upon for constructing the MICS CSIA framework stem from diverse scientific fields and epistemological approaches, incorporating distinct perspectives and framings not only of impact assessment but also citizen science. These go hand in hand with not only diverse but also often very comprehensive data collection methods. A key step in the completion of the framework will therefore be the careful comparison, alignment and (if appropriate) combination of relevant indicators per domain and theme.

To illustrate the application of the MICS CS IA framework by citizen science projects, and since not all citizen science projects are alike in terms of the resources available for assessing the impacts of their activities, the report presents a range of use cases. Two major determinants are used to broadly distinguish different scenarios for the use of the MICS CS IA framework: a) resources and expertise; b) timing.

The steps involved in testing and validating the draft MICS CS IA framework will be undertaken in the remainder of the project life time and will be reported on in deliverable MICS D2.7. Across these activities, the feasibility of diverse and comprehensive data collection methods and the implications for data management will require attention. Similarly, the curation of the MICS CSIA framework during and after the project life time will need careful consideration.

1 Introduction

1.1 Background on MICS

The MICS project develops approaches and tools to assess citizen-science impacts. These approaches and tools can help to plan and implement projects in ways that lead to more robust results.

The MICS project specifically aims to:

- provide comprehensive, participatory and inclusive metrics and instruments to evaluate citizen science impacts;
- implement an impact-assessment knowledge-base through toolboxes for methods application, information visualisation, and delivery to decision makers, citizens and researchers;
- improve the effectiveness of nature-based solutions through test-site development and citizen-science tool validation;
- generate new approaches that strengthen the role of citizen science in supporting research and development;
- foster a citizen-science approach to increase the extent to which scientific evidence is taken up by policy makers through recommendations and guidelines.

The result is an integrated platform where these metrics and instruments are available for use by anyone involved in a citizen-science project wanting to understand its impact, whether at the planning stage or several years after the project's conclusion. This platform is validated by pilot testing in four test and validation sites across Europe. The four test and validation sites are in the UK, Italy, Hungary and Romania. These sites explore the applicability of MICS impact-assessment tools in regions with differing needs, contexts, and approaches to nature-based solutions, and with various levels of citizen-science application. For example, in Western Europe, river restoration is increasingly carried out within an ecosystem-based management framework at river or catchment scale; in Southern Europe, river restoration tends to be issue-specific with some ecosystem relevance; in Central and Eastern Europe, river restoration is about ecosystem protection and related to existing infrastructure.

1.2 Purpose

The MICS project is tasked with setting up and implementing an Impact Assessment framework for citizen science projects that serves to capture impacts in five distinct domains: society, science, environment, economy and governance. This report is a deliverable of Work Package 2 (WP2) – 'Methods for measuring citizen-science impact' which provides the conceptual insights for the development of MICS approaches and tools to assess citizen-science impacts. The purpose of this report is to present the draft MICS Citizen Science Impact Assessment framework which constitutes the overarching structure within which novel and appropriate impact assessment methods will be provided for citizen science projects and which will be implemented via the MICS online platform.

1.3 Structure of the report

This report is organised as follows. Following this introductory chapter, section 2 recaps on the guiding principles for the MICS Citizen Science Impact Assessment framework that had been presented in MICS deliverable D2.2. Section 3 presents the methodological approach and steps applied for constructing the overarching MICS Citizen Science Impact Assessment framework. Section 4 presents the progress towards the draft framework at three different levels of abstraction: i) the overarching impact domains; ii) the intervention logic; and iii) the identified conceptual and practical approaches within each domain (e.g. clusters of themes, indicators). Moreover, the chapter considers the completion and curation of the MICS framework. Section 5 presents the practical steps involved in the application of the framework in different scenarios, detailing five distinct use cases. Section 6 concludes with an indication of which MICS Work Packages and tasks will capitalise on the results of this report.

2 Background

2.1 Definition of key terms

This section presents relevant key terms and terminology as background information for this report on the MICS CSIA framework. Specifically, we present explanations of the elements of an intervention, the types of results in results-chain assessment approaches, the additional aspects that differentiate the Theory of Change from the (linear) intervention logic and key elements of a monitoring and assessment framework,.

Box 1: Key terms and terminology

Elements of an Intervention

Objectives define and delineate the purpose and goals of a project, program or policy. Ideally, they are formulated to be SMART (Specific, Measurable, Achievable, Realistic, Time-dependent) in relation to the concept.

Concept articulates what action needs to be taken and how in response to a challenge or problem that needs solving.

Inputs are resources such as people, raw materials, energy, information (including the concept), or finance that are put into a system such as a project, program or policy to obtain a desired output.

Activities are the actions undertaken by the intervention; tasks undertaken to transform inputs into outputs. Activities are usually based on strategies.

Outputs (see definition in 'types of results')

Types of results in results-chain assessment approaches

Outputs are what is directly produced or supplied by an intervention, they often relate to the expected deliverables of the intervention and consist of tangible products or services produced as a result of the activities (and can be subject to external factors).

Outcomes capture the immediate changes in a situation, including behavioural changes that result from the intervention outputs (including intended and unintended, positive and negative changes). They generally have a clear link with the intervention, but are influenced by external factors as well.

Specific outcomes are emerging, observable.

Wider outcomes consist of the social, institutional, economic and environmental changes triggered by and attributable to (use of) the outputs and are typically more difficult to observe and/or attribute.

Impacts broadly define the (widespread) changes over a longer period of time that result from an accumulation of outcomes and affect the wider economy and society beyond those directly affected by the intervention. They are strongly influenced by external factors.

Elements of a Theory of Change

Impact domain or domains of change refers to a specific (sub) system, sector or thematic area of envisaged change(s) of an intervention.

Strategies are successful approaches which a review of the state-of-the-art has identified that helped similar communities or organisations to achieve the kinds of results the project, programme or policy is attempting to elicit.

Assumptions are statements about accepted cause and effect relationships, or estimates of a fact deducted or from the known existence of other fact(s). They provide a basis for the generation of concepts, strategies, and actions by enabling the creation of "what if" scenarios to simulate possible situations and explain how and why the strategy will work. Assumptions can be misleading when accepted as reality without examination; the Theory of Change approach ensures assumptions are transparent and accessible to validation.

Influential factors or external factors are outside influences that can impact the ability of a project or investment to achieve its strategic goals and objectives. These external factors might include competition; social, legal and technological changes, and the economic and political environment.

Elements of a monitoring and assessment framework

Monitoring: The supervision of activities in progress to ensure they are on-course and on-schedule in meeting the objectives and performance targets.

Assessment: The process of determining, judging or deciding the amount, value, quality, or importance of a something (e.g. a person or a situation); as well as the resulting judgment.

Evaluation: Rigorous analysis of completed or ongoing activities that determine or support (management) accountability, effectiveness, and efficiency (i.e. an assessment with a judgment based on organization-internal criteria). Evaluation of completed activities is called ex-post evaluation, post-hoc evaluation, or summative evaluation. Evaluation of current or on going activities is called in-term evaluation.

Impact assessment is the study of the effects of a new project or intervention (i.e. an assessment with a judgment based on organization-external factors). Impact assessments can be conducted ***ex ante*** as a study of possible negative consequences (e.g. environmental impact assessment), or ***ex post*** to determine the summary benefits and consequences of a policy or project with dispersed effects on larger populations or geographical areas.

Validation is the assessment of an action, decision, concept, plan, or transaction to establish that it is correct, complete, being implemented (and/or recorded) as intended, and/or delivering the intended outcome (i.e. an assessment including a binary judgments such as correct/incorrect). Preliminary validation based of ongoing activities can be used as part of adaptive management to inform adjustments of assumptions and derivative actions

Baseline: Clearly defined starting point from where implementation begins, improvement is judged, or a comparison is made. A baseline study is an analysis of current situation to identify the starting points for a program or project, providing an initial collection of data which serves as a basis for comparison with the subsequently acquired data.

Formative Evaluation provides information about an intervention or project during the design and development stage (see also monitoring) in order to make changes that improve the final design or implementation.

Summative Evaluation is a form of evaluation assesses outcomes or impacts of a “settled” project. Summative evaluation provides information about the impact of an intervention or project; what is assessed should be tied to project goals and objectives, however there should be an effort to document unintended outcomes as well.

Indicator is a (set of) criterion(s) that help determine what data needs to be collected to assist in assessing progress of a program and where it is on track to achieving its goals and objectives

Process indicators serve to monitor the implementation of an intervention, project or programme in terms of reaching intended targets and quality as well as activities.

Outcome and impact indicator serve to monitor progress of an intervention, project or programme in terms of achieving its objectives and envisaged changes (e.g. in knowledge, attitudes, behaviour) in the short term (outcomes) and long term (impacts).

Sustainable Development Goals Tiers of indicators

Tier 1: Indicator is conceptually clear, has an internationally established methodology and standards are available, and data are regularly produced by countries for at least 50 per cent of countries and of the population in every region where the indicator is relevant.

Tier 2: Indicator is conceptually clear, has an internationally established methodology and standards are available, but data are not regularly produced by countries.

Tier 3: No internationally established methodology or standards are yet available for the indicator, but methodology/standards are being (or will be) developed or tested. *(As of the 51st session of the UN Statistical Commission, the global indicator framework does not contain any Tier III indicators)* (UNSTATS, 2018*)*

Participatory evaluation involves the stakeholders of an intervention, project or programme in the evaluation process at any stage of the evaluation process (evaluation design, data collection, analysis, reporting) and may involve quantitative and qualitative data. The type and level of stakeholder involvement will necessarily vary depending on the level of impact evaluation (e.g. local impacts vs. policy changes). (Gujit, 2014)

Source: based on EC, 2015; Morra Imas and Rist, 2009; Van Es et al., 2015; Wehn et al., 2017

2.2 Recap of guiding principles for the MICS Impact Assessment framework

In order to inform the generation of the MICS Citizen Science Impact Assessment framework, guiding principles had been produced and presented in MICS deliverable D2.2. We briefly recap the results of that work here, as it sets the scene for the activities reported on in this deliverable (D2.3).

The guiding principles were produced based on desk research as well as empirical research to capture insights from different sources. Desk research reviewed general impact assessment frameworks (nine in total) as well as CS-specific impact assessment frameworks (15 in total); empirical research was used to tap into the current practices and insights of citizen science project coordinators (10 projects).

The resulting guiding principles for the MICS Impact Assessment framework (see Table 1), cover the following aspects:

- Purpose of citizen-science impact assessment
- Non-linear impact journeys rather than impact silos
- IA data collection methods & information sources
- Relative vs. absolute impact
- Comparison of IA results across citizen-science projects
- Cumulative enhancement of the framework over time.

A key characteristic of the MICS Impact Assessment framework is not only its conceptual grounding in latest insights, but its flexibility in terms of the *purpose* for which citizen science projects undertake impact assessment activities and the *resources* (means) that they have at their disposal. Providing flexibility for both aspects will maximise the usability of the MICS

Impact Assessment framework – and therefore the *impact* that the MICS IA framework itself will have among the community of citizen science practitioners.

In the MICS case studies, we will 'practice what we preach' with respect to citizen science by involving the citizen scientists, community members and other stakeholders in each case study in the impact assessment activities. Arguably they are equally - or even better - placed to inform and judge the evolving impacts of their citizen science activities. This involvement will entail the joint research agenda-setting (via the agreement of community-level indicators during the co-design process) as well as joint data collection, analysis and interpretation/identification of required action.

Table 1 Guiding principles for the MICS CS IA framework

Key aspect	Description	Guiding principle for MICS CS IA framework
Purpose of citizen-science impact assessment	The reasons for impact assessment of citizen-science projects differ from 'mere' impact reporting to learning for improved (future) implementation and even ex ante IA to substantiate proposal and grant applications.	The MICS CS IA framework needs to be able to accommodate a range of reasons, purposes and timing of undertaking IA of citizen-science projects. This requires the provision of process as well as results-related indicators, benchmarks and feedback on the extent to which and the ways in which envisaged results are and can be achieved, feeding into the adaptive management of citizen-science projects.
Non-linear impact journeys rather than impact silos	The limitations of linear conceptualisations of the logic framework are increasingly evident, especially in the field of citizen-science. Moreover, evidence from citizen-science impact assessments has shown that impact journeys are not linear within domains but that they 'zigzag' *across* domains.	The MICS CS IA framework needs to provide sufficient flexibility in the selection of relevant impact domains and respective intermediary outcomes. Users need to be able to *plan and trace impact pathways in and across the MICS domains (*society, economy, environment, governance, and science). For this, sound distinctions between outputs, outcomes and impacts in each domain are essential; moreover, causal relations not only between intermediary outcomes and impacts within a given domain but also *between outcomes in different* domains must be identifiable and traceable. Similarly, it needs to be possible to select and adjust over time which SDGs the citizen-science project intends and actually contributes to
IA data collection methods & information sources	Sound IA of citizen-science projects involves a range of data collection methods and ideally includes not only participants but relevant stakeholders and beneficiaries who can provide evidence of (evolving) impacts.	The way in which users provide evidence needs to allow and guide them within a wide range of suitable IA data collection methods and stakeholders to be involved, but without being prescriptive. Moreover, data collection for impact assessment of citizen-science activities under the MICS CS IA framework should allow its users to 'practice what we preach' by involving citizen scientists in the collection of evidence about emerging impacts (e.g. the CLI approach), entailing measurement not only against 'scientific'

Key aspect	Description	Guiding principle for MICS CS IA framework
		indicators but also against community-defined success.
	Citizen-science projects have different resources (financial, time, qualified staff) at their disposal for their IA efforts which affect the extent of their IA efforts and hence the type and range of evidence that they can provide.	The MICS CS IA framework should provide sufficient and appropriate guidance, instructions as well as links to relevant resources to support IA data collection efforts of CS projects.
Relative vs absolute impact	The limitations of sticking to absolute and fixed measures of impact (typically quantified) are becoming increasingly evident, including in the field of citizen science. Sound IA needs to measure impact to relative to the context and the goals and objectives of citizen science projects.	The MICS CS IA framework needs to provide the means to enter and measure progress against project-specific objectives and taking contextual realities into account (geographical, socio-economic setting, resources available (time, financial, staff, etc.)).
Comparison of IA results across citizen-science projects	The diversity of CS projects in terms of thematic issues addressed, stakeholders involved, extent and type of IA undertaken, etc., can make it challenging to compare results across projects.	The MICS CS IA can provide room for comparability of IA results that are based on different methods and information sources by using consistent overarching categories of definitions but distinguishing *confidence levels* (or similar, e.g. via a colour scheme) that stem from and indicate the (limited) range of underlying data sources. This can serve to generate individual as well as aggregate results.
Cumulative enhancement of the framework over time	The collective advancement of impact assessment theory and practice in the field of citizen science relies on reflection and cumulative additions, based on insights across projects and methods.	In order to remain relevant over time and serve the CS IA community, the MICS CS IA needs to be built on collective and cumulatively evolving intelligence, based on additional user inputs and definitions as well as more structured reflection and quality control (peer review) to check whether appropriate items/definitions/methods are being used.

Source: MICS D2.2 (Wehn et al., 2020a).

3 Approach

3.1 Literature search and analysis

The approach for the systematic literature search and analysis is illustrated in Figure 1. The work done in MICS D.2.2 was expanded by conducting a systematic literature search in the Web of Science and Wiley. The main aim of this literature search was to identify additional impact assessment methodologies, frameworks or approaches already applied in the context of citizen science projects that can inform the MICS impact assessment framework. The keywords in the search therefore included terminology that referred to the concept of Citizen Science (including, e.g. community-based monitoring, Citizen Observatories, participatory action research, etc.), as well as impact assessment terminology (e.g. output, outcome, impact, assessment, evaluation, etc.). The combination of the initial list of literature from D2.2, the result of our systematic search, as well as 12 publications that were identified by the authors via backward and forward snowballing, resulted in an initial list of 9507 publications. After removing the duplicates and screening the topic, abstract and keyword, a shortlist of 92 publications were selected for full-text review. Next, the full text of the publications in the shortlist were browsed to determine their relevance for inclusion in our full-text review, based on the subject matter addressed in the papers. During this process, 15 publications were discarded, resulting in a final shortlist of 77 publications that are included in our synthesis.

Before analysing the literature in the shortlist, and because of involvement of two MICS team members in the WeObserve impact Community of Practice (CoP), a synergy was identified between this effort and research interest and activities in the WeObserve Impact CoP. Therefore, the literature analysis was planned as a collaborative effort between a task force that included both MICS team members and members the WeObserve impact CoP. This task force team had nine members (5 MICS team members, 2 WO CoP members and 2 members that were involved in both groups).

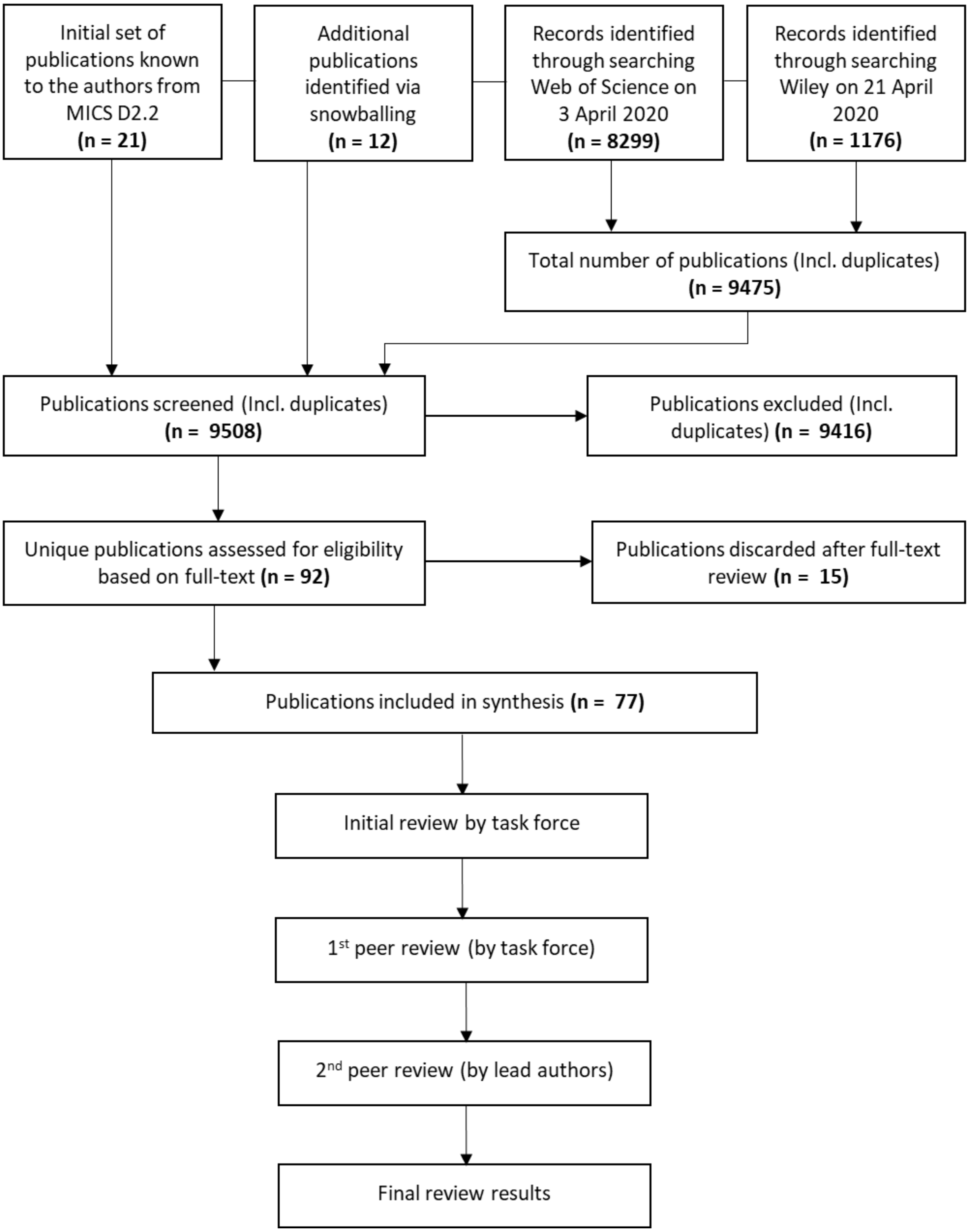


Figure 1 Summary of the systematic literature review

The full-text reviews were conducted in three steps. In step 1, each task force member reviewed 6 to 8 publications and recorded the review results in a table. Also, a marked version of the reviewed publications (with highlights of the relevant sections for this analysis) was saved for future reference. The structure of this table was adopted from the work in MICS D2.2 (i.e. Table 3 in Wehn et al., 2020a) and enhanced (from the focus on strengths and weaknesses and lessons learned) to capture the following:

- ***Scope and purpose of assessment:*** whether the publication proposes formative evaluation, summative evaluation or a comprehensive/holistic approach (i.e. analysis of context, process and (evolving) impacts)
- ***Conceptual relevance:*** insights of the publication for the purpose of developing the MICS IA framework (e.g. insights on themes or indicator level).
- ***Thematic content:*** coverage of specific theme(s) per MICS domain (e.g. in the society domain: learning outcomes at individual or societal levels).
- ***Participatory evaluation:*** whether the method involves citizen scientists not only in sharing their perceptions or collecting data on evolving impacts but also devising relevant impact assessment indicators for their citizen science initiatives.

The review captured whether a publication focused on measuring impacts (at different levels of abstraction) in one or more generic impact domains (i.e. sector or thematic area of envisaged change(s)). Specifically, in the context of the MICS project, five main domains are of interest: *society, economy, environment, science & technology, and governance*. While the three domains of sustainable development (environment, society and economy) are well-known and accepted, the context of citizen science warrants the focus on the two additional domains (science & technology, and governance). The science & technology domain is considered by MICS due to the inherent nature of citizen-science's alignment with/use of the scientific process and resulting (potential) implications for the scientific system, scientific paradigms and technological artefacts. A separate governance domain is considered owing to the links of citizen-science processes and results in monitoring, (environmental) management and (public) decision making processes.

Brief definitions of each impact domain that guided the review are as follows:

- ***Society impact domain:*** individual as well as collective (societal) values, understanding, action and well-being (including relationships)
- ***Economy impact domain:*** production and exchange of goods and services among economic agents; entrepreneurial activity
- ***Environment impact domain:*** constitution of the bio-physical environment, e.g. quality or quantity of specific natural resource(s) or ecosystems
- ***Science & technology impact domain***: the scientific process (method) as well as research more broadly; the scientific system (institutions; science policy; incentive structures), scientific paradigms (Kuhn, 1970) and resulting technological artefacts

- ***Governance impact domain:*** the processes and institutions through which decisions are made (Lautze et al., 2011), both informal and formal (e.g. public policy), and relationships/partnerships

Step 2 of the full-text reviews consisted of internal peer-review process. During this step, each member of the task force peer-reviewed the publications that had already been reviewed by other members of the task force. The peer-reviewers had access to the marked versions of the publications. This step worked as a quality control mechanism to ensure that the reviews were thorough and consistent. Moreover, the peer-review process helped to reduce subjective judgments about the reviewed impact assessment approaches/methodologies.

In step 3, the peer review results were cross-checked by the authors and any discrepancies between the initial and first peer review results were resolved via in-depth discussion among the authors.

3.2 MCIS CSIA framework construction

The steps involved in constructing (and eventually validating) the MICS Citizen Science Impact Assessment framework are illustrated in Figure 2. The results from the review of the citizen science literature on impact assessment (i.e. core themes and indicators by MICS impact domain; see steps explained in the previous section) and the insights generated from the general impact literature (reporting in MICS D2.2, Wehn et al., 2020a) are combined and organised within a holistic intervention logic (the Theory of Change, ToC) and using the five MICS impact domains.

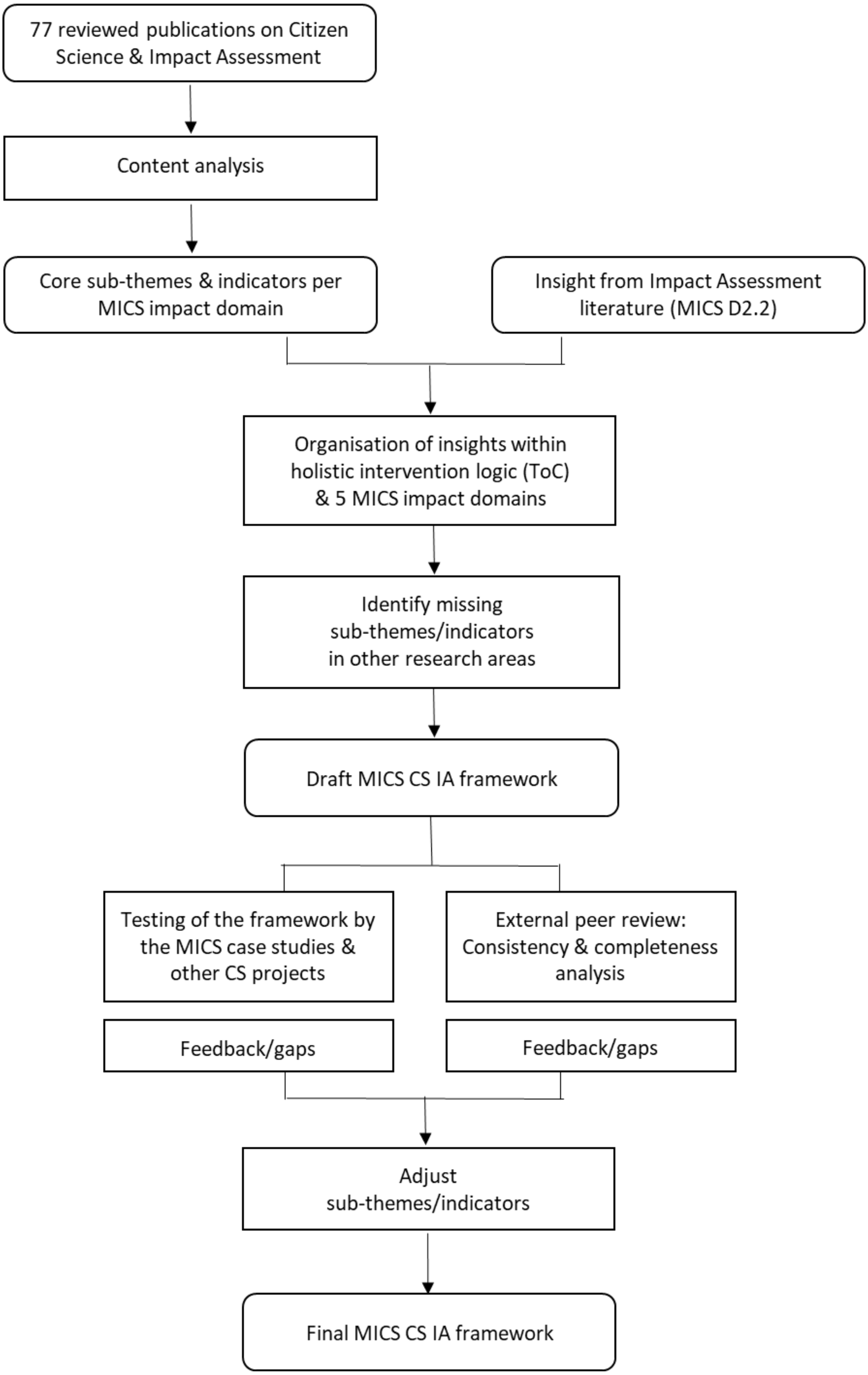


Figure 2 Summary of MICS CS IA framework construction & validation process

Per domain, publications are grouped according to the MICS impact domains and within those, according to themes. Clusters of indicators within each theme will be reviewed and relevant ones selected, based on the strengths and weaknesses reported in the literature review. The details of selected indicators will be entered in the draft MICS CSIA framework in Excel according to the indicator characteristics protocol (see detailed description in section 3.3).

3.2.1 MICS indicator characteristics definition

A fundamental step in developing the MICS IA methodology was the development of an indicator characteristics list. This list builds on the work for defining indicator characteristics by MoRRI (Monitoring Responsible Research & Innovation) (Raven et al., 2015). The MoRRI indicator characteristics were used as a starting point and, where relevant, were adopted, refined or supplemented with indicator characteristics relevant for the MICS context. The criteria for adopting, refining or adding indicator characteristics were relevance, clarity and overall composition. For example, MoRRI is based on existing (secondary) data sources, whereas in MICS, data sources can be primary, secondary or estimates.

The development of the MICS indicator characteristics resulted in a list of 17 items which are presented in Table 1Table 2. A detailed comparison between the MICS and the MoRRI indicator characteristics that further clarifies the similarities and differences between the two is presented in Annex 1.

Table 2 Overview of MICS indicator characteristics

MICS Indicator Characteristics	Description
Name of Indicator	Informative short name for the indicator
Description	Succinct description of the indicator (what is it an indicator of)
Domain	Main domain to which the indicator contributes insights [society, science, economy, environment, governance]
Qualitative/Quantitative	Type of data (quantitative or qualitative). In some cases, the basic data will be qualitative (interview transcripts, national reports or similar) which require coding / categorisation in order to be useful for monitoring purposes.
Primary/Secondary data	Indicator based on: • Primary data (that needs to be collected) or • Secondary data (already existing) • estimates
Source of data	• Primary data: specification of data collection method (e.g. survey, interview, focus group discussion, observation, etc.) • Secondary data: specification of existing database, document (specific page numbers, exact tables etc.), and direct links to the data source in question (if available) • Estimates (summaries): expert judgement, e.g. project coordinator

MICS Indicator Characteristics	Description
Time-series	For primary data: • Time-series required (yes/no; if yes, how frequent) For secondary data: • Time-series available (yes/no) and (if applicable) actual years for which data are available
Unit of measurement (observation)	Unit of measurement (observation), e.g. nominal, ordinal, interval
Unit of analysis	Unit of analysis (e.g. country, organisation, individuals (e.g. citizens), publications etc.)
Analytical level (logic model)	Analytical level in the intervention logic model to which the indicator is oriented (i.e. context, input, process, output, outcome, impact).
Links with indicators in other domains	Domain(s)/indicator(s) to which the indicator (also) relates
Data collection	Details on how data should be collected for this indicator • Method (survey / questionnaire, data retrieved from databases, structured/semi-structured/explorative interviews, focus groups, observation, desk research, document analysis, ethnographic field studies, etc.) • Questions asked • Type & # of respondents / informants, incl. size of this population
Indicator building	Explanation of how results are calculated from collected data. For quantitative sub-indicators, specify the unit (e.g. #, %, etc.)
Availability of data	Extent of data availability for the indicator and sub-indicators (e.g. low, moderate, high)
Feasibility	Feasibility of measuring the indicator given constraints on resources and time.
Comments/caveats	Additional comments/caveats
Source of indicator definition	(Original) source of definition of the indicator and sub-indicators (incl. link)

4 Towards a draft MICS CSIA framework for measuring citizen science impacts

The overall aim of the MICS CSIA framework is to synthesise existing methods and indicators in a coherent framework and to indicate gaps where indicators are still needed. To this end, this section presents the draft framework at three different levels of abstraction: i) the overarching impact domains; ii) the intervention logic; and iii) the identified conceptual and practical approaches within each domain (e.g. themes and indicators).

4.1 The MICS impact domains

The MICS impact domains (science, society, economy, environment and governance were introduced in section 3.1. As part of setting up the overall MICS CSIA framework, here we draw attention to their inter-relations (see Figure 3). In particular, these domains should be considered not as separate 'silos'; rather, they help capture the breadth, depth and complexity of the impacts of citizen-science in different dimensions of the socio-technical-environmental systems.

Specifically, the environment domain is considered at the heart of the MICS CSIA framework, as it is dependent on and impacted by the other domains. The governance domain is depicted as an overarching domain, given that the processes and structures captured in this domain pertain to and impact on the other four domains. The middle circle shows the society, science & technology and the economy domains as mediators (and users) between the bio-physical environment and the social structures they are governed by.

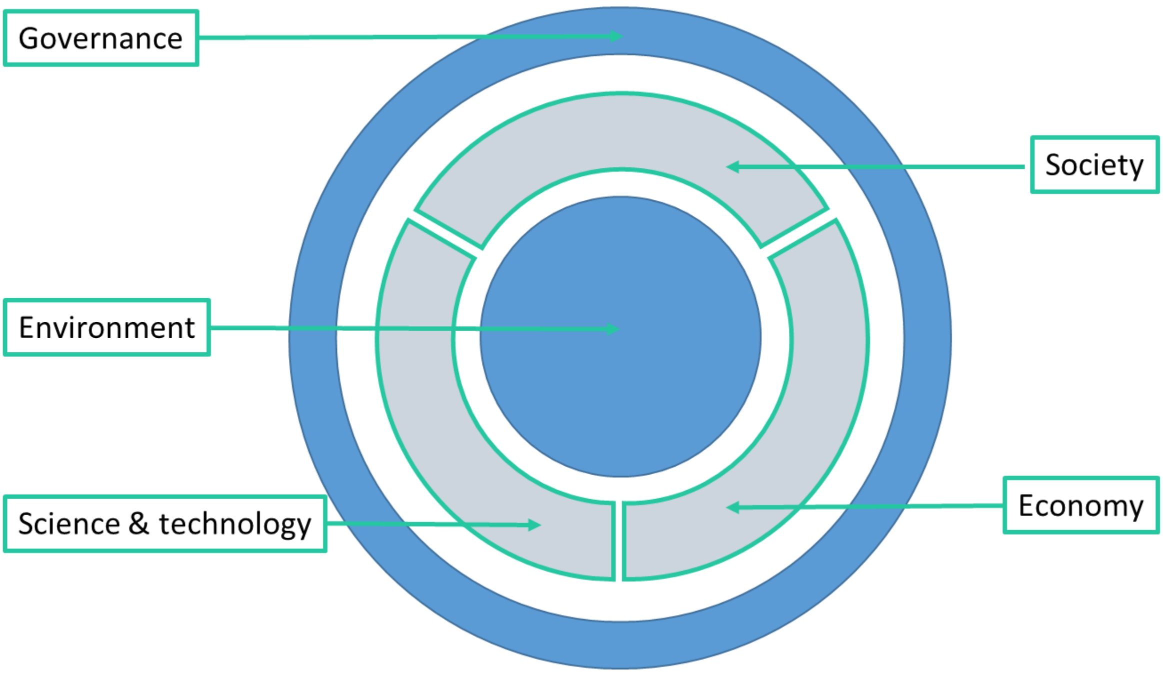


Figure 3 Overview of the MICS Citizen Science impact domains

4.2 Holistic intervention logic

The intervention logic (also known as results chain or logical framework approach) is behind many impact assessment efforts of public interventions and - in particular – the assessment of *research* activities, namely the MoRRI framework (Monitoring Responsible Research & Innovation RRI) (Ravn et al., 2016) as well as evaluations of citizen science efforts (e.g. DITOS consortium, 2016). This logic considers an intervention (e.g. a given program or project) in terms of its **objectives**, **inputs**, **activities**, **outputs**; the use or application of the resulting outputs may lead to **outcomes** or changes that are beyond the immediate sphere of influence of the intervention. Such changes may be (un)desired and/or un(expected) and the extent of their obtainment may be affected positively or negatively by contextual or external factors.

The 'richer' version of this intervention logic, the Theory of Change (ToC), is argued to strengthen the (otherwise difficult) case for attributing observed outcomes or changes to a given intervention or its actions (Ravn et al., 2016; Van Es et al., 2015) since it requires not only the specification of the intervention elements listed above, but also the articulation of **intermediate steps, assumptions, hypotheses** and **assumed causal relations** underlying the intervention's design and how envisaged changes may be achieved. Moreover, the ToC draws attention to the importance of capturing (comprehensively) the context of interventions that, ultimately, aim to trigger changes (of people, organisations or even systems) and to the fact that perspectives on 'what needs to change and why' (Van Es et al., 2015, p. 13) may differ.[1]

As argued in MICS deliverable D2.2 (Wehn, et al., 2020a), the Theory of Change stands out for its structure for both, impact assessment and guidance towards achieving impacts, alongside the realisation of what is (and what is not) under immediate control of the intervention or project (i.e. the spheres of control, influence and interest, see illustration in Figure 4). Impact assessments of citizen science initiative have already revealed the 'nested' and sequential nature of changes across impacts domains, for example, environmental changes are conditional on social and institutional changes in managing the natural resource(s) in focus of the citizen science initiative (Wehn et al., 2020b). The MICS CS IA framework will therefore allow users to specify and capture layered and related intermediary outcomes along **impact pathways that cut across different MICS impact domains**.

[1] As a project management tool, one of the strengths of the ToC is to trigger discussion early on among project partners/participants on the intended changes, their rationale and (different/parallel) means to achieve them.

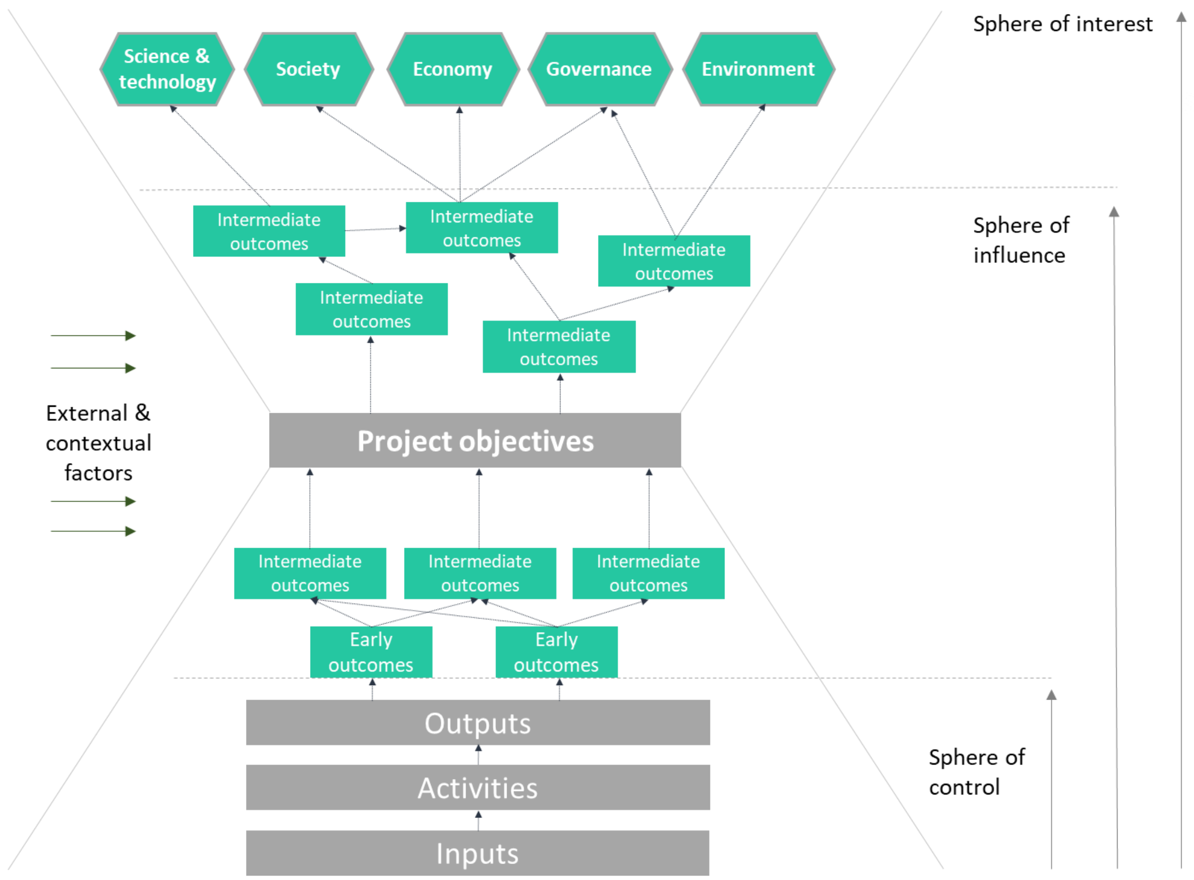


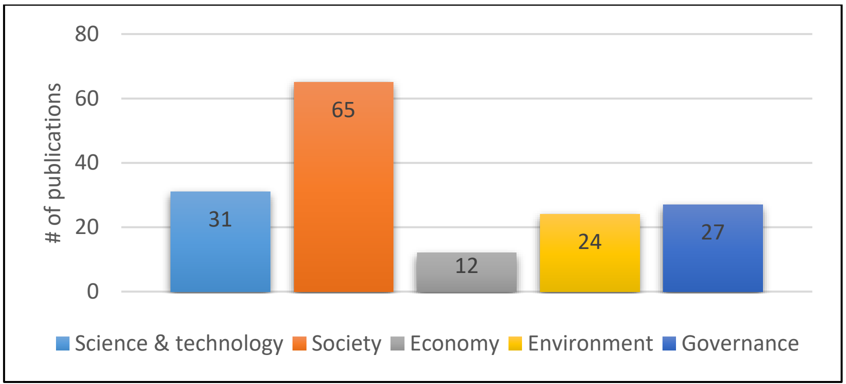
Figure 4 Theory of change elements

Source: Compiled from Van Es et al. (2015)

A considerable number of impact assessment efforts in the citizen science field (20 out of the 77 publications in this review) draws attention to the need to consider *comprehensively* the **context** of a given citizen science initiative, the **process** or means by which it is being implemented and, last but of course not least, its impacts. Along with this comes the understanding that impact assessment is a 'moving target' in the sense that the results of one stage or phase of project implementation generate new realities, and hence a changed context. For the MICS CSIA framework, this results in demands for comprehensively capturing the initial situation and the (evolving) context and, hence, an enhancement of the project information sheet presented in Annex 1 of MICS deliverable D2.4 to include relevant context-related parameters. Similarly, process indicators are considered alongside outside and impact indicators.

4.3 Themes and indicators per MICS domain

As is evident from Figure 5**Error! Reference source not found.**, the CS IA literature review resulted in distinctly different results per MICS impact domain, with the largest number of publications (65) by far in the society impact domain and the lowest in the economy domain (12).



* Some publications contribute insights to more than one domain

Figure 5 Relevant publications identified per domain (n=77)

Each of the reviewed publications considers one or more of the five impact domains (see

Figure 6), with the exception of two publications that focus on generic impact assessment approaches. A detailed overview of the relevance of all reviewed publications per domain is presented in Annex 2. The majority of the reviewed approaches focus on measuring impacts in one or two domains (31 and 20, respectively) and only two out of the 77 publications refer to all five domains.

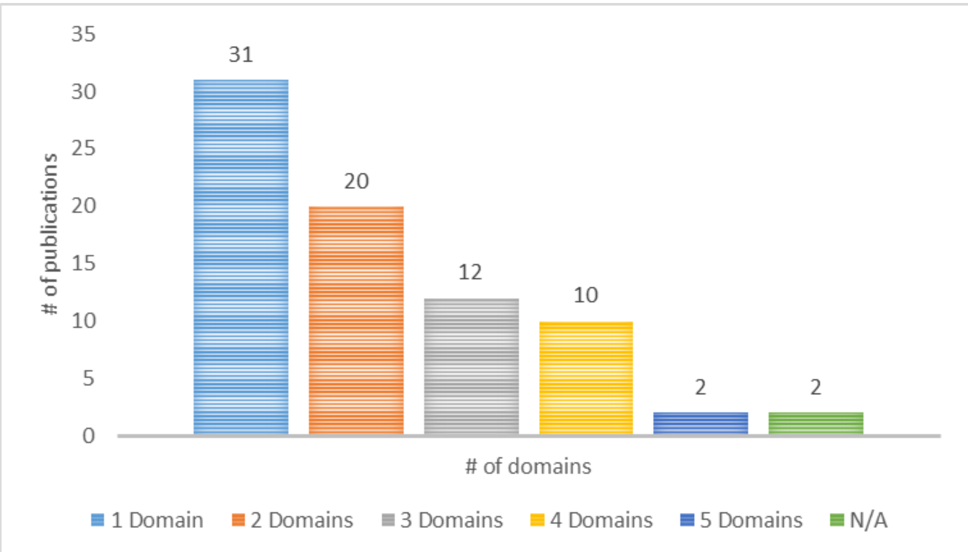


Figure 6 Number of domains addressed per publication (n=77)

Along with the definition of indicators, the literature describes how evidence needs to be collected. The analysis of the methodological approaches used or referred to per impact domain reveals that a mixed methods approach (qualitative and quantitative) is by far the most commonly used approach for capturing impacts of citizen-science in the different domains (see Figure 7). The low percentage of quantitative methods used in all five domains is noteworthy, and perhaps particularly for the economy domain. Overall, it can be argued that this is indicative of the difficulties (and inappropriateness) with quantifying the impacts of citizen science.

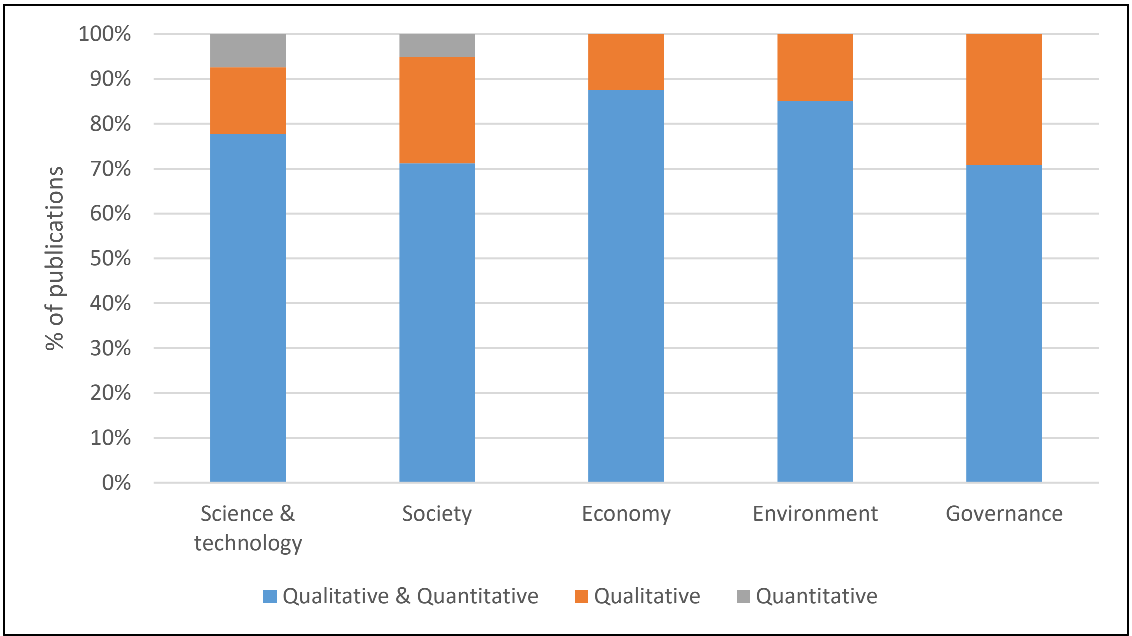


Figure 7 Methodological approach used for capturing citizen-science impacts (per domain) (n=77)

The methods used span across - and often combine - a range, such as observation, (semi)structured interviews, questionnaire-based surveys, observation and document analysis (incl. using checklists) and involve gathering data from a variety of stakeholders (including non-participants) to capture the diversity of views about the baseline situation (even in retrospect) and evolving outcomes and impacts at multiple times throughout the process.

4.3.1 Society domain

In the society domain, there is a general distinction in the reviewed literature between individual and collective level outcomes and changes in knowledge, attitude and behaviour. One key theme relates to (individual and social) learning outcomes. Other salient themes relate to changes in relationships and partnerships among societal actors, community dynamics (including capacity, well-being and livelihoods) and changes in understanding of and attitudes towards science, which provide cross-cutting links to the science domain. More than 30 publications in this domain provide specific indicator-level insights.

Table 3 Society domain themes & indicators

Theme(s)	Indicators	Description	Reference
X		Individual (learning) outcomes	Friedman (2008); National Research Council (2009); Pólvora and Nascimento (2017); Peter et al. (2019)
X		Social (learning) outcomes	Hermans et al. (2011); Gibbons et al. (2016)
X		Individual and societal outcomes	Shirk et al. (2012); Hobbs and White (2016); Groulx et al. (2017); Jordan et al. (2016); Blackstock et al. (2007); Gharesifard et al. (2019 a,b); Graef et al. (2018); Cargo & Mercer (2008); Haywood (2015); Cook et al. (2017); Constant and Roberts (2017); Trickett and Beehler (2017); Trimble and Lazaro (2014)
X		Engagement behaviours and activities	Grudens-Schuck and Sirajuddin (2019)
X		Participation satisfaction and participant knowledge related to health research	D'Agostino McGowan et al. (2015)
X		Partnership processes: individual and societal	Oetzel et al. (2018)
X		Change in sense of place and behaviour (at individual level)	Evans et al. (2005)
X		(intermediary) CBPR outcomes	Jagosh et al. (2015)
X		Community level outcomes related to empowerment and community capacity	Sandoval et al. (2012)
X		Community -institutional relations	Arora et al. (2015)
X		media-based community education (on newspaper coverage)	Granner et al. (2010)
X		Not specified	Bonney et al. (2014); Schäfer and Kieslinger (2016); Coulson et al. (2018)
X	X	Categories of individual and societal outcomes (Change in Knowledge & attitudes, Behaviour & ownership, Motivation & engagement)	Kieslinger et al. (2017; 2018)
X	X	Individual learning outcomes (Improved participant understanding of science content; Enhanced participant understanding of science process; Better participant attitudes toward science; Improved participant skills for conducting science; Increased participant interest in science as a career)	Bonney et al. (2009a)
X	X	Individual learning outcomes (Change in Awareness & knowledge; Engagement or interest; skills; attitudes; behaviours; other (case specific)	Bonney et al. (2009b)
X	X	Individual learning outcomes (Change in Interest in Science & the Environment; Self-efficacy; Motivation; Knowledge	Phillips et al. (2012; 2014; 2018)

Theme(s)	Indicators	Description	Reference
		of the Nature of Science; Skills of Science Inquiry; Behaviour & Stewardship)	
X	X	Individual outcomes (increase in awareness, knowledge, understanding of ecology; understanding of the science process; engagement with and interest in science and nature; motivation to participate; science process and inquiry skills; environmental stewardship behaviours; science and ecological identity), and societal outcomes (enhanced social capital; community capacity; economic impact (job creation); trust between public, scientists, and land managers)	Jordan et al. (2012)
X	X	Individual and societal outcomes (individuals engaged and developed increased capacity; Enabling organizations and business to become more sustainable; Livelihood assets enhanced)	Chandler et al. (2017)
X	X	Societal outcomes related to human health	Woods et al. (2016)
X	X	Individual and societal outcomes (Information; Capacities; Social capital; Distribution of risks)	Wehn et al. (2017, 2019, 2020b)
X	X	Science learning and literacy (Awareness, knowledge, or understanding of STEM concepts, processes, or careers; Engagement or interest in STEM concepts; Attitude towards STEM concepts, processes, or careers; Behaviour related to STEM concepts, processes, or careers; Skills based on STEM concepts, processes, or careers.)	Haywood and Besley (2013)
X	X	Value creation (change in knowledge, skills and understanding of participants)	Guldberg et al. (2019)
X	X	Individual and society impacts including community building, civic action, identity and activism, experience and efficacy,	Woods et al. (2019)
X	X	individual learning (beliefs, values, attitudes)	Smajgl and Ward (2015)
X	X	Societal outcomes including improvement in the health of community; Change in credibility/trust; Increase in generalizable knowledge and practices	Szilagyi et al. (2014)
X	X	Individual and societal impacts (Increased awareness of conservation and the environment; Creating next-generation conservation leaders and champions; Improved wellbeing and livelihoods; Enhanced capacity and empowerment of all stakeholders in conservation; Greater ownership; increased trust; change in tolerance and attitudes towards nature; Change in widening perspectives; Developing and enhancing skills sets)	Pocock et al. (2018)
X	X	Societal impact indicators across five dimensions (Knowledge democracy; Citizen-led research; Participatory dynamics; Integrity; Transformative change)	Gresle et al., (2019)
X	X	Public engagement outcomes (Collaboration; Communication; Interaction; Project Appeal; Sustained Engagement; Public Contribution)	Cox et al. (2015)
X	X	Societal knowledge exchange outcomes (Increased knowledge, awareness or understanding; new skills	Fazey et al. (2014)

Theme(s)	Indicators	Description	Reference
		learned by participants; attitude change; behaviour change; creation of innovations and new Ideas; Provision of information; new networks or structures, Improved communication)	
X	X	Public understanding of science (Change in Interest in science and nature; Self-efficacy for science and environmental action; Motivation for science and environmental action; Skills of science inquiry; Data interpretation skills; Knowledge of the nature of science; Environmental stewardship)	Bonney et al. (2015)
X	X	Individual and societal outcomes (Change in engagement, communication, attitude and behaviour)	Van Brussel and Huyse (2018)
X	X	Focus on community-university engagement: Includes indicators on Community-Engaged Research; Community-Engaged Learning; Being a Good Neighbour; Knowledge Mobilization	Tremblay (2017)
X	X	Individual and societal outcomes (Change in Scientific knowledge of community members; understanding of community members about scientific processes; attitude towards science; attitude towards the environment)	Brossard et al. (2005)
X	X	Change in awareness and Knowledge; Social and cultural response to resource characteristics of citizen science project	Chase and Levine (2016)
X	X	24 indicators about knowledge and management of animals that threaten agricultural crops (Environmental citizenship as a proxy for capturing learning process and outcomes)	Villasenor et al. (2020)
X	X	Process indicators about community engagement and participation (e.g. number and categories of stakeholders engaged; benefits and challenges of participation)	Butterfoss (2006)
X	X	Process, outcome and perception indicators related to Capacity building; Equal participation of males and females; Gender perspective on science & technology content; Organisational scientific capacity; Scientific capacity of the public and Social inclusion	DITOs Consortium (2016)
X	X	Individual and societal outcomes (by participating in environmental stewardship projects; Educating and engaging the public; Creating knowledgeable and credible volunteers in the local community; Generating advocates for natural resource agencies; Increasing self-confidence of volunteers; Developing community through social connections)	Merenlender et al. (2016)
X	X	Social changes, including capacity building and empowerment	Tremblay et al. (2017)

4.3.2 Science & Technology domain

The themes and indicators in the science and technology domain, on the one hand, focus on largely quantifiable outputs of the scientific process (data, publications, citations). One the other hand, the approaches serve to capture changes to the scientific process via public participations and community engagement, changes in community-academia relations and enhancements of the scientific knowledge base. About half of the 31 publications contributing to this domain provide concrete indicator-level insights.

Table 4 Science & technology domain themes & indicators

Theme(s)	Indicators	Description	Reference
X		Science products (Research findings and publications)	Shirk et al. (2012)
X		Examples of scientific outputs (Datasets and information about a topic of interest; Scientific publications), as well as outcomes and impacts (Advancement in scientific understandings about a topic; Improved relationship between science, society and authorities)	Gharesifard et al. (2019 a,b)
X		Contribution to scientific advancements by providing data points and other research inputs (e.g. local insights)	Haywood (2015)
X		Scientific data, evidence or insights	Glasgow and Emmons (2007)
X		Data-related outcomes of collaborative science (collected data, analysed data, revised ideas)	Jordan et al. (2016)
X		Research process and outcomes (focus on participatory health research), including effect on question/ design/ understanding of findings; Effect on research quality; Change of focus and/or orientation for future research	Cook et al. (2017)
X		Science related outcomes (e.g. scientific discoveries related to continuous monitoring of species)	Ballard et al. (2017)
X		Science products (open hardware, software and other tools) used by participants	Pólvora and Nascimento (2017)
X		Long term outcomes related to Health/Health Equity	Oetzel et al. (2018)
X		Not specified	Bonney et al. (2014); Schäfer and Kieslinger (2016); Arora et al. (2015); Peter et al. (2019)
X		Co-governance of research processes and outcomes	Jagosh et al. (2012)
X	X	Categories of scientific contribution including Numbers of papers published; Numbers of citations; Numbers of grants received; Size and quality of citizen science databases; Numbers of theses; Frequency of media exposure	Kieslinger et al. (2017; 2018)
X	X	Measures of scientific contribution (Numbers of papers published in peer-reviewed journals; Numbers of citations of results; Numbers of researchers publishing citizen science research papers; Numbers and sizes of grants received for citizen science research; Size and quality of citizen science databases; Numbers of graduate theses completed using citizen science data; Frequency of media exposure of results)	Bonney et al. (2009a)

Theme(s)	Indicators	Description	Reference
X	X	Programmatic outcomes (understanding of natural systems; audience reach, engagement with the public; understanding of program strengths and weaknesses; understanding of community issues; understanding of participant experiences, motivation, satisfaction; accessibility and utility of data; contribution to scientific research and monitoring, peer-reviewed publications; relationship between program and community)	Jordan et al. (2012)
X	X	Indicators of scientific contribution (Number of people and number of person hours dedicated to collecting scientific data; Peer reviewed publications; Popular publications and outreach events)	Chandler et al. (2017)
X	X	Categories of science products including Written material; Data; Management and Policy[2]; Communication material	Wiggins et al. (2018)
X	X	Participatory engagement (*acceptance criteria* e.g. influence, transparency, representativeness, and *process criteria* e.g. task definition, cost-effectiveness relate to research procedure	Haywood and Besley (2013)
X	X	Enhancement of Data	Pocock et al. (2018)
X	X	Science related performance indicators including Data Value (Publication Rate, Completeness of Analysis, Academic Impact); Project Design and Resource Allocation (Resource Savings, Distribution of Effort, Effective Training)	Cox et al. (2015)
X	X	Process, outcome and perception indicators related to Science initiatives & events	DITOs Consortium (2016)
X	X	Scientific outcomes (via contributing data through citizen science to inform research or management; Supporting work of natural resource professionals)	Merenlender et al. (2016)
X	X	Focusing on community-university engagement: Includes indicators on Community-Engaged Research (CER); Institutional and Policies Support (focusing on internal support of community-university engagement)	Tremblay (2017)
X	X	Community participation in research (process focus)	Khodyakov et al. (2013)

4.3.3 Environment domain

The themes in the environmental domain focus on the status of environmental resources, e.g. resulting from conservation efforts, ecosystem functions, services and resilience, as well as impacts of environmental status on human health and livelihoods (cutting across to the society domain) and outcomes for agricultural productivity (cutting across to the economy domain). About half of the 24 publications contributing to this domain provide concrete indicator-level insights.

[2] Includes indicators relevant for governance domain

Table 5 Environment domain themes & indicators

Theme(s)	Indicators	Description	Reference
X		Outcomes for socio-ecological systems as a whole	Shirk et al. (2012)
X		Examples of environmental outputs (Improved protection of natural resources; Improved status quo of water resources or the environment)	Gharesifard et al. (2019 a,b)
X		Agricultural productivity outcomes (Soil fertility, Water availability, Agro-diversity)	Graef et al. (2018)
X		Conservation outcomes	Jordan et al. (2016)
X		Conservation outcomes (e.g. species and land management.)	Ballard et al. (2017)
X		Impact of CS for collecting data, environmental change and reduced environmental harm	Pólvora and Nascimento (2017)
X		Environmental health (related to environmental justice)	Cargo & Mercer (2008)
X		Environmental outcomes related to understanding of wildlife and species identification	Evans et al. (2005)
X		Impacts for agricultural and natural resource management	Johnson et al. (2003)
X		Not specified	Bonney et al. (2014); Schäfer and Kieslinger (2016); Coulson et al. (2018)
X	X	Development of resilience of the socio- ecological systems	Kieslinger et al. (2017; 2018)
X	X	Enhancing natural and socio-cultural capital to create a sustainable environment (Taxa of conservation significance enhanced; Natural habitats enhanced; Ecosystem services enhanced; Cultural heritage components enhanced; Livelihood assets enhanced)	Chandler et al. (2017)
X	X	Environmental impact on human health	Woods et al. (2016)
X	X	Direct and indirect environmental impacts (Quality of natural resources/fighting pollution; Biodiversity of flora, fauna and landscapes; Environmental risks)	Wehn et al. (2017, 2019, 2020b)
X	X	Impact related to soil moisture and climate change knowledge & sustainable environment action	Woods et al. (2019)
X	X	Ecosystem and resilience (Improved conservation action leading to better environment including ecosystem function, ecosystem services and resilience)	Pocock et al. (2018)
X	X	Environmental outcomes related to geographic scale, range of resource, life cycle of species, accessibility and visibility of species	Chase and Levine (2016)
X	X	24 indicators about knowledge and management of animals that threaten agricultural crops (e.g. reduce the effect of animals that affect crops using insect traps; Reduce the effect of production damage by implementing cultural practices)	Villasenor et al. (2020)

4.3.4 Economy domain

The themes in the economy domain cover demand and supply side aspects of citizen science, including the generation of entrepreneurial activities. While the total number of contributions in this domain is already small (9), out of these, only four publications actually contribute concrete indicators.

Table 6 Economy domain themes & indicators

Theme(s)	**Indicators**	**Description**	**Reference**
X		New entrepreneurial initiatives promoted by participants; establishment of alternative relationships with economic assets	Pólvora and Nascimento (2017)
X		Examples of economic outputs, outcomes and impacts	Gharesifard et al. (2019 a,b)
X		Production, income, market participation	Graef et al. (2018)
X		Economic capital	Hermans et al. (2011)
X		Economic potential and market opportunities as 'wider innovation potential' of CS	Kieslinger et al. (2017; 2018)
X		Economic impact of the technologies developed by the projects	Johnson et al. (2003)
X	X	Demand side (job creation)	Jordan et al. (2012)
X	X	Supply and demand side of CS • Supply: company growth, international trade & investment, innovation & research, competitiveness • Demand: employment, conduct of business, value added of CS (data)	Wehn et al. (2017, 2019, 2020b)

4.3.5 Governance domain

The contributions in the governance domain cover a wide ranges of themes, including the policy cycle as well as actually changes in policy itself, multi-level interactions among actors and their power dynamics, communication, relationships and trust. Most contributions highlight relevant themes and only six publications provide specific indicator-level insights.

Table 7 Governance domain themes & indicators

Theme(s)	**Indicators**	**Description**	**Reference**
X		Formal and informal communication of monitoring results to community members	Shirk et al. (2012)
X		Power dynamics, participation dynamics	Gharesifard et al. (2019 a,b)
X		Decision making, authority/power, social justice/equity	Hassenforder et al. (2016)
X		Shared/common language, policy links, (dis)trust, political support	Hermans et al. (2011)
X		Consensus building and changing actor relationships	Gibbons et al. (2016)
X		Conservation decision making	Jordan et al. (2016)
X		Policy change (focus on participatory health research)	Cook et al. (2017)

Theme(s)	Indicators	Description	Reference
X		Policy change (focus on environmental conservation research)	Ballard et al. (2017)
X		Participation characteristics	Blackstock et al. (2007)
X		Policy change	Trimble and Lazaro (2014)
X		Policy environment, agency capacity, social justice (focus on participatory health research)	Oetzel et al. (2018)
X		trust-related mechanisms	Jagosh et al. (2015)
X		Stakeholder participation, conversation action	Pocock et al. (2018)
		Policy change	Woods et al. (2016)
X		Impact of citizen science on policy formation and implementation	Haklay (2015)
X	X	Authentic contributions to management plans and policy	Chandler et al. (2017)
X	X	Change to formal and informal institutions (participation, power dynamics, set up)	Wehn et al. (2017, 2019, 2020b)
X	X	Impact related to engagement with policy, civic action, identity & activism	Woods et al. (2019)
X	X	Formal and informal processes and outcomes related to trust and policies, practices, power relations	Lucero et al. (2018)
X	X	Adoption of CS results by policy makers	Van Brussel and Huyse (2018)
X	X	Policies, regulations & frameworks aspects of public engagement (process, outcomes)	DITOs Consortium (2016)

4.4 Completion and curation of the MICS CS IA framework

As presented in the previous sections, per domain, relevant publications have been grouped according to the MICS impact domains and, within those, according to themes. In the next step, clusters of indicators within each theme will be reviewed and relevant ones selected, based on the strengths and weaknesses reported in the literature review. The details of selected indicators will be entered in the draft MICS CSIA framework in Excel according to a tailored MICS indicator characteristics protocol (presented in section 3.2.1). The structure of the Excel is as follows (see Table 8).

Table 8 Excel structure of draft MICS CS IA framework

Tab	Description
Start here	Table with description of the indicator items that are used in the five MICS impact domains
Intervention logic	Summary of the MICS intervention logic (illustration)
Overview of MICS Impact Domains	Table of the five MICS impact domains and summary of themes & indicators per domain
Project information sheet	Adjusted project information sheet (from MICS D2.2) with comprehensive context information about citizen science project (generic)

Tab	Description
Society	List of relevant indicators for the society domain (with details according to the MICS indicator characteristics protocol)
Science and Technology	List of relevant indicators for the science & technology domain
Economy	List of relevant indicators for the economy domain
Environment	List of relevant indicators for the environment domain
Governance	List of relevant indicators for the governance domain

An illustration of how the domain tabs are completed with relevant indicators is presented in Figure 8.

The development of the framework thus far has resulted in distinctly different inputs per MICS impact domain, with the largest number of relevant publications in the society impact domain and the lowest in the economy domain. It is therefore necessary to identify missing themes and indicators, drawing on other relevant research areas.

Moreover, the inputs drawn upon in this report stem from diverse scientific fields and epistemological approaches, incorporating distinct perspectives and framings not only of impact assessment but also citizen science. These go hand in hand with diverse and often comprehensive data collection methods. A key step in the completion of the framework will therefore be the careful comparison, alignment and (if appropriate) combination of relevant indicators per domain and theme. Also, many citizen-science projects may have difficulties to generate an empirically-based baseline situation (ex ante) with respect to the initial stage of knowledge, understanding, attitudes and behaviour of (future) key stakeholders and especially citizen scientists. The MICS framework therefore needs to provide guidance on how to simulate this, e.g. by drawing on comparisons between participants and non-participants and integrating estimates of past projects.

The steps involved in testing and validating the draft MICS CS IA framework will be undertaken in the remainder of the project life time and will be reported on in deliverable MICS D2.7.

As indicated in section 3.2, the MICS framework will be tested in the MICS case studies and piloted by the wider citizen science community while in parallel being subjected to external peer review. During the lifetime of the MICS project, the insights generated by the testing, piloting and peer review will be incorporated, whether as refined or additional indicators provided by the scientific community and citizen scientists. A tiered level of indicators (similar to the SDG Tier 1-2 and 3 system of indicators[3]) may be used to indicate the maturity level or peer review status of new indicators that are under review by the MICS consortium. A similar system may need to be set up and maintained for curation of the MICS framework beyond the lifetime of the project and will require explicit attention during the remaining project life time.

[3] Tier 1 and 2: indicator is conceptually clear and has an internationally established methodology vs. Tier 3: no internationally established methodology or standards are yet available for the indicator, but methodology/standards are being (or will be) developed or tested.

Figure 8 Illustration of indicators entered in the Economy domain

Economy - Indicators ID				
Indicator Characteristics				
Name of Indicator	**Company growth**	**International trade & investment**	**Innovation & research**	**Com**
Primary/Secondary data	Primary (surveys) and Secondary data	Primary (surveys) and Secondary data	Primary (surveys) and Secondary data	Prima
Description	<copy from D1.10>			
Qual/Quantitative	Quantitatve	Quantitative & qualitative	Quantitatve	Quar
Source of data	dedicated survey	dedicated survey	dedicated survey	dedic
Time-series	Yes, survey should be repeated	Yes, survey should be repeated	Yes, survey should be repeated	Yes,
Unit of measurement (observation)	absolute values & nominal (see data collection)	absolute value	absolute value	abso
Unit of analysis	Organisation	Organisation	Organisation	Orga
Analytical level	Outcome; Impact			
Links with indicators in other domains	n.a.	n.a.	n.a.	n.a.
Data collection	Survey - questions: How many jobs are currently directly related to [CO topic] and enabling technologies? What is the nature of these jobs? (junior, medior, senior position(s)) [nominal] How many of your products/services are relevant for the provision of COs? What was your organisation's annual turnover in [year]? What is your organisation's market share in the business of COs? How many clients does your organsition have in the CO business?	Survey - questions: How many international clients does your organsition have in the CO business? What specific customer segments does your organisation serve related to COs? How much has your organisation invested in CO-related activities in [year]?	Survey - questions: How many IPRs related to COs and enabling technologies (patents, trademarks, copyright, other know-how rights) does your organisation hold? How many CO-related research projects is your organisation currently involved? In total, what is your organisation's budget (income & own investment) in these CO-related research projects?	Surve What does Whic How for C How orgai
Indicator building	Items: # subject-related jobs Nature of jobs # of CO related products/services Turnover Market share in the business of Cos	Indicators: # of international clients CO business and enabling tech-nologies Customer segments (sectors) related to CO Amount of investment in CO-related activities <explain relation of analysed results across items above>	Indicators: IPR (patents, trademarks, copyright, other know-how rights) # of CO-related research projects Total budget of CO-related research projects <explain relation of analysed results across items above>	Indic # of # of # of <exp

5 Scenarios & use cases of the MICS framework in practice

To illustrate the application of the MICS CS IA framework by citizen science projects, this chapter presents a range of use cases, since not all citizen science projects are alike in terms of the resources available for assessing the impacts of their activities. Moreover, the MICS CS IA framework may become available or salient to a project only during its lifetime, i.e. when the project is already running. These two major determinants (i) resources and expertise; ii) timing) are used to broadly distinguish different scenarios for the use of the MICS CS IA framework. In addition, a particular characteristic is the use of participatory evaluation based on indicators devised with and by citizen scientists themselves. This results in five distinct use cases of (see Table 9 Overview of MICS CS IA use casesTable 9). In the subsections below, we describe the steps involved in using the MICS CS IA framework in each use case.

Table 9 Overview of MICS CS IA use cases for different scenarios

	MICS CSIA used from the start of the CS project	**MICS CSIA used *later*, i.e. not from the start of the CS project**
Maximum resources & expertise	Use case A, Use case C	Use case D
Minimum resources & expertise	Use case B	Use case E

5.1 Use case A: Maximum resources & expertise, MICS CS IA framework used from the start of the CS project

1. Enter general project info, incl. objectives, type of CS project and details of stakeholders involved
2. Select relevant impact domains & intermediary outcomes within selected domains, enter assumptions for achieving these
3. Depending on choices made, compilation of
    i. relevant indicators for this project
    ii. methods for collecting baseline data
    iii. coordination of data collection across stakeholders & time
4. Enter baseline data <u>based on empirical research</u>
    - receive system feedback in terms of confidence level of CSIA approach
    - receive system feedback on means to enhance/maximise impact
5. Enter results from subsequent data collection efforts [frequency depending on method prescription]
    - receive system feedback in terms of confidence level of CSIA approach
    - receive system feedback on progress towards envisaged impacts (relative to baseline)
    - receive system feedback on means to enhance/maximise impact
6. [repeat step 5 till project ends]

5.2 Use case B: Minimum resources & expertise, MICS CS IA framework used from the start of the CS project

1. Enter general project info, incl. objectives, type of CS project and details of stakeholders involved
2. Select relevant impact domains & intermediary outcomes within selected domains, enter assumptions for achieving these
3. Depending on choices made, compilation of
    i. relevant indicators for this project
4. Enter baseline data based <u>on estimates</u>
    a. receive system feedback in terms of confidence level of CSIA approach
    b. receive system feedback on means to enhance/maximise impact
5. Enter subsequent results [frequency depending on method prescription] <u>based on estimates</u>
    a. receive system feedback in terms of confidence level of CSIA approach
    b. receive system feedback on progress towards envisaged impacts (relative to baseline)
    c. receive system feedback on means to enhance/maximise impact
6. [repeat step 5 till project ends]

5.3 Use case C: Maximum resources, MICS CS IA framework used from the start of the CS project & with participatory evaluation

1. Enter general project info, incl. objectives, type of CS project and details of stakeholders involved
2. Select relevant impact domains & intermediary outcomes within selected domains, for achieving these
    a. Select/generate relevant indicators with citizen scientists
    b. Enter indictors in the MICS CSIA according to the MICS indicator characteristics protocol
3. Depending on choices made, compilation of
    i. relevant indicators for this project
    ii. methods for collecting baseline data
    iii. coordination of data collection across stakeholders & time
4. Enter baseline data <u>based on empirical research</u>
    a. receive system feedback in terms of confidence level of CSIA approach
    b. receive system feedback on means to enhance/maximise impact
5. Enter results from subsequent data collection efforts [frequency depending on method prescription]
    a. receive system feedback in terms of confidence level of CSIA approach

   b. receive system feedback on progress towards envisaged impacts (relative to baseline)
   c. receive system feedback on means to enhance/maximise impact
6. [repeat step 5 till project ends]

5.4 Use case D: Maximum resources & expertise, starting with MICS CS IA framework half way through the CS project

1. Enter general project info, incl. objectives, type of CS project and details of stakeholders involved
2. Select relevant impact domains & intermediary outcomes within selected domains, for achieving these
3. Depending on choices made, compilation of
   i. relevant indicators for this project
   ii. methods for collecting baseline data
   iii. coordination of data collection across stakeholders & time
4. Enter baseline AND current status data <u>based on past reports from the project/estimates</u>
   a. receive system feedback in terms of confidence level of CSIA approach
   b. receive system feedback on progress towards envisaged impacts (relative to baseline)
   c. receive system feedback on means to enhance/maximise impact
5. Enter results from subsequent data collection efforts [frequency depending on method prescription]
   a. receive system feedback in terms of confidence level of CSIA approach
   b. receive system feedback on progress towards envisaged impacts (relative to baseline)
   c. receive system feedback on means to enhance/maximise impact
6. [repeat step 5 till project ends]

5.5 Use case E: Minimum resources & expertise, starting with MICS CS IA framework half way through the CS project

1. Enter general project info, incl. objectives, type of CS project and details of stakeholders involved
2. Select relevant impact domains & intermediary outcomes within selected domains, enter assumptions for achieving these
3. Depending on choices made, compilation of
   ii. relevant indicators for this project
4. Enter baseline AND current status data based <u>on estimates</u>

   a. receive system feedback in terms of confidence level of CSIA approach
   b. receive system feedback on progress towards envisaged impacts (relative to baseline)
   c. receive system feedback on means to enhance/maximise impact
5. Enter subsequent results [frequency depending on method prescription] <u>based on estimates</u>
   a. receive system feedback in terms of confidence level of CSIA approach
   b. receive system feedback on progress towards envisaged impacts (relative to baseline)
   c. receive system feedback on means to enhance/maximise impact
6. [repeat step 5 till project ends]

5.6 Summary

A key element in the use case scenarios presented above it the feedback provided by the system upon data entered by users. The precise nature of this feedback in terms of detail, functionality and interfaces is subject to the developments undertaken in WP3. Moreover, it needs to be clarified to what extent such system feedback requires detailed (human) analysis, can be fully automated and whether it will operate only during the lifetime of the MICS project or beyond.

In terms of the use case scenarios, the MICS case studies of citizen science initiatives in Hungary, Romania, Italy and the United Kingdom are all located in the 'maximum resources & expertise' range (see Table 10). They differ in terms of the timing of the application of the MICS CSIA framework: the citizen science activities in the UK case studies already started in 2015, it will apply the MICS CSIA framework in the 'used later' scenario. The other three case studies will used the MICS CSIA framework from the start of their citizen science activities that are being co-designed in WP4.

Table 10 Overview of MICS case studies in the different MICS CSIA use case scenarios

	MICS CSIA used from the start of the CS project	**MICS CSIA used *later*, i.e. not from the start of the CS project**
Maximum resources & expertise	Romania case study Hungary case study Italy case study	UK Case study
Minimum resources & expertise		

6 Conclusions & next steps

This report has presented the draft MICS Citizen Science Impact Assessment framework which constitutes the overarching structure within which novel and appropriate impact assessment methods will be provided for citizen science projects and which will be implemented via the MICS online platform in WP3. The draft framework will be tested in the MICS case studies and piloted by the wider citizen science community while in parallel being subjected to external peer review.

The results of this report will feed into the MICS following activities:

WP2 Methods for measuring citizen science impact

- Selection of final set of indicators per domain & completion of the indicator characteristics for selected indicators (Task 2.3 Establishment of a methodology and indicators for the citizen-science impact assessment)
- Identify missing themes and indicators within domains (Task 2.3 Establishment of a methodology and indicators for the citizen-science impact assessment)
- Wider piloting by the citizen science community and peer review of the framework (Task 2.6 Development and maintenance of the conceptual framework)

All of the above activities contribute to D2.7: A finalised version of the conceptual framework

WP3 Toolboxes for methods application, information visualisation and

- Translation of the framework into the MICS online platform (Task 3.4 Development and maintenance of the platform), which will contribute to D3.5 Participatory, adaptive, personalised, information-delivery web platform, period-2 prototype (P2P)

WP4 Test site development and tool validation

- Testing of the framework by the MICS case studies (Task 4.4 Application of the citizen-science impact methodology)

This activity contributes to all upcoming deliverables in WP4, namely:

- D4.1 Report on pilot testing in the Western Europe region (UK)
- D4.2 Report on pilot testing in the Southern Europe region (IT)
- D4.3 Report on pilot testing in the Central and Eastern Europe region (HU)
- D4.4 Report on pilot testing in the Central and Eastern Europe region (RO)
- D4.5 Comprehensive evaluation report

Across these activities, the feasibility of diverse and comprehensive data collection methods and the implications for data management will require attention. Similarly, the curation of the MICS CS IA framework during and after the project life time will need careful consideration.

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Annexes

Annex 1 Comparison of MoRRI and MICS Indicator Characteristics

The following table shows how the list of selected MICS indicator characteristics relates to the list of indicator characteristics in MoRRI (Ravn et al., 2016).

MICS Indicator Characteristics	MoRRI Indicator Characteristics	Comparison notes
Name of Indicator	Name of Indicator	No change
Description	Description	Same indicator characteristic - refined definition in MICS
Domain		New in MICS
Qual/Quantitative	Qual / Quant	No change
Primary/Secondary data	Primary/Secondary data	No change
	Need for supplementary data collection	Only in MoRRI
Source of data	Source of data (specific references, page numbers, links, exact tables etc.)	Same indicator characteristic - refined definition in MICS
	Date	Only in MoRRI
Time-series	Time-series	Same indicator characteristic - refined definition in MICS
	Potential time series data	Only in MoRRI
Unit of measurement (observation)	Measurement level	Same indicator characteristic - refined definition in MICS
Unit of analysis	Unit of analysis	No change
	Coverage (specific countries, institutions etc. covered)	Only in MoRRI
	Attributes	Only in MoRRI
	Assessment of RRI indicators	Only in MoRRI
Analytical level (logic model)	Analytical level (logic model)	No change
	Analytical level (aggregation)	Only in MoRRI
	Is indicator based on aggregation/disaggregation	Only in MoRRI
	Sub-categorisation from dimension typology (functional vocabulary)	Only in MoRRI
Links with indicators in other domains	Interlinkages with other RRI dimensions	Closely-related indicator characteristic - refined definition in MICS
	Data collection specifications	Only in MoRRI
Data collection	Data collection methods	Closely-related to indicator characteristic - refined definition in MICS
Indicator building		New in MICS
Availability of data		New in MICS
	Representation issues	Only in MoRRI
Feasibility	Feasibility issues	Closely-related indicator characteristic - refined definition in MICS
Comments/caveats		No change
Source of indicator definition		Only in MICS

Annex 2 MICS Impact domains addressed per reviewed publication

Publication	Domain relevance				
	Science	Society	Economy	Environment	Governance
Arora et al. (2015)	Y	Y			
Ballard et al. (2017)	Y			Y	
Blackstock et al. (2007)		Y			Y
Bonney et al. (2009a)	Y	Y			
Bonney et al. (2009b)		Y			
Bonney et al. (2014)	Y	Y		Y	
Bonney et al. (2015)		Y			
Bremer et al., (2019)	Y	Y			Y
Brossard et al. (2005)		Y			
Butterfoss (2006)		Y			Y
Cargo & Mercer (2008)		Y		Y	
Chandler et al. (2017)	Y	Y		Y	Y
Chase and Levine (2016)		Y		Y	
Constant and Roberts (2017)		Y			
Cook et al. (2017)	Y	Y			Y
Coulson et al. (2018)		Y		Y	
Cox et al. (2015)	Y	Y			
D’Agostino McGowan et al. (2015)		Y			
DITOs Consortium (2016)	Y	Y			Y
Evans et al. (2005)		Y		Y	
Fazey et al. (2014)		Y			
Friedman (2008)		Y			
Gharesifard et al. (2019 a,b)	Y	Y	Y	Y	Y
Gibbons et al. (2016)		Y			Y
Glasgow and Emmons (2007)	Y				
Graef et al. (2018)		Y	Y	Y	
Granner et al. (2010)		Y			
Gresle et al., (2019)		Y			
Groulx et al. (2017)		Y			
Grudens-Schuck & Sirajuddin (2019)		Y			
Guldberg et al. (2019)		Y			
Haklay (2015)					Y
Hassenforder et al. (2016)					Y
Haywood (2015)	Y	Y			
Haywood and Besley (2013)	Y	Y			
Hermans et al. (2011)		Y	Y		Y
Hobbs and White (2016)		Y			
Jacobs et al. (2010)	N/A	N/A	N/A	N/A	N/A
Jagosh et al. (2011)					Y
Jagosh et al. (2012)	Y				
Jagosh et al. (2015)		Y			Y
Johnson et al. (2003)			Y	Y	
Jordan et al. (2012)	Y	Y	Y		
Jordan et al. (2016)	Y	Y		Y	Y
Khodyakov et al. (2013)	Y				
Kieslinger et al. (2017; 2018)	Y	Y	Y	Y	
Lucero et al. (2018)					Y
Merenlender et al. (2016)	Y	Y			
National Research Council (2009)		Y			

Publication	Domain relevance				
	Science	Society	Economy	Environment	Governance
Oetzel et al. (2018)	Y	Y			Y
Peter et al. (2019)	Y	Y			
Phillips et al. (2012; 2014; 2018)		Y			
Pocock et al. (2018)	Y	Y		Y	Y
Pólvora and Nascimento (2017)	Y	Y	Y	Y	
Reed et al. (2018)	N/A	N/A	N/A	N/A	N/A
Sandoval et al. (2012)		Y			
Schäfer and Kieslinger (2016)	Y	Y		Y	
Shirk et al. (2012)	Y	Y		Y	Y
Smajgl and Ward (2015)		Y			
Szilagyi et al. (2014)		Y			
Toomey & Domroese, (2013)		Y			
Tremblay (2017)		Y			
Tremblay et al. (2017)	Y	Y			
Trickett and Beehler (2017)		Y			
Trimble and Lazaro (2014)		Y			Y
Van Brussel and Huyse (2018)		Y			Y
Villasenor et al. (2020)		Y		Y	Y
Wehn et al. (2017, 2019, 2020b)		Y	Y	Y	Y
Wiggins et al. (2018)	Y				
Woods et al. (2016)		Y		Y	Y
Woods et al. (2019)		Y		Y	Y