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ECHO

ENGAGING CITIZENS IN SOIL SCIENCE:
THE ROAD TO HEALTHIER SOILS

Deliverable 2.1
"List of methods to leverage citizen science methods for soils"

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Project Coordinator

Prof. Tanja Mimmo
Free University of Bolzano, Italy
Tel: +39 0471 017161
tanja.mimmo@unibz.it

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Short description of the deliverable

This deliverable selects the most suitable citizen science methods and provides recommendations to refine ECHO's methodologies based on the findings. It summarises the collaborative work of the ECHO Task 2.1 (“Selection of citizen science methods for monitoring soils”). This task examined each project previously identified in the initial matrix from Task 1.1 (“State of the art on Citizen Science initiatives for monitoring soil health”) and allowed the application of the assessment frameworks developed in Task 1.2 (“Assessment framework for citizen science methods”) and Task 1.3 (“Citizen-generated Soil Data Quality assessment framework”). This deliverable gathers the gaps identified in the assessed existing citizen science methods and citizen-generated soil data quality, and details the most suitable ones. Additionally, it discusses the citizen science approaches and toolkit, the citizen-generated soil data quality and the level of citizen participation in ECHO.

Versioning and contribution history

Version	Date	Modified by	Notes
1	13/11/2024	Alba Peiro (IBERCIVIS)	Draft version
2	15/11/2024	Alba Peiro (IBERCIVIS), Ana Maria Ventura (SOLUTOPUS), Olga Viridiana Huerta (UHOH) and Elisavet Papadopoulou (AFS)	Revised version 1
3	22/11/2024	Roy Neilson (HUTTON), Tanja Mimmo (UNIBZ), Claudia Capello (UNIBZ) and Manuel Pulido (UEX)	Revised version 2
4	26/11/2024	Alba Peiro (IBERCIVIS)	Final version

Foreword

Soil is a vital, yet often disregarded, resource that supports life on Earth by providing the foundation for agriculture, forests, and various other natural ecosystems. However, soil degradation is a growing concern around the world, and it can have severe consequences for our planet like reduced crop yields, increased greenhouse gas emissions, and decreased biodiversity. The ECHO project aims to prevent this by bringing together citizens and volunteer scientists from around Europe to work towards a common goal of protecting and preserving our soils, thus contributing to the transition towards healthy soils of the EU Mission: "A Soil Deal for Europe".

ECHO will generate new data on the health status of EU soils, complementing existing soil mapping and monitoring in EU Member States and Scotland, including the EU Soil Observatory (EUSO). The project will develop and deploy 28 tailor-made citizen science initiatives across EU Member States and Scotland, considering different land-uses, soil types, and biogeographical regions, as well as stakeholder needs. With 16 participants from all over Europe, including 10 leading universities and research centres, 4 SMEs, and 2 Foundations, under the coordination of the Free University of Bolzano-Bozen, ECHO will assess 16,500 sites in different climate and biogeographic regions to achieve its ambitious goals.

The project aims to engage citizens in protecting and restoring soils by building their capacities and enhancing their knowledge. Citizens will thereby not only actively contribute to the project's data collection but also promote soil stewardship and foster behavioural change across the EU. The ECHOREPO, a long-term open access repository with a direct link to the EUSO, will make the citizen science data available for exploitation not only by scientists but also by citizens, policy makers, farmers, landowners and other end-users, providing added value to existing data and other relevant soil monitoring initiatives. ECHOREPO will thus provide valuable information about the state of soil health in various regions, and help citizens make informed decisions about land use and conservation.

We believe that the ECHO project will have a significant impact on soil health and citizen engagement across Europe and become an important step towards protecting and preserving our soil for future generations. By working together, we can ensure that our soil remains healthy and productive, and that we continue to enjoy the many benefits it provides.

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1. Introduction

Citizen science (CS) projects specifically focused on soils began emerging after 2010 (Ranjard, 2020; Gascuel et al., 2023) and increased with the support of the Mission Soil 'A Soil Deal for Europe' (European Commission, 2021a). Mission Soil is one of the five Research and Innovation Missions to seek solutions in response to major societal challenges, aligning with global commitments such as the UN Sustainable Development Goals (SDGs). CS projects can accelerate the measurement of global progress toward the SDGs by assisting traditional soil monitoring programmes (Rossiter et al., 2015; Fritz et al., 2019).

With its CS approach, ECHO will accelerate progress by focusing directly on the eight soil health indicators defined in the Mission Soil Implementation Plan (European Commission, 2021b). Additionally, ECHO will implement innovative approaches, harmonizing knowledge and techniques from similar CS projects to ECHO, to ensure high-quality data collection and consistency. Therefore, Task 2.1, "Selection of Citizen Science Methods for Monitoring Soils" is crucial, as it focuses on evaluating existing methods, selecting those appropriate for ECHO and offering recommendations that inform T2.2, "Development of a Citizen Science Toolbox".

This task is directly based on the outcomes of WP1 "Enabling high-impact citizen science for soil monitoring". In Task 1.1, a detailed matrix was constructed to provide an overview of the state-of-the-art projects, initiatives, or activities (from both inside and outside the European Union) that have already involved citizens in monitoring soil health, encompassing both soil biodiversity and pollution. Additionally, as part of both Task 1.2 and 1.3, two assessment frameworks were developed: one for **Citizen Science Methods (CSMs)** and another for **Citizen-Generated Soil Data Quality (CGDQ)**. Finally, in Task 1.4, the first version of the ECHO Monitoring and Evaluation Framework was established, enabling the identification and selection of some key engagement factors for these CS projects.

The initial matrix from Task 1.1 "State of the art on Citizen Science initiatives for monitoring soil health" has served as a valuable repository of CSMs for the current task. In this deliverable, the assessment frameworks developed in Task 1.2 "Assessment framework for citizen science methods" and Task 1.3 "Citizen-generated Soil Data Quality assessment framework" are applied to the previously identified projects, to evaluate the quality of soil data produced by their methodologies, as done in previous similar reviews (Head et al., 2020). This approach offers valuable insights and recommendations for inclusion in the toolbox for Task 2.2.

Therefore, the **objectives of Task 2.1** are to:

1) Apply the assessment frameworks from Task 1.2 and Task 1.3 to the initiatives and projects included in the matrix from Task 1.1.
2) Categorise the methods for soil monitoring and quality of the data gathered, into three groups, based on their suitability for adoption within ECHO.
3) Identify gaps in those existing CSMs and CGDQ.
4) Select the most suitable CSMs and CGDQ.
5) Provide recommendations to refine ECHO's methodologies based on the findings.

2. Context

2.1. Connection with Task 1.1: the repository of projects

During Task 1.1 “State of the art on Citizen Science initiatives for monitoring soil health” we identified 91 relevant projects but, of those, only 71 initiatives and activities aligned with our criteria of having actively engaged citizens through CS approaches to monitoring soil health, biodiversity, and pollution (Ibercivis Foundation, 2023).

From that selection, 54 projects were classified as having citizen engagement as the main focus. This classification could be further divided into projects that had a clear soil focus and those that did not focus on soil as the main objective. Thus, a 4-way matrix could be constructed that comprised four clear categories A, B, C, and D (Fig. 1). Categories C and D were those defined where citizens had a contributory role. Whereas categories A and B were defined where citizens had clear collaborative and co-created roles, as per the classification of public participation in scientific research projects established by Shirk et al. (2012). Moreover, we used the broad classification of types of soil indicators, physical, chemical, or biological, as described by Bünemann et al. (2018). However, these categories were not always clearly delineated, as many properties reflect multiple soil processes (Lehmann et al., 2020).

The identified projects assessed the following types of soil indicators (corresponding to “Methods”, as specified in Section 3.1) through different CSMs:

- Biological indicators: including biodiversity of bacteria, fungi, protozoa, insects, worms, or other invertebrates, and decomposition rate.
- Chemical indicators: including pH, SOC, SOM, and pollution (trace metals or microplastics).
- Physical indicators: including texture, structure, colour, moisture, water infiltration, and temperature.
- Mixed indicators: for projects assessing indicators that span more than one category cutting across multiple categories (corresponding to “Toolkits”, as specified in Section 3.1).

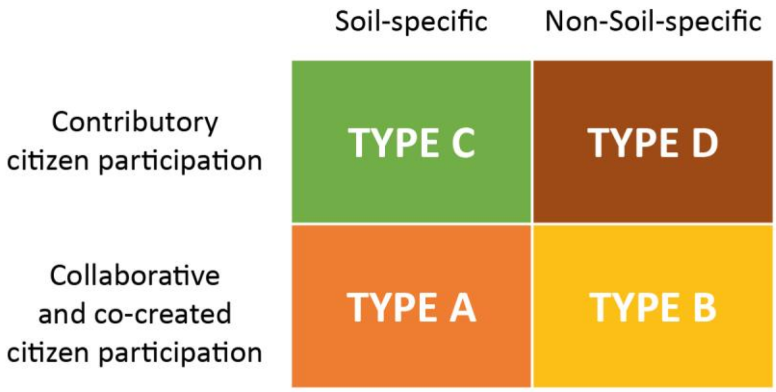

Figure 1: Relationship between the classification of public participation in scientific projects of Shirk et al (2012), soil specificity, and the classification of D1.1.

This repository of 54 projects is the final set used for the assessments in the present Task 2.1. However, during the development of this task, it became apparent that a significant portion of the online information for 6 of these projects (in some cases, all of it) had disappeared since our initial review, leading us to exclude them from the current assessment and thus, reducing the number of projects to 48.

2.2. Connection with Tasks 1.2 and 1.3: the assessment frameworks

The CSMs and CGDQ assessment frameworks, developed during Tasks 1.2 and 1.3, respectively were those applied to the 48 projects from Task 1.1 for the current task. The criteria for each assessment framework are detailed in Table 1 and include a total of 61 questions and sub-questions (see Deliverables 1.2 and 1.3, and Annex 1) to be answered for each project. The scoring scales and thresholds to obtain a final score for the CSMs used in those projects were also established during Tasks 1.2 and 1.3 and are indicated later under Section 3.3.

Table 1: Criteria or dimensions established for the two ECHO assessment frameworks detailed in T1.2-1.3 and D1.2-1.3.

Assessment framework for CSMs in soil monitoring (Task 1.2)	Assessment framework for CGDQ (Task 1.3)
1) SIMPLICITY	1) RELEVANCE
2) COSTS	2) ACCURACY
3) TEMPORAL AND SPATIAL GRANULARITY	3) ACCESSIBILITY
4) DATA REPLICABILITY	4) COHERENCE
5) DATA RELIABILITY	5) INTERPRETABILITY
	6) COMPATIBILITY
	7) ADAPTATION

2.3. Connection with Task 1.4: the engagement factors

Some participant indicators established within the first version of the Monitoring and Evaluation Framework developed in Task 1.4 were also considered in Task 2.1. Participant indicators in ECHO track the engagement and demographics of individuals involved in the project. Here, we include engagement factors such as the participation scale, when possible, as this information was also previously gathered during Task 1.1, and participant feedback on their experience. Other metrics from the participant indicators included demographic breakdown (e.g., age, gender, education level), geographic distribution of participants, and level of involvement (e.g., one-time participants vs. ongoing contributors). However, whilst we found these participant indicators informative in the earlier ECHO tasks these metrics couldn’t be included in Task 2.1 due to the lack of available information for each assessed project.

3. Methodology

3.1. Constructing the matrix

An initial matrix was constructed, as a table created in a spreadsheet (using Teams), to facilitate the application of both assessment frameworks to the 48 projects by all partners. Automated cells enabled answers for each question and sub-question to be selected from the criteria (Table 1), and to automatically generate the final score for both assessments, according to the scoring scales established in previous tasks (see Sections 2.2 and 3.3). That initial matrix evolved into a detailed table (see Section 4.1) that gathered the essential information from each project, into the sections displayed in Table 2, that facilitated evaluation of CSMs for this deliverable.

Table 2: Sections from the table of this deliverable used to evaluate methods and toolkits for soil health assessment and monitoring (see Section 4.1).

Column	Description	Source
Name	Name of the project, initiative, or activity that actively engaged citizens through CS approaches to monitor soil health, biodiversity, and pollution.	From Task 1.1 (Ibercivis Foundation, 2023).
Degree of citizen engagement	Contributory or collaborative and co-created projects.	From Task 1.1 (Ibercivis Foundation, 2023) and based on Shirk et al. (2012).
Main objective	Soil-centric or non-soil-centric.	From Task 1.1 (Ibercivis Foundation, 2023).
Type of project	A, B, C, or D.	From Task 1.1 (Fig. 1; Ibercivis Foundation, 2023).
Type of soil monitoring	Depending on the type of health indicators (Biological, Chemical, or Physical indicators) and if they focus on one indicator (method) or multiple indicators (toolkit).	Based on Task 1.1 (Ibercivis Foundation, 2023) and Bünemann et al. (2018)., but reviewed in this deliverable.
Engagement factor 1: Participation scale	Number of participants, sometimes mixed up with the total number of samples collected.	From Task 1.1 (Ibercivis Foundation, 2023).
Engagement factor 2: CS feedback	Available participant feedback: Yes or No.	New in this deliverable.
Final score for the assessment of CSMs	Green (approved and recommended for adoption), yellow (require further analysis but have the potential for adoption), or red (not advisable for use and rejected).	New in this deliverable.
Final score for the assessment of CGDQ		

3.2. Partner contributions

Ibercivis (Spain) led this task, but every ECHO partner contributed. We requested each partner to contribute to the first objective of the present task, and we all applied the assessment frameworks from Task 1.2 and Task 1.3 to all initiatives and projects included in the matrix from Task 1.1.

This collaborative approach was established through two online meetings and mailing threads with all partners, ensuring clarity in the process and addressing any concerns. Projects were distributed among partners depending on their responsibilities in WP2, prioritizing projects they were familiar with, had expertise in, or those initiatives presented in their native languages. They were able to delve into the details of each project, using the information from the Task 1.1 matrix as a starting point and continuing by re-visiting the specific project website(s), materials, and databases, as well as carrying out some direct interviews with key representatives or stakeholders associated with those projects. The ECHO partners answered every question and sub-question included in the initial matrix on Teams, and the bespoke Excel sheet automatically generated the final score for both assessments. This allowed us to directly categorise the methods used in the projects, for soil monitoring and the quality of the data gathered, into three groups, based on their suitability for adoption within ECHO (see Section 3.3).

Afterward, Ibercivis (Spain), SOLUTOPUS (Portugal), UHOH (Germany), and AFS (Greece) contributed to the rest of the objectives of the present task, by analysing this categorization, identifying gaps in those existing CSMs, selecting the most appropriate and providing recommendations to refine ECHO methodologies based on the deliverable findings.

3.3. Scoring scales and categorization

Each project or initiative has been assessed at two levels following instructions from Tasks 1.2 and 1.3. First, different minor scoring scales (Fig. 2) were assigned to every question and sub-question for each criterion (Table 1). Second, final scores (Fig. 3) were assigned to each project: one for the CSM and one for the CGDQ, depending on the final sum of minor scoring scales. A slight correction to the thresholds of the final scores had to be done in the present task after the original ones posed difficulties during the assessment and are directly corrected in Figure 3. Originally, the approval threshold was “ or or up to 40% of and/or overall in all criteria”.

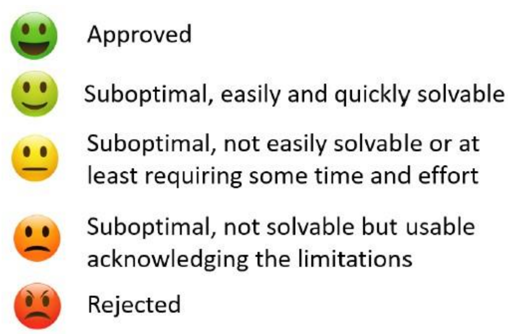

Figure 2: Minor scoring cores for each question and sub-question considered in the evaluation, established in D1.2 and D1.3.

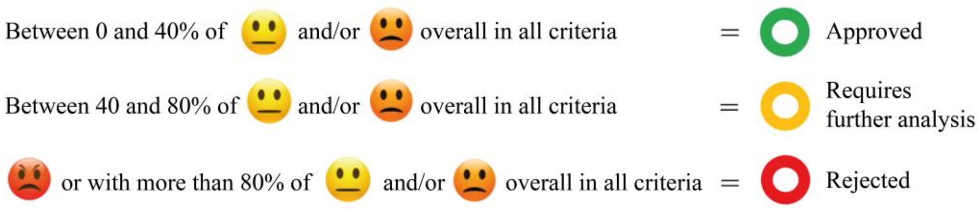

Figure 3: Thresholds and final scores for the suitability of methodologies for integration into ECHO's activities, established in D1.2 and D1.3 but corrected in the present deliverable.

3.4. Limitations

The following key limitations and challenges were encountered:

- Information availability or loss: between initial and full review of projects, documentation and data had been taken offline, leading to their exclusion from the current assessment. With older projects, there was a greater probability of finding online errors, broken links and deleted websites.
- Variable applications of the assessment frameworks: even using two comprehensive and standardized assessment frameworks, the chosen methodology involved the application and evaluation conducted by different individuals, which could impact final results.
- Low representativeness of intermediate minor scores (Fig. 2) and consequently no representativeness of the final intermediate score (yellow, "Requires further analysis," Fig. 3): subtle nuances in the sub-questions may have led to an inclination towards extreme final scores when applying the assessment frameworks. This issue may have had a greater impact on projects with a final score of 'approved' (green, Fig. 3), suggesting that some may be closer to a 'requires further analysis' score (yellow, Fig. 3). However, this did not affect projects with a 'rejected' score (red, Fig. 3), as the reasons for rejection were always clear.

For these reasons, and even with the diverse methods used, the application of these assessments should be considered representative rather than comprehensive. Although a substantial number of projects have been assessed, there remains the possibility that information on some projects may have been under- or overestimated. Nevertheless, these challenges were addressed whenever possible by following the systematic approach of the chosen methodology, which included sourcing information from multiple databases and, when necessary, consulting experts in the field to fill any gaps in the available information. This review was broad in scope and allowed us to derive meaningful insights into CSMs and the quality of citizen-generated data.

4. Results

4.1. Final scores of the assessment frameworks

Table 3 provides the main information regarding the level of citizen engagement, type of soil monitoring, engagement factors and the final scores for the assessments (as described in Table 2).

Table 3: Final assessment scores according to the CSM and CGDQ frameworks.

Name	Degree of citizen engagement Col/Co = Collaborative/ co-created Con = Contributory	Main objective SC = Soil-centric NSC = Non-soil-centric	Type of project See Figure 1	Type of soil monitoring	Engagement factors		Final assessment scores	
					Participation scale	CS feedback	CSMs	CGDQ
Bodemdierendagen	Con	SC	C	Biological method	Unknown	NO		
CALeDNA	Con	SC	C	Biological method	6001	YES		
Earthworm watch	Con	SC	C	Toolkit	1678	YES		
MINAGRIS	Con	SC	C	Toolkit	19395 but ongoing	NO		
Observatoire de la QUalité Biologique des Sols (QUBS)	Con	SC	C	Biological method	Ongoing	YES		
Open Soil Atlas	Col/Co	SC	A	Toolkit	77	NO		
Programa de Conservación de Suelos	Con	SC	C	Toolkit	69	NO		
SoilSafe Aotearoa	Con	SC	C	Chemical method	Ongoing	NO		
Vigilantes del Suelo	Con	SC	C	Toolkit	<2100	NO		
Collectifs	Col/Co	NSC	B	Biological method	768	YES		
Gärtnern für den Umweltschutz	Con	SC	C	Toolkit	Unknown	NO		
Knoxville-Tennessee Environmental Soil and Stream Testing (K-TESST)	Con	SC	C	Toolkit	Unknown	YES		
NOCMOC	Con	NSC	D	Toolkit	Unknown	NO		
Observatoire agricole de la biodiversité	Con	NSC	D	Biological method	4600	YES		
OPAL Soil & Earthworm Survey (UK)	Con	SC	C	Toolkit	2671	NO		
The Citizen Science Soil Health Project	Col/Co	SC	A	Toolkit	Unknown	YES		
Vigie-nature école	Con	NSC	D	Biological method	768	NO		
360 Dust Analysis	Con	SC	C	Chemical method	Unknown	YES		
Beweisstück Unterhose	Con	SC	C	Biological method	1000	NO		
bodemleven	Con	SC	C	Biological method	Unknown	NO		
BRIDGES	Col/Co	SC	A	Toolkit	62	NO		
CiDéSol	Col/Co	SC	A	Chemical method	Unknown	NO		
CurieuzeNeuzen in de tuin (CNIDT)	Con	SC	C	Physical method	5000	NO		
Expedition Erdreich	Con	SC	C	Biological method	9000	NO		
GROW Observatory	Col/Co	SC	A	Physical method	20500	YES		
HeavyMetal Citizen	Col/Co	SC	A	Chemical method	44	NO		
Soil Your Undies Challenge - University of New England	Con	SC	C	Biological method	280	NO		
Tea Bag Index (TBI)	Con	SC	C	Biological method	<2500	YES		
TeaComposition Initiative	Con	SC	C	Biological method	~ 8000	YES		
TeaComposition Project	Con	SC	C	Biological method	Unknown	YES		
TeaTime4App	Con	SC	C	Biological method	245	YES		
TeaTime4Schools	Con	SC	C	Biological method	54	YES		
Citizens of the Crust: a biocrust assessment project	Con	NSC	D	Biological method	87	YES		
FARM NET ZERO and Farm Carbon Toolkit	Col/Co	NSC	B	Toolkit	Unknown	NO		
Garden Roots	Col/Co	SC	A	Chemical method	25	NO		
MAKING SENSE	Con	NSC	D	Chemical method	Unknown	NO		
MicroBlitz	Con	SC	C	Biological method	Unknown	YES		
MO DIRT (Missourians Doing Impact Research Together)	Con	SC	C	Toolkit	869	NO		

Name	Degree of citizen engagement Col/Co = Collaborative/ co-created Con = Contributory	Main objective SC = Soil-centric NSC = Non-soil-centric	Type of project See Figure 1	Type of soil monitoring	Engagement factors		Final assessment scores	
					Participation scale	CS feedback	CSMs	CGDQ
Nuestros suelos	Col/Co	SC	A	Chemical method	Unknown	NO		
Plante ton slip	Con	SC	C	Biological method	Unknown	NO		
SCENT	Con	NSC	D	Physical method	Unknown	NO		
SHOWCASE	Col/Co	NSC	B	Biological method	Unknown	NO		
Soil Moisture Active Passive (SMAP)	Con	SC	C	Physical method	Unknown	YES		
Soil Sampling Toolkit by Citizen Science Community Resources	Con	SC	C	Chemical method	Unknown	YES		
Soils, Science and Community Action (SoilSCAN)	Col/Co	SC	A	Toolkit	42	YES		
SoilSkin – La Piel Viva del Suelo	Con	NSC	D	Biological method	Unknown	NO		
The Tea Bag Experiment - Tepåseförsöket	Con	SC	C	Biological method	Unknown	NO		
Using CS to develop solutions for healthy soils through phytomining	Col/Co	SC	A	Chemical method	Unknown	NO		
Indiana Collaboration for Lead Action and Prevention Latrobe Valley Dust Research Expedition Boden Grower CS Project CS project on SH and soil awareness (Science Year 2020 Bioeconomy) Alsóban az élet	Excluded of the application of the assessment frameworks							

4.2. Citizen science methods or toolkits

In this deliverable, the term method refers to a protocol designed to evaluate a single soil health indicator, whereas toolkit refers to protocols aimed at measuring multiple indicators (Table 2). Out of the 48 CSMs and toolkits assessed, Table 4 summarizes the numbers that were approved or rejected. Additionally, Figure 4 groups these methods and toolkits according to the CSM and CGDQ assessment frameworks, based on the findings shown in Table 3.

Table 4: Results of the application of both assessment frameworks

	Final score after the CSMs assessment		Final score after the CGDQ assessment	
	Approved and recommended for adoption	Not advisable for use and rejected	Approved and recommended for adoption	Not advisable for use and rejected
Methods	7	27	18	16
Toolkits	10	4	6	8

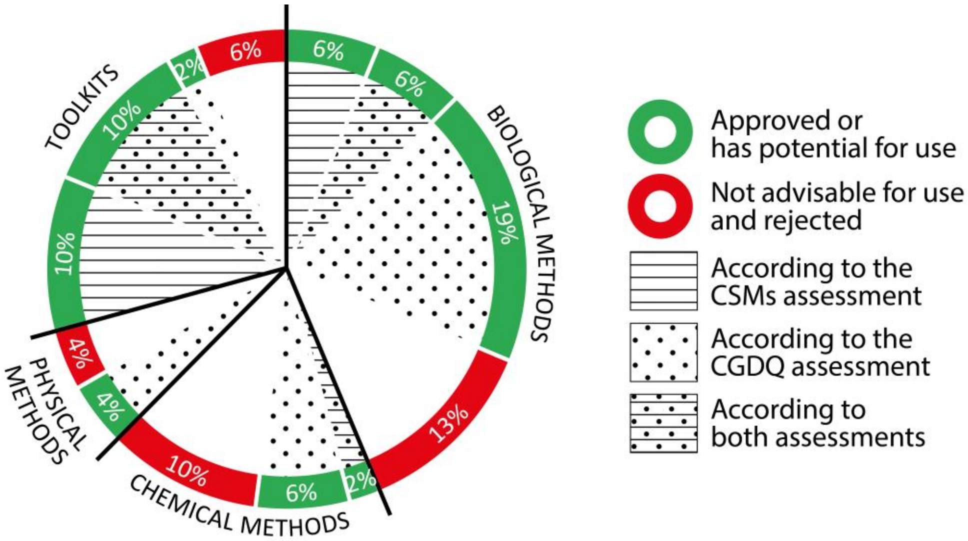

Figure 4: Approved and rejected methods or toolkits, according to the assessment frameworks.

4.3. Citizen participation and feedback

The application of both assessment frameworks provides additional feedback regarding the suitability or unsuitability of the different levels of citizen participation and feedback factors (Table 2). Figures 5 and 6 compare the approved methods and toolkits according to the CSM and CGDQ assessment frameworks, for both factors, respectively, based on the findings shown in Table 3.

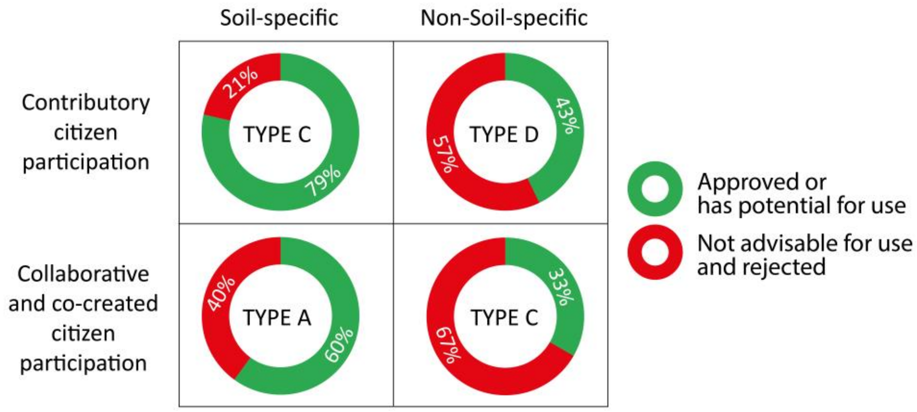

Figure 5: Approved and rejected methods and toolkits, according to the assessment frameworks, in comparison with the levels of citizen participation and therefore each type of project (see Fig. 1 and Table 2).

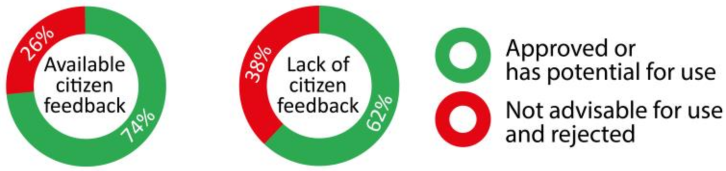

Figure 6: Approved and rejected methods and toolkits, according to the assessment frameworks, in comparison with the availability or lack of citizen feedback (see Table 2).

5. Discussion

5.1. Characteristics of the methods or toolkits unsuitable for ECHO: Identifying gaps

5.1.1. Based on the assessment of citizen science methods

In order of frequency (most first), we present the gaps identified from the CSM assessment of methods and toolkits that resulted in a recommendation not to adopt in ECHO (see Annex 2 for more details):

1º. Unsuitable and inflexible temporal granularity (TEMPORAL AND SPATIAL GRANULARITY Criteria, Table 1):

Most initiatives implemented protocols where the sampling frequency, interval, or duration were not compatible with the objectives and capabilities of ECHO. Two examples were: the need to revisit the sampled area to observe changes or improvements in soil health over time, or the requirement to bury elements of the kit for a specific period, such as at least one month, to measure a particular indicator. These methods or toolkits would not allow for the design of effective data collection and analysis strategies that align with the activity goals and research questions of ECHO.

2º. Unavailable protocols (DATA REPLICABILITY Criteria, Table 1):

Many sampling protocols were not available on the project websites. On many occasions, due to improper maintenance of the websites given the age of the projects (see Section 3.4), but also because they have been provided to participants through internal channels and were not publicly accessible. This has potential to impact data replicability and reproducibility in ECHO, which are crucial in CS studies to enhance the scientific value of the data collected and to ensure that the data collected can be independently verified and used by other researchers or organizations.

3º. Equipment required (COSTS Criteria, Table 1):

Several methods required specialised and/or expensive equipment that was not provided by the project in advance. Examples include GPS devices, accurate weighing scales, specific chemical solutions, and amber lab jars. This could impact the quality of the data collected, as participants might substitute these items with alternatives that could alter the results if the required equipment was difficult to find. Additionally, the cost of this equipment needs to be considered, as it could affect ECHO's planning and budgeting, potentially forcing a reallocation of resources.

4º. Non estimable costs (COSTS Criteria, Table 1):

In line with the required equipment, some methods involved the use of multiple tools or the application of several measurements, making it difficult to estimate and quantify costs, and this information was typically not provided by the projects. Thus, again impacting ECHO's planning and budgeting.

5º. Difficult and specificity of tools and indications (SIMPLICITY Criteria, Table 1):

When tools for data collection in the assessed methods were difficult to use, the instructions were unclear for non-experts, and neither the tools nor the instructions could be adapted or simplified. In ECHO, we prioritise simplicity, a key factor in citizen science that improves the data quality and ensures activities are accessible, inclusive, harmonized, and engaging for a wide range of participants.

6º. Unsuitable and inflexible spatial granularity (TEMPORAL AND SPATIAL GRANULARITY Criteria, Table 1):

One initiative implemented a method where the sampling spatial distribution, level of detail, or resolution was not compatible with the objectives and capabilities of ECHO. For example, the requirement to mix soil samples collected from nearby places to measure contamination and heavy metals in a broader area. This method would not allow for the design of effective data collection and analysis strategies that align with the activity goals and research questions of ECHO.

5.1.2. Based on the assessment of citizen-generated soil data quality

In order of frequency (most first), we present the gaps identified from the CGDQ assessment of toolkits that resulted in a recommendation not to adopt in ECHO (see Annex 2 for more details):

1º. Inaccessible data and FAIR principles not applied (ACCESSIBILITY Criterion, Table 1):

Data or results did not adhere to FAIR principles (Findable, Accessible, Interoperable, and Reusable). and were frequently unavailable, inaccessible, or difficult to consult via project websites or platforms. This was often due to improper maintenance given the project age (see Section 3.4) or restrictions on public access. In several instances, results were limited to summaries, which restricted their utility for further applications.

2º. Difficult tasks (ACCURACY Criterion, Table 1):

Certain tasks were overly complex, making them difficult to understand and perform, which hinders data collection. This can affect data accuracy and introduce bias, compromising data quality. For this document, it was essential to prioritize methods that yielded accurate results, and where measurements align as closely as possible with true values and minimize bias.

3º. Protocols unsuitable for other regions (ADAPTATION Criterion, Table 1):

Occasionally, protocols were complete but specific to particular European biogeographical regions or soil type(s), limiting data collection in other regions and complicating their general adaptation. This restricted the broader objectives of capturing soil biodiversity, enhancing the usability and relevance of soil data, and supporting informed decision-making in land management and environmental conservation across varied geographic areas and ecosystems.

4º. Unclear objectives (ACCURACY Criterion, Table 1):

In some cases, project goals were not clearly defined or were open to misinterpretation by participants, which can compromise the feasibility of data collection, resultant accuracy (as noted in gap 2), and interpretability. Without sufficient clarity in data definitions, terminology, or limitations, data users may be unable to use the data effectively.

5º. Uncertain data checks (ACCURACY Criterion, Table 1):

Quality assurance measures, such as data checks, expert or volunteer validation, and standardized testing or calibration methods to address potential errors or bias, were uncommon among the identified projects. This lack of measures can compromise both the quality and accuracy of the resulting data (as noted in gaps 2 and 4).

6º. Uncertain analytical protocol (RELEVANCE Criterion, Table 1):

Occasionally, CS initiatives did not specify the analytical protocols used to assess soil parameters. In such cases, they may not employ the LUCAS protocol or other equally rigorous standards suitable for adoption in ECHO. This lack of rigour undermines the relevance and usability of the data for specific purposes, such as assessing key soil indicators as required by data users.

7º. Difficult data formats (ACCESSIBILITY Criterion, Table 1):

For some projects, the data format was neither user-friendly nor compatible with commonly used software and tools, preventing the use of accessible, compatible formats with datasets deriving from these methods. This hinders data accessibility, and subsequent interoperability and reuse (see gaps 1 and 7).

8º. Non-standardised protocols (INTERPRETABILITY Criterion, Table 1):

Consistent with the uncertain analytical protocols (see gap 6), projects did not always follow international or standard protocols for data collection, making these protocols difficult for later adaption. This lack of clarity reduced the interpretability of citizen-generated data, meaning that results and insights derived from the data were often hard to understand or explain.

5.2. Characteristics of the methods or toolkits suitable for ECHO: Selection

5.2.1. Based on both assessments

A) Biological methods

Results of **both assessment frameworks** identified that 6% of the assessed projects or initiatives that employed methods to measure biological soil health indicators were approved or recommended for adoption in ECHO (Fig. 4). These biological methods are (Table 3 and Ibercivis Foundation, 2023):

BIODIVERSITY

- **Project:** Bodemdierendagen

List of tools: Magnifying glass, shovel and the cart describing different soil organisms.
Organisms sampled: Earthworms, slugs, snails, spiders, woodlice, millipedes, centipedes, beetles, ants and moles.
Brief description of the activity: Dig a hole and visually identify, describe and count organisms, following instructions from the provided protocols.
Link to website, guidelines and data for quality details:

https://bodemdierendagen.nl/nl
https://bodemdierendagen.nl/nl/tips
https://invoer.bodemdierendagen.nl/resultaten/

- **Project:** Observatoire de la QUalité Biologique des Sols (QUBS)

List of tools: Mustard, water, watering can, ramp, twine or stakes, blender and measuring tape.
Organisms sampled: Earthworms.
Brief description of the activity: Pour water previously mixed with mustard onto the sampling site, wait for earthworms to go to the surface, and visually identify, describe and count them, following instructions from the provided protocols.
Link to website, guidelines and data for quality details:
https://www.qubs.fr/
https://www.qubs.fr/aspifaune
https://www.qubs.fr/noctambules
https://www.qubs.fr/operation-escargots
https://www.qubs.fr/recherche

- **Project:** CALeDNA

List of tools: Gloves, tubes, Whirl-pak, Box and scoop (water meter & soil meter; optional)
Organisms sampled: DNA from microbes, fungi, plants, animals.
Brief description of the activity: Take a photo that best captures the sampled ecosystem, put on gloves, clear debris or leaf litter with a stick, fill the provided tube with soil, place closed tubes in the Whirl-pak, and place in the CALeDNA Box provided. It was optional to use a water meter or soil meter to collect additional information and record it in the app.
Link to website, guidelines and data for quality details:
https://ucedna.com/
https://ucedna.com/kit-training
https://data.ucedna.com/
https://data.ucedna.com/taxa

B) Chemical methods

Results of **both assessment frameworks** identified that 2% of the assessed projects or initiatives that employed methods to measure chemical soil health indicators were approved or recommended for adoption in ECHO (Fig. 4). These chemical methods are (Table 3 and Ibercivis Foundation, 2023):

HEAVY METALS:

- **Project:** SoilSafe Aotearoa

List of tools: Trowel and a bag for soil samples.

Measured elements: Arsenic, cadmium, chromium, copper, manganese, lead, nickel, and zinc.
Brief description of the activity: Collect samples using a trowel or other tool to collect a cricket ball sized amount of soil at each location. Double-bag up your soil samples by location and seal them up tight. Afterward, scientists analysed samples using X-ray fluorescence spectrometry.
Link to website, guidelines and data for quality details:
https://soilsafe.auckland.ac.nz/
https://www.youtube.com/watch?v=0sRg0IPQ9I0&t=17s
https://iupui-earth-science.shinyapps.io/MME_Global/

C) Toolkits

Results of **both assessment frameworks** identified that 10% of the assessed projects or initiatives that employed methods to measure multiple soil health indicators were approved or recommended for adoption in ECHO (Fig. 4). These toolkits are (Table 3 and Ibercivis Foundation, 2023):

- **Project:** Earthworm watch

List of tools: Chart, pen or pencil, spade or trowel, mustard, water, large plastic bag, clock or watch, containers and vinegar.
Assessed indicators: Biodiversity (Earthworms), carbonate content, moisture, texture and colour.
Brief description of the activity: Dig a hole, pour one bottle of mustard water into it and collect any earthworms that appear within five minutes. Then take a handful of soil in their hands, observe, squeeze and fit it into different categories. Take a scoop of soil and add a few drops of vinegar to it. Watch it for about a minute and see if it fizzes.
Link to website, guidelines and data for quality details:
https://www.earthwormsoc.org.uk/earthwormwatch
https://www.earthwormwatch.org/sites/default/files/EarthwormWatchInstructionBooklet_2.pdf
https://www.earthwormwatch.org/sites/default/files/EarthwormandSoilChart.pdf
https://www.earthwormsoc.org.uk/earthworm-data

- **Project:** MINAGRIS

List of tools: Smartphone with the project's app
Assessed indicators: Visual contamination, texture and biodiversity.
Brief description of the activity: Record the coordinates and land use of the sampling site, observe the debris, and count, measure and describe it. Add further information regarding texture and organisms, as well as photos of your observations.
Link to website, guidelines and data for quality details:
https://minagris.eu/joomla/
https://play.google.com/store/apps/details?id=com.spotteron.soilplastic&hl=es&pli=1

ECHO
ENGAGING CITIZENS IN SOIL SCIENCE: THE ROAD TO HEALTHIER SOILS
Co-funded by the European Union
UK Research and Innovation

- **Project:** Open Soil Atlas

List of tools: Water, Scale, Vinegar, Baking soda, small plate, Shovel or spade, Glass jar, Kitchen knife, Spoon or stick, Garden gloves.

Assessed indicators: Biodiversity (earthworms and other biological activity, like bugs, animal feaces), pH, contamination, erosion, colour and texture.

Brief description of the activity: Determine the sampling site, observe and describe the surroundings, take photos and compare them with the ones from the protocols. Count earthworms and describe any other biological activity (bugs, animal feaces). Dig a hole and observe the soil profile, determine colour and texture with the ribbon method and Jar Test. Determine pH with the Vinegar/Baking soda test. Upload the gathered data to the digital entry form in the app.

Link to website, guidelines and data for quality details:
https://terrific-spike-fc0.notion.site/Open-Soil-Atlas-ENG-45a9724323cd4cf6bcfa352634936f94
https://www.mitforschen.org/sites/default/files/assets/projekte/user-4879/pdf/OSA%20Benutzer_innenhandbuch.pdf
https://terrific-spike-fc0.notion.site/OSA-Map-abaadf18576348cb93dab448abe511ec
https://www.mitforschen.org/sites/default/files/assets/projekte/user-4879/pdf/OSA%20Final%20Paper%20(Englisch).pdf

- **Project:** Programa de Conservación de Suelos

List of tools: Thermometer, scale, shovel, cylinder and hammer, rod and meter, pH strips, beaker, a specific toolkit for the soil breathing rate and a field sheet.

Assessed indicators: Vegetation cover, biodiversity, temperature, infiltration rate, compaction, texture, pH, breathing rate and organic carbon content

Brief description of the activity: Observe crops and organisms, and measure soil temperature. Stick the rod into the ground and measure its depth. Stick the cylinder into the ground, fill it with water and time its infiltration speed. Carry out the texture by moulding a soil cylinder, the pH test and the breathing test, and determine soil colour.

Link to website, guidelines and data for quality details:
https://www.vitoria-gasteiz.org/wb021/was/contenidoAction.do?lang=en&locale=en&idioma=en&uid=u_2498e010_162d6fd8d27__7e82
https://www.vitoria-gasteiz.org/docs/wb021/contenidosEstaticos/adjuntos/es/24/24/82424.pdf
https://lurzain.eus/

- **Project:** Vigilantes del suelo

List of tools: Pen, smartphone, hydrogen peroxide, distilled water, water, plastic glass, tray, spoon, ruler, cylinder, hammer, pH stripes and a shovel

Assessed indicators: Vegetation cover, biodiversity, infiltration rate, compaction, pH, and organic matter content.

Brief description of the activity: Observe and describe your surroundings, stick a pen into the ground and measure its depth. Stick the cylinder into the ground, fill it with water and time its infiltration speed. Dig a hole and observe and describe organisms. Carry out the pH test and pour some hydrogen peroxide on a soil sample to estimate the level of reaction.
Link to website, guidelines and data for quality details:
https://vigilantesdelsuelo.es/
chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://vigilantesdelsuelo.es/wp-content/uploads/2024/01/Guia-vigilantes-suelo.pdf
https://play.google.com/store/apps/details?id=com.reactnativeplantilla&hl=es_419

5.2.2. Based on the assessment for citizen science methods

A) Biological methods

Results of the **CSMs assessment framework** identified that 6% of the assessed projects or initiatives that employed methods to measure biological soil health indicators were approved or recommended for adoption in ECHO (Fig. 4). These biological methods are (Table 3 and Ibercivis Foundation, 2023):

BIODIVERSITY

- **Project:** Collectifs

List of tools: Funnel equipped with a filter, alcohol tube and tube stopper, a small plastic pot, mixture of water and propylene glycol and a small plexiglass plate.
Organisms sampled: Meso and macrofauna.
Brief description of the activity: Collect a soil sample, put it on the pot, funnel and filter. Let mesofauna fall inside the alcohol tube and send them to the laboratory. Additionally, bury the plate almost to its top with the propylene glycol inside. Collect the macrofauna that falls inside and send them to the laboratory.
Link to website, guidelines and data for quality details:
https://collectifs-biodiversite.universite-lyon.fr/
https://collectifs-biodiversite.universite-lyon.fr/etudes-scientifiques/#resultats-de-letude-des-oiseaux-de-2022

- **Project:** Observatoire agricole de la biodiversité

List of tools: Mustard, water, watering can, ramp, twine or stakes, blender and measuring tape
Organisms sampled: Earthworms

Brief description of the activity: Determine the sample area, water the soil with a diluted water/mustard solution on three plots. Wait for earthworms to rise to the surface, collect, count and identify them, and rinse them with clean water.
Link to website, guidelines and data for quality details:
https://www.observatoire-agricole-biodiversite.fr/
https://www.observatoire-agricole-biodiversite.fr/les-protocoles/vers-de-terre

- **Project:** Vigie-nature école

List of tools: Mustard and water
Organisms sampled: Earthworms
Brief description of the activity: Water the soil with a diluted water/mustard solution on three plots. Wait earthworms to rise to the surface, collect, count and identify them.
Link to website, guidelines and data for quality details:
https://www.vigienature-ecole.fr/
https://www.vigienature-ecole.fr/vdt

B) Toolkits

Results of the **CSMs assessment framework** identified that 10% of the assessed projects or initiatives that employed methods to measure multiple soil health indicators were approved or recommended for adoption in ECHO (Fig. 4). These toolkits are (Table 3 and Ibercivis Foundation, 2023):

- **Project:** Gärtnern für den Umweltschutz

List of tools: Spade, Spoon/small hand scoop, bucket, Plastic bag, Spray bottle with tap water, jars, Distilled water, pH test strips (replaceable by Vinegar and Baking powder), every tool for the Berlese method, Plastic plant pot with holes in the bottom, Coffee filters, Kitchen scales, Bowl, water and coloured water, and all the Tables for evaluation.
Assessed indicators: Texture, pH, humus content, biodiversity, water storage and infiltration.
Brief description of the activity: Take a soil sample and carry out the texture by moulding a soil cylinder and the pH test and determine soil colour. Use the colour charts for pH and humus content. Develop the Berlese method for biodiversity.
Link to website, guidelines and data for quality details:
https://www.h-brs.de/de/izne/gaertnern-umweltschutz
https://www.h-brs.de/sites/default/files/ctw_umweltlabor_workshops_1_aktionsheft_bodenfruchtbarkeit_bf_040821.pdf

- **Project:** Knoxville-Tennessee Environmental Soil and Stream Testing (K-TESST)

List of tools: Tubes, capsules, plastic droppers, distilled water, dish soap/detergent, tap water and measuring device.
Assessed indicators: Contamination (nitrogen and phosphorus), pH and texture.

Brief description of the activity: Collect a soil sample, fill the small containers with it and with water, shake it and allow the mixtures to sit undisturbed. Use the dropper to add the liquids from the containers and the capsules to add the powders. Wait a few minutes for colour to develop and determine the concentration or pH. For texture, fill a tube with soil, water and dish soap/detergent and let layers begin to separate. Calculate the percentages of each granulometry.

Link to website, guidelines and data for quality details:
https://sites.google.com/vols.utk.edu/k-tesst/home
https://sites.google.com/vols.utk.edu/k-tesst/soil-tests?authuser=0

- **Project:** NOCMOC

List of tools: None, only the questionnaire and protocols.

Assessed indicators: Vegetation cover, soil structure, texture and colour.

Brief description of the activity: Observe and describe your surroundings, vegetation and sampling site. Carry out the texture by moulding a soil cylinder and determine soil colour.

Link to website, guidelines and data for quality details:
https://www.nocmoc.eu/#predstavitev
https://www.nocmoc.eu/dokumenti/2023delovniZvezek.pdf

- **Project:** OPAL Soil & Earthworm Survey

List of tools: Mustard, magnifier, small shovel, spade or trowel, re-used plastic bottles of water, containers, Bin bags or trays, protective gloves, camera, pen, pH strips and vinegar.

Assessed indicators: Biodiversity (Earthworms and other insects), vegetation cover, compaction, moisture, texture, pH and carbonate content.

Brief description of the activity: Determine the sample area, observe and describe it, and water the soil with a diluted water/mustard solution on three plots. Wait until earthworms rise to the surface, collect, count and identify them. Stick a pen in the ground and measure its depth. Collect a soil sample and carry out the texture by moulding a soil cylinder. Determine pH with water and the pH stripes. Open the sachet of vinegar and pour a few drops onto the soil.

Link to website, guidelines and data for quality details:
https://www.imperial.ac.uk/opal/surveys/soilsurvey/
https://www.imperial.ac.uk/media/imperial-college/research-centres-and-groups/opal/SOIL-16pp-booklet_legacy.pdf

- **Project:** The Citizen Science Soil Health Project

List of tools: A zip lock freezer bag.

Assessed indicators: pH, NPK, trace, microbes and more.

Brief description of the activity: Determine the sample area, collect one soil sample and freeze it. Then send it to the lab, where the Haney and PLFA tests will be performed.

Link to website, guidelines and data for quality details:
https://soilhealthproject.org/index.html
https://soilhealthproject.org/uploads/1/4/2/0/142058316/soilsamplinginstructions.pdf

5.2.3. Based on the assessment for citizen-generated soil data quality

A) Biological methods

Results of the **CGDQ assessment framework** identified that 19% of the assessed projects or initiatives that employed methods to measure biological soil health indicators were approved or recommended for adoption in ECHO (Fig. 4). These biological methods are (Table 3 and Ibercivis Foundation, 2023):

DECOMPOSITION RATE

- **Projects:** All based on the Tea Bag Index (TBI; Keuskamp et al., 2013): Bodemleven, Expedition Erdreich, TeaComposition Initiative, TeaComposition Project, TeaTime4App and TeaTime4Schools.

List of tools: Standardized tea bags, shovel, wooden sticks, an oven, scale and a smartphone/GPS device.
Brief description of the activity: Store the coordinates, weigh the tea bags and bury them for 60-90 days (**Note:** meanwhile, some of them measured other optional indicators, like root penetration, biodiversity, pH, texture, moisture or colour, but their main purpose is to estimate the decomposition rate). Dig the tea bags up, dry them following instructions and weigh them again (**Note:** some projects also analysed DNA in the laboratory). Enter all collected data into the database.
Links to websites, guidelines and data for quality details:
https://bodemleven.be/
https://bodemleven.be/wp-content/uploads/2023/06/Bodemleven-handleiding.pdf
https://dashboard.bodemleven.be/
https://expedition-erdreich.bonares.de/
chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://expedition-erdreich.bonares.de/files/EE_LuA_barr.pdf
https://expedition-erdreich.bonares.de/de/ueber-die-aktion-1705.php#mapdesc
https://www.teacomposition.org/
https://www.teacomposition.org/approach/
https://teacomposition.sydney.edu.au/
https://teacomposition.sydney.edu.au/map/
https://www.teatime4schools.at/teatime4app
https://www.teatime4schools.at/tea-bag-index

- **Projects:** All based on the undies' method: Beweisstück Unterhose and Soil Your Undies Challenge - University of New England.

List of tools: Cotton undies, shovel, wooden sticks, an oven, scale and a smartphone/GPS device.
Brief description of the activity: Store the coordinates and bury the undies for at least 60 days (**Note:** meanwhile, some of them measured other optional indicators, like pH, texture, or contamination, but their main purpose is to estimate the decomposition rate). Dig the undies up, take a photo and/or return soiled undies in a zip lock bag.
Links to websites, guidelines and data for quality details:
https://www.beweisstueck-unterhose.ch/
https://www.beweisstueck-unterhose.ch/images/Downloads/Anleitung_BeweisstueckUnterhose_ohne_set.pdf
https://www.beweisstueck-unterhose.ch/karte
https://www.unediscoveryvoyager.org.au/soilyourundies/
https://www.unediscoveryvoyager.org.au/wp-content/uploads/2021/08/SYU-Burial-Instructions-2021.pdf
https://www.cottoninfo.com.au/sites/default/files/tools/cotton-soil-map/index.html

B) Chemical methods

Results of the **CGDQ assessment framework** identified that 6% of the assessed projects or initiatives that employed methods to measure chemical soil health indicators were approved or recommended for adoption in ECHO (Fig. 4). These chemical methods are (Table 3 and Ibercivis Foundation, 2023):

HEAVY METALS

- **Project:** 360 Dust Analysis

List of tools: Ziplock plastic bags, permanent marker, trowel, a small box, and water.
Measured elements: Organic carbon, phosphorus and potassium concentration Traces of arsenic, chromium and plumb.
Brief description of the activity: Determine the sample area, collect three soil samples and send them to the lab. The concentration of trace elements in the samples of soil collected will be measured using X-ray fluorescence spectrometry.
Link to website, guidelines and data for quality details:
https://www.360dustanalysis.com/gardensafe
https://iupui-earth-science.shinyapps.io/MME_Global/

- **Project:** All based on seeding: CiDéSol and HeavyMetal Citizen.

List of tools: Pots and seeds (*Raphnus sativus*, *Spinaca oleracea* or *Noccaea caerulescens*).
Measured elements: Metals like zinc, cadmium, lead, hydrocarbons and Nitric acid
Brief description of the activity: Cultivate the seeds, observe and take notes of it growing process. Harvest the plant for lab analysis.
Link to website, guidelines and data for quality details:

https://www.cocreate.brussels/projet/cidesol/
https://www.cocreate.brussels/projet/cidesol/
https://cityzenboden.com/
https://zenodo.org/record/4785321/files/HMCZ_Data.xlsx?download=1
data (excel)
https://cityzenboden.com/results/

C) Physical methods

Results of the **CGDQ assessment framework** identified that 4% of the assessed projects or initiatives that employed methods to measure physical soil health indicators were approved or recommended for adoption in ECHO (Fig. 4). These physical methods are (Table 3 and Ibercivis Foundation, 2023):

MOISTURE

- **Project:** CurieuzeNeuzen in de tuin (CNIDT)

List of tools: Sensor and a guide
Measured elements: Moisture, texture and temperature
Brief description of the activity: Stick the sensor into the ground for regular samples.
Link to website, guidelines and data for quality details:
https://curieuzeneuzen.be/
https://metadata.vlaanderen.be/srv/dut/catalog.search#/metadata/3f507fd9-24c0-40ab-9328-29f0dff571fe
https://curieuzeneuzen.be/voor-deelnemers/#handleiding

- **Project:** GROW Observatory

List of tools: Sensor and a guide
Measured elements: Real time moisture data
Brief description of the activity: Stick the sensor into the ground for regular samples.
Link to website, guidelines and data for quality details:
https://growobservatory.org/
https://growobservatory.org/data/
https://knowledge.growobservatory.org/knowledge-base/quick-start-guide-to-setting-up-your-sensors/

D) Toolkits

Results of the **CGDQ assessment framework** identified that 2% of the assessed projects or initiatives that employed methods to measure multiple soil health indicators were approved or recommended for adoption in ECHO (Fig. 4). These toolkits are (Table 3 and Ibercivis Foundation, 2023):

- **Project:** BRIDGES

List of tools: Litterbags, shovel, and wood sticks.
Assessed indicators: Decomposition rate, soil texture and colour, and Biodiversity.
Brief description of the activity: Determine the sample area, observe and describe it, as well as the organisms you find. Bury the litterbags for 40 days. Then dig them up and send them to the laboratory for DNA analysis. Collect a soil sample and carry out the texture by moulding a soil cylinder and determining soil colour.
Link to website, guidelines and data for quality details:
https://www.progetto-bridges.it/
https://www.progetto-bridges.it/wp-content/uploads/2022/09/Quaderno-Citizen-Science_per-file-PDF.pdf
https://kf.kobotoolbox.org/#/forms/a6fRbTMwVeHoLW3pnVsXVw/data/table

6. Recommendations for the ECHO Citizen Science Toolbox

Regarding the citizen science approaches and toolkit in ECHO

The approved evaluations based on the CSMs assessment framework point to **simple, user-friendly, low-cost approaches that allow collecting reliable data following easily accessible and reproducible protocols**.

The eight soil health indicators that will be measured in ECHO include vegetation and forest cover, landscape heterogeneity, soil structure and texture, biodiversity (visually in-site and off-site with microbial diversity using DNA-based technologies), presence of pollutants and nutrients (visually in-site and off-site with heavy metal assessment and micro X-Ray Fluorescence), soil organic matter and pH. These indicators encompass the biological, chemical, and physical aspects of soils, representing a multi-indicator approach and thus a **toolkit type of soil monitoring**.

The projects and procedures described in Sections 5.2.1 and 5.2.2 detail specific methods for measuring biodiversity, heavy metals and nutrients, as well as toolkits for assessing other indicators relevant to ECHO, including vegetation and forest cover, landscape heterogeneity, soil structure and texture, DNA, presence of visual pollutants, soil organic matter and pH. While there are slight variations among the different project protocols, this review provides a **foundation for the ECHO toolkit and procedures to measure all eight soil health indicators**, building on and adapting methods developed by similar projects. By doing so, we will be implementing methods that have been previously adapted to participants and different citizen groups. Moreover, some of the methods already adhere to standardized and published scientific protocols that ensure consistency and reliability. For further details of the procedures followed in these CS projects, please refer to their websites and materials listed in the sections above.

One of the engagement factors considered is the availability of citizen feedback. A total of 74% of the assessed projects that provide accessible citizen feedback were approved and are suitable for ECHO (Fig. 6). This demonstrates the **importance of citizen feedback for simple approaches** that make activities accessible and engaging for a broad range of participants. The simplicity criterion, in this deliverable, not only enhances the inclusivity of CS initiatives but also improves data quality. A smaller percentage of projects (62%; Fig. 6) lacked accessible citizen feedback but have not been rejected, as feedback could potentially be integrated into these projects with time. While important, the lack of citizen feedback alone is not a basis for exclusion.

Regarding the citizen-generated soil data quality in ECHO

Approved evaluations based on the CGDQ assessment framework emphasized **approaches that allowed the collection of relevant, accurate, and easily interpretable data, which are mainly accessible and compatible with existing soil monitoring systems. Additionally, these data should ensure consistency across different contributors and adaptability across various biogeographical regions.**

The projects and procedures described in Sections 5.2.2 and 5.2.3 detailed specific contexts for the CGDQ. The duration of ECHO, which is above the average compared with similar projects, allows the collection of high-quality data by contributors from a broad range of different biogeographical regions. For further details of the procedures followed in these CS projects, please refer to their websites and materials listed in the sections above.

ECHO's focus on the **eight soil health indicators defined in the Mission Soil Implementation Plan enhances the relevance of future data collection and quality**. In this deliverable, the relevance of this criterion reflects the usability of the data to serve specific purposes for data users, specifically the measurement of key soil indicators.

Regarding the level of citizen participation in ECHO

It is noteworthy that 79% of approaches in soil-specific contributory projects and 60% in collaborative or co-created projects (Type C and Type A projects, respectively; Figs. 1 and 5) were considered suitable for ECHO. This suggests that the most effective **level of citizen participation in ECHO's scientific research may lie between contributory and co-created methodologies**. A mixed citizen science approach can therefore with confidence be implemented at various scales and in diverse contexts, due to the wide geographical scope of ECHO. At European level, citizen scientists will primarily contribute and analyse data, while at regional and local levels, they will have the option to engage in collaborative and co-created activities organized by ECHO Ambassadors and the ECHO project consortium. This approach guarantees a strong connection between citizens and the project community, as well as with the main actor in ECHO, **soil**.

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European Commission. (2021b). EU Mission Soil Deal for Europe: Implementation plan. Retrieved from https://research-and-innovation.ec.europa.eu/knowledge-publications-tools-and-data/publications/all-publications/implementation-plans-eu-missions_en (Accessed on 13/11/2024).

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Annex I: Questions and sub-questions of the Assessment Frameworks

	Assessment framework of T1.2: Citizen Science Methods		
	CRITERIA	QUESTION	SUB-QUESTION
1	SIMPLICITY	Was the toolkit previously tested by different citizen groups and are the results from that testing available?	Can we obtain the information from the original project's members?
2		Are the tools for data collection easy to use and are indications clear for non-experts?	Can we adapt them to make them simpler?
3		Does feedback from users exist and is it accessible?	
4		Is the language used in the material plain and clear without jargon and technicalities?	Can we adapt the language to make it simpler and easier to understand?
5		Do the activities require more than two hours?	
6		Are the method accessible to individuals with disabilities?	Can we adapt it, so it is more accessible?
7	COSTS	Are information about costs provided or easily estimable?	Can we obtain the information from the original project's members?
8		Does it require specialised/costly equipment not available to the project?	
9		Are the costs associated with recruiting, training, and supporting participants affordable?	
10		Are the costs for participants equal to zero or affordable?	Can we reduce the costs or find sponsors for it?
11		Are communication and outreach low cost (website, social media, etc)?	
12		Do data analysis and storage involve costs not planned in ECHO?	Are those costs somehow affordable?
13	TEMPORAL AND SPATIAL GRANULARITY	Is the sampling frequency adequate to the variable tested	Can we obtain the information from the original project's members?
14		Is this frequency suitable for ECHO' activities?	Can we change it to make it suitable?
15		Is it possible to evaluate if the spatial granularity is adequate to the variable tested?	Can we obtain the information from the original project's members?
16		Is this spatial granularity suitable for ECHO' activities?	Can we change it to make it suitable?
17		Are there enough human and material resources to cover the defined spatial and temporal granularity?	Can we lower the cost or find sponsors?
18	DATA REPLICABILITY	Are detailed sampling protocols available?	Can we obtain the sampling protocols from the original project's members?
19		Are the sampling protocols standardised and not subjected to personal interpretation?	Can we standardise them?
20		Is comprehensive training offered?	Can we offer it?
21		Is there clear information on how to properly label, organise and store the collected data?	Can we provide these indications?
22		Are elements that can potentially limit or ensure replicability described?	
23		Are data and metadata available for comparison/integration?	Can we obtain the data and metadata from the original project's members?
24	DATA RELIABILITY	Are detailed sampling protocols available?	Can we obtain the sampling protocols from the original project's members?
25		Do the sampling protocols define each step and factor to be taken in consideration?	Can we complete the sampling protocols?
26		Are opportunities (time and channels) for data validation and review provided?	Can we provide them?
27		Does the project implement procedures for participants to access and validate their own data?	Can we implement such procedures?
28		Does the project provide participants with channels where addressing questions, concerns or issues related to data collection?	Can we provide them?

	Assessment framework of T1.3: Citizen-Generated Data Quality		
	CRITERIA	**QUESTION**	**SUB-QUESTION**
29	RELEVANCE	Does the data collection align with the project's objectives?	Can the data collection be adapted to ECHO's objectives?
30		Are data timeliness and frequency in line with what is requested by the objectives?	Are data timeliness and frequency suitable for or adaptable to ECHO?
31		Do the measured parameters include i) soil structure; ii) soil organic carbon; iii) soil biodiversity; iv) vegetation cover; v) soil nutrients; vi) presence of pollutants, excess nutrients and salts; vii) landscape heterogeneity; and viii) forest cover?	Can we add the missing parameters in the protocols?
32		Are the parameters assessed using the LUCAS or equivalent analytical protocols?	Are the methods used still rigorous and scientifically sound?
33	ACCURACY	Are the project goals well defined and easily understandable by the volunteers?	Can that compromise the feasibility of data collection?
34		Are tasks simple and easy to understand and perform?	Can the difficulty of the tasks affect the quality of the data collected?
35		Are instructions, training, pre-tests, volunteer assessment, expert validation, replication, and application of statistical tools appropriate to support the volunteers in data collection?	Can we provide or modify them to make it appropriate?
36		Are there quality assurance measures like data checks, validation by experts or volunteers, and standardised testing or calibration methods in place to address potential errors or biased data?	Are the data still of good quality or can we provide these measures?
37		Are indications and processes of data collection clear and straightforward?	Can we modify them to make them clear and straightforward?
38	ACCESSIBILITY	Are data freely accessible and easy to consult?	Can the project coordinator grant us access to the data?
39		Do project data follow FAIR (Findable, Accessible, Interoperable and Re-usable) principles?	Can we apply FAIR principles to dataset collected following this method?
40		Is the data format user-friendly and compatible with commonly used software and tools?	Can we use user-friendly, compatible data formats for the dataset deriving from this method?
41		Does the project provide comprehensive metadata and documentation, including details on data collection methods, variables, units of measurement, and potential limitations?	Can we add this documentation in the data collection protocols?
42		Does the project provide support for users like forums, help centres, or dedicated support channels (email address) where questions can be answered?	Can we provide this assistance for data collection and collected data?
43	COHERENCE	Are timescales and geographic extents of the data commensurate with project objectives?	Can we adapt them to the ECHO objectives?
44		Are guidelines about type of data required, format and specific instructions provided?	Can we produce them?
45		Did the project develop workshops, tutorials, documentation, or online resources to train participants on data collection?	Can we offer this training?
46		Are data consistent across different contributors?	Can we identify and correct the causes of the lack of consistency?
47		Are information about the data collection process available to help in understanding the context and potential biases?	Can we obtain them from the project coordinator/participants?
48		Does data collection process adhere to ethical standards?	Can we ensure that in ECHO data collection process will adhere to ethical standards?
49	INTERPRETABILITY	Are the project's objectives clear enough to guide the interpretation process?	Can we align data interpretation process with ECHO's objectives?
50		Does the project adhere to international/standard protocols in data collection (instrument/tool)?	Can we adapt the protocols to do so?
51		Does the project use visualizations that are easy to understand and explain?	Can we use charts, graphs, and other visual aids that can help convey complex information in an accessible manner?
52		Does the project ensure that the interpretation is accessible to a broader audience, including those without a technical background?	Can we produce distinct summaries of the collected data for distinct stakeholders (Lay, informative and descriptive summaries)?
53		Is the language clear and plain to avoid ambiguity and misinterpretation?	Can we adapt the language to be plain and clear?

54	COMPATIBILITY	Does the project use common data formats and standards for encoding and structuring information?	Can we ensure compatibility with widely accepted standards such as XML, JSON, and CSV?
55		Does the data system allow interoperability between different software, hardware, or data formats?	Can we make changes to ensure interoperability between different systems?
56		Is documentation for data interoperability standards, protocols, and processes available?	Can we make it available?
57		Are units of measurement for numeric data consistent and compatible?	Can we adapt the protocols to have consistent and compatible units of measurement?
58	ADAPTATION	Do the protocols allow data collection in all the European biogeographical regions?	Can we modify the protocols to make them applicable in all European regions?
59		Do the protocols allow data collection in all the types of soil?	Can we adapt the protocols to all types of soil?
60		Can soil data indicators such as land cover, climate, and topography be integrated for multi-layer analysis for all soil types?	Can we adapt the protocols to make the integration possible for all types of soil?
61		Is it possible to use spatial interpolation techniques to estimate soil indicator values in areas with limited or no direct measurements?	Can we adapt the protocols to make data interpolation possible for all soil indicators?

Annex II: Gaps identified during the application of the Assessment Frameworks

Name	CSMs final assessment score	Rejection reason	CGDQ final assessment score	Rejection reason
Collectifs				Inaccessible data
Gärtnern für den Umweltschutz				Inaccessible data
Knoxville-Tennessee Environmental Soil and Stream Testing (K-TESST)				Inaccessible data
NOCMOC				Inaccessible data + Protocols unsuitable for other regions
Observatoire agricole de la biodiversité				Inaccessible data
OPAL Soil & Earthworm Survey (UK)				Inaccessible data
The Citizen Science Soil Health Project				Inaccessible data
Vigie-nature école				Inaccessible data
360 Dust Analysis		Unavailable protocols		
Beweisstück Unterhose		Unsuitable and unadaptable temporal granularity		
bodemleven		Unsuitable and unadaptable temporal granularity		
BRIDGES		Unsuitable and unadaptable temporal granularity		
CiDéSol		Unsuitable and unadaptable temporal granularity		
CurieuzeNeuzen in de tuin (CNIDT)		Unsuitable and unadaptable temporal granularity		
Expedition Erdreich		Unsuitable and unadaptable temporal granularity		
GROW Observatory		Non-estimable costs + Equipment required		
HeavyMetal Citizen		Unsuitable and unadaptable temporal granularity		
Soil Your Undies Challenge - University of New England		Unsuitable and unadaptable temporal granularity		
Tea Bag Index (TBI)		Unsuitable and unadaptable temporal granularity		
TeaComposition Initiative		Unsuitable and unadaptable temporal granularity		
TeaComposition Project		Unsuitable and unadaptable temporal granularity		
TeaTime4App		Unsuitable and unadaptable temporal granularity		
TeaTime4Schools		Unsuitable and unadaptable temporal granularity		
Citizens of the Crust: a biocrust assessment project		Unavailable protocols		Unclear objectives
FARM NET ZERO and Farm Carbon Toolkit		Unsuitable and unadaptable temporal and spatial granularity		Inaccessible data
Garden Roots		Unsuitable and unadaptable spatial granularity		Inaccessible data
MAKING SENSE		Unavailable protocols		Non-standardized protocol + Uncertain data checks + Inaccessible data
MicroBlitz		Non-estimable costs + Unavailable protocols		Inaccessible data
MO DIRT (Missourians Doing Impact Research Together)		Difficult and unadaptable tools and indications + -Non-estimable costs + Equipment required		Unclear objectives + Difficult tasks + Protocols unsuitable for other regions
Nuestros suelos		Unsuitable and unadaptable spatial granularity		Difficult tasks + Inaccessible data
Plante ton slip		Unsuitable and unadaptable temporal granularity		Inaccessible data
SCENT		Unavailable protocols		Inaccessible data
SHOWCASE		Equipment		Difficult tasks + Inaccessible data
Soil Moisture Active Passive (SMAP)		Equipment required		Difficult tasks
Soil Sampling Toolkit CS Community Resources		Equipment required		Inaccessible data
Soils, Science and Community Action (SoilSCAN)		Equipment required		Difficult data format
SoilSkin – La Piel Viva del Suelo		Unavailable protocols		Inaccessible data
The Tea Bag Experiment - Tepåseförsöket		Non-estimable costs		Inaccessible data
Using CS to develop solutions for healthy soils through phytomining		Unavailable protocols		Inaccessible data