An End-to-End Workflow for Processing Multilingual Stakeholder Workshop Data: A Soil Health Case Study

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Abstract

Stakeholder workshops often produce diverse qualitative and ordinal data that are difficult to process consistently, transparently, and reproducibly, particularly in multilingual settings. To address these challenges, we developed an end-to-end workflow for systematic processing of multilingual participatory workshop data.

The workflow integrates multilingual preprocessing, structured data management, computational analysis, automated reporting, and interactive dissemination. It incorporates a range of data analysis methods, including large language models. The workflow supports both qualitative exploration and quantitative comparison of stakeholder perspectives across workshops and contexts. We also propose a structured approach based on large language models for topic extraction and intensity scoring, which transforms qualitative workshop inputs into comparable quantitative representations of obtained results.

The proposed workflow is demonstrated in the EU BENCHMARKS project, which involves multiple workshops, stakeholder groups, land-use contexts, and languages. The main contribution of this work is a transparent, reproducible, and adaptable workflow for the systematic handling of multilingual participatory workshop data that supports reproducible analysis, scalable dissemination, and cross-workshop comparison.

1 Introduction

Stakeholder engagement is widely recognised as an important part of environmental research and policy. In Agenda 21 action plan of United Nations, public participation was described as a key requirement for sustainable development (United Nations, 1992). In his literature review, Reed (2008) concludes that there is evidence that stakeholder participation can enhance the quality of environmental decisions and increases the chance that the results are used in practice. This is also reflected in the field of soil health, where stakeholder engagement plays an important role across research, policy, and practice. The EU Mission "A Soil Deal for Europe" reinforces this approach through Living Labs and Lighthouses, where citizens, practitioners, and researchers work together on soil health challenges (European Commission, Directorate-General for Research and Innovation, 2025).

Soil health cannot be discussed independently of local context. Pedoclimatic conditions influence what soil health goals and management practices are appropriate in a given region. In addition, economic capacity and policy priorities are country specific and vary across pedoclimatic regions. Perceptions of what counts as healthy soil, as well as management priorities and practices, also vary between regions (Schulte et al., 2019). Because of these differences, soil health monitoring and management depend on direct engagement with local stakeholders.

Workshops are one of the most common formats for stakeholder engagement. They allow direct discussion between land managers, researchers, authorities, and other actors. When workshops are organised in local language and adapted to regional conditions, they can help to identify locally relevant challenges and management options (Keesstra et al., 2016; Bouma, 2020). There are several established stakeholder engagement methods, such as Participatory Rural Appraisal (PRA) and its derivatives (Chambers, 1994), Q-methodology (Sneegas et al., 2021), and the Nominal Group Technique (Manera et al., 2019). However, these approaches require substantial preparation, strict and careful facilitation, and typically longer workshops. They can be difficult to apply in shorter workshop sessions, especially when there are many case study teams with different levels of facilitation experience involved. In practice, many workshops rely on simpler formats such as post-it notes, flipcharts, grouping similar statements together, and voting with stickers. These methods work well for discussion, but the data they produce is fragmented and difficult to analyse.

Multilingual settings of workshops, which are common in European research projects, introduce additional complexity to data processing and interpretation. Translation of workshops' outputs can introduce shifts in meaning and terminological issues. van Nes et al. (2010) showed that translating qualitative data reduces contextual nuance and alter interpretation, especially when translated terms do not have direct equivalents. Moreover, Squires (2009) found that only a small percentage of studies meet all the criteria recommended by the cross language methods literature for the production of trustworthy results in cross language studies. The back translation method (Brislin, 1970) is an established approach for improving translation accuracy but is often too resource intensive to implement in larger projects. Advanced machine translation tools and multilingual large language models can solve most translation tasks but the problem of the correct use of terminology and the need for verification of results still remains.

Stakeholder workshops generate different types of outputs such as short remarks and statements, ranked lists, and votes on selected items. As a result, the input to data analysis consists of free-text inputs combined with ordinal and numerical data. In the book on social research methods, Bryman (2016) provides methodological guidance on qualitative and quantitative data analysis as well as on software supporting these process. However, heterogeneous and fragmented workshop data can be difficult to analyse. Data analysis inputs are often incomplete, repetitive, or phrased differently across sites. Manual qualitative coding approaches, such as Thematic Analysis (Braun and Clarke, 2006) and the more formal Framework Method (Ritchie and Spencer, 1994; Ritchie and Lewis, 2003) can generally be applied to such data, but they require careful interpretation and expert involvement, and are not suitable for highly heterogeneous and large datasets. In addition to classical text mining tools, topic modelling approaches based on LLMs such as BERTopic (Grootendorst, 2022) can be used to analyse large volumes of short text inputs to group similar statements, extract interpretable topics, and identify outliers. Some authors report promising results when LLMs are applied within structured workflows and combined with human review (Wen et al., 2025; Dunivin, 2025). However, when such tools are used without documented prompts, clearly defined analytical steps, and without human review, reliability and transparency of outputs are not guaranteed (JMIR Editorial, 2024). The challenge is therefore not the lack of analytical tools but how to apply them consistently within a documented and reproducible process to obtain trustworthy results.

In quantitative research, reproducible workflows and structured reporting are already well established (Berthold et al., 2007; Podpečan et al., 2012; Xie, 2015; Kranjc et al., 2017; Granger and Pérez, 2021). For participatory workshop data, such approaches are less common. Often, translation, analysis, and reporting are handled as separate tasks. Dissemination is also often accomplished using static, manually or semi-automatically created documents. This is a simple and reliable method, but it does not allow for the production of a large number of documents, easy updates when data or analysis changes, and comparisons across sites. In some domains, such as public health, interactive dashboards are becoming popular as they allow for comparisons and exploration of data and results (Rabiei et al., 2024; Stahlman et al., 2025). Such approaches could also be introduced in agricultural and environmental projects, where results from different regions must be interpreted together. In summary, stakeholder engagement, qualitative analysis, and computational tools are well covered in the existing literature. What is still missing is a practical end-to-end workflow that connects workshop data collection, multilingual preprocessing, analysis, reporting, and dissemination in one structured and documented process.

In large international projects, workshops outputs consist of fragmented short text inputs and ranked data in multiple languages, which must be translated, structured, analysed, and communicated across sites. While existing tools support specific tasks within this chain, they provide limited guidance on how to process and transform raw workshop data into comparable and actionable results. Data handling often remains ad hoc, insufficiently undocumented, difficult to reproduce, and hard to scale. This paper addresses this gap by presenting and documenting an easily reproducible end-to-end workflow for the collection, analysis, and dissemination of multilingual stakeholder workshop data related to soil health within a single structured process, and discusses its implementation in the EU BENCHMARKS project.

The paper is structured as follows. The Materials and Methods section introduces and describes the proposed workflow. The Results section presents the implementation, adaptation, and application of the workflow to the BENCHMARKS use case. The Discussion and Conclusions section reviews the conceptual contributions of the workflow, presents insights from its implementation in BENCHMARKS, and discusses limitations and future improvements.

2 Materials and methods

2.1 Workflow overview

To support the systematic processing of stakeholder workshop data, we designed a reproducible and adaptable end-to-end workflow. It transforms unstructured, multilingual input into structured data, applies both computational and qualitative analysis, and produces outputs that can be shared, compared, and updated. The workflow is an end-to-end solution and thus extends beyond typical data analysis and reporting workflows. It consists of the following steps:

1. workshop organization and data collection;
2. data preprocessing;
3. database construction;
4. data analysis and knowledge extraction;
5. reporting and quality control;
6. knowledge dissemination via reports, research papers, and an interactive web application.

Figure 1 depicts the workflow, its inputs, outputs, and intermediate steps. Most steps require human intervention and cannot be performed automatically if valid and reliable results are to be ensured. However, the design of the workflow which consists of smaller, well-defined steps ensures that most of the work requires only light supervision, verification of correctness, and minor adjustments to apply the workflow to a specific problem at hand. For example, ensuring terminological correctness during data preprocessing (step 2) is a step which requires domain knowledge and must be performed by an expert. Similarly, the involvement of an expert in the respective domain is necessary in the quality control step (step 5). This step ensures that the information and knowledge disseminated to stakeholders and involved parties is accurate, relevant, and up to date. This is particularly important when generative AI tools are used in the data analysis and knowledge extraction step (step 4).

2.2 Workshop organization and data collection

Workshop organization is an integral part of the workflow as it directly influences the quality, structure, and interpretability of collected data. Within the first step of the workflow there is also data collection which encompasses gathering, transcription, and digitalisation of data provided by workshop participants. In general, data can take different forms, including post-it notes, blackboard snapshots, audio recordings, and data collected via mobile applications. Collection can be manual or automatic, depending on context and available tools.

The workflow can be applied across different workshop formats including variations in duration, group size, and event type. Group size may range from individual participants to larger groups, although very small groups are not recommended, as they may affect the robustness of subsequent analysis, even when analytical methods that are less sensitive to group size are used. Such variations in group size can influence later analytical steps and may require additional clustering or other aggregation steps.

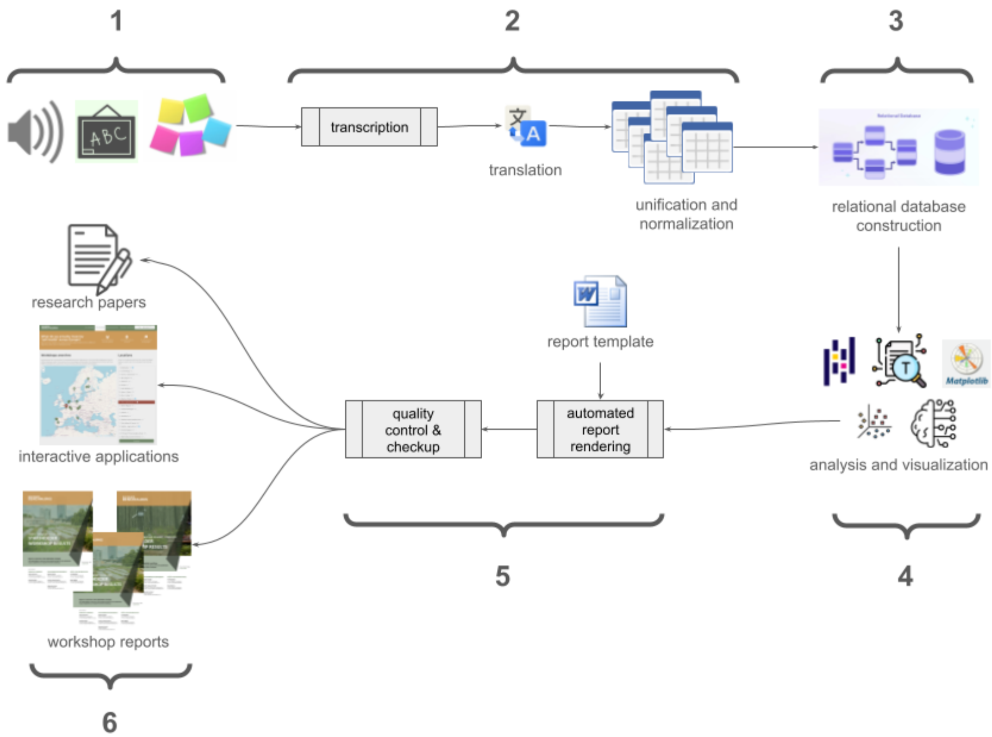

Figure 1: Overview of the end-to-end workflow for processing multilingual stakeholder workshop data showing its six steps (1: data collection, 2: preprocessing, 3: database construction, 4: analysis, 5: reporting, 6: dissemination) and the resulting outputs. Key sub-steps within individual stages are also indicated.

While structured workshop activities are not a requirement, they facilitate subsequent analysis by separating data by topic and enabling more focused inputs. This allows the analysis to be carried out in smaller, manageable parts and simplifies verification and quality control. When activities are less structured, the workflow can still be applied, but additional effort may be required during preprocessing and analysis. Facilitators are required to guide the workshop process. Common instructions and common output formats are also important to ensure comparability when multiple workshops are conducted across different locations within a coordinated study or activity. At the same time, local flexibility is encouraged to account for context-specific needs and constraints. Such flexibility is acceptable as long as the required level of standardisation is maintained.

In our experience, analogue data collection methods such as post-it notes, posters, and paper templates help participants focus on content, and is thus the preferred choice in the data collection step in the workflow. An additional advantage of analogue approaches is that they do not require the use of digital tools, which can otherwise introduce distractions, technical barriers, or connectivity issues, particularly for participants who are not familiar with such applications. This reduces the cognitive and technical burden on participants and allows greater attention to be devoted to the discussion topics rather than to data entry or tool usage. A notable drawback of analogue collection is the need for later transcription but the transcription phase can also act as a noise filter, as data is read and reviewed.

The basic data unit in the workflow is a single text entry (one post-it note or one recorded response, for example) and may range from a single word to a short paragraph. Data units are anonymous and linked to groups rather than individuals. During analysis, data units belonging to the same category (same activity, question, and group, for example) are typically concatenated. The collection of other types of data such as ordinal, numerical, and demographic data is optional but supported.

2.3 Data preprocessing

The data preprocessing step involves cleaning and transformation of the collected data. Depending on the data and actual use case, preprocessing may include translation, terminology checks and correction, type conversion, normalization, scaling, parsing, aggregation, handling of missing values, and deduplication. Certain preprocessing operations may be applied later as part of specific analysis methods.

As part of data cleaning, ambiguous and low-quality inputs are addressed by domain experts. Expert judgement is used to interpret unclear handwriting and incomplete statements. To support consistent decisions across teams, the use of a common guidebook is recommended. A similar approach is applied in language harmonisation, such as unifying spelling variants and domain-specific terms. Validation of the collected and structured data (e.g. spreadsheets) is performed before database construction, typically through manual inspection of completed templates. As these preprocessing steps involve interpretation and modification of the original data, tracking such changes becomes relevant. The current workflow does not propose systematic tracking of preprocessing modifications. However, change tracking can be implemented using features such as track changes in spreadsheets, combined with a database that supports data versioning. This is particularly relevant in settings with frequent updates or strict reproducibility requirements.

In many applications, particularly in large international studies, workshops are held in different countries and multiple languages. To allow joint analysis, workshop data must be translated into a common language while preserving meaning and contextual nuances. Translation is typically performed using available document translation software, although manual translation may be used when data volumes are low. This is followed by manual proofing to ensure accuracy. Terminology must then be checked for consistency across workshops and unified where necessary, regardless of the translation method used, as inconsistencies at this stage may propagate through subsequent analysis. Additional automated checks can applied later when the data is imported into the database.

2.4 Database construction

Database construction follows data preprocessing and is closely connected to it. However, the use of a database is not mandatory. The data can also be stored in files or read directly from structured spreadsheets. Nevertheless, introducing a database layer adds flexibility and reduces complexity when collecting and combining data for later analyses. It supports querying, avoids repeated file parsing, and simplifies reuse of the same data across multiple analysis steps.

For storing and organising workshop data, both relational and non-relational database approaches need to be considered. When the data is highly structured and follows a clear schema, relational databases are a suitable choice. In our workflow, relational data storage is the preferred approach for storing workshop and demographic data as these data are inherently structured and relational in nature. When activities and their datasets are conceptually independent, using several smaller databases can reduce database schema complexity and simplifies queries. In other settings, a single database may be more appropriate but this choice is dependent on the specific project context.

The database schema defines how individual data units and their relationships are stored and organised. Individual data units are stored as cell values in the underlying data tables. One data unit (a single post-it note, for example), corresponds to one cell value. Links to activities, questions, groups, land use types and workshops are represented through the database schema.

Although the database schema can be updated if needed, such changes introduce additional work, including schema restructuring and updating data analysis methods. Larger schema changes usually indicate that initial design and planning were insufficient. For this reason, schema design should be considered carefully and early in the workflow, preferably during workshop planning.

In the proposed workflow, the data is written to the database once during initial population and then accessed multiple times during analysis and reporting. The preferred storage solution is small, local database files with simple and transparent schemas which are easy to share and understand. They lower technical barriers for other researchers and support inspection without specialised infrastructure. This approach aligns well with open-science principles by facilitating reproducibility and reuse, while ensuring long-term accessibility of structured workshop data.

2.5 Data analysis and knowledge extraction

The data analysis and knowledge extraction step is the central stage of the workflow, where structured workshop data is transformed into analytical outputs that can be compared, interpreted, and disseminated. The choice of analytical methods depends on the type of available data and on the research questions.

2.5.1 Inputs and outputs

The workflow supports different types of inputs. In a basic implementation, the inputs include collections of data units (individual text entries such as workshop contributions, for example), ranked and voted lists, and optional demographic or categorical data. Other input types are also possible (audio transcripts, survey responses, and questionnaires, for example) as well as various structured metadata. The workflow can be extended to handle additional data types by implementing appropriate data analysis methods and result rendering routines. The outputs of the analysis depend on the available inputs and selected methods. Typical graphical outputs include charts such as bar charts, radial bar charts, histograms, heatmaps, two dimensional data projections and boxplots. Textual outputs include summaries of responses, lists of extracted topics, and answers to analytical questions generated from the data using large language models, and other text mining results. Numerical outputs include topic intensities, comparisons of ranked lists, descriptive statistics and results of statistical tests, as well as results of machine learning methods such as clusters or numerical predictions. Graphical and tabular outputs are prepared in publication-ready quality to allow direct use in reports and interactive dissemination tools. Finally, outputs may also include trained machine learning models, rules, detected outliers, and other artifacts that can be reused in similar data analysis scenarios.

2.5.2 Analytical methods by data type

Most importantly, the proposed workflow does not prescribe a fixed set of methods. Instead, it defines a structured environment in which appropriate methods can be implemented based on the available data and analytical goals.

For qualitative text data, common methods include tokenization, lemmatization, term frequency and term frequency–inverse document frequency (TF–IDF) based text analysis, which highlights terms that are frequent in a given text but relatively rare across the full dataset, phrase and keyword extraction, clustering, topic modelling, and large language model (LLM) based analysis. These methods support exploration of dominant themes and comparison across workshops or groups. If required, sentiment analysis or supervised classification methods can also be applied. For ranked or voted data, the analysis commonly focuses on comparing priorities across groups or workshops. Rank comparison metrics and descriptive statistics support identification of similarities and differences between ranked lists and the derivation of consensus rankings. For demographic or categorical data, the analysis usually involves counting participants by category (age, gender, and stakeholder type, for example) and comparing distributions across workshops or groups.

2.5.3 Reproducibility

Reproducibility is an important aspect of data analysis. Most statistical methods and traditional text mining approaches are reproducible when random seeds and software versions are controlled. However, LLMs and other generative AI tools are typically non-deterministic, especially in externally hosted cloud-based environments, and their outputs may vary across runs or change over time as models are updated.

To support reproducibility as much as possible while maintaining high output quality when using LLMs, the workflow encourages recording model names and versions, storing prompt templates, setting random seed and temperature parameters (they control reproducibility and variability of outputs generated by LLMs), and repeating model calls where appropriate. Aggregating repeated outputs is also proposed to reduce random variation. Nevertheless, expert review of the results produced by LLMs and other generative models remains necessary in most use cases.

2.5.4 Topic extraction and intensity analysis

Our workflow proposes a procedure for topic extraction and intensity scoring to solve the most common type of research question in participatory workshop settings. It is designed to analyse corpora of qualitative text data, commonly found in stakeholder workshops. The objective is to derive a stable set of topics from free-form text and estimate their relative intensity in a way that allows simple comparison across stakeholder groups and workshops.

Recent studies show that LLMs can support qualitative text analysis. The DECOTA methodology developed by Player et al. (2025) automatically derives codes, themes, and their prevalence from large free-text datasets and shows good agreement with human coding. Beaumont et al. (2025) found that LLMs can be used to quantify the salience of text statements by assigning numerical rankings. The proposed procedure builds on these ideas by combining repeated topic extraction, merging of semantically similar topics, and intensity scoring to support reliable and comparison across stakeholder groups and workshops.

The procedure consists of three main steps (Figure 2). In the first step (1), candidate topics are extracted from a selected collection of text data (all stakeholder groups, for example) using repeated prompting of an LLM. This results in multiple sets of potentially overlapping topics. In the second step (2), these sets are consolidated by merging semantically similar items and resolving subsumptions using the same LLM. This reduces variability caused by the nondeterministic nature of LLMs, and also enables the use of smaller, less capable language models with shorter context window (Atil et al., 2024). In such case, the input data can be split into smaller chunks of appropriate size and the process is performed on every chunk. In addition, the second step can also cluster topics which is useful when the number of discovered topics is large.

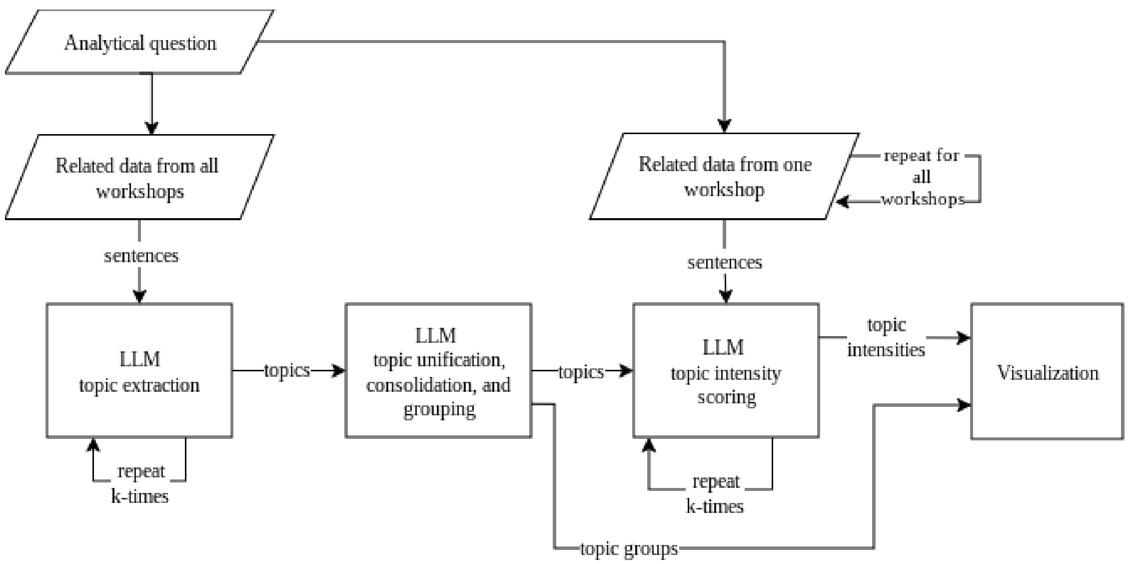

Figure 2: Flowchart of the topic extraction and intensity analysis procedure. The first step extracts candidate topics through repeated prompting of a large language model (LLM). In the second step, semantically similar and overlapping topics are consolidated into stable topic groups. The final step 3 estimates and visualizes topic intensities within selected stakeholder groups or workshops.

Finally, in the third step (3), the consolidated set of topics is used as input for quantitative scoring. The language model is prompted to assign an intensity score to each topic on a fixed scale using a selected subset of input data (one workshop or a selected stakeholder group, for example). It is recommended to use a scoring system which provides sufficient granularity while remaining simple and intuitive such as the 0-5 score. The scoring step is repeated multiple times, and scores are averaged to further reduce stochastic variation. The final results, which includes discovered topics clustered into meaningful groups, and intensities of topics in a selected subset of data, supports direct comparison of qualitative inputs across groups or workshops. Most importantly, intensity scores are not directly influenced by the size of the input data thus allowing the comparison between groups or workshops of different size. Although larger groups typically produce more text and may cover a wider range of topics, topic intensity scores are interpreted relative to the analysed text collection and do not increase with group size. Approaches such as non-zero mean and diversity index can be used when comparing the results across groups or workshops.

2.5.5 Reporting and quality control

In the proposed workflow reporting is treated as an integral part of the analytical process. Its role is to transform analytical outputs into structured and interpretable results suitable for different end users. To support consistency and scalability, reports should be generated from predefined templates with automatically populated content. The parametrization of templates allows easy regeneration of reports when data or analysis outputs are modified or updated. Furthermore, templates ensure that all reports follow the same structure, which also simplifies comparison across workshops. They also reduce manual variation and the risk of errors while supporting reuse, adaptation, updating, and sharing of results across workshops and projects. It also improves scalability, as manually writing large numbers of similar reports is often not feasible. The reporting step should be implemented using a technologies that are widespread, easy to use and reliable. Microsoft Office Word documents, HTML documents, and LaTeX documents are three examples of popular technologies which satisfy the criteria and align well with other workflow components.

Quality control is a mandatory step in the reporting process. With the rise of generative AI tools, the importance and complexity of this step has increased enormously. Even though we experience almost daily improvements in the quality of AI generated content, human intervention is still mandatory. Automatically generated content must be checked for biases, spurious content as well as hallucinations. Templates simplify quality control because reports share the same structure, which makes comparison faster and more systematic. Typically, quality control includes a visual check to ensure that content is rendered correctly, followed by verification of factual correctness for generated content, checks of internal consistency across report sections, and verification that the reported results align with the specific workshop context. Quality control is often an iterative process, particularly when reports are regenerated following updates to data, analysis outputs, or generated content. This is common when using generative models or when analysis parameters change. While the initial review iteration may require more effort, subsequent iterations are typically shorter and faster.

The elements of the reports are linked to underlying data and analysis results. This makes it easier to identify the source of errors and to verify reported values. Comparison between report versions is also simplified, as reports generated from the same template differ only in parameter values and content rather then in structure.

2.5.6 Knowledge dissemination

Knowledge dissemination represents the final stage of the workflow and focuses on making analysed and validated results accessible to different audiences. Ideally, the dissemination should support not only delivery of final outputs, but also exploration, comparison, reuse, and easy updates. This requires dissemination solutions that support both structured reporting and interactive exploration of results. The proposed workflow supports dissemination to several audience types, including workshop participants, practitioners, the general public, researchers, and policy actors. Different dissemination formats may be used depending on audience needs and levels of engagement. Typical outputs include written reports, briefs, and web-based resources. Selected outputs such as images or charts may also be reused for scientific publications or policy-oriented communication. The workflow is designed to support structured reporting through both static and interactive formats. Static reports provide a stable and citable reference. Interactive tools complement reports by allowing users to explore results dynamically, compare workshops or groups, and focus on selected aspects of the data. Such tools are particularly useful when results need to be compared across regions, contexts, or time points. Interactive dissemination tools should build directly on the same structured data and analysis outputs used for report generation. This ensures consistency between static and interactive outputs and avoids duplication. Shared data schemas and output formats ensure consistency across dissemination channels when analysis results are updated.

Dissemination is also closely linked to transparency and reproducibility. Providing access to structured outputs, together with clear documentation of the analytical process, supports interpretation by stakeholders and facilitate reuse by other researchers. The workflow therefore treats dissemination as a continuation of the analytical process rather than as a separate final step.

3 Results and discussion

3.1 The BENCHMARKS project use case

In this section we present the implementation and results of the proposed end-to-end workflow in a real-world setting. The workflow was applied in the EU-funded BENCHMARKS project, which served as a large-scale case study. The BENCHMARKS project focuses on soil health monitoring and aims to develop robust, contextually relevant soil health monitoring strategies based on scientific evidence and stakeholder participation. Within this framework, workshops involving land stewards, scientists, policy makers, and citizens play a central role in collecting qualitative and semi-quantitative data relevant for the development of soil health monitoring frameworks (Reed et al., 2009).

3.1.1 BENCHMARKS workshop organization, data collection and preparation

Stakeholder workshops play a central role in the BENCHMARKS project by providing the participatory basis for the co-creation of context-specific soil health monitoring frameworks. The workshops were conducted across 22 case study sites in Europe and involved more than 500 participants representing agricultural, forestry, and urban land-use context across a wide range of pedoclimatic conditions.

The overall aim was to identify local soil health priorities, explore management challenges, and define stakeholder needs to ensure that the proposed soil health indicators were both relevant and usable. Workshops were designed to encourage inclusive engagement from a broad range of participants, including land stewards, public authorities, researchers, citizens, and private sector actors. The workshop structure accommodated agricultural, forestry, and urban contexts, while still producing comparable outputs. Workshops were organised and partly facilitated by local partners to ensure adaptation to local context, while following common guidance to maintain comparability between case study sites.

Across all workshops, land stewards constituted the largest stakeholder group. Within this group, male participants outnumbered female participants (approximately a 3:1 ratio), while most other stakeholder groups showed a more balanced gender distribution. A clear predominance of female participants was observed only among knowledge and education actors (Figure 3).

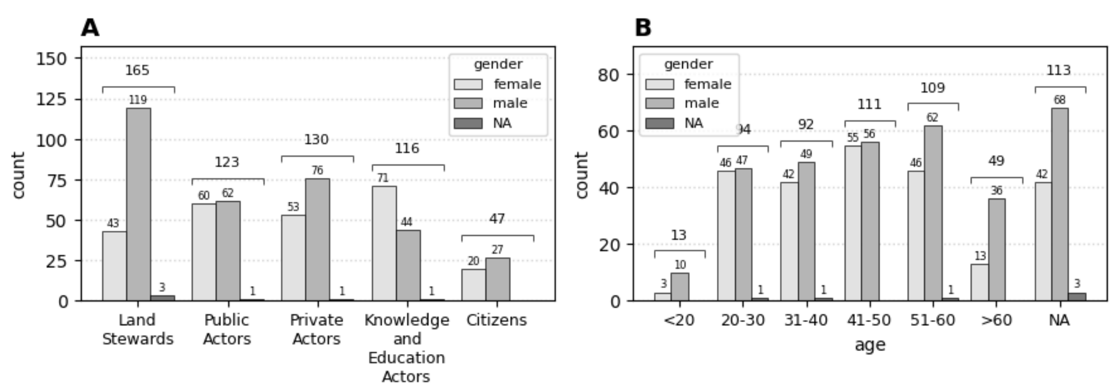

Figure 3: Gender and age distribution of participants across all BENCHMARKS workshops. (A) Gender distribution by stakeholder group. (B) Gender distribution by age group. Total participant counts are provided for each category.

The age distribution of stakeholders shows that participants younger than 20 were clearly under-represented, while those older than 60 were less represented than the middle age groups. The remaining age groups were more balanced, including with respect to gender composition. Both extreme age categories (< 20 and > 60) were predominantly male. Finally, a substantial proportion of participants did not disclose their age.

Workshops began with an introduction to the day's goals, a short presentation of the BENCHMARKS project, and clarification of key concepts such as soil health. Participants were also invited to introduce themselves and share their expectations. After these opening steps, the core activities followed. Each workshop followed a common structure consisting of three core activities (Table 1). The first activity addressed perceived challenges and objectives related to soil health in the local context. The second focused on prioritisation of soil functions, as well as links between soil functions, management practices, and stakeholder activities. The third addressed stakeholder needs, opportunities, and required support mechanisms for improving soil health management.

Name of activity	**Description and main activity question**	**Type of data produced**
Challenges and objectives in soil health	Perceived challenges and objectives for soil health in the local context. Main question: 1. What are the main challenges for soil health from your perspective?	Qualitative
Soil function prioritization	Prioritization of soil functions based on stakeholder values and land use needs as well as soil health objectives and land management practices related to the prioritized soil functions. Main questions: 1. What are your objectives related to the chosen soil functions? 2. What are you currently doing to support agriculture/promote soil health? 3. What are the practices/activities that are necessary to take to the future for resiliency and the promotion of soil health?	Quantitative & Qualitative
Needs and opportunities	Support needs and opportunities for improving soil health management. Main questions: 1. What do we need from each other in our region to foster a resilient and future-oriented agriculture that prioritizes and promotes soil health? 2. How can BENCHMARKS (and other EU projects) provide support to you? 3. What types of tools or resources would assist you in enhancing soil health on your land?	Qualitative

Table 1: Core BENCHMARKS workshop activities, associated guiding questions, and generated data types.

The central design principle of the BENCHMARK workshops was the prioritization of analogue in-room data collection methods. Participants recorded their inputs on post-it notes, posters, and structured templates. This lowered barriers for those with limited digital experience and supported more inclusive participation. It also kept attention on dialogue rather than screens. A drawback of this approach was the additional post-workshop processing workload, as data had to be transcribed into digital form afterwards.

A common limitation of participatory workshops is the tendency for discussions to be dominated by more outspoken individuals. To address this, participants were first asked to write their opinions silently on post-it notes. They were then guided to share one opinion at a time, ensuring space for all voices. This procedure was applied consistently across all activities.

Immediately after each workshop, the collected material was digitized. Post-it notes and other written inputs containing qualitative and semi-quantitative data were transcribed into structured Excel templates prepared by the coordination team. These templates standardized the format of the results, allowing comparison across sites and languages. Demographic information was also recorded to enable analyses by age, gender, stakeholder type, and land-use context.

Transcription was initially done in the local language. The translation phase that followed combined document translation services (OnlineDocTranslator and Google's translation tools) with manual translation. Next, translations and terminology were reviewed and corrected where necessary. The final step in post-workshop data processing was to verify the structure of the translated files and ensure that the spreadsheets complied with the format required for database construction.

The data preprocessing step was followed by the development of relational data storage. In BENCHMARKS, four SQL databases were designed and populated: one for each workshop activity and one for demographic data. Because no cross-activity analyses were planned, the relational structures of the four databases were kept relatively simple. They were defined using the Peewee ORM library Leifer (2024). All entities, their attributes and relationships were modelled using Peewee's class-based model definitions, which greatly simplified the process of database creation as well as data retrieval. The versatile in-process SQLite RDBMS (Hipp, 2021) was used for back-end data storage because of specific requirements (mostly read-only after creation but read-heavy).

3.1.2 BENCHMARKS data analysis

The design and implementation of the BENCHMARKS data analysis workflow were shaped by the workshop activities and associated data types described in Table 1, as well as the requirements of the dissemination process. The selection of algorithms and analytical methods was guided by the central research question underlying the multi-stakeholder workshops: namely, that soil health objectives, challenges, and management vary in perception, understanding, and application across different regions in Europe.

The implementation of the data analysis step consists of several parts organised as follows. First, three aggregation modules, one for each workshop activity described in Table 1, load, parse, and inspect the workshop data stored in Excel spreadsheets and store them in the corresponding relational database. Next, there are three analysis modules, one for each workshop activity, that perform data analysis at the level of individual workshops. Additional analysis modules host methods selected for use in the first two dissemination options (workshop reports and the web tool). A rendering module compiles the selected results from other modules, the table of report variables and their values or descriptions, images, and the report template into the final report document, ready for inspection and quality control. Finally, there are a number of supporting modules that provide API access to AI tools, host common variables, definitions, and colour schemes, and supply utilities such as QR code generation. A parallel analysis branch contains several closely related modules tailored specifically for BENCHMARKS scientific publications (research papers), thereby supporting the third dissemination option. The implementation of the entire data analysis backbone relies on open-source tools and libraries and supports both an interactive environment for rapid testing and development and large-scale code execution for production.

To address the central research question, the data analysis module implements several statistical, machine learning, and AI methods. First, basic demographic data are collected and visualized including age, gender, stakeholder distribution, and their combinations. Next, participants' inputs from Activity 1, assigned to one of the predefined categories (Societal, Political, Environmental, Economic, Technological, Research, and Land Management), are transformed into TF-IDF vectors using a standard text mining pipeline consisting of tokenisation, lemmatisation, and vectorisation. Multi-word phrases are then extracted and presented in a frequency table with a colour map to support comparison across workshops and stakeholder groups. Using this table, users can identify where phrases such as "combat climate change," "increase fertility in the long term," "organic matter," or "phytosanitary products" appear most frequently. A separate table containing only the most frequent words and phrases is also generated. In addition, the RAKE method for automatic keyword extraction is also implemented (Rose et al., 2010). Word frequency information is also used to generate word clouds, which are visual representations of the frequency table and can provide a quick overview of key themes and support exploratory comparison of workshop outputs. Participants' text inputs are also used for topic modelling, where the data are visualised, clustered, and the discovered topics concisely summarized using an LLM. A combination of UMAP, HDBSCAN, and the OpenAI GPT model is used in a BERTopic pipeline (Grootendorst, 2022) with Figure 4 illustrating the resulting topic clusters and their LLM-generated summaries.

The BENCHMARKS data analysis module also implements methods for comparing ranked lists of soil functions and stakeholder priorities across workshops and stakeholder groups.

Activity 2, which focuses on soil functions, soil health objectives, and management and stakeholder

Figure 4: Visualization of participants' responses in Activity 1 ("What are the main challenges for soil health from your perspective?") from a forestry workshop in Austria. Each dot represents one textual unit (post-it note). Positions of dots were generated using UMAP dimensionality reduction, applied to embedding vectors of textual inputs. Dot colours represent semantically related clusters identified using density-based clustering.

	Urban	Agriculture	Forest
Citizens	1.0	1.0	0.4
Knowledge and Education Actors	0.6	0.4	0.6
Land Stewards	0.5	1.0	0.6
Private Actors	0.6	0.5	1.0
Public Actors	1.0	0.5	1.0

Figure 5: Alignment of stakeholder rankings of soil functions with the overall consensus ranking across all three land-use types and all workshops in BENCHMARKS. Alignment was computed using the normalized Discounted Cumulative Gain (nDCG) method. A score of 1 indicates perfect alignment; scores between 0.5 and 0.75 indicate moderate alignment; scores between 0.3 and 0.5 indicate weak alignment; and values below 0.3 indicate divergence.

activities affecting soil health, collects numerical data representing participants' votes for soil functions (primary production, nutrient cycling, water regulation and purification, habitat provision, carbon and climate regulation, and pest and disease suppression). For each stakeholder group, a ranked list of soil functions with votes is available. To analyse rankings, the module implements two methods: the Rank-Biased Overlap (RBO) method, which compares ranked lists with potential ties (Webber et al., 2010), and the normalized Discounted Cumulative Gain (nDCG) (Järvelin and Kekäläinen, 2002), which also takes into account the actual number of votes. nDCG evaluates a ranking relative to an ideal ranking, which can be either another group or the consensus, thus allowing a broader range of comparisons. The module also implements visualisation of rank analysis results. Figure 5 shows the alignment of stakeholder group soil function rankings relative to the consensus ranking across all three land uses and all workshops using the nDCG method. A score of 1 means perfect alignment with the consensus, while a score between 0.3 and 0.5 means weak alignment. For example, citizens' votes are aligned with the consensus in the urban and agricultural land use cases but only weakly in the forestry land use case. All stakeholder groups except knowledge and education actors align with the consensus vote in at least one land use case. Knowledge and education actors' votes, however, agree only moderately in the urban and forestry land use cases and weakly in agriculture.

Most of the data collected in BENCHMARKS consists of free-form text (answers to guiding questions and ideas) transcribed and translated from post-it notes. To derive more structured qualitative and quantitative insights with reduced need for expert interpretation, we applied the topic discovery and intensity analysis procedure introduced in Section 2.5.4. The procedure produces a list of topics along with estimated topic intensities and clustered visualisations presented as radial bar charts. This enables straightforward comparison of stakeholder groups and workshops in relation to specific guiding questions or discussion themes. In addition, aggregated visualisations were implemented to support comparisons across multiple stakeholder groups, workshops, and land-use contexts.

Figure 6 shows the comparison of topic intensities related to the Activity 1 question ("What are the main challenges for soil health from your perspective?") between agricultural workshops in Austria and the Netherlands. We used the GPT-4o-mini LLM model, which was found to be a good compromise between speed, cost, and quality. The analysis reveals several notable differences but also many common points. Waste management, soil sealing, and erosion are strongly represented in the Austrian workshop but only weakly in the Dutch workshop with differences of up to two units on the 0–5 intensity scale. In contrast, climate change, soil compaction, and financial pressure received the maximum intensity score in both workshops. The remaining topics differed by no more than one unit on the 0–5 scale.

3.1.3 Reporting and quality control in BENCHMARKS

The implementation of the reporting and quality control step in the BENCHMARKS project was designed to meet the following requirements: (a) design and development of the report template, taking into account the project's visual identity; (b) production of a large number of written reports sharing a common structure; and (c) multiple internal and external quality control cycles.

The BENCHMARKS workshop report template used the Microsoft Word document format, which ensures compatibility and ease of use. The template was prepared by a graphic designer in collaboration with the technical team and refined jointly. However, additional templating support was required to allow automated population of the template with content. The python-docx-template library (Lapouyade, 2024) allowed us to use special template tags and filters inside the document, which were rendered with the actual content in the following stage.

In the report generation stage, reports for all BENCHMARKS workshops were produced by instantiating the template variables with corresponding values. A wide variety of content was inserted into the reports programmatically, including statistics, charts, chart explanations obtained using vision-capable LLMs, summaries of large text collections, images, and QR codes. Some content was generated dynamically, while other elements were retrieved from the file system (data analysis results, for example), queried from databases, or retrieved from the common template variable spreadsheet (workshop data, image locations, and LLM prompting instructions, for example).

In BENCHMARKS, the quality control step was especially demanding because the workflow implementation also relied on large language models for data analysis, chart interpretation, and text summarisation. Therefore, the generated reports were thoroughly reviewed by experts, workshop organisers, and other team members to ensure correctness, completeness, and adherence to the report

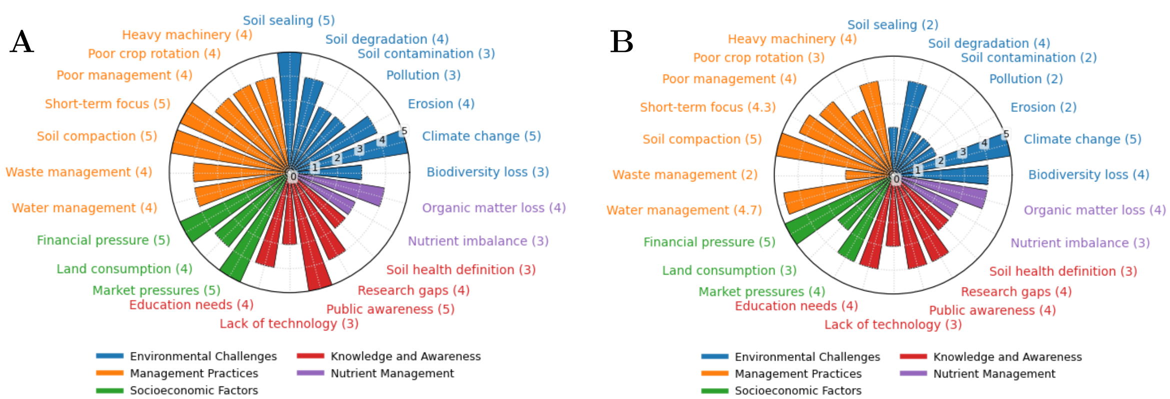

Figure 6: Comparison of topic intensities related to perceived soil health challenges from an agricultural workshop in Austria (A) and the Netherlands (B). The topics and intensities were identified, quantified, and clustered using the developed LLM-based topic intensity analysis method and the GPT-4o-mini model.

template. The work package team, together with case study leaders and partners, conducted several quality control iterations covering different stages of the report generation process including template construction, template rendering, report content, and end-user feedback.

3.1.4 Knowledge dissemination

In the BENCHMARKS workflow implementation, knowledge dissemination is achieved through generated reports, scientific papers, and, most importantly, through the Stakeholder Insights Explorer (SIX)

SIX[1] is a web-based interactive platform for dynamic knowledge sharing and cross-regional comparison of workshop results. It enables comparison of selected stakeholder workshop results together with additional supporting data and analytical outputs not included in the generated reports. It gives stakeholders, case study leaders, policy analysts, and researchers direct access to standardised outputs through an intuitive interface designed for comparative analysis. Unlike static reports, the tool enables users to explore workshop data interactively across regions. Two main visualisation modes are supported: exploration of individual workshop results and cross-workshop comparison through side-by-side visualisation. Figure 7 shows selected parts of the user interface featuring side-by-side comparison of analytical results.

The core functionality of the SIX tool is organised into three integrated modules. The geographic visualisation module displays workshop locations on an interactive map, allowing users to select regions and view location-specific data. The workshop comparison module supports simultaneous analysis of up to five regions using standardised visualisations generated during data analysis. The detailed reporting module provides access to structured outputs from the automated reporting pipeline, including activity-specific visualisations.

The tool is implemented as a modern web application using React. State management relies on the React Context API, while interactive mapping is handled by the Leaflet JavaScript library using custom markers and tooltips for workshop locations. The back-end consists of a REST API server connected to the BENCHMARKS databases and also serves static assets, including generated reports and visualisations. The API provides two main endpoints: one for retrieving workshop metadata and another for accessing detailed workshop results, including participant statistics, land-use types, stakeholder distributions, and report content. SIX is directly linked to the implemented data processing pipeline through the use of the same data schemas, column naming conventions, and output formats as the automated report generation module. The data flow proceeds from the databases to React components, which render visualisations using the same datasets that populate the static reports. This design ensures consistency between static and interactive outputs and supports real-time updates when workshop data or analyses are revised or extended.

4 Discussion and Conclusions

4.1 Conceptual contribution of the end-to-end workflow

The workflow presented in this paper was designed to offer a complete end-to-end solution for processing stakeholder workshop outputs that are diverse, multilingual, and often analogue in form. It was developed in the context of soil health research, but its structure is adaptable to other participatory settings where unstructured and multilingual data are common. Additionally, it can be simplified for projects with less complex analytical and dissemination requirements or extended with additional analytical modules to support more complex analytical tasks, heterogeneous data structures, and advanced dissemination requirements.

The core idea of the workflow is the integration of all processing stages, from workshop organisation and data collection to reporting and dissemination. In practice, these stages are often handled separately, resulting in fragmented documentation and reduced reproducibility. By linking the stages through structured data transformations and shared outputs, the workflow improves traceability of analytical results. Another important design principle was the treatment of reporting as an integral part of the analytical process rather than as a separate activity. Reports are not written manually, but are generated from analytical results which are linked back to the data stored in the database. If

[1] https://ecoenvai.ijs.si/benchmarks/stakeholder-insights-explorer/

Figure 7: Side-by-side comparison of selected results from forest, urban, and agricultural stakeholder workshops in the SIX interactive web tool. The top panel shows stakeholder and age distributions in each workshop compared with all workshops. The middle panel presents a radar chart of soil health challenges identified by participants, together with a visualization of participants' responses in Activity 1. The bottom panel summarizes current soil health–supporting practices reported by different stakeholder groups.

the input data is modified, reports can be regenerated. This supports iterative updates and reduces inconsistencies across dissemination outputs.

The workflow also explores the integration of state-of-the-art LLMs into participatory data analysis. We designed an LLM-based data analysis approach especially suitable for analysing raw text data commonly produced in participatory research. The proposed topic extraction and intensity analysis procedure aims to transform heterogeneous qualitative inputs into comparable quantitative representations that can support cross workshop and cross stakeholder analysis. However, the workflow treats human quality control as a mandatory component when using generative AI tools, acknowledging the risks associated with hallucinations, unstable outputs, and limited reproducibility. The workflow illustrates how stakeholder workshop data can be handled in a more systematic and repeatable way. More broadly, the workflow highlights the importance of treating participatory workshop data as structured research material that benefits from the same principles of traceability, reproducibility, and systematic quality control commonly expected in other forms of scientific data analysis.

4.2 Insights from the BENCHMARKS implementation

Applying our workflow in the BENCHMARKS project made its strengths and weaknesses visible. The analogue-first workshop design proved effective in practice as participants engaged actively and discussions remained focused. Although this decision resulted in additional manual work after the workshops, the workload remained manageable. However, this observation also highlights an important trade-off between participant accessibility during data collection and the increased effort required for later transcription and preprocessing. For this reason, such an approach may become less suitable for larger workshops with more activities, more participants, and larger volumes of collected data.

Automatic translation services proved useful for multilingual workshop processing, provided that consistent translation of terminology could be ensured. In cases where the consistent and correct use of terminology is mandatory, careful review by experts is recommended, or the use of translation software that ensures consistent terminology usage.

We found that, during the preparation of the BENCHMARKS workshop data, a significant amount of time was spent checking and correcting the Excel spreadsheets into which the data had been entered. This reflected the difficulty of balancing human readability and ease of data entry with the structural consistency required for automated database population. Based on these findings, preprocessing structures should be designed to balance both human usability and machine readability as early as possible in the workflow.

In the BENCHMARKS project, the use of a lightweight, embedded database proved to be the right decision. Based on the experience gained, we can conclude that embedded databases are well suited for storing data from multilingual stakeholder workshops, provided that there are no special requirements, such as data volumes exceeding the capacity of an embedded database, different user access rights, and similar constraints. Their transparency and low infrastructure requirements also support reproducibility and easy sharing of structured workshop data.

Data analysis is the most project-specific step of the methodology; therefore, the experiences and conclusions drawn from the BENCHMARKS implementation are less generalizable in this regard. Nevertheless, several important observations can still be made. Since the final outputs of the workflow (reports) are typically intended for different types of end users, some of whom are not domain experts, and because the volume of data requires that most of the analysis is automated, the primary emphasis should be placed on selecting analytical methods that produce easily understandable results. This reduces or eliminates the need for expert interpretation, which is slow, costly, and difficult to scale. Our experience suggests that a controlled and limited use of LLMs can accelerate and improve the interpretation of results. However, this inevitably requires validation of the outputs by domain experts (which is nevertheless faster than full expert interpretation). The developed method for analysing and quantifying topics proved to be practical and effective in the BENCHMARKS implementation. It produced clear and understandable results that avoided many of the typical drawbacks associated with LLM use, such as hallucinations and lack of reproducibility.

In the BENCHMARKS project, quality control played a central role due to the pilot use of language models, and it was carried out strictly and consistently. This experience highlighted the importance of treating quality control as a continuous process rather than as a final verification step. Our experience suggests that quality control is most efficient when implemented as a parallel, iterative process that runs alongside automated data analysis and automated report generation. The implementation of automated reporting through the use of templates, variables, and rendering routines greatly simplified the production of high-quality reports, particularly in situations where data or analytical outputs change over time.

The implementation of dissemination using the developed SIX tool in the project enabled stakeholders to access results directly in a standardized format through an intuitive interface that also supports comparative analysis. Although the additional workload and development effort are not negligible, the platform substantially improved accessibility and comparative exploration of workshop results. This suggests that interactive dissemination tools can provide significant additional value in projects where comparison, transparency, and broad accessibility of results are important objectives.

4.3 Limitations and future improvements

Although the proposed end-to-end workflow was designed to be robust, it still has several limitations that depend partly on the specific requirements of a given implementation. The preferred method of data collection in the proposed workflow is analogue, which requires an additional transcription and translation step. The explicit introduction of shared glossaries could improve robustness and further simplify and standardize the translation process.

The integration of language models into some of the core components of the workflow is innovative, but it also introduces important methodological challenges. It may jeopardize reproducibility due to the non-deterministic nature of the models, the release of new versions, and the discontinuation of older ones. The use of locally deployed language models, over which full control can be maintained, could address some of these issues, although potentially at the cost of lower output quality. Furthermore, the proposed method for topic identification and intensity estimation is still at an early stage of development and offers several opportunities for further improvement. Combining it with classical text mining methods and statistical approaches could improve the explainability of the results. Establishing an explicit link between identified themes and the original textual inputs could also improve traceability and quality control.

When applied in projects similar to BENCHMARKS, the workflow components for report production and dissemination already satisfy most of the key requirements. Nevertheless, several areas for future improvements remain open. These include dissemination through social media platforms, which is not currently supported by the workflow, and the integration of LLMs into the SIX application to enable analysis, interpretation, and comparison of results through a conversational interface.

4.4 Concluding remarks

The presented work shows that stakeholder workshops can generate data that are both inclusive and scientifically sound, provided that data collection, analysis, and reporting are treated as connected steps within a clearly documented and repeatable workflow. By using structured data management, computational analysis, clear reporting rules, and systematic quality control, participatory research can meet the same standards of transparency and reproducibility expected in other areas of science.

Author Contributions

VP: Conceptualization, Methodology, Software, Data curation, Formal analysis, Writing – original draft, Writing – review & editing. BB: Conceptualization, Software, Writing – original draft, Writing – review & editing. CV: Conceptualization, Funding acquisition, Methodology, Supervision, Writing – review & editing FV: Conceptualization, Supervision, Writing – original draft, Writing – review & editing. RC: Conceptualization, Supervision, Funding acquisition, Writing – review & editing. MD: Conceptualization, Supervision, Writing – review & editing

Software and data availability

Our BENCHMARKS implementation of the proposed workflow cannot be made publicly available because it is tightly linked to databases that contain personal and potentially identifiable information. The implementation is also specific to the BENCHMARKS workshop design, data structure, and reporting templates.

A selection of the analytical results is available through the public Stakeholder Insights Explorer (SIX) tool: https://ecoenvai.ijs.si/benchmarks/stakeholder-insights-explorer/. An anonymised sample of the project databases can be provided by the authors upon reasonable request.

Competing Interests

The authors declare that they have no competing interests.

Use of AI Tools

Artificial intelligence (AI) tools were used to support the preparation of this manuscript. Specifically, large language models (LLMs) assisted in translation, grammar checking, text editing for clarity and conciseness, and generating alternative phrasings. All substantive content, methodological descriptions, interpretations, and conclusions were developed by the authors. The authors reviewed, edited, and approved all AI-assisted text.

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