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

Vid Podpečan[1,*], Bojan Blažica[1], Fabio Volkmann[2], Carmen Vazquez Martin[3], Rachel Creamer[3], Marko Debeljak[1]

[1]Jožef Stefan Institute, Jamova 39, 1000 Ljubljana, Slovenia
[2]Climate Farmers Academy, 10178 Berlin, Germany
[3]Soil Biology Group, Wageningen University & Research, Droevendaalsesteeg 3a, 6708 PB Wageningen, The Netherlands

Corresponding author: vid.podpecan@ijs.si

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Abstract

This paper presents an end-to-end workflow for the collection, analysis, and dissemination of multilingual stakeholder workshop data related to soil health. Stakeholder workshops often produce diverse qualitative and ordinal data which is difficult to process consistently and transparently, especially in multilingual settings. The proposed workflow provides clear guidance for collecting, translating, organising, analysing, and reporting data originating from stakeholder workshops.

The workflow covers the complete process from data collection, preparation and structured storage to analysis, reporting, and dissemination. It builds upon a range of data analysis methods, including large language models. It is designed to support the analysis of diverse types of data and enables both qualitative exploration and comparison based on derived numerical scores and rankings. We also propose a structured approach based on large language models to topic extraction and topic intensity scoring which allows comparing stakeholder perspectives across workshops and contexts. Finally, a templated reporting process and an interactive online tool support clear and consistent communication of results to stakeholders and other audiences.

The proposed workflow is demonstrated in a large European research project involving multiple workshops, stakeholder groups, land-use contexts, and languages. The main contribution of this work is a transparent and adaptable workflow that integrates multilingual data handling, analysis, and reporting into a single framework for stakeholder-based soil health research.

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 especially relevant in soil health research. 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 define what is feasible in a given region. Economic capacity and policy priorities differ between countries. 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 concrete challenges and management options (Keesstra et al., 2016; Bouma, 2020). There are several established participatory 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.

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 methods consists of free-text inputs combined with ordinal and numerical data. In his book about social research methods, Bryman (2016) gives methodological guidance on qualitative and quantitative data analysis as well as on software to assist in this process. However, the situation becomes more complicated in multilingual setups, which are common in European research projects. Translation 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 too difficult to implement in larger projects. State-of-the-art 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.

The analysis of heterogeneous and fragmented workshop data can itself be challenging task. 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 mostly be applied to such data, but they require careful interpretation and expert involvement, and are not suitable for highly heterogeneous and massive datasets. On top of the collection of classical text mining tools, topic modelling approaches based on LLMs such as BERTopic (Grootendorst, 2022), can be used to analyze 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 (JMIR Editorial, 2024), reliability and transparency of outputs are not guaranteed. 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, and documentation is incomplete. Finally, dissemination also presents a challenge. It is most 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 other domains, 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 are also needed in environmental projects, where the results from different regions must be interpreted together.

Overall, there is extensive literature on stakeholder engagement, qualitative analysis, and computational tools. 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. This need is particularly visible in large international projects, where many workshops generate fragmented data in different languages.

Despite the availability of the required components, building blocks are rarely connected within a single, documented process. In large international projects, workshops generate fragmented short text inputs and ranked data in multiple languages, which must be translated, structured, analysed, and communicated across sites. Existing tools address only parts of this chain and do not provide clear guidance on how to move from raw workshop data to comparable and reusable results that can be disseminated. Data handling often remains ad hoc, 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 one 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. In the Discussion and Conclusions section we review conceptual contributions of the workflow, present insights from its implementation in BENCHMARKS, and discuss limitations and future improvements.

2 Materials and methods

2.1 Workflow overview

To support the systematic processing of stakeholder workshop data, we developed 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. Virtually all the steps require human intervention and cannot be performed automatically in order to ensure expected, valid results. However, the design of the workflow which consist of smaller, well-defined steps ensures that most of the work only requires light supervision, verification of correctness, and small modifications required for the workflow to be applied to the problem at hand. For example, ensuring terminological correctness during data preprocessing (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 mandated in the quality control step (5). This is a crucial step which ensures that the information and knowledge disseminated to stakeholders and involved parties is correct, relevant, and up to date. This is especially important with respect to the current state of generative AI tools if they are used in the data analysis and knowledge extraction step (4).

2.2 Workshop organization and data collection

Workshop organization is not strictly a part of the analytical workflow. However, it is discussed here because good workshop design and organisation directly affect the quality, structure, and interpretability of collected data.

The data collection step 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 is agnostic to workshop duration, group size, and event type. Group size may also vary and can include single-person groups (though this is not recommended) because analytical methods that are not sensitive to group size are also available. However, such extreme choices affect

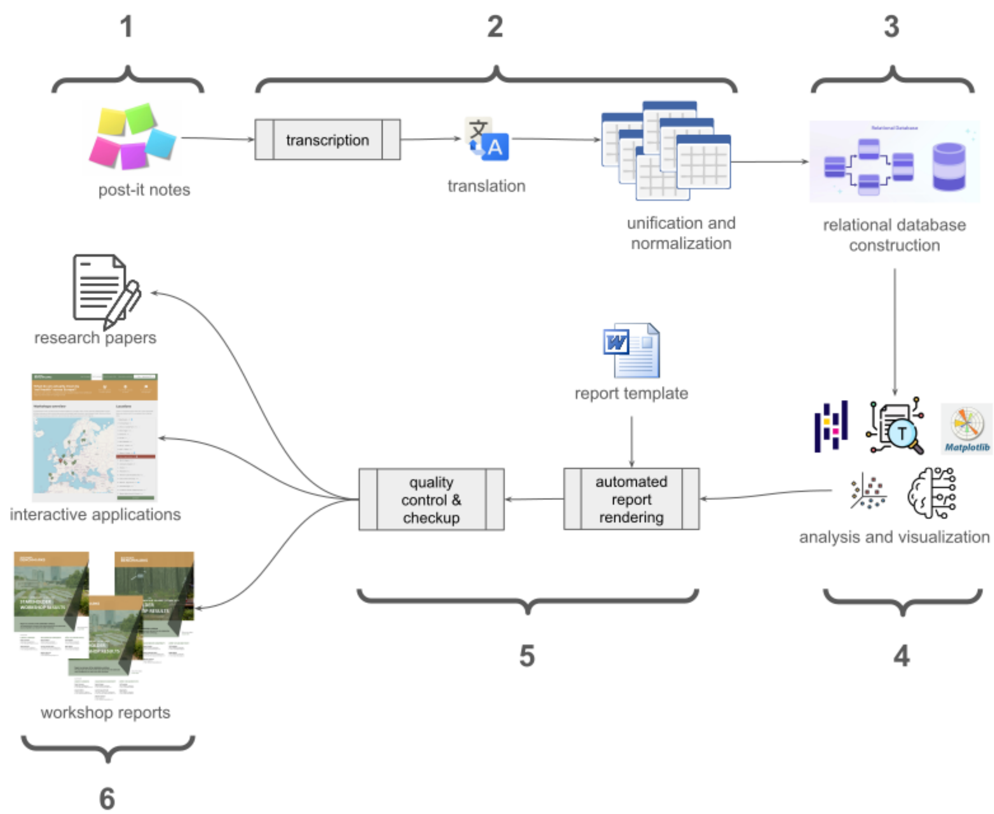

Figure 1: An overview of the steps of the end-to-end workflow for multilingual stakeholder workshop data.

later analysis and may require additional clustering or other aggregation steps. Structured workshop activities can make the subsequent analysis simpler but are not required. Nevertheless, using clearly defined activities helps separate data by topic and thus leads to more focused inputs allowing the data analysis to be carried out in smaller, manageable parts. This also simplifies verification and quality control. When activities are less structured, the workflow can still be applied, but more 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. At the same time, local flexibility is encouraged to account for context-specific needs and constraints. This flexibility is acceptable as long as the required level of standardisation is maintained.

In our experience, analog 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. A drawback of analog 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 written input 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 (e.g. same activity, question, and group) 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 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.

In multilingual settings, data preprocessing includes translation of workshop data into a common language. Most commonly, translation is performed using publicly available document translation services or local translation software but manual translation is also an option when the amount of data is low. This is followed by manual proofing. Next, terminology must be checked for consistency across workshops and unified where necessary. Similar checks can be applied regardless of the translation technology used.

In its current form the workflow does not envision tracking of preprocessing changes. However, a combination of track changes in spreadsheets and a data versioning capable database enables the tracking of all changes and versioning of the data. This option may be relevant in settings with frequent updates or strict reproducibility requirements.

Ambiguous and low-quality inputs are handled by domain experts during preprocessing. Expert judgement is used to interpret unclear handwriting and incomplete statements. A common guidebook is recommended to support consistent decisions across all teams. The same approach applies to language harmonisation such as unifying spelling variants or domain-specific terms.

Validation of the collected and structured data (spreadsheets) needs to be performed before database construction (manual inspection of filled templates). Additional automated checks are applied later when the data is imported into the database.

2.4 Database construction

Database construction is closely connected to data preprocessing. Strictly speaking, the use of a database is not mandatory. The data can also be stored in files or read directly from structured spreadsheets. However, 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.

In general, there exist two main approaches to systematic data storage: relational and non-relational databases. 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 way for storing workshop and demographic data as it is relational in nature. In addition, when activities and their datasets are conceptually independent, using several smaller databases reduces schema complexity and simplifies queries. In other settings, a single database may be more appropriate but this choice is project-specific.

Individual data units are stored as cell values in the underlying data tables. One data unit (e.g., a single post-it note), corresponds to one cell value. Links to activities, questions, groups, land use types and workshops are represented through the database schema.

Database schemas can be updated if needed, but 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.

Typical access patterns are read-heavy and write-light. The data is usually written once during initial database population and then read many times during analysis and reporting. Small, local database files with simple and transparent schemas 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 because it facilitates reproducibility and reuse and ensures long-term accessibility of structured workshop data.

2.5 Data analysis and knowledge extraction

The data analysis and knowledge extraction step is the core of our workflow. It supports transformation of structured workshop data 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 inputs include text corpora composed of individual text units, ranked and voted lists, and optional demographic or categorical data. Other input types are also possible (e.g., audio transcripts, survey responses, questionnaires) as well as various structured metadata. The workflow can be extended to handle additional data types if needed 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, 2D data projections, boxplots etc. Textual outputs include summaries of responses, lists of extracted topics, answers to direct analytical questions based on the data using LLMs, and any other text mining results. Numerical outputs include topic intensities, ranked lists comparisons, various statistics and statistical tests, and results of machine learning algorithms such as clusters, numerical predictions, etc. Graphical and tabular outputs should be prepared in publication-ready quality to allow for direct use in reports and interactive results dissemination tools. Finally, outputs can also include trained machine learning models, rules, outliers, and other artifacts that are not directly used in dissemination but 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 provides a structured environment in which appropriate methods can be selected or implemented based on data availability and analytical goals.

For qualitative text data, common methods include tokenization, lemmatization, term frequency and tf–idf-based text analysis, phrase and keyword extraction, clustering, topic modelling, and 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, analysis focuses on comparison of priorities across groups or workshops. Rank comparison metrics and descriptive statistics support identification of similarities and differences between ranked lists and consensus rankings. For demographic or categorical data, analysis usually involves counting participants by category (e.g. age, gender, stakeholder type) 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 in most cases 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, and repeating model calls where appropriate. Aggregating repeated outputs is also proposed to reduce random variation. Nevertheless, expert review of the results produced by generative models remains mandatory in most use cases.

2.5.4 Topic extraction and intensity analysis

Our workflow proposes a dedicated procedure for topic extraction and intensity scoring. It is designed to analyze corpora of qualitative text data, commonly found in stakeholder workshops. The aim is to obtain a stable set of topics from free-form text and estimate their relative intensity in a way that allows simple comparison across different groups.

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. Furthermore, Beaumont et al. (2025) found that LLMs can be used to quantify the salience of text statements by assigning numerical rankings. Our approach builds on these ideas by combining topic extraction with repeated consolidation followed by intensity scoring to support reliable and repeatable comparison across stakeholder groups or entire workshops.

The proposed procedure consists of three main phases (Figure 2). In the first phase (1), candidate topics are extracted from a selected collection of text data (e.g., all stakeholder groups) 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. 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.

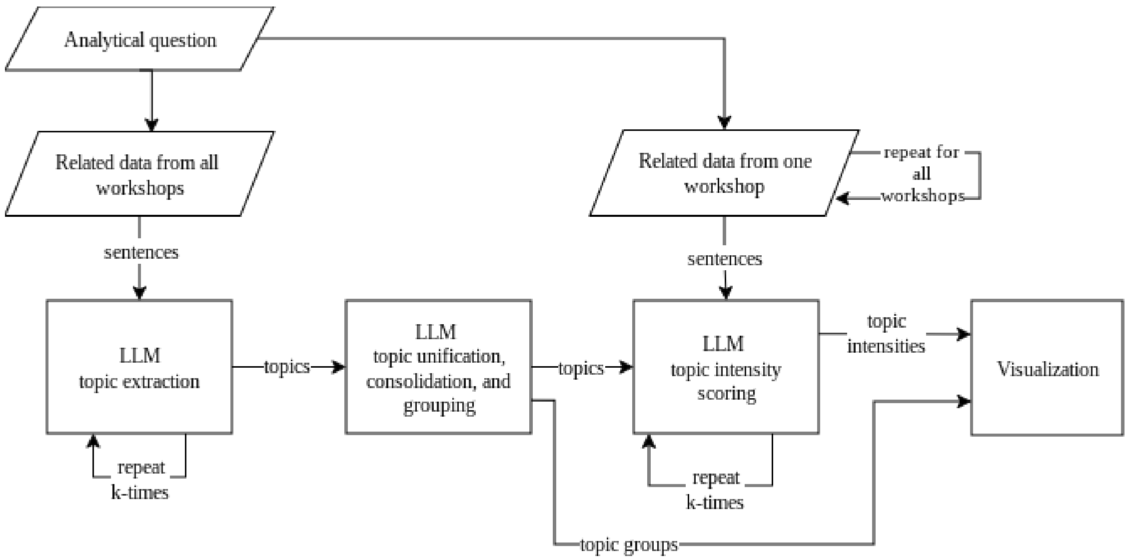

Figure 2: Hybrid flowchart illustrating topic extraction and intensity analysis based on large language models. The procedure extracts a stable set of topics relevant to the analytical question from the selected document set and subsequently computes and visualizes the intensity of the same topics within a chosen subset of the input data.

Finally, in the third phase (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 (e.g., a selected stakeholder group). It is recommended to use a scoring system which provides sufficient granularity while remaining simple and intuitive (e.g., 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 workshops or groups. 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. Even though larger groups produced more text and cover a wider range of topics, the intensity estimates themselves are relative to the input text collection and do not increase with group size. Approaches such as nonzero mean and diversity index can be used when comparing the results across groups or workshops.

2.5.5 Reporting and quality control

In our end-to-end workflow reporting is treated as an integral part. It is a transformation step that converts analytical outputs into structured results for end users. Report design and templating focus on defining a common structure and a set of parameters that can be populated automatically. 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, supports reuse, adaptation, updating, and sharing of results across workshops and projects. It also enables scaling, as manually writing large numbers of similar reports is often not feasible. The reporting step should be implemented using a technology which is 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 al-most 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 cycles are expected, particularly when content is updated or regenerated. This is common when using generative models or when analysis parameters change. While the first quality control cycle may require more effort, subsequent cycles 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. Version comparison is also simplified, as reports generated from the same template differ only in parameter values and content but not in structure.

2.5.6 Knowledge dissemination

Knowledge dissemination is the final step of the workflow. Its focus is on making analysed and validated results accessible to different audiences. Ideally, the dissemination is not limited to just delivering final outputs, but also supports exploration, comparison, reuse, and easy updates. To achieve this, appropriate techologies and solutions should be used when implementing the dissemination step. 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. We envision the ideal implementation 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. Using shared data schemas and output formats allows updates to analysis results to be reflected consistently across dissemination channels.

Dissemination is also closely linked to transparency and reuse. Providing access to structured outputs, together with clear documentation of how results were produced, supports interpretation by stakeholders and 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 use case. The workflow was applied in the EU-funded BENCHMARKS project, which served as a large-scale use case. The BENCHMARKS project focuses on soil health monitoring and aims to build robust, meaningful soil health monitoring strategies based on scientific evidence and stakeholder participation. In this context, workshops with diverse groups, land stewards, scientists, policy makers, and citizens, are a key tool for collecting qualitative and semi-quantitative data relevant for developing 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, providing the participatory foundation for co-creating a robust, context-specific soil health monitoring framework. They were conducted across 22 diverse case study sites in Europe, involving more than 500 participants and covering different land-use types (agriculture, forestry, and urban) and a wide range of pedoclimatic conditions.

The overall aim was to identify local priorities for soil health, explore management challenges, and define stakeholder needs so that the proposed soil health indicators would be both relevant and usable. Workshops were designed to encourage inclusive engagement from a broad spectrum of participants, including land stewards, public authorities, researchers, citizens, and private sector actors. The structure was flexible enough to be applied in agricultural, forest, or urban contexts, while still producing outputs that could be compared across sites. Workshops were organised and partly facilitated by local partners to ensure alignment with local context, while following common guidance to support comparability across sites.

When combining data from all workshops, land stewards represent the largest stakeholder group. In this group, male participants strongly outnumber females (approximately a 3:1 ratio), while most other stakeholder groups show a more balanced gender distribution. The only group with a clear female predominance is knowledge and education actors (Figure 3).

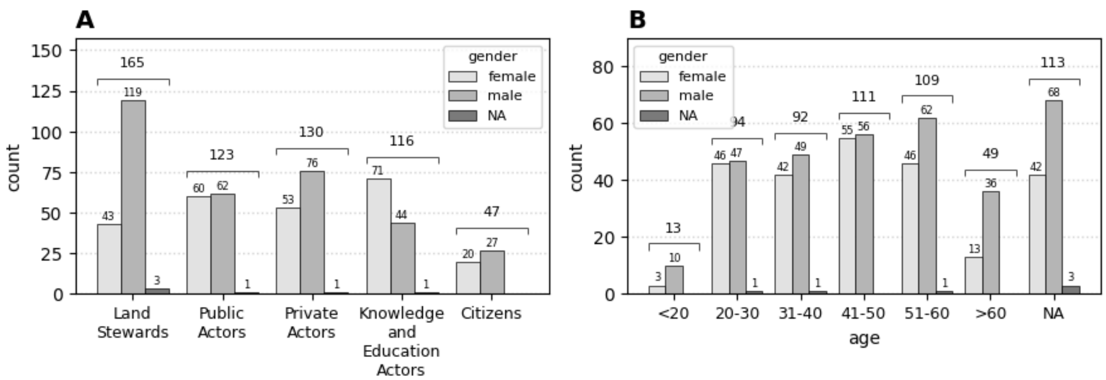

Figure 3: Stakeholder statistics across all BENCHMARKS workshops. (A) Gender distribution within stakeholder groups, including total group size. (B) Gender distribution within age groups, including total group size.

The analysis of stakeholder age shows that participants younger than 20 are clearly underrepresented, while those older than 60 are less represented than the middle age groups. The remaining age groups are more balanced, including in terms of gender composition. Both of the extreme age categories (< 20 and > 60) consist predominantly of male participants. Finally, a significant 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 a 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 independent activities (Table 1). The first activity focused on perceived challenges and objectives related to soil health in the local context. The second activity addressed prioritisation of soil functions, as well as links between soil functions, management practices, and stakeholder activities. The third activity focused on stakeholder needs, opportunities, and required support mechanisms for improving soil health management.

The central design principle and a distinctive element of BENCHMARK workshop implementation was to prioritize analog methods for in-room data collection. Participants recorded their inputs on post-it notes, posters, and structured templates. This lowered barriers for those with limited digital experience and supported more equal participation. It also kept attention on dialogue rather than on screens. The drawback was the additional workload after workshops: the burden was shifted from the workshop setting to the processing stage.

A common limitation of open participatory workshops is that only the most outspoken individuals may be heard. 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. 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,

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: Description of core BENCHMARKS workshop activities, main questions and types of data produced.

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 used document translation services (OnlineDocTranslator and Google's translation tools) as well as manual translation. Next, the translation and terminology were checked and corrected where necessary. The final step in post-workshop data processing was to verify the structure of the translated files and to review the spreadsheets for compliance with the format required for database construction.

The data preprocessing step was followed by the construction 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 substantially simplified. 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 backend data storage because of specific requirements (mostly read-only after creation but read-heavy).

3.1.2 BENCHMARKS data analysis

The organisation and implementation of the data analysis workflow step in BENCHMARKS were determined by the organisation of the workshop into separate activities, the types of collected data, and the requirements of the dissemination step. The selection of algorithms and methods used in the analysis allowed examination of the hypothesis and related questions raised within multi-stakeholder workshops: namely, that soil health objectives, challenges, and management vary in perception, understanding, and application across different regions in Europe.

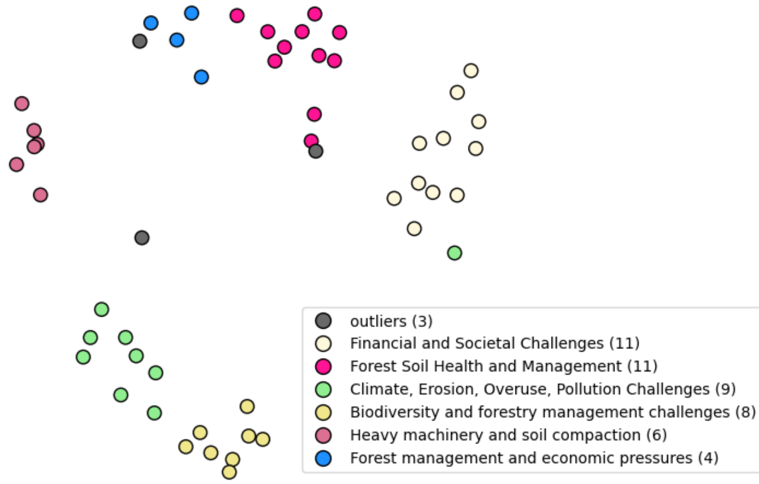

Figure 4: Visualization of participants' responses in Activity 1 ("What are the main challenges for soil health from your perspective?") from a forestry workshop in Austria. Each dot represents one textual unit (post-it note). Positions of dots were obtained using UMAP dimensionality reduction, applied on embedding vectors of text units. Colours of dots represent cluster membership which was obtained using density-based clustering.

The implementation of the data analysis step consists of several parts organised as follows. First, there are three aggregation modules, one for each workshop activity, which 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. Third, there are three additional analysis modules that host analysis methods selected for use in the first two dissemination options (workshop reports and a 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. In a parallel data analysis branch, there are several closely related analysis modules that are tailored specifically for BENCHMARKS-related scientific publications (research papers), thus serving the third dissemination option. The implementation of the entire data analysis backbone relies on open-source tools and libraries, is largely reusable, and supports both an interactive environment for rapid testing and development and large-scale code execution for production.

To address the overarching hypothesis, the data analysis module implements several statistical, machine learning, and AI methods and approaches. First, basic demographic data are collected and visualised: age, gender, stakeholder distribution, and their combinations. Next, participants' inputs from Activity 1, which were assigned to one of the predefined categories (Societal, Political, Environmental, Economic, Technological, Research, Land Management), are transformed into TF-IDF vectors using a typical text mining pipeline (tokenisation, lemmatisation, vectorisation). Multi-word phrases are then extracted. The results are shown in a frequency table with a colour map for easy comparison. Using this table, the user can quickly identify where phrases such as "combat climate change," "increase fertility in the long term," "organic matter," or "phytosanitary products" most often appear and how frequently. A separate table showing only the most frequent words and phrases is also computed. In addition, the RAKE method for automatic keyword extraction is also available (Rose et al., 2010). Word frequency information is also used to produce word clouds, which are visual representations of the frequency table and can serve as a first-pass exploration tool, enable comparative insights, and provide a quick overview of key themes. Participants' text inputs are also used in topic modelling, where the data are visualised, clustered, and the discovered topics concisely described using an LLM. A combination of UMAP, HDBSCAN, and the OpenAI GPT model is used in a BERTopic pipeline (Grootendorst, 2022). Figure 4 shows the result of topic modelling, where participants' responses are visualised, clustered, and succinctly summarised.

The BENCHMARKS data analysis module also implements methods for comparing ranked lists.

	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 nDCG method. A score of 1 indicates perfect alignment; 0.5–0.75 indicates moderate alignment; 0.3–0.5 indicates weak alignment; and values below 0.3 indicate divergence.

Activity 2, which focuses on soil functions, soil health objectives, and management and stakeholder activities affecting soil health, collects numerical data representing participants' votes for soil functions to prioritise (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 nDCG method (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 versus 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. In order to obtain direct, unambiguous qualitative as well as quantitative answers that do not require extensive expert interpretation, we applied the topic discovery and intensity analysis developed for our workflow. This procedure returns a list of topics along with estimated topic intensities and a clustering of topics organised into a radial bar chart. As such, it allows for straightforward comparison of different stakeholder groups or workshops in relation to a selected guiding question or discussion. In addition, an aggregated visualisation using

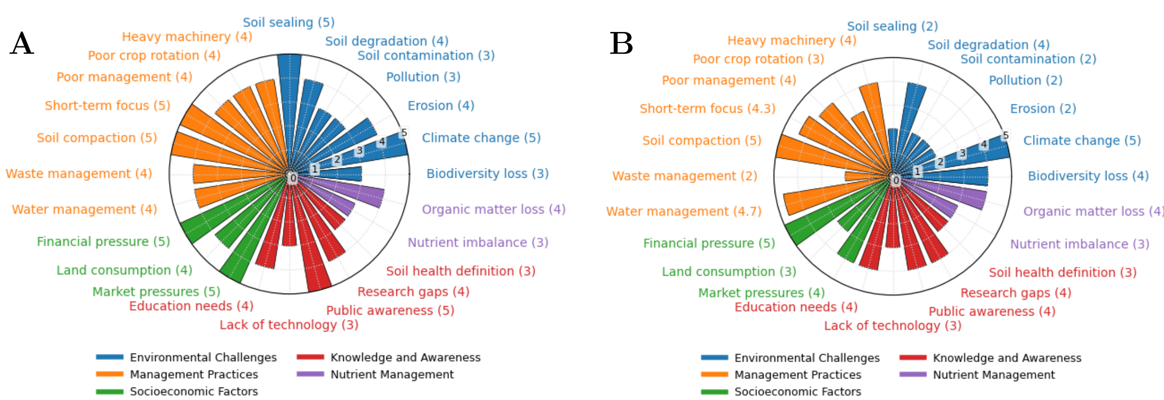

Figure 6: Comparison of topic intensities related to the recognized soil health challenges from an agricultural workshop in Austria (A) and the Netherlands (B). The topics and intensities were discovered and quantified using the developed method for topic intensity analysis using LLMs (GPT-4o-mini).

heatmaps was also implemented, allowing comparison across several groups, workshops, or land uses. 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 agriculture 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. Topic analysis clearly reveals that there are few significant 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 (the difference is two units on the 0–5 scale). On the other hand, climate change, soil compaction, and financial pressure reached the maximum in both workshops. The intensities of the remaining topics are not significantly different between the two workshops (1 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 had to satisfy 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, a special technology had to be employed to allow automated population of the template with actual 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 variables with actual values. A wide variety of content was inserted into the reports programmatically: statistics, charts, chart explanations obtained using vision-capable LLMs, summaries of large bodies of text, images, as well as QR codes. Some of the content was produced on the fly, while some was read from the file system (e.g., results of data analysis), queried from the databases, or read from the common template variable spreadsheet (e.g., workshop data, image locations, and LLM prompting instructions).

In BENCHMARKS, the quality control step was especially demanding because the workflow implementation also relies on large language models for data analysis, chart analysis, and text summarisation. Therefore, the generated reports were thoroughly checked by experts, workshop organisers, and other team members to ensure correctness, completeness, and adherence to the template. The work package team, as well as case study leaders and partners, performed several quality control cycles for different parts of the report creation procedure (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 the dissemination of generated reports, scientific papers, and, most importantly, via the Stakeholder Insights Explorer (SIX), a web-based interactive tool that allows interactive comparison of selected stakeholder workshop results, as well as additional data and knowledge that are not available in the generated reports.

BENCHMARKS SIX[1] is the primary channel for dynamic knowledge sharing and cross-regional comparison of workshop results. It gives stakeholders, case study leads, 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 data interactively across regions. Two main visualisation modes are supported: exploration of individual workshop data and cross-workshop comparison through side-by-side visualisation. Figure 7 shows parts of the user interface featuring side-by-side comparison of the results of the analysis.

The tool's core functionality is organised into four 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 the simultaneous analysis of up to five regions using standardised visualisations generated during data analysis. The detailed reporting

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

Figure 7: Side-by-side comparison of selected results from a forest, urban, and agricultural stakeholder workshop in the 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, and the visualization of participants' responses in Activity 1. The bottom panel summarizes current soil health–supporting practices reported by different stakeholder groups.

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, with custom markers and tooltips for workshop locations. The backend consists of a REST API server connected to the BENCHMARKS databases. It 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 by using the same data schemas, column naming conventions, and output formats as the automated report generation module. The data flow runs from the databases to React components, which render visualisations using the same datasets that populate static reports. This design ensures consistency between static and interactive outputs and allows 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 to the processing of stakeholder workshop outputs that are diverse, multilingual, and often analog 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. It can be simplified for smaller projects or extended with additional analytical modules where more complex data is available. The workflow tightly connects all stages of processing which reduces ad hoc decisions and makes it easier to understand how a reported result was produced. An important design choice was to treat reporting as a part of the analytical process. Reports are not written manually from scratch but they are generated from analytical results which are linked back to the data stored in the database. If the input data is modified, the report can be regenerated. This makes updates easier and reduces inconsistencies between different outputs.

In the workflow, state-of-the-art LLMs are considered an important tool. We proposed and developed an LLM-based data analysis approach especially suitable for analysing raw text data commonly produced in participatory environmental research. The approach yields easily interpretable quantitative results which allow comparison across stakeholder groups and workshops. However, by integrating quality control the workflow ensures that any LLM-based results are reviewed by humans to ensure that they are free from spurious content and hallucinations.

Our end-to-end workflow demonstrates that stakeholder workshop data can be handled in a systematic and repeatable way. By treating participatory data in an organized, documented, and reusable way, the results gain credibility and reusability.

4.2 Insights from the BENCHMARKS implementation

Applying the workflow in the BENCHMARKS project made its strengths and weaknesses visible. The analog-first workshop design worked well in practice. Participants engaged actively, and discussions were focused. Although this decision resulted in more manual work after the workshops, the amount of work was still manageable. However, it should be noted that such a solution is probably not suitable for larger workshops with a larger number of activities, more participants, and a larger amount of data collected.

Automatic translation services have performed well and are generally recommended, provided that consistent translation of terminology can 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. The reason for this was the failure to maintain a balance between ease of data entry and ease of reading structured data when populating the relational database. Based on these findings, it is recommended that, at the data preparation stage, such structure is required that optimally meets both requirements.

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 the use of embedded databases for storing data from multilingual stakeholder workshops is sensible and recommended, 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.

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 conclusions can still be made. Since the final outputs of the workflow (reports) are typically intended for different types of end users some of who 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. We found that the 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 fast, reliable, and efficient. It produces clear and understandable results that do not suffer from the typical drawbacks associated with LLM use such as hallucinations or lack of reproducibility.

In the BENCHMARKS project, quality control played an important and central role due to the pilot use of language models, and it was carried out strictly and consistently. In other types of projects, its role may be significantly reduced; nevertheless, we recommend that quality control is 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 automation greatly simplified the production of high-quality reports and is recommended for any type of project that requires the production of a non-trivial number of reports.

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, we recommend such approach in all cases where interactive, easily accessible, and wide dissemination of results is required, particularly when different comparisons and integrations are also needed.

4.3 Limitations and future improvements

Although our end-to-end workflow is designed to be robust, it has certain limitations (which largely depend on the specific needs of a given implementation). The preferred method of data collection in the proposed workflow is analogue, which requires an additional translation step. The explicit introduction of shared glossaries would make the workflow more robust and would simplify and standardize the translation process.

The integration of (large) language models into some of the core components of the workflow is innovative, but also a bold decision that may have negative consequences. 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 local language models, over which we have full control, could address some of these issues (albeit at the potential cost of lower result quality). Furthermore, the proposed method for topic identification and intensity estimation is still in an early stage and can be improved in many ways. Combining it with classical text mining methods and statistical approaches would contribute to improved explainability of the results. An explicit link between the identified themes and the original textual inputs could also serve as an additional by-product, useful for quality control and enabling full traceability.

When applied in projects similar to BENCHMARKS, the workflow steps addressing report production and dissemination do not present major limitations, as they already cover most of the key requirements. Among the remaining minor open questions, however, are the possibility of dissemination via social media, which the workflow in its current form does not address, and the potential 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, as long as data collection, analysis, and reporting are treated as connected steps within one clearly documented (and thus repeatable) process. By using structured data management, computational analysis, clear reporting rules, and strict and consistent quality checks, participatory research can meet the same standards of transparency and reproducibility that are 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. CVM: 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

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.

Competing Interests

The authors declare that they have no competing interests.

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