SOILGUARD

Sustainable soil management to unleash soil biodiversity potential and increase environmental, economic and social well-being

Grant Agreement no. 101000371

D 5.4: SOILGUARDIANS app Alpha Version

WP	WP5 Prediction of soil-mediated ecosystem services delivery, value and wellbeing based on soil biodiversity			
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Contents

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Abbreviations and Acronyms

Acronyms	Description
AI	Artificial Intelligence
API	Application Programming Interface
CS	Countryside Survey
DSS	Decision Support System
ES	Ecosystem Services
ETL	Extract, transform, load
GAMs	Generalized Additive Models
HTTP	Hypertext Transfer Protocol
IAM	Identity and access management
IdM	Identity Management
JSON LD	JavaScript Object Notation for Linked Data
JWT	JSON Web Token Introduction
LOI	Loss on Ignition
MongoDB	Mongo DataBase
NCP	Nature's contribution to people
NoSQL	non-Structured Query Language
OICD	OpenID Connect
OTU	Operational Taxonomic Unit
pH	potential hydrogen
REML	Restricted maximum likelihood
SNoK	Soil Network of Knowledge
SSM	Sustainable Soil Management
TLS	Transport Layer Security
UA	University of Alicante
UI/UX	User interface/ User experience
UKCEH	UK Centre for Ecology & Hydrology

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List of Figures

The research leading to these results has received funding from the European Union Horizon 2020 Research & Innovation programme under the Grant Agreement no. 101000371.

1. Introduction

The SOILGUARDIANS app stands as a pioneering initiative within the scope of SOILGUARD project, responding to the pressing need for sustainable soil management practices in the face of escalating land degradation and climate change. Developed collaboratively by a consortium of leading organizations, the app emerges as a transformative tool designed to address critical knowledge gaps related to soil biodiversity, ecosystem services (ES) (or Nature's Contributions to People – NCPs), and their intricate connections to human wellbeing.

In a landscape where environmental stressors, management strategies, and policy interventions significantly impact soil-mediated ecosystem services, the SOILGUARDIANS app endeavours to offer an innovative solution. At its core, the app brings together a social network-based forum and a Decision Support System (DSS), in the service of the Soil Network of Knowledge (SNoK) and stakeholders invested in sustainable soil management (SSM).

The development of the SOILGUARDIANS app follows an incremental approach that includes the co-creation of a conceptual and analytical framework, development of evidence chains, operationalization through modelling approaches and a robust prediction mechanism for soil-mediated ecosystem services delivery and value. The app is not only a repository of knowledge, but also a dynamic platform designed to predict and assess the impacts of soil management strategies on soil biodiversity and ecosystem services.

Key features of the app include **a Datasets and Metadata Portal**, a dedicated **Forum** fostering collaborative knowledge exchange and **Region-Specific Soil Management tools**. The app's architecture leverages an ontology and hypermodels to create a **Decision Support System,** capable of providing a dynamic assessment of synergies and trade-offs between ecosystem services, linked to soil biodiversity.

As the app progresses through alpha and beta versions, user testing and iterative improvements, it anticipates active engagement from stakeholders, SNoK members, and the wider community. This user-centric approach ensures that the final version of the SOILGUARDIANS app aligns seamlessly with the needs of its users, becoming a vital instrument in the co-creation of evidence-based conservation recommendations and policy frameworks.

The SOILGUARDIANS app embodies a collaborative vision for sustainable soil management. It aims to contribute to the global standard for assessing soil biodiversity, creating a paradigm shift in how stakeholders, policymakers, and the conservation community approach soil health and sustainable land use. The app, with its innovative features and participatory design, positions itself as a cornerstone in the journey toward a resilient and sustainable future.

The alpha version of the SOILGUARDIANS app represents a significant milestone in the project's objective to develop a user-friendly tool for assessing and predicting impacts on soil-mediated NCPs and human wellbeing. This report details the progress made in achieving this milestone, focusing on the key tasks outlined in the project plan.

D5.4 (SOILGUARDIANS app Alpha Version) consists of the online deployment of the first preliminary release of the SOILGUARDIANS app with this associated report. The SOILGUARDIANS app is an emerging design process, so various updates will appear throughout the SOILGUARD project. The developing team remains open to suggestions and feedback from both internal and external partners of SOILGUARD.

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D5.4 is structured as follows: Section 1 gives an introduction, by stating the purpose and the target group of the SOILGUARDIANS app. Section 2 describes the overall approach and methodology that was followed for the completion of the deliverable. Section 3 highlights the technical system architecture of the application and the implemented components. Section 4-6 consists of a manual-guide for the users, including how the SOILGUARDIANS app features can be used in an optimal manner and lastly, Section 7 and Section 8 refer to the feedback incorporation and the investigation of the future/next steps in the development of the beta version respectively.

1.1 Purpose, Target Group and Benefits

The purpose of this deliverable is to present SOILGUARDIANS app, an innovative tool that will integrate a social network-based forum and a Decision Support System (DSS) to facilitate the exchange of knowledge related to Sustainable Soil Management (SSM) and soil biodiversity. The primary objective is to create a user-friendly platform that enables stakeholders, particularly members of the Soil Network of Knowledge (SNoK) – described below, to actively engage in the participative design and sharing of insights.

The SOILGUARDIANS app is designed to address a diverse user base, engaged in various aspects of soil management, biodiversity conservation and policymaking. Scientists and researchers in fields such as soil biodiversity, ecosystem services, and environmental sciences can access and contribute to the latest research findings and models through the app. Policymakers at different levels, including local, regional, and national government agencies, can utilize the app's insights for evidence-based decision-making regarding soil management and conservation policies. Individuals involved in land management, such as farmers and landowners, can benefit from the app by understanding the impact of different practices on soil biodiversity, NCPs, and human well-being. Conservationists and non-governmental entities focused on environmental conservation can leverage the app for informed decision-making and collaborative initiatives. Academic institutions can use the app as an educational tool, providing students with real-world examples and data related to soil biodiversity, NCPs, and sustainable soil management. Additionally, the app may have features accessible to the general public, raising awareness about the importance of soil-related aspects. SNoK members, actively involved in the development and testing phases, are an integral part of the target group, contributing to the participative design of SOILGUARDIANS and providing valuable feedback.

The SOILGUARDIANS app comprises a tool that converges advanced technology with environmental supervision, offering benefits to advance sustainable soil management and biodiversity conservation. With a user-friendly interface, the app facilitates seamless navigation for diverse user groups, from scientists and policymakers to practitioners and the broader community.

The incorporation of evidence chains and models formalizes the relationships between soil biodiversity, NCPs, and human well-being. This framework provides users with insights into the complex interactions within ecosystems, enhancing the understanding of the consequences of land degradation, soil management and climate change with the use of a powerful Decision Support System (DSS), that leverages advanced computing to offer advanced tools for decision-making, including assessments, management strategy evaluations, diagnoses, and predictions related to soil biodiversity and NCPs.

A distinctive feature is the region-specific soil management functionality, tailoring strategies to the unique needs and challenges of different biogeographical regions. The alpha version introduces predictive hypermodels, developed through various modeling approaches, allowing users to anticipate and respond to

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potential environmental, economic, and social costs associated with different scenarios of land degradation and climate change.

Following a continuous development and integration approach, the app represents evidence chains and models developed in the earlier stages of the project. Subsequent updates, informed by ongoing data collection and user feedback, ensure the app remains dynamic and relevant throughout the project's lifespan.

Moreover, the app's connection with the conservation community, ensures that generated insights and recommendations align with the goals and priorities of conservationists, policymakers, and practitioners working towards sustainable environmental practices.

1.2 Contribution of Partners

As the lead partner of T5.3, WINGS oversees the development of the application, including the overall design, functionality, and implementation of the alpha version. WINGS leads the technological aspects, bringing expertise to the forefront in creating a user-friendly tool. Responsible for defining interaction mechanisms with the Soil Network of Knowledge (SNoK) in WP1 and facilitating participative design, WINGS ensures that the app aligns with the needs of users. In addition, WINGS takes charge of translating stakeholder requirements into software specifications, forming the backbone of the tool, like creating essential components such as the Data Platform, Model Repository, Model Execution Engine, AI-based Model Reconfiguration, and the Decision Support System (DSS) Engine. Throughout the development, WINGS ensures a continuous integration approach, allowing for the incremental release of updates based on evolving data and user feedback.

UICN, as the Work Package 6 (WP6) leader, contributes to the alpha version by ensuring the flow of information and usability of the SOILGUARDIANS app, for the conservation community and policymakers. UICN facilitates the connection between the analysis, recommendations and insights generated within WP6 and the functionalities of the SOILGUARDIANS app. This involves aligning the outputs of conservation, policy and management practices with the capabilities of the app, ensuring that it serves as a valuable tool for decision-makers and the broader conservation community.

UKCEH, as a key partner, leads the development of evidence chains that underpin the alpha version of the SOILGUARDIANS app. Leading Task 5.1, UKCEH collaborates with other partners to create directed graphs representing relationships between soil biodiversity, NCPs. This critical work lays the foundation for the alpha version, providing a consistent guide for modelling linkages across the evidence chains. Furthermore, UKCEH plays a central role in operationalizing evidence chains (Task 5.2), utilizing various modelling approaches to simulate different parts of the chains that underlie the alpha version.

LEITAT's role in the development of the SOILGUARDIANS app involves active participation in Task 5.1, contributing to the creation of evidence chains that form the backbone of the app's functionality. By collaborating with other partners in synthesizing evidence, LEITAT aids in constructing directed graphs that encapsulate the relationships between soil biodiversity. As part of the consortium, LEITAT also facilitates the transfer of data from relevant WPs (WP2, WP3, WP4) to WP5, ensuring a smooth integration process for the alpha version of the app.

Lastly, UA plays a key role in the development of the SOILGUARDIANS app, by contributing to the creation of evidence chains, linking soil biodiversity to values. UA is involved in operationalizing these chains, providing Soilguard data from WP2 and utilizing diverse modelling approaches to assess the environmental, economic,

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and social costs of soil management. UA's contributions enhance the functionality and predictive capabilities of the SOILGUARDIANS app.

Each partner's unique expertise contributes to the comprehensive development, testing, and validation of the app, making it a collaborative endeavour with a broad impact.

2. Overall Approach – Methodology

The development methodology of the SOILGUARDIANS app (alpha version) was executed with a systematic and structured approach, with emphasis on collaboration and user feedback and is subject to continuous improvement to deliver a powerful and user-friendly SOILGUARDIANS app. Specifically, the following sections detail the key steps and methodologies employed throughout the development lifecycle:

2.1 Requirements Gathering

Requirements gathering marked the initial phase in the development process. Through close collaboration with the Soil Network of Knowledge (SNoK) and engaging stakeholders, a continuous consultation process embarked to define interaction mechanisms, user requirements and wish-lists. This ongoing and iterative approach played a crucial role in shaping the alpha version of the app, ensuring that it is closely aligned with the evolving needs and expectations of our intended users. As the app progresses to subsequent design and development stages, it remains committed to continuous consultation, allowing for adaptation and refinement in response to user feedback and emerging requirements.

The outcome of these interactions was a comprehensive list of prioritized requirements, ensuring that the app's design aligns with user expectations.

Requirement	Description	Priority
Authentication	Secure authentication and authorization mechanism using KeyCloak service to ensure only authorized users with different roles access the app.	Must
Visualization of SOILGUARD Data and Metadata	Functionality to visualize soil data and metadata through an interactive interface.	Must
Forum	Social network-based forum to facilitate discussions and knowledge-sharing among users, including the Soil Network of Knowledge (SNoK).	May
Region-Specific Soil Management	Provide tailored recommendations for soil management based on region-specific data.	Must
Data Acquisition	Gather data from various sources, including experiments, user inputs, external sources and climate data through APIs.	Must
Data Availability	Create an app that works anywhere in the European landscape	Must
Benchmarking	Compare local soil data with European-wide standards (e.g., LUCAS survey data) for soil properties like pH, soil carbon, and bulk density.	Must
Evidence Chains and Models	Integrate models that formalize causal relationships between soil biodiversity, ecosystem services (ES) and human well-being.	Must

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Transforming to NCP (Nature's Contributions to People)	Assess environmental, economic, and social costs of soil management practices, aligning with global initiatives.	Must
Access to SOILGUARDIANS App (Alpha Version)	Provide access to the Alpha version for testing and feedback from selected stakeholders, including SNoK members.	Must

2.2 Design and Wireframing

Based on the gathered requirements, the design and wireframing phase commenced. Interaction mechanisms with the SNoK were defined and platform wireframes were created by WINGS. These wireframes, such as those presented in Figure 1 and Figure 2, acted as visual blueprints for the app's structure and input/output data types. Stakeholder feedback was actively sought and incorporated into the design to ensure a user-centric approach. Specifically, consultation took place not only during the general WP meetings (e.g. on 29/3, 18/5, 4/7, 9-10/11), but also during dedicated app sessions (e.g. 30/5, 26/7, 25/10) and workshops (e.g. in Athens Periodic meeting M24 6-8/6).

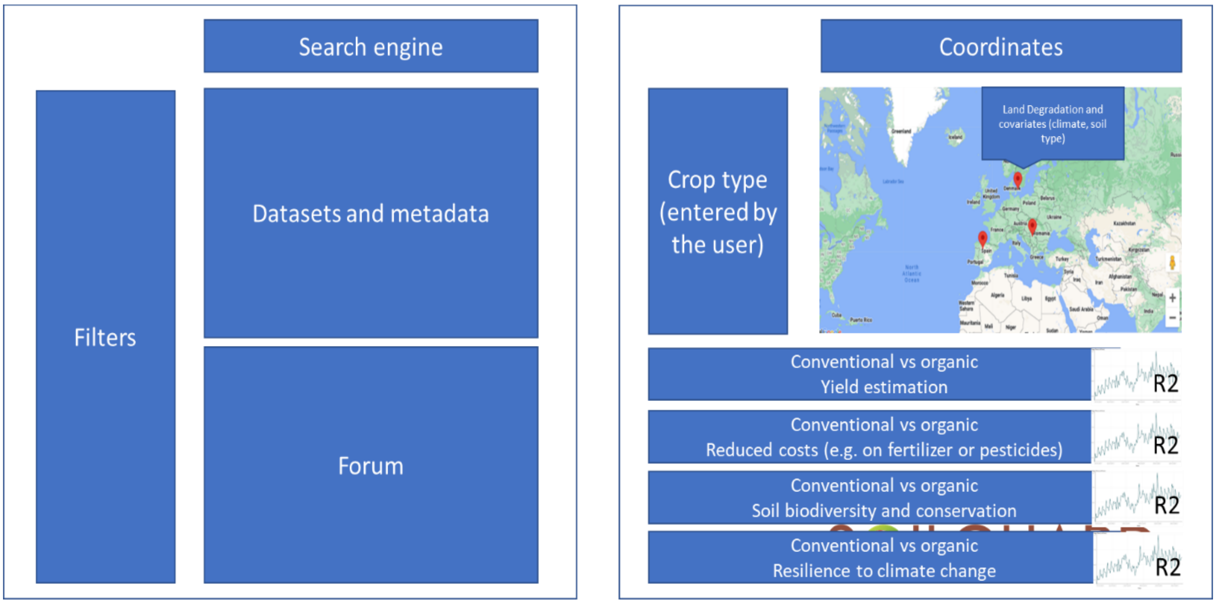

Figure 1. First wireframes of structure and type of input/output data for the App.

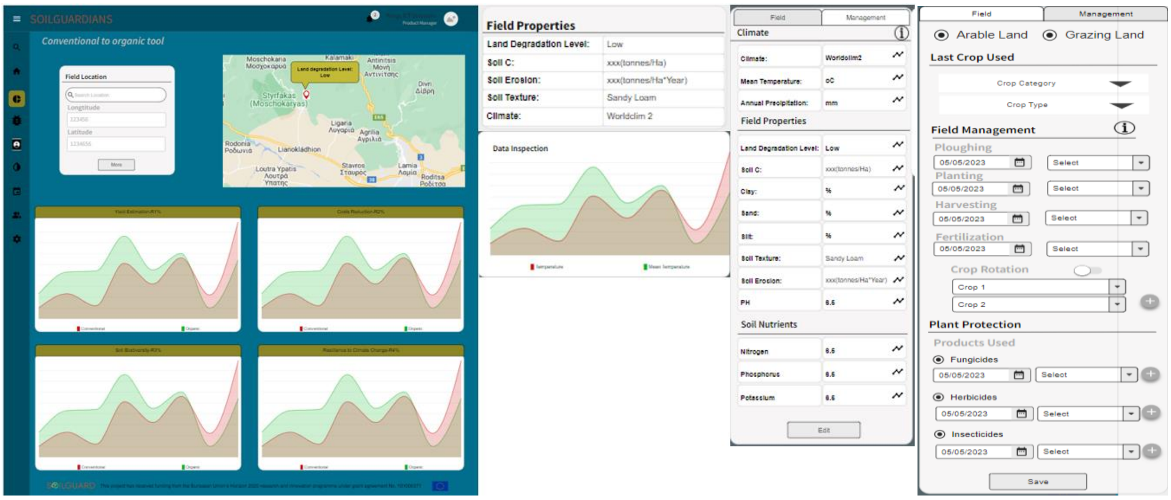

Figure 2. Wireframes presented to partners during SOILGUARDIANS App Workshop, held in 24M Meeting in Athens for discussion.

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2.3 Development

The actual development phase involved translating stakeholder requirements into software specifications. This phase laid the technical foundation, integrating the preliminary evidence chains and models developed in earlier tasks. The collaboration among partners, especially between WINGS, UKCEH, and UICN, played a crucial role in achieving a cohesive and functional system. Specifically, the following procedures were followed.

2.3.1 Data Collection and Algorithm Development

The initial phase in developing the SOILGUARDIANS app, was the critical phase involving Data Collection and Algorithm Development. This phase was challenging from a variety of aspects. Firstly, gathering precise data on soil biodiversity, NCPs and sustainable soil management practices proves to be inherently challenging due to the diversity and regional variations of these elements. To address the above, the project team engaged in extensive consultations with SNoK and relevant stakeholders to enhance the accuracy and relevance of the collected data.

Moreover, the app had to navigate through diverse data sources, each with its own formats and standards. Ensuring the quality of this data and integrating it into the system becomes imperative for the app's overall effectiveness. To address the complexity arising from diverse data sources with different formats and standards, a robust data integration strategy was implemented. The app was designed to navigate through various data formats, ensuring compatibility and reliability.

The development of robust algorithms and models introduced another layer of complexity. These components serve as the analytical backbone of the app and bring together ecological aspects, statistical methods and advanced computing techniques. The challenge was to create models that can effectively assess the impact of soil management practices on both soil biodiversity and NCPs. An interdisciplinary approach was adopted, combining ecological insights, statistical methods and advanced computing techniques. The challenge of creating models capable of assessing the impact of soil management practices on both soil biodiversity and NCPs was addressed through iterative refinement and validation processes. The models were fine-tuned to generate reliable predictions and recommendations that could adapt to diverse scenarios.

This interdisciplinary approach is crucial for generating predictions and recommendations that are not only reliable but also adaptable to various scenarios. The success of the SOILGUARDIANS app lies in overcoming these challenges, creating a system that can gather, integrate, and analyze diverse data. In this way, users may depend on the app for insights into soil management practices and their intricate relationships with biodiversity and NCPs.

2.3.2 Scalability, Adaptability and Continuous Maintenance

Ensuring scalability, adaptability and continuous maintenance is integral to the app's functionality. Design considerations allowed for scaling and adaptation across diverse regions, accommodating variations in soil types and agricultural practices. Customization to address regional disparities in soil characteristics, climate conditions and management techniques is also crucial for the app's effectiveness, and enables adaptability.

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The dynamic nature of the field demands a commitment to continuous maintenance. As fresh insights emerge in soil biodiversity and sustainable soil management, the app should undergo regular updates. This involves integrating new data, refining algorithms, resolving bugs, and incorporating user feedback. Such proactive measures guarantee the SOILGUARDIANS app's longevity, ensuring it remains pertinent and valuable in evolving landscapes.

2.3.3 UI/UX and User Engagement

Accordingly, navigating the UI/UX and fostering user engagement presented a set of challenges in the app's development. The design process involved creating an interface that adeptly communicates complex soil data, recommendations, and incorporates social networking features, demanding a delicate balance.

Critical to user satisfaction is the establishment of an intuitive and accessible app interface across various devices. User experience is paramount for ensuring not only ease of use but also active engagement.

Beyond the technical aspects, success lies in effective communication with stakeholders—farmers, land managers, policymakers, and the scientific community. Convincing these diverse groups to embrace and contribute to the app, requires a user-friendly design that vividly demonstrates the app's value through tangible benefits. Encouraging ongoing user engagement is also necessary part of the strategy and involves continuous efforts to stimulate adoption and to make the app an indispensable tool within the user community.

2.3.4 Privacy and Data Security

Addressing the critical concern of Privacy and Data Security is of great importance for the app's success, particularly considering its involvement in collecting and analyzing sensitive data. The development process demanded meticulous attention to implementing robust measures that shield user data, ensuring compliance with privacy regulations, and establishing a foundation of trust among users. By prioritizing privacy and security, the app not only adheres to ethical standards but also fosters confidence among users, contributing to a resilient and reliable platform.

Throughout the collaborative development of the SOILGUARDIANS app, extensive discussions among the partners have revolved around safeguarding farmers' privacy and preventing the identification of specific land plots. Recognizing the sensitivity of agricultural data, particularly in terms of location, the partners have explored various strategies to address this concern.

One approach under consideration is to provide users with a broader, more generalized area of the data acquisition site instead of pinpointing super-specific locations. By implementing this practice, the app can still deliver valuable insights and recommendations without compromising the privacy and security of individual farmers. This broader spatial representation not only protects the identity of farmers and their lands but also aligns with privacy-preserving principles in data management. These discussions underscore the commitment of the project partners to uphold ethical standards and ensure the responsible use of agricultural data within the SOILGUARDIANS app.

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2.3.5 Validation and Calibration

Ensuring the robustness of the SOILGUARDIANS app involved focusing on validation and calibration processes. Validating the accuracy and reliability of the app's models and algorithms is a fundamental step. This rigorous procedure entailed comparing the predictions and recommendations generated by the app with ground truth data, field observations and established scientific literature. Through this validation, the app can substantiate its efficacy in providing trustworthy insights into soil biodiversity and multifunctionality.

Furthermore, the calibration of the app may become necessary to refine its performance based on real-world feedback. This process involves adjusting and fine-tuning the algorithms to enhance their precision and relevance. The goal is to enable the app to effectively assess, diagnose, and forecast the region-specific status of soil biodiversity and multifunctionality, directly contributing to societal well-being.

2.4 Alpha Version

The alpha version poses a crucial milestone, in which the integrated evidence chains and models were implemented into the SOILGUARDIANS app, along with the benchmarking tool, as shown in Figure 3. This version aimed to provide a rudimentary yet end-to-end proof-of-concept of the Decision Support System (DSS). The initial set of features and functionalities will be made available for testing and evaluation and will thus be shared among the partners.

The alpha version is comprised of the centralised repository with data generated from the project partners and two primary tools for data visualization, i.e. the Benchmarking tool and the NCPs prediction output of the integrated models for specified locations in Europe.

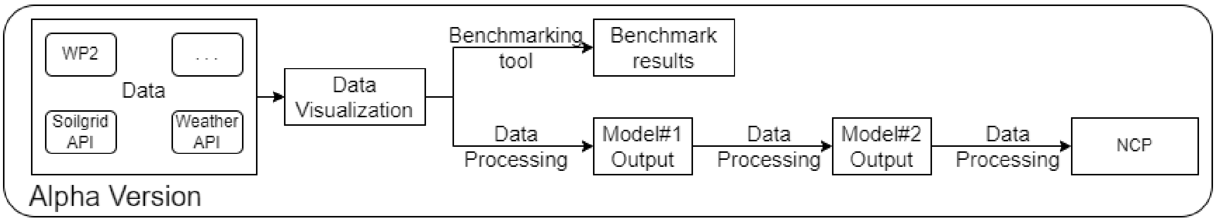

Figure 3. Diagrammatic representation of SOILGUARDIANS app (alpha version).

2.5 User Testing and Feedback

To ensure the usability and effectiveness of the alpha version, SNoK members will be granted access to the alpha version of the application. User testing will be conducted to gather feedback on navigation, services, and overall user experience. The feedback obtained during this phase is going to be instrumental in refining and enhancing the app. More details can be found in Section 8.

2.6 Beta Version

Building on the insights gained from user testing, the beta version development phase will be initiated. This involves addressing identified issues, expanding features and preparing for broader testing. The collaboration with stakeholders and the SNoK will continue to ensure that the app aligned with user expectations.

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2.7 Deployment and Demonstration

Upon the completion of the beta version, the deployment phase is to be initiated. The app will be made accessible to a wider audience (which will be agreed upon with the partners) for demonstration purposes. Stakeholders, including conservation communities and policy makers, are to be engaged to showcase the capabilities and potential impact of the SOILGUARDIANS app.

2.8 Iterative Improvements

Following the evaluation, an iterative improvement process will be implemented. Identified issues and opportunities for enhancement will be addressed through incremental updates. This iterative approach aims at refining the app continuously, based on user feedback, technological advancements, and evolving project requirements.

2.9 Final Version

The final version is going to represent the culmination of the iterative development process. It will incorporate all enhancements, improvements, and features identified through user testing and stakeholder engagement. The final version will serve as a robust and fully-featured tool aligned with the objectives of the SOILGUARD project.

3. Technical Architecture and Components Description

The following deployment diagram (Figure 4) depicts the architecture of the "SOILGUARDIANS app." as deployment (distribution) of software artefacts to deployment targets (nodes). The following distinct sections can be detected:

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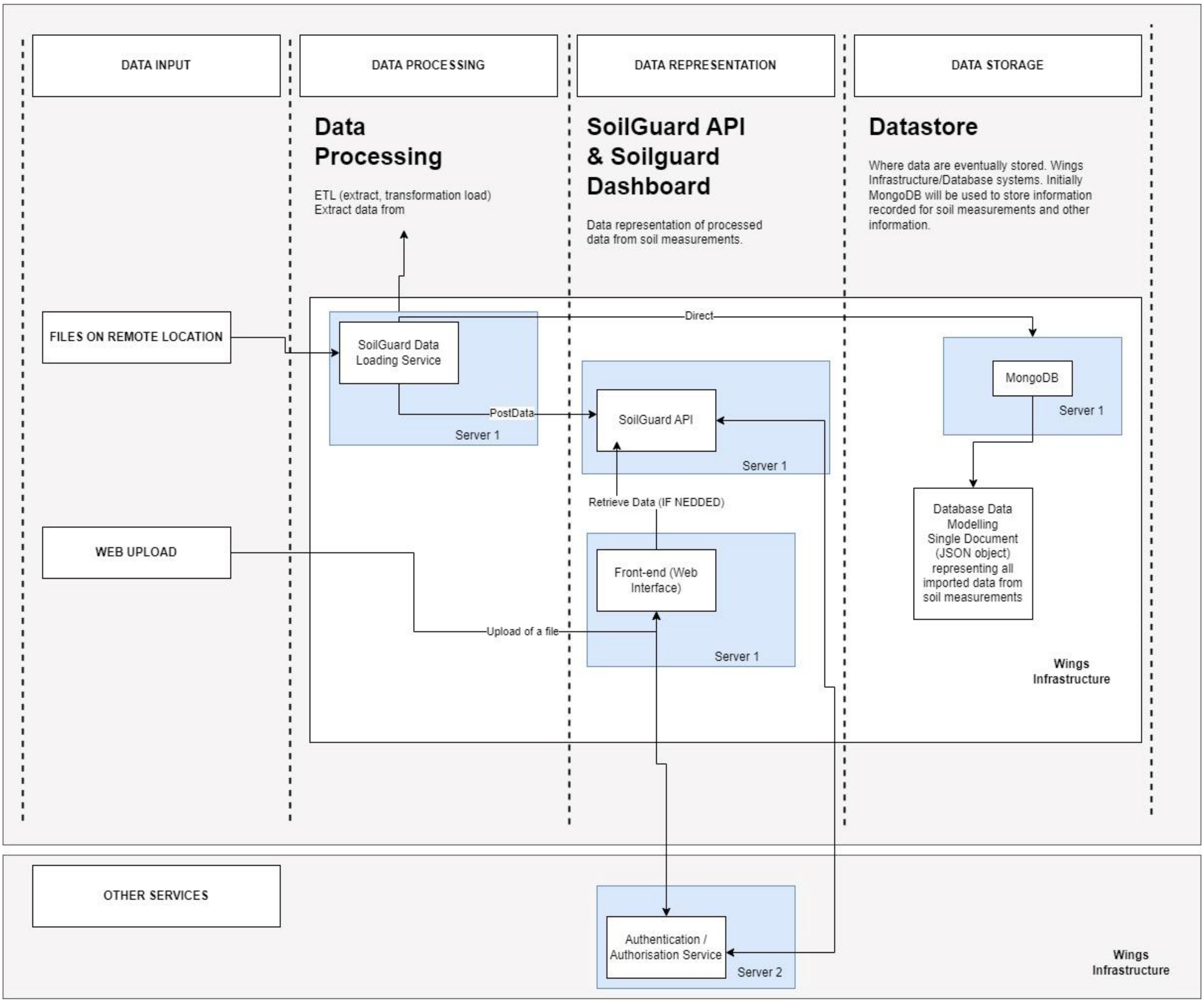

Figure 4. System architecture of the SOILGUARDIANS app.

3.1 Data Input and Processing

The technical architecture of the SOILGUARDIANS app encompasses data input, where users are provided with flexible options. Firstly, there is the capability to upload files from either local or remote locations. This functionality accommodates users who may have their data distributed across different environments. Secondly, a user-friendly front-end interface enables direct web uploads, streamlining the data input process.

Moving to data processing, a critical component is the Extract, Transform, Load (ETL) process facilitated by a dedicated service or software embedded within the application server (SOILGUARDIANS-service). The ETL process is fundamental for the system as it involves extracting data from the source, transforming it if necessary to align with the system's requirements, and subsequently loading it into the database. This process ensures that the data is in the appropriate format and structure, laying the foundation for seamless and

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accurate processing downstream. The incorporation of ETL functionality enhances the efficiency and reliability of the SOILGUARDIANS app by maintaining data integrity and coherence throughout the system.

3.2 Data Access and Representation:

Within the technical architecture of the SOILGUARDIANS app, a pivotal component involves the access of processed and stored data through an Application Programming Interface (API) (Figure 5). This feature ensures that the data can be easily retrieved and interacted with by different parts of the system. The SOILGUARDIANS-service takes a central role in this process, acting as a gateway for accessing the data through the API. By leveraging SOILGUARDIANS API, various components within the system, such as the web server and other services, can efficiently communicate with and retrieve data from the backend (Figure 6). This integration facilitates seamless interactions and collaborations within the system, fostering an environment where different elements can work cohesively to enhance the overall functionality of the SOILGUARDIANS app.

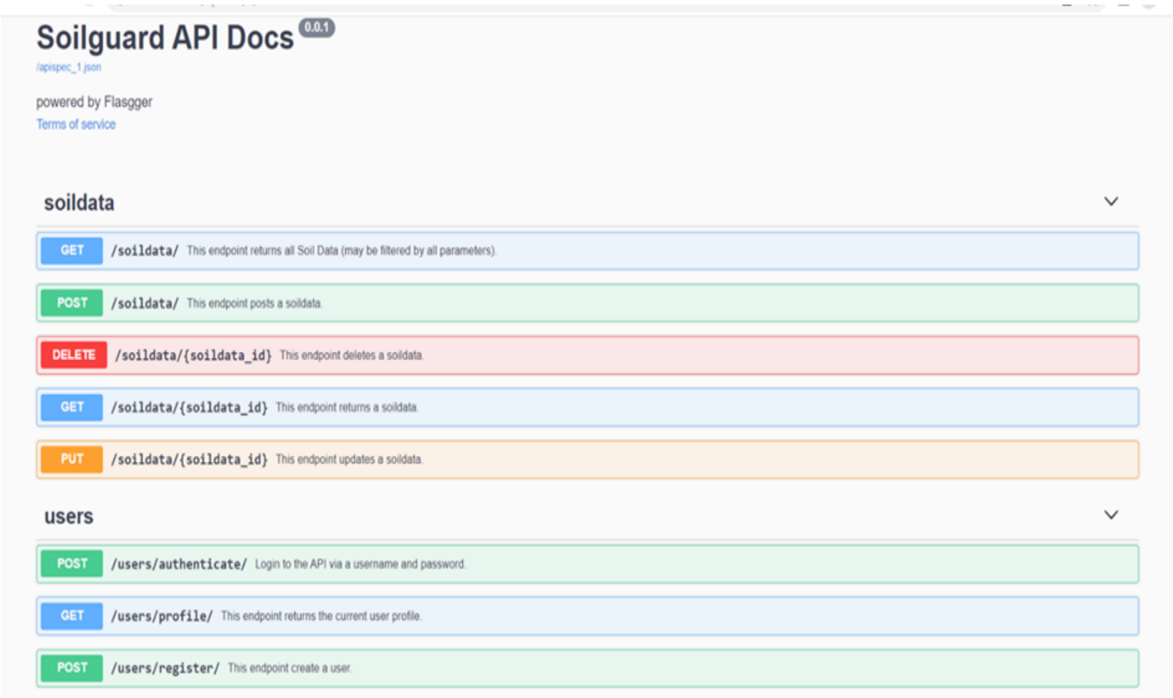

Figure 5. SOILGUARD API. The SOILGUARDIANS-service plays a crucial role in providing access to the data through an API. The API allows other components of the system, including the web server and potentially other services, to interact with and retrieve data from the backend.

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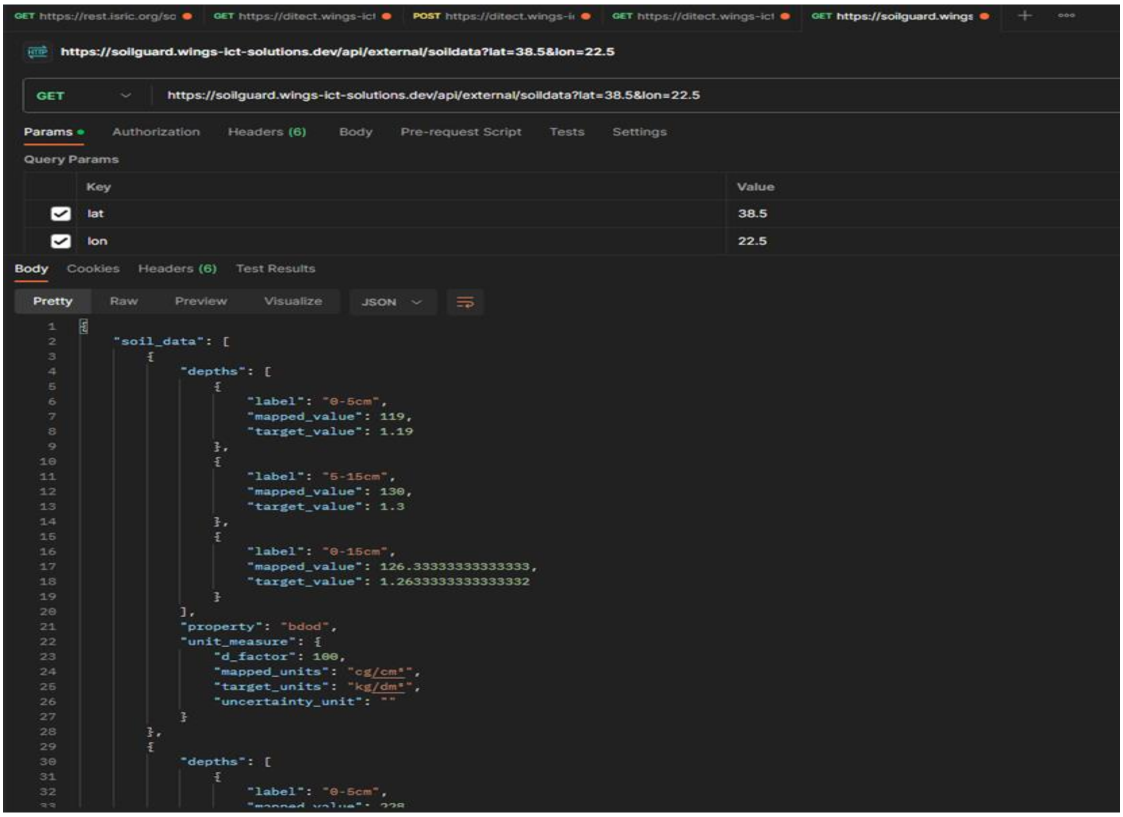

Figure 6. Results output as delivered from the SOILGUARDIANS API.

Additionally, the architectural design incorporates representation of data through a front-end. The front-end dashboard is the user interface, where users can interact with the data. It visually represents the information stored in the system, providing an intuitive and accessible way for users to understand and analyze the data.

Moreover, the dashboard includes a reverse proxy, enhancing communication control, security, and optimization between clients and the SOILGUARDIANS app. The reverse proxy acts as an intermediary between client requests and web servers, providing an extra layer of security. In this setup, the reverse proxy also manages TLS encryption for the communication channel between clients and the server, further ensuring the confidentiality and integrity of the data. This holistic approach, combining data representation through the front-end dashboard and the implementation of a reverse proxy, contributes to a robust and secure infrastructure for the SOILGUARDIANS app.

3.3 Data Storage

In the context of the SOILGUARDIANS app's technical architecture, the data storage component is realized through the implementation of MongoDB, as the chosen database system (Figure 7). MongoDB, a NoSQL database, is selected for its capacity to efficiently store data in flexible, JSON-like documents. This flexibility

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is especially advantageous in handling diverse data types that may be inherent to soil-related information. The decision to use MongoDB aligns with the dynamic nature of the data generated and managed by the app.

MongoDB's structure of storing data within a single document contributes to improved efficiency in both storage and retrieval processes. This design choice facilitates streamlined interactions with the database, allowing for swift access to relevant information. By leveraging MongoDB's document-oriented approach, the SOILGUARDIANS app can effectively manage the varied and complex data associated with soil biodiversity, NCPs, and sustainable soil management practices. This strategic use of MongoDB as the datastore enhances the app's overall performance, scalability, and adaptability to the dynamic requirements of soil-related data management.

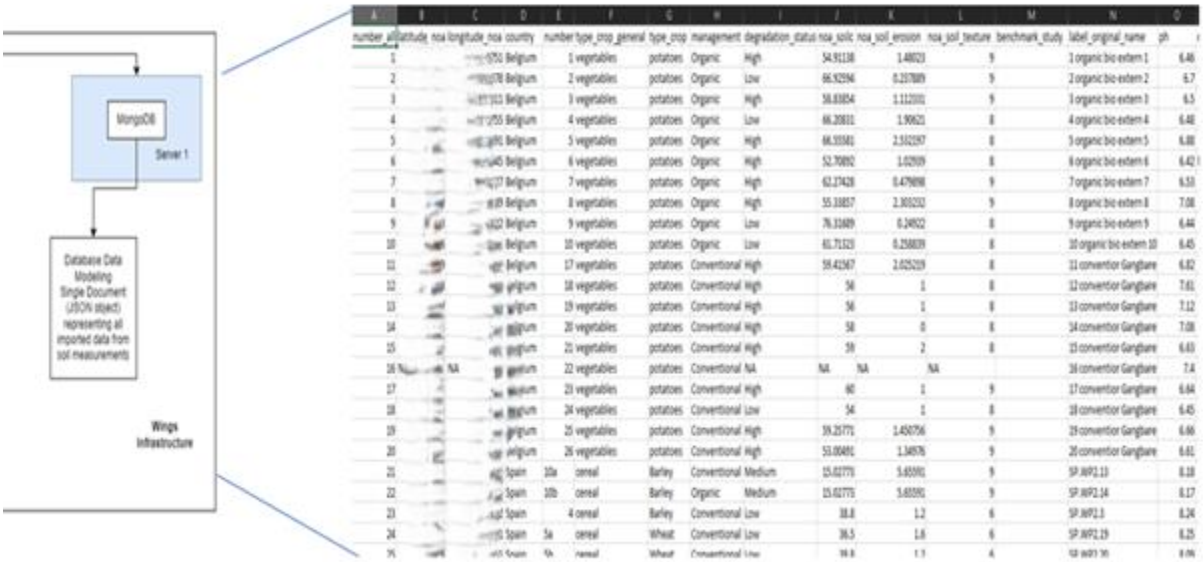

Figure 7. Visual representation of the operation of MongoDB for WP2 datasets. Longitude and latitude have been blurred because of data privacy.

3.4 Authentication/Authorization Service:

Within the SOILGUARDIANS app's technical architecture, the Authentication/Authorization Service is a critical component ensuring secure access and identity management. The Identity and Access Management system (IAM) or IdM (Identity Management) framework serves as the backbone for authenticating user identities and managing their privileges. This includes verifying access permissions for files, networks and other resources based on user requests. IAM systems, including the chosen solution Keycloak, provide administrators with tools to dynamically adjust user roles and monitor user activities.

Keycloak, an open-source identity and access management solution, is employed to centralize user authentication, allowing users to authenticate once rather than individually with each application. The chosen

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client protocol, OpenID Connect (OIDC), enhances the authentication and authorization processes. OIDC, an extension of OAuth 2.0, enables clients to confirm the End-User's identity based on the Authentication Server's verification. The integration of Json Web Token (JWT) standards further ensures secure data transmission, defining a compact and web-friendly format for identity tokens.

The default Signature Algorithm for JWT tokens is RS256, an asymmetric algorithm using a public/private key pair. This robust security measure aligns with the app's commitment to safeguarding user information. The web server, serving the SOILGUARDIANS UI, establishes communication with the SOILGUARDIANS-service through the HTTP protocol on port 8080. This communication flow ensures that user requests are appropriately processed and handled within a secure and authenticated environment, contributing to the overall integrity and reliability of the SOILGUARDIANS app.

4. Alpha Version Authentication: (Implemented)

To access the alpha version, follow the provided link. By accessing the web page, the user is shown the SOILGUARDIANS welcome page (Figure 8). To access the page's features, click on "sign in" as shown in the picture. Ensure that you have the necessary credentials for authentication or create a new user by selecting the "register" button (Figure 9) and fill your personal information. For demonstration purposes, a tester user was created and shared among the consortium members (Username: soilguard Password: 101000371).

If any authenticating issues are encountered, refer to the technical support.

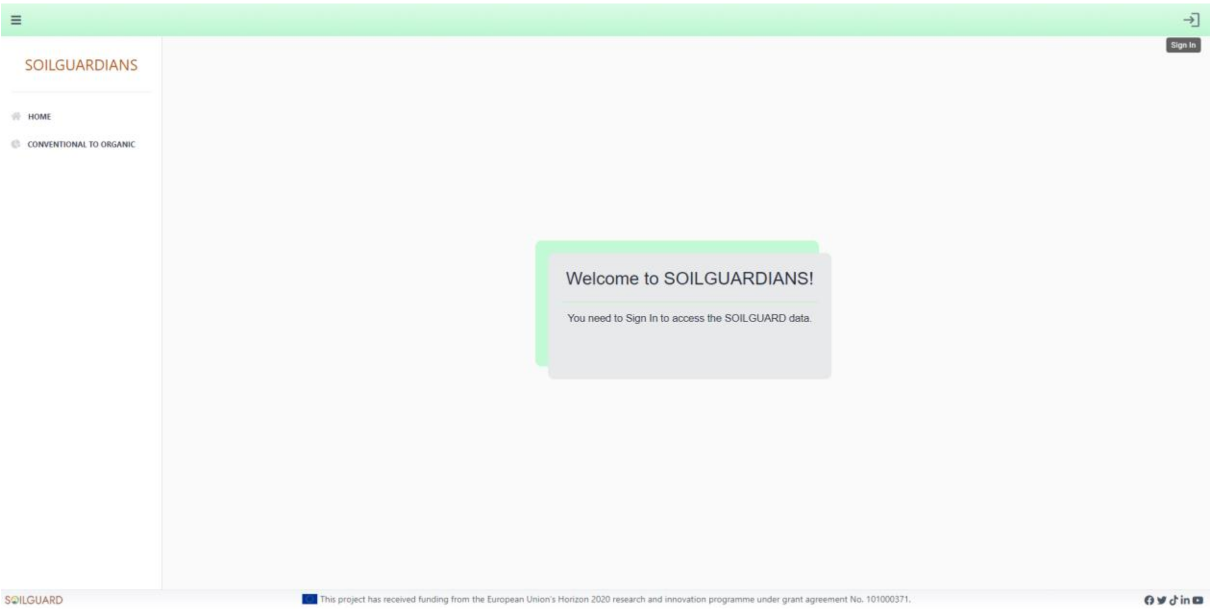

Figure 8. SOILGUARDIANS app (alpha version) welcome page.

The research leading to these results has received funding from the European Union Horizon 2020 Research & Innovation programme under the Grant Agreement no. 101000371.

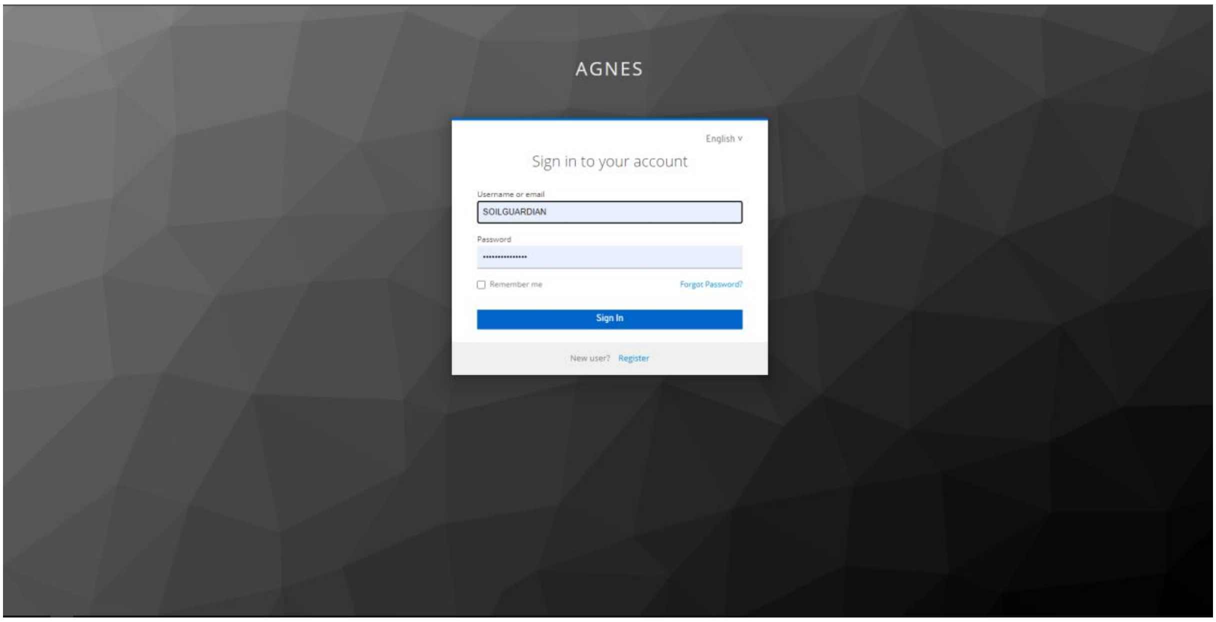

Figure 9. SOILGUARDIANS app (alpha version) log in page

Feature	Status of implementation	Next Steps
Authentication	Implemented	Multi-layered security principle to provide multiple levels and roles of authentication security.

5. SOILGUARDIANS app- Visualization of SOILGUARD Data and Metadata (Implemented)

Upon successful authentication, the user is redirected by default to the datasets and metadata portal (Figure 10). The Datasets and Metadata Portal comprises a centralized repository within the SOILGUARDIANS app, providing users with access to a diverse range of datasets and associated metadata. It serves as a comprehensive resource hub, facilitating informed analysis by allowing users to explore, filter, download, and contribute datasets related to soil biodiversity, NCPs, and human well-being. So far, based on the WP2 datasets, the available filters refer to the Country, the coordinates, the (General) crop type, as well as the Management and Degradation status of the field experiment. More than one filters can be applied at the same time for more specific results. These data will only be available to SOILGUARD project partners upon registration. The rest of the users will not have access to this information as sensitive information (longitude and latitude) is included. There will be a generalization to a regional level (within a specific km of distance) of the data before SOILGUARD data is becoming public.

The research leading to these results has received funding from the European Union Horizon 2020 Research & Innovation programme under the Grant Agreement no. 101000371.

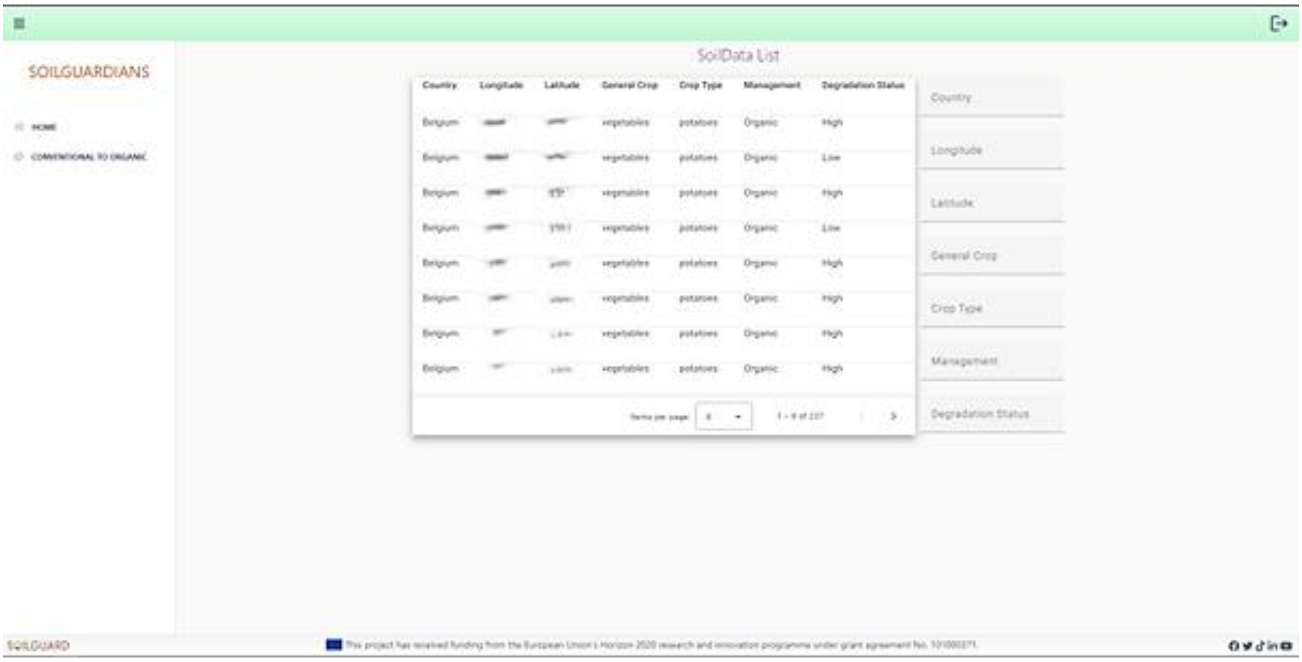

Figure 10. SOILGUARDIANS app (alpha version) datasets and metadata portal. These data will only be available to SOILGUARD project partners upon registration. Longitude and latitude have been blurred because of data privacy.

This feature enhances the app's functionality by promoting transparency and collaboration. Researchers, policymakers, and other stakeholders can seamlessly access relevant data, fostering a data-driven approach to soil management. The inclusion of metadata ensures the contextual understanding of datasets, contributing to the reliability and credibility of information shared within the SOILGUARD community. The database is regularly updated based on the WP2 experiments.

Feature	Status of implementation	Next Steps
Visualization of SOILGUARD Data and Metadata	Implemented	Gather user feedback and refine data visualization features based on suggestions.
		Generalization of geolocation to a regional level (within a specific km of distance) of the SOILGUARD data before it is becoming public.

6. SOILGUARDIANS app – Forum (In development)

The SOILGUARDIANS app will integrate a dynamic Forum, operating on social network principles. This collaborative space will allow users, including members of the Soil Network of Knowledge (SNoK), to engage in discussions, share insights, and exchange knowledge related to Sustainable Soil Management (SSM) and soil biodiversity. The Forum cultivates a participative environment where community members can contribute to the collective understanding of soil-related challenges and solutions. The Forum feature promotes community-driven learning and knowledge exchange. It fosters a sense of "belonging" and encourages active participation. This interactive space is crucial for the co-creation of knowledge, aligning

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with the project's collaborative objectives. Additionally, it enhances communication among diverse stakeholders, including researchers, practitioners and policymakers.

In Figure 11 there is a representation of how the forum tab looks like in the SOILGUARDIANS app, including the following suggested domains:

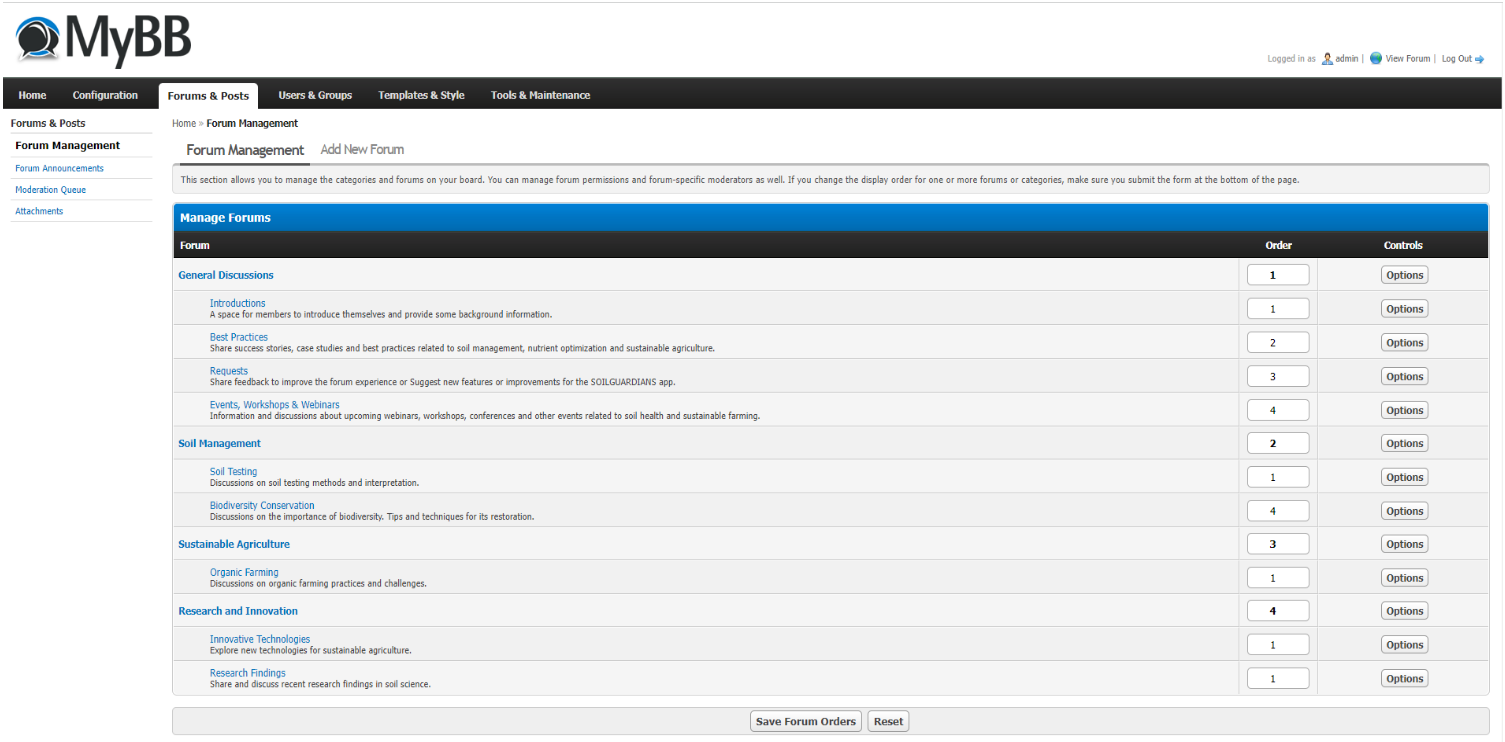

Figure 11. Forum of the SOILGUARDIANS app

1. **Welcome and Introduction:**
   - **Announcements:** Official updates and announcements from the SOILGUARD project team.
   - **Introductions:** A space for members to introduce themselves and provide some background information.
2. **General Discussions:**
   - **Soil Health and Fertility:** Discussions on various soil-related topics, including soil quality, nutrient management, soil erosion, and organic matter.
   - **Sustainable Agriculture:** Discussions on sustainable farming practices, agroecology, crop rotation, and soil conservation techniques.
   - **Sensor Technologies:** Discussions on different types of soil sensors, their applications, data collection, and interpretation methods.

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- **Data Analysis and Modeling:** Discussions on data analysis techniques, predictive modeling, and algorithms used in soil assessment and monitoring.
- **Field Trials and Case Studies:** Discussions and sharing of experiences related to implementing soil assessment technologies in real-world agricultural settings.
- **Policy and Regulations:** Discussions on policies, regulations, and initiatives related to soil management and sustainable agriculture.

3. **Technical Support:**
    - **Sensor Setup and Troubleshooting:** Questions, tips, and troubleshooting related to setting up and calibrating soil sensors.
    - **Data Interpretation and Analysis:** Support and guidance on interpreting sensor data, analyzing soil health indicators, and making informed decisions.
    - **Platform Usage:** Support and assistance for using the SOILGUARD platform or any other associated tools.
4. **Resources and Knowledge Sharing:**
    - **Research Papers and Publications:** Sharing and discussions of relevant research papers, articles, and publications related to soil assessment, monitoring, and sustainable agriculture.
    - **Webinars and Events:** Information and discussions about upcoming webinars, workshops, conferences, and other events related to soil health and sustainable farming.
    - **Best Practices and Success Stories:** Sharing success stories, case studies, and best practices related to soil management, nutrient optimization, and sustainable agriculture.
5. **Collaboration and Networking:**
    - **Collaboration Opportunities:** Discussion on potential collaborations, research partnerships, and funding opportunities related to soil assessment and sustainable agriculture.
    - **Job Postings and Career Opportunities:** Sharing job postings, internships, and career opportunities in the field of soil science and sustainable agriculture.
    - **Networking:** A space for members to connect, network, and exchange ideas and experiences.

Feature	Status of implementation	Next Steps
Forum	In development	Complete development and implement user feedback from beta testers.
		SOILGUARD partners to provide the forum with content.
		Make the forum public.

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7. SOILGUARDIANS app – Region-Specific Soil Management (Implemented)

The SOILGUARDIANS app stands as a combination of advanced environmental science and digital innovation, committed to advancing Sustainable Soil Management (SSM) and biodiversity conservation. With a robust technical architecture, the app seamlessly integrates diverse features designed to provide users with comprehensive insights into soil ecosystems. The app systematically acquires soil-related data from various sources through APIs, ensuring the latest and diverse information for nuanced decision-making. Its modeling capabilities utilize Generalized Additive Models (GAMs) for predicting taxonomic responses to environmental changes and Random Forest Models for linking taxonomic changes to functional potential. A transformative aspect is the app's ability to assess the environmental, economic, and social costs of soil management practices, aligning with global initiatives valuing nature and NCPs. Integration of gene functional mapping and predictions related to Nature's Contributions to People (NCPs) offers a holistic view. Benchmarking allows users to analyze soil properties for a user-specified location against typical soil values, aiding in identifying best practices and understanding the typicality of soil properties at a location compared to elsewhere in Europe.

7.1 Data Acquisition

The second tab is dedicated to the data acquisition component of the Region-Specific Soil Management feature and involves the systematic gathering of soil-related data from diverse sources. The user can select the area of his/her interest on the integrated map and retrieve valuable information for the region-specific climate or soil properties (Figure 12). This information is retrieved mainly from external sources to allow upscaling of relationships derived using data collected in SOILGUARD project from various sensors and experiments, but also external sources, such as the eleven different soil properties (Table 1. Soil properties returned from SoilGrid data for different depths) from open SoilGrids data (SoilGrids250m v2) and climate data from weatherapi, both extracted through APIs. The aim is to provide up-to-date and comprehensive information for effective decision-making (Figure 13). SOILGRIDS was selected based on the requirement to create an app that works anywhere in the European landscape, therefore requiring external datasets. After the review of multiple products such as JRC’s LUCAS 2009, and EcoDataCube we decided that SOILGRIDS was the most appropriate option. Although some individual user locations are likely to be different from mapped / modelled spatial datasets, SOIGUARDIANS app will allow the user to correct or provide their own input data for certain soil parameters.

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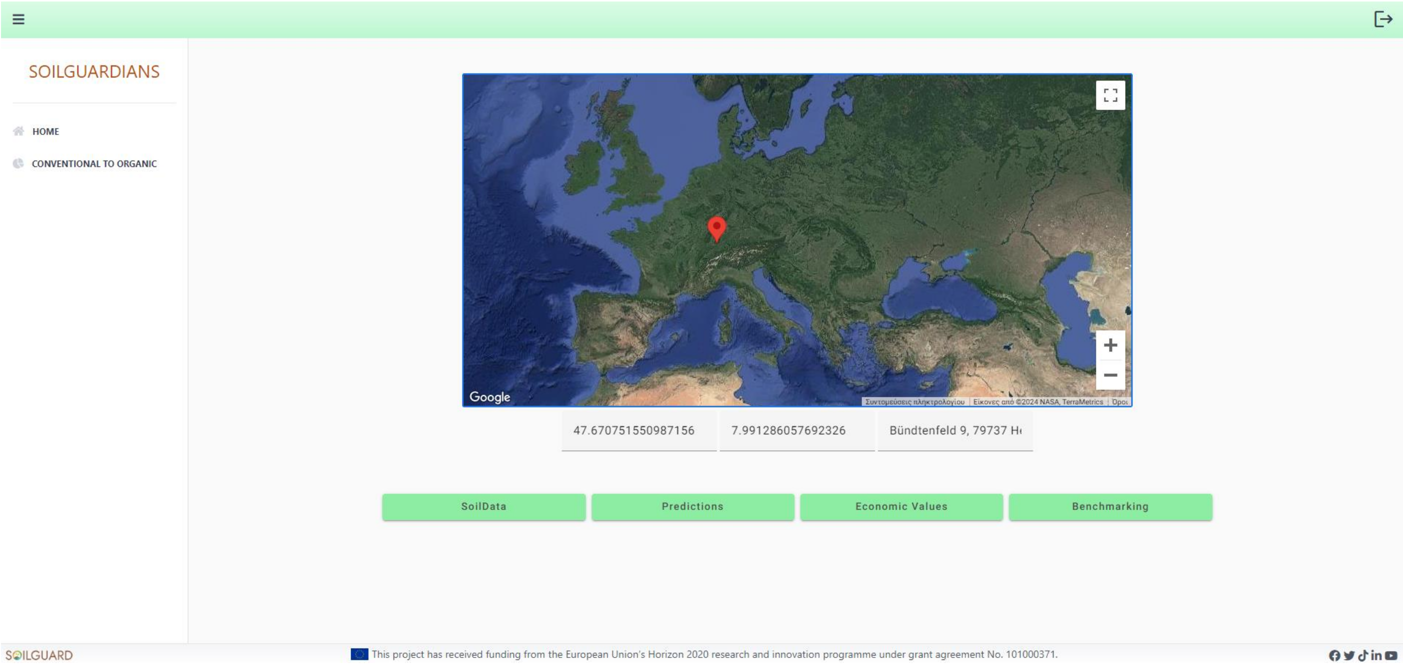

Figure 12. SOILGUARDIANS app (alpha version) region specific soil management feature. The user can select the area of his/her interest on the integrated map. A pin shows up in the area where the user clicked.

Table 1. Soil properties returned from SoilGrid data for different depths.

Name	Description	Mapped units	Conversion factor	Conventional units
bdod	Bulk density of the fine earth fraction	cg/cm^3	100	kg/dm^3
cec	Cation Exchange Capacity of the soil	mmol(c)/kg	10	cmol(c)/kg
cfvo	Volumetric fraction of coarse fragments (> 2 mm)	cm3/dm3 (vol‰)	10	cm3/100cm3 (vol%)
clay	Proportion of clay particles (< 0.002 mm) in the fine earth fraction	g/kg	10	g/100g (%)
nitrogen	Total nitrogen (N)	cg/kg	100	g/kg
phh2o	Soil pH	pHx10	10	pH
sand	Proportion of sand particles (> 0.05 mm) in the fine earth fraction	g/kg	10	g/100g (%)
silt	Proportion of silt particles (≥ 0.002 mm and ≤ 0.05 mm) in the fine earth fraction	g/kg	10	g/100g (%)

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soc	Soil organic carbon content in the fine earth fraction	dg/kg	10	g/kg
ocd	Organic carbon density	hg/m³	10	kg/m³
ocs	Organic carbon stocks	t/ha	10	kg/m²

Data acquisition is foundational to the app's functionality, ensuring that decision-makers have access to the latest and most relevant information. The different data sources enhance the app's responsiveness to dynamic changes in soil conditions, climate, and management practices and can be further normalised and used by the incorporated models. This feature aligns with the project's goal of promoting sustainable soil management based on current and accurate data.

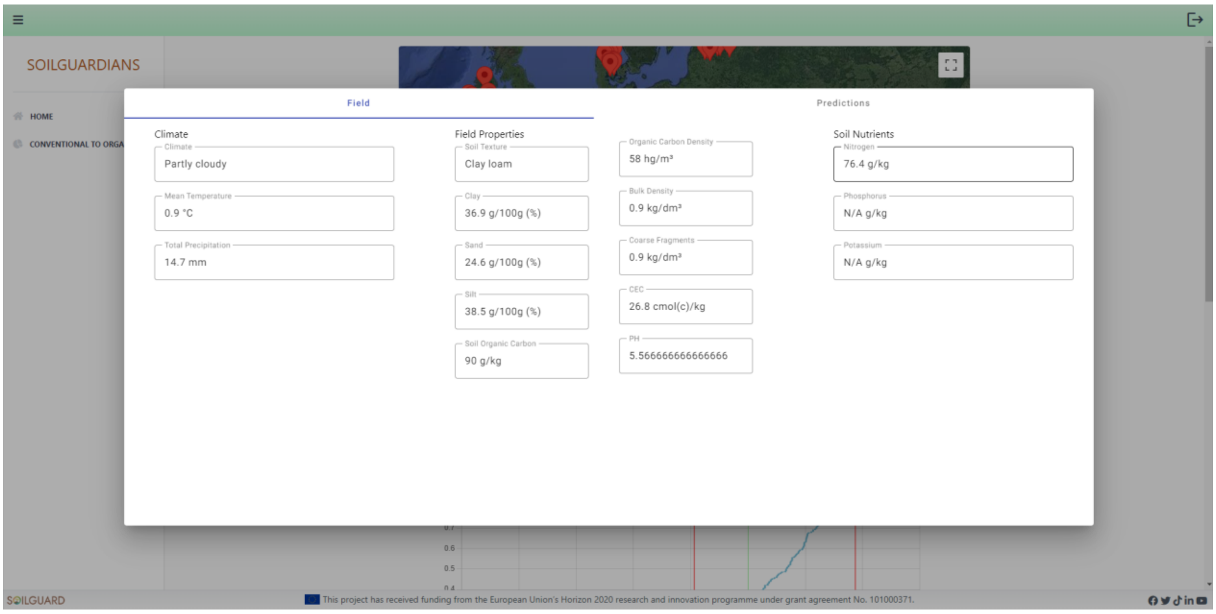

Figure 13. Region specific soil properties gathered from diverse soil-related data sources.

Feature	Status of Implementation	Next Steps
Data Acquisition	Implemented	Expand data sources and improve data integration with external APIs such as soils data, climate data, and separately processed data on potential crop yield
		The user will be able to correct or provide own input data for certain soil parameters.

7.2 Benchmarking

The Benchmarking feature within Region-Specific Soil Management involves the comparative analysis of soil management practices and outcomes. This service can be accessed by the user after selecting a specific location on the integrated map and selecting "Benchmark". So far, users can compare basic soil properties of a selected location against European data, towards fostering a data-driven approach to decision-making. Moreover, benchmarking enables users to assess how different soil management strategies perform in

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comparison to well-defined benchmarks. This information is crucial for identifying best practices. So far, the benchmarking feature gives the user an insight of how typical the three given soil properties (pH, Soil Carbon and Bulk Density) are for the selected location, compared to rest of Europe soil types (Figure 14). This service was designed based on the most recent EU – wide survey of soils (LUCAS 2018).

Benchmarking adds a critical evaluative dimension to the app, empowering users to make informed choices based on the comparative performance of soil management strategies. This feature supports evidence-based decision-making by providing a reference point for assessing the effectiveness of interventions. It contributes to the overall goal of promoting sustainable practices by identifying and promoting best-performing strategies. Benchmarking is seamlessly integrated with the Decision Support System (DSS), providing users with practical insights for optimizing soil management strategies.

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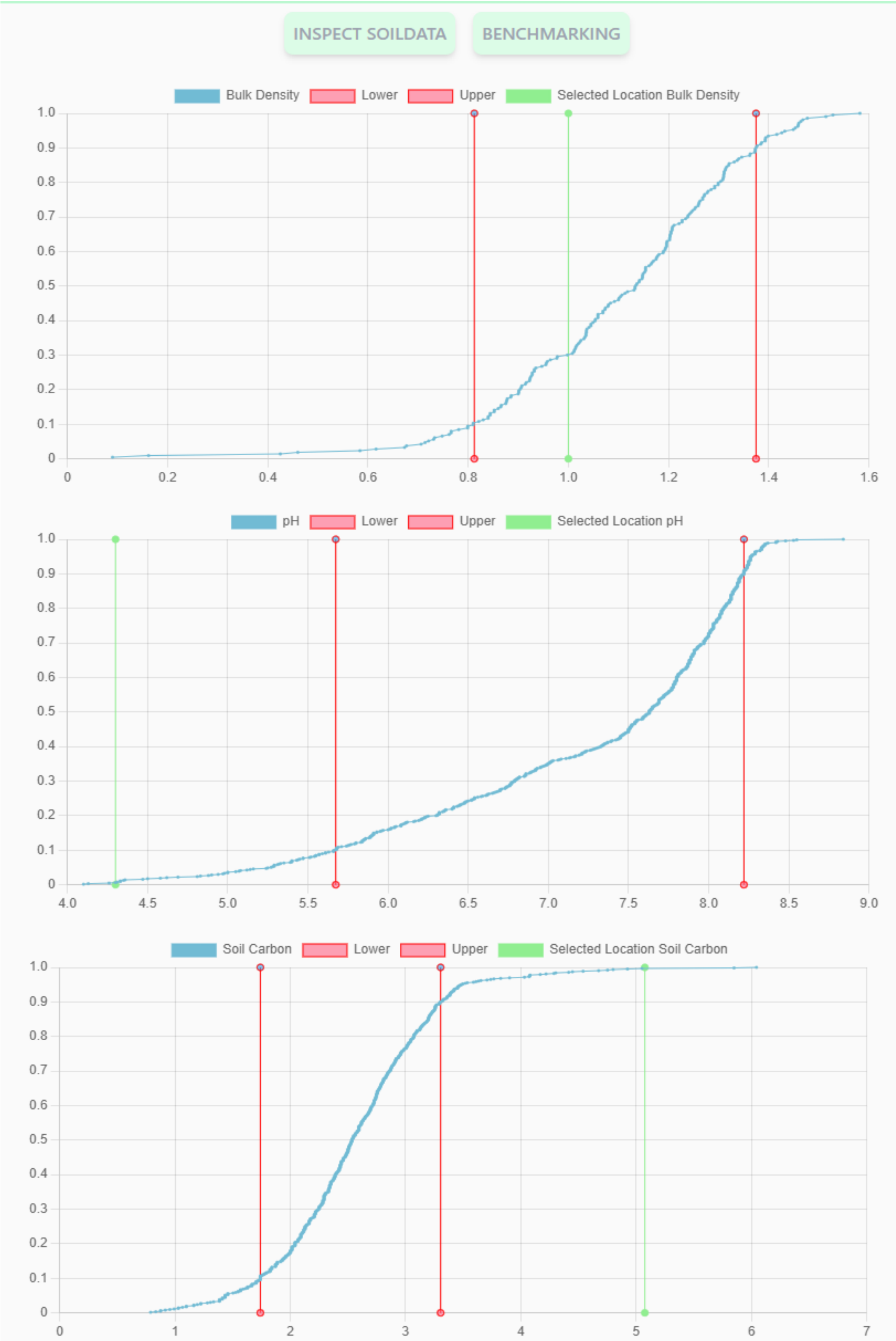

Figure 14. Region specific benchmarking soil properties compared to similar land types in Europe.

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Feature	Status of Implementation	Next Steps
Benchmarking	Implemented	Refine the benchmarking algorithm for European datasets.

7.3 Evidence chains and Models

Evidence Chains and Models within the SOILGUARDIANS app are designed to formalize the causal relationships between soil biodiversity, NCPs, and human well-being. These are represented as directed graphs, illustrating the intricate connections between various nodes. The models provide a structured framework for understanding the impact of environmental stressors, management strategies, and policy interventions.

This feature contributes to the scientific rigor of the app by integrating evidence-based models. It allows users to visualize and comprehend the complex relationships within soil ecosystems. The inclusion of evidence chains enhances the app's predictive capabilities, providing stakeholders with insights into the potential consequences of different interventions on soil-mediated ES and human well-being. So far, two models are incorporated in the SOILGUARDIANS app, predicting microbial communities based on relevant soil data from the gridded datasets and the second model predicting functional genes from the predicted microbial community (Figure 15). Together, these allow representation of key soil functions relating to nutrient and carbon cycling, as well as properties around disease regulation and infiltration.

Regarding the modelling of taxonomic response to environmental change The SOILGUARDIANS app utilizes Generalized Additive Models (GAMs) to establish a proof of concept for its predictive capabilities. The models were developed by UKCEH using the Countryside Survey (CS) dataset, a UK distributed soil survey comprising 1000 soil samples across diverse habitats. The GAM approach was chosen for its interpretability in an ecological context, and its visualizations enable a nuanced understanding of specific niche preferences. GAMs were built on the Operational Taxonomic Unit (OTU) level using 16S data.

The modelling process has been already described in deliverable 5.1 and it includes the following steps:

1. **Data Preprocessing:** Samples with less than 5000 reads and OTUs with a prevalence of less than 30 samples were discarded. This ensures the quality of the data used in the modeling process.
2. **Model Generation:** The R mgcv package was employed to fit GAM distributions for the top 1000 most dominant taxa. Smooth functions of pH and LOI, along with an interaction term, were used as predictors of rarefied OTU abundance. The negative binomial family was chosen, and restricted maximum likelihood (REML) was selected for parameter smoothing estimation.
3. **Validation:** Initial validation was performed by splitting the CS data into training and test subsets (40% and 60%, respectively). Once the viability of GAMs was established, models were rerun on the complete CS dataset and further validated with independent data.
4. **Ongoing Refinements:** The modeling approach is continuously refined. Current efforts involve incorporating climate variables as additional predictors and translating the approach to leverage Soilguard and LUCAS data, enhancing the robustness and applicability of the models.

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Within the SOILGUARDIANS app, Random Forest Models play a crucial role in linking context-specific changes in taxonomic communities to functional potential. This integration aims to enhance the understanding of the functional aspects of soil ecosystems, contributing to the app's comprehensive analysis of soil biodiversity and NCPs. The modelling relationships between organism abundance and gene functional potential has been extensively described in deliverable 5.1 and it includes the following steps:

1. **Proof of Concept:**
    - **Dataset Selection:** Utilization of the Countryside Survey (CS) dataset, a UK distributed soil survey.
    - **GAM Modeling:** Generation of Generalized Additive Models (GAMs) on the Operational Taxonomic Unit (OTU) level using 16S data.
    - **Training and Testing:** Initial validation with a split of CS data into training and test subsets.
2. **Linking Taxonomy to Function:**
    - **Model Expansion:** Extending the modeling approach to link taxonomic information to functional potential.
    - **Random Forest Models:** Generation of Random Forest Models predicting functional genes from bacterial taxonomic composition.
3. **Data Preprocessing:**
    - **Normalization:** Rarefying metagenome read numbers to the lowest read number across all samples.
    - **Gene Filtering:** Discarding genes not present in at least 30 samples.
    - **Amplicon Data Processing:** Removing samples with a read number of <5000 and rarefying to the lowest read number across sites.
    - **OTU Filtering:** Retaining only UGRASS OTUs with a >=97% hit to the GAM modeled CS OTUs.
4. **Model Generation:**
    - **Training and Test Subset:** Randomly splitting UGRASS data into training and test subsets (75%/25% split).
    - **Predictor-Response Setup:** Generating random forest regression models per gene with rarefied gene abundance as the response variable and observed 16S taxa as predictors.
5. **Model Validation:**
    - **Prediction Sets:** Generating two sets of functional gene predictions on the test subset of the UGRASS data.
    - **Performance Assessment:** Evaluating the performance of random forest models at the community and gene levels.
        - Using the VegDist function to assess sample similarity.

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   - Correlating sample distances within observed and predicted data using the mantel test statistic.

6. **Incorporation into SOILGUARDIANS:**

   - **Functional Insight:** Bringing a functional genomics perspective to the app, connecting taxonomic information to the potential functional capabilities of the soil microbiome.
   - **Operationalized Evidence Chains:** Ensuring seamless chaining of GAM models and Random Forest Models for an integrated analytical framework within the app.
   - **Recalibrating relationships with Soilguard and European data:** Re-calculating and updating the equations initially tested on UK datasets to instead run and be valid for European data, including adding a climate-component to increase the regional accuracy, and allow predictions for future climate conditions.
   - **Validation for Reliability:** Conducting a robust validation process to ensure the reliability of functional predictions.

file_gene_name	original_gene_name	10%ile	90%ile	Median
"phi-Carotenoid synthase" (EC 1.3.-.- and EC 2.1.1-)	"phi-Carotenoid synthase" (EC 1.3.-.- and EC 2.1.1-)	17.8262	66.29362667	30.69653333
(3R)-hydroxymyristoyl-[ACP] dehydratase (EC 4.2.1.-)	(3R)-hydroxymyristoyl-[ACP] dehydratase (EC 4.2.1.-)	8.817626667	13.486	9.870966667
(3R)-hydroxymyristoyl-[acyl carrier protein] dehydratase (EC 4.2.1.-)	(3R)-hydroxymyristoyl-[acyl carrier protein] dehydratase (EC 4.2.1.-)	1075.91948	1172.945633	1129.0099
(GlcNAc)2 ABC transporter, ATP-binding component 1	(GlcNAc)2 ABC transporter, ATP-binding component 1	28.89248667	68.67513333	44.79496667
(GlcNAc)2 ABC transporter, ATP-binding component 2	(GlcNAc)2 ABC transporter, ATP-binding component 2	8.213766667	29.64599333	21.47476667
(GlcNAc)2 ABC transporter, periplasmic substrate-binding protein	(GlcNAc)2 ABC transporter, periplasmic substrate-binding protein	15.73570667	38.95842	24.2714
(GlcNAc)2 ABC transporter, permease component 1	(GlcNAc)2 ABC transporter, permease component 1	17.11048667	38.90614667	29.39873333
(GlcNAc)2 ABC transporter, permease component 2	(GlcNAc)2 ABC transporter, permease component 2	24.41311333	86.11978667	48.187
(Pyruvate) Oxoisovalerate Dehydrogenase Alpha & Beta Fusion like	(Pyruvate) Oxoisovalerate Dehydrogenase Alpha & Beta Fusion like	17.85859333	38.15675333	20.38183333

original_gene_name	file_gene_name	Interim_relevance_code	Carbon_cycling	Nitrogen_cycling	Phosphorus_cycling	Heat_Osmotic_Stress	Virulence	Phages
Acetyl-CoA acetyltransferase (EC 2.3.1.9)	Acetyl-CoA acetyltransferase (EC 2.3.1.9)	1	1	0	0	0	1	0
Cytochrome c heme lyase subunit CcmF	Cytochrome c heme lyase subunit CcmF	1	1	0	0	0	1	0
Cytochrome c heme lyase subunit CcmH	Cytochrome c heme lyase subunit CcmH	1	1	0	0	0	1	0
formate dehydrogenase formation protein FdhE	formate dehydrogenase formation protein FdhE	1	1	0	0	0	1	0
Formate dehydrogenase O alpha subunit (EC 1.2.1.2)	Formate dehydrogenase O alpha subunit (EC 1.2.1.2)	1	1	0	0	0	1	0
Formate dehydrogenase O beta subunit (EC 1.2.1.2)	Formate dehydrogenase O beta subunit (EC 1.2.1.2)	1	1	0	0	0	1	0
Formate dehydrogenase O gamma subunit (EC 1.2.1.2)	Formate dehydrogenase O gamma subunit (EC 1.2.1.2)	1	1	0	0	0	1	0
Glycerol kinase (EC 2.7.1.30)	Glycerol kinase (EC 2.7.1.30)	1	1	0	0	0	1	0

Figure 15. Example outputs of GAMs and RFs models.

Feature	Status of Implementation	Next Steps
Evidence Chains and Models	Implemented	Validate models with new datasets and optimize performance for the following models. Carbon (complete); Yield (complete); Water infiltration (in development); Water storage (in development); Nutrient processing (in development); Aesthetic landscapes (in development)
		Integrate WP2 & WP3 outputs as input to evidence chains

7.4 Transforming to NCP

Transforming the evidence chains and models to NCP comprises a feature that facilitates a holistic assessment of the environmental, economic, and social costs associated with soil management practices. This part is crucial as it aligns with the broader goal of evaluating the value of soil-mediated ES and presenting the information in a simple and easy-to-digest form for the end user. So far, model outputs are standardized and

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used to calculate a functional abundance matrix and high-level function score (HLFS), so as to create a positive/negative relationship for the adjusted score and summarize NCP scores in a radar graph, which can be accessed by the user in the second tab of the soil properties (Figure 16).

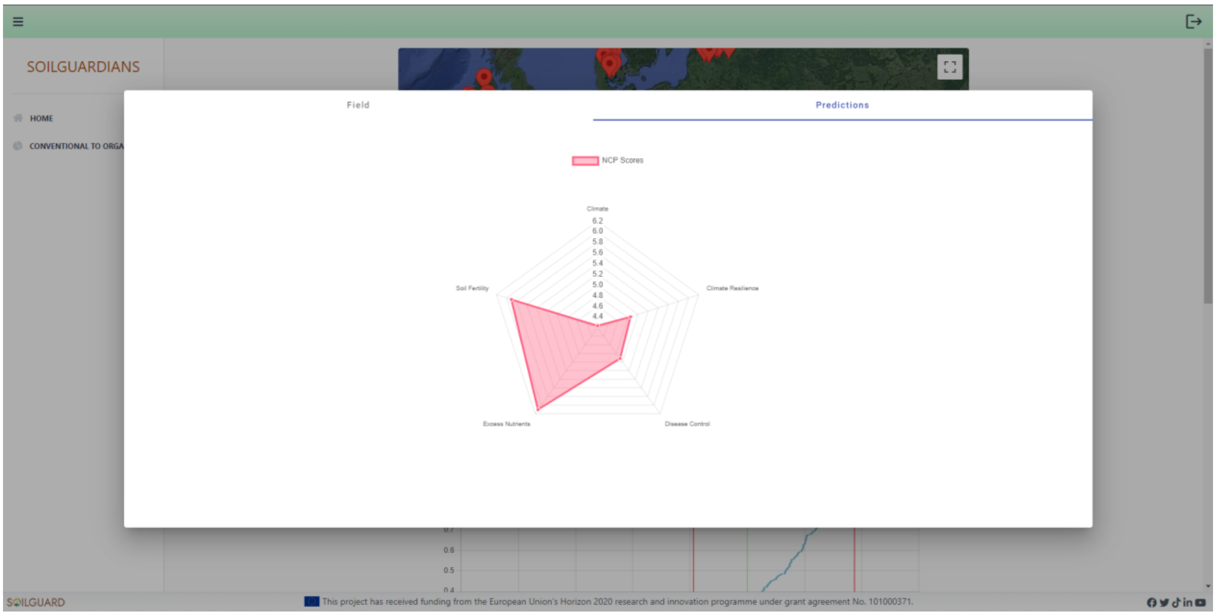

Figure 16. Radar diagram summarizing NCP scores based on region specific soil properties.

The integration of gene functional mapping and Nature's Contributions to People (NCPs) predictions into the SOILGUARDIANS app involves the following key steps, which were described in deliverable 5.1 and developed by UKCEH:

- **Curated gene functional mapping table was developed.** The SEED Subsystem Ontology Database was employed for gene ontology annotations, even though it wasn't specifically curated for environmental research. This involved identifying relevant functional categories like "Nitrogen metabolism," "Phosphorus metabolism," and "Carbohydrates." Using the hierarchical structure of the SEED database, genes were linked to subsystems at different levels, allowing for nuanced interpretations of how functions connect to NCPs.

- **The relevance of genes to SOILGUARD:** This was established by incorporating outputs from the WP5 Value Chains Workshop, refining the workshop table based on connections to soil properties measured in WP2/WP3 and their relevance to NCPs in WP4/WP5.

- **Definition of functional categories:** Categories "Carbon cycling," "Nitrogen cycling," and others were defined, and a gene functional mapping table was created. Ongoing refinement involves exploring level 3 SEED Subsystem annotations for a more detailed mapping of genes to functions.

- **Future refinements:** specific NCPs requiring additional data inputs were addressed. For water infiltration predictions, a study by Robinson et al. (2022) was utilized, providing a response function

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linking soil porosity to soil organic matter content. Predictions were upscaled using European soil maps and WP2 data characterizing soil properties.

This integration into the SOILGUARDIANS app involves the representation of NCP predictions, including water infiltration, offering a comprehensive assessment of Nature's Contributions to People. The heat/osmotic stress function was acknowledged as currently out of scope for the app.

Transforming evidence chains to NCP also aligns with global initiatives focused on valuing nature and NCPs. This feature provides a standardized framework for assessing the impact of soil management and enhances the app's utility by offering a common language that resonates with broader sustainability and conservation agendas.

Feature	Status of Implementation	Next Steps
Transforming to NCP (Nature's Contributions to People)	Implemented	Continue refining NCP calculations and integrate additional ecosystem services. Progress so far on valuation is: Carbon (complete); Yield (complete); Water infiltration (not possible to value); Water storage (in development); Nutrient processing (in development); Aesthetic landscapes (in development)
		Transforming the NCP calculations to tailored recommendations for soil management based on region-specific data.

7.5 Access to SOILGUARDIANS app (Alpha Version)

Accessing the alpha version of the SOILGUARDIANS app is a straightforward process designed to involve users in the initial testing phase. To explore the features and functionalities of the alpha version, simply follow https://soilguard.wings-ict-solutions.dev/. This link will direct you to the dedicated platform where you can engage with the app, navigating through sections and tools.

Feature	Status of Implementation	Next Steps
Access to SOILGUARDIANS App (Alpha Version)	Implemented	Collect user feedback, resolve issues and prepare for beta version release.

8. First Feedback from a User Perspective

The First Feedback feature is a crucial component designed to gather initial user perspectives on the SOILGUARDIANS app. It involves gathering feedback from users, especially members of the Soil Network of Knowledge (SNoK), who engage with the app's alpha version. This process aims to capture user experiences, preferences, and insights to refine and enhance the app's usability and functionality.

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Anticipating first feedback is a proactive strategy to ensure user-centric design and functionality. By seeking input from users early in the development process, the project team can address potential usability issues, improve navigation, and enhance overall user satisfaction. This feature aligns with principles of participatory design, where end-users play a crucial role in shaping the final product. The iterative nature of receiving user feedback ensures that the app evolves based on real-world usage, contributing to its effectiveness and relevance.

The feedback received during the periodic meeting in Athens from 6/6 to 8/6 (M24) and during SOILGUARD 30CM revealed valuable insights for the app's improvement. Discussions included examining possible ways of integrating biodiversity into the app's framework, addressing multilingual challenges in the app's features, as well as incorporating easily identifiable indicators for farmers. The importance of a user-friendly menu explaining complex soil components and providing interactive elements, such as games, to enhance user familiarity with microorganism-related terms was also explored. Discussions also emphasized the need to link the app with external pages, offering both basic and in-depth information and adding layers of progress to the analysis. The importance of incorporating videos to explain complex terminology was highlighted. Participants discussed the need for benchmarks, reliability measures and practical recommendations for farmers and policymakers. Different perspectives were shared on determining suitable buffer zones, considering factors like country-specific characteristics, resolution, and data aggregation. Most importantly, the need to protect the privacy of the data owner for either personal or business perspective, e.g., by not revealing the location for data collected under Soilguard and shown (or able to be interrogated) within the app, was highlighted (more details can be found in section 2.3.4). Overall, the feedback emphasized the necessity of addressing diverse user backgrounds, simplifying complex concepts, and providing practical, region-specific insights.

In the near future, the improved version of the app (beta version) will be facilitated through WP1- SNoK, and involve an iterative co-creation process with various stakeholders. This approach will allow for ongoing discussions and collaboration to refine the SOILGUARDIANS app. The involvement of different stakeholders ensures a diverse range of perspectives and insights are considered, contributing to the enhancement of the app's features and functionality. This collaborative effort aims to create a more robust and effective tool, meeting the diverse requirements of users and providing practical, region- specific solutions.

9. Conclusions – Next Steps

The SOILGUARDIANS app. alpha version comprises a piece of software made available for the partners before the general release of the application. It forms the foundation for a robust and user-friendly tool that will contribute to the assessment and prediction of soil-mediated Nature Contributions to People and human wellbeing. The insights that will be gained from the alpha version implementation and user feedback, will be used as a guideline for the future development of the beta version. The continuous development and integration approach will be maintained, with a focus on refining and expanding the capabilities of the SOILGUARDIANS app.

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