Systematic review of digital tools

Systematic review of available digital land use decision support tools

MOSAIC

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Table of Contents

List of Figures

List of Tables

Acronyms and abbreviations

AI - Artificial Intelligence

CORDIS - Community Research and Development Information Service

CRAFTY - Competition for Resources between Agent Functional Types

DLE - Digital Learning Environment

DSS - Decision Support System

DST - Decision Support Tools

EnBiLA - Energy and Biodiversity Landscape Assessment

EU - European Union

GIS - Geographic Information System

INBO - Instituut voor Natuur- en Bosonderzoek

ILVO - Flanders Research Institute for Agriculture, Fisheries and Food

ISA - Instituto Superior de Agronomia

KIT - Karlshruher Institut Fuer Tecnhologie

PL - Policy Lab

PRISMA - Preferred Reporting Items for Systematic Reviews and Meta-Analyses

RQ - Research Questions

SLR - Systematic Literature Review

UNL - Universidade Nova de Lisboa

VITO - Vlaamse Instelling voor Technologisch Onderzoek

WoS - Web of Science

WP - Working Package

Introduction

About MOSAIC

For many decades already, the scientific community warns about the detrimental impact of current **land use practices** on biodiversity, soil fertility, water reserves, climate change, to name a few, eroding the safe operating space for humanity on Earth (Rockström et al., 2009; Richardson et al., 2023).

Yet, despite the piles of reports with irrefutable evidence, not much change can be seen on the ground. Facts, figures and scenarios of the future we are heading for appear not to be enough to convince land use decision-makers to make more sustainable choices.

MOSAIC therefore wants to contribute to a better understanding of why this is the case, and, more importantly, contribute to the solutions. To that effect, MOSAIC investigates the **drivers behind land use choices**. Are farmers, business managers, nature conservationists, policy makers and other land use decision-makers **aware** of what is at stake? And what role can they play to find a solution? What kind of land use do they favour and why? What motivates them to go for their choice? How can their decisions be aligned or reconciled with policy targets in the fields of climate change mitigation and adaptation, biodiversity and renewable energy? What **tools and incentives** can help to align these individual land use decisions on the ground with high-level policy targets and international agreements aimed at the conservation of our common home?

To investigate these questions, six **Policy Labs**, comprising a diverse array of decision-makers in Belgium, Denmark, Hungary, Portugal, Switzerland, and a European Lab, are set up as pivotal platforms for MOSAIC's transdisciplinary research. Each one is linked to a specific case of land use decision-making. These Policy Labs help the researchers investigate these questions and allow practitioners to co-create relevant knowledge, so the gained knowledge becomes truly actionable for them.

MOSAIC's modellers will build upon this knowledge about drivers and motivations to characterise expected future land use patterns – an indispensable tool in land use policy processes. Based on spatial, social and economic insights, potential displacement effects can be made visible, as well as evolutions jeopardising European biodiversity, climate and renewable energy goals.

To enable this, the Policy Labs get the support of a **Digital Learning Environment** (DLE) in which MOSAIC bridges the siloes of researchers' and practitioners' worlds. During the project, this environment allows for knowledge transfer, learning, evaluation and collaboration between researchers and practitioners, both within the cases and in cross-case settings. After the project, this learning environment will live on to give answers to the research questions outlined above, questions about the practical implementation of these learnings; and will it function as a source of inspiration for those wanting to render land use more sustainable in other places as well.

This way, MOSAIC will showcase in six cases how policy, science and society can work hand-in-hand on concrete solutions to accelerate the transition towards more sustainable land use.

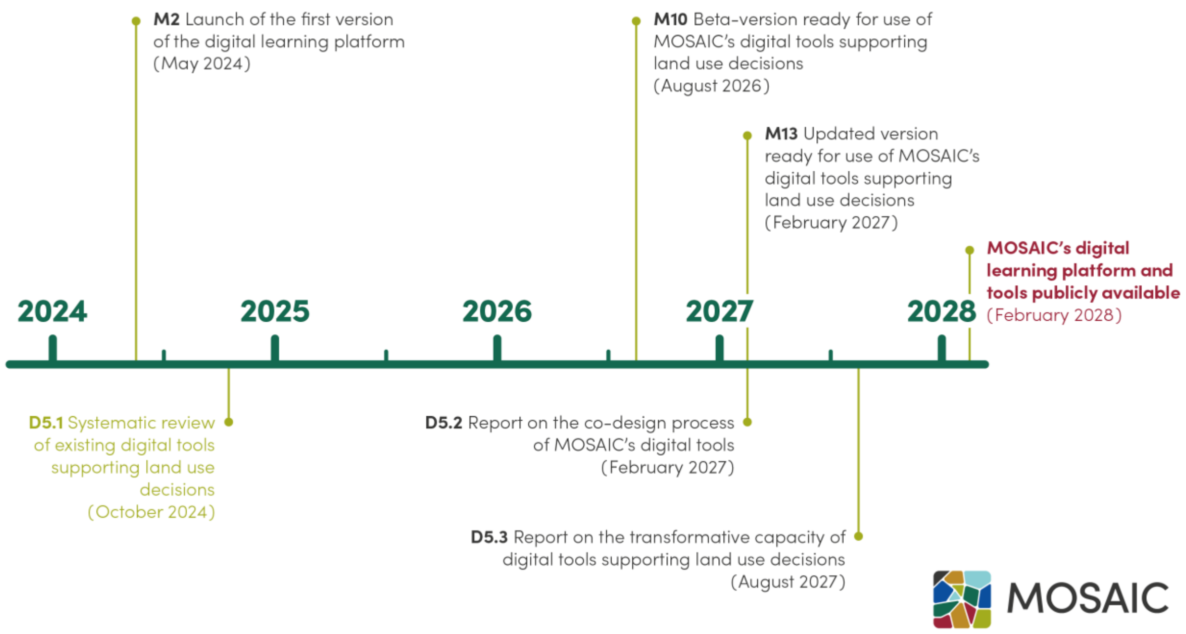
About this report

This report is part of MOSAIC's work package 5 (WP5). The main aim of this work package is to develop a digital learning environment that feeds land use decision makers in a hands-on way with the latest relevant scientific findings, hence making them actionable so they can be readily deployed to influence individual land use decision makers. It comprises digital tools facilitating the integration of local land-use challenges and European sustainability goals.

WP5 will achieve this goal through:

(1) A review of the potentials and limitations of existing digital tools supporting land use change, in order to develop recommendations for increasing their uptake in decision processes. This report gives an overview of this tasks' objectives and main outcomes.
(2) The specification and co-design of various model-based digital tools harnessing the results from MOSAIC's WP3 (research on drivers behind land use decisions) and WP4 (spatial modelling of future land use patterns).
(3) Testing existing and newly developed model-based digital tools in MOSAIC's Policy Labs, so that their role in facilitating the understanding of land use transformations can be critically assessed among diverse types of land use decision makers.

The scheme below gives an overview of the consecutive order of the different milestones and reports leading towards WP5's main outcome, namely a fully operational digital learning platform, including tools that help land use decision makers to merge local spatial challenges with relevant European sustainability objectives. This report, that is Deliverable 5.1, is indicated in green.



SUMMARY

The current report (D5.1) is the outcome of task 5.1 carried out in **Work Package 5 (WP5) - Digital Learning Environment for supporting sustainable land use decisions**. In the last few decades, the emergence of digital technologies has changed the economy's and society's development, leading to new research areas. One of the most recent and relevant is understanding how digital tools can aid in shaping the future by supporting land use decisions and what factors enable their uptake in projects and policy cycles.

In this framework, the present systematic literature review has been conducted to answer the following research questions:

a) What is a digital land use decision support tool, and what are their key features and functionalities?
b) What are the best practices and success factors for developers in designing and deploying digital land use decision support tools?
c) How do users perceive the effectiveness and usability of digital land use Decision Support Tools (DST) in real-world decision-making processes?
d) What are the benefits, advantages, main challenges, and limitations of using these digital tools compared to traditional decision-making methods?

These research questions fit into the overall MOSAIC project in three ways: firstly, to provide novel and relevant theoretical and empirical knowledge in systematising concepts, definitions, and scopes within the digital tools topic related to land use decisions, then contextualising how they can provide contributions within the holistic framework of the MOSAIC Policy labs (WP2), encompassing their core focus in land use decision and involvement of stakeholders.

Secondly, to provide insight for co-creating the digital learning environment (task 5.2) by capturing the perspectives of the developers and users of existing tools, focusing on understanding their embeddedness in their specific contexts and the opportunities for generalisation across multiple geographical contexts and different spatial and temporal scales.

Thirdly, to create a digital portfolio from which digital tools can be selected to experiment with in the real-life Policy Lab and measure changes in motivations and drivers behind land use decisions (Task 5.3).

Adopting the PRISMA 2020 method, described in the **systematic literature review** section**,** led to the identification of 55 digital tools within a universe of databases that covered the CORDIS, Scopus, Web Of Science and other sources**.** In this sense**,** the **results** section presents the digital portfolio in the form of a comprehensive table describing the main characteristics of each tool identified, followed by a quantitative and qualitative description of the review. This section also includes a narrative on a selection of inspiring digital tools for the six policy labs of the MOSAIC project, disclosing the implications of these results for the MOSAIC project's research and innovation and elaborating on them.

The following section delves into **exploring potentials and limitations of existing digital tools** based on insights collected from MOSAIC partners and developers of some relevant digital tools and a sample of users. This information has been complemented by the insights from a workshop realised with developers to validate the reviews and to co-develop innovative

ideas to increase the interoperability and synergies between the tools and MOSAIC's modelling outputs (Task 5.2).

The last section with the **conclusions,** presents a summary of recommendations aimed at enhancing the adoption of digital tools from the MOSAIC project's perspective, while also considering a more comprehensive approach for their use by stakeholders in decision making. It concludes by highlighting the contributions of Task 5.1 to the Digital Literacy on Land Use Decision Support Tools and the Digital Learning Environment.

1 OVERVIEW

1.1 Decision Making in a Digital Era

The transition of our society through a Digital Era undeniably represents the most recent long wave of humanity's socio-economic evolution (Hilbert, 2020). It is an upscaling process that has drastically demonstrated its transformative potential across different sectors, in line with the demand for rapid and effective solutions associated with an even faster rate of economic innovation, social acceleration and environmental change.

However, what does digitalisation mean, and why is it so relevant in today's world?

Digitalisation refers to the straightforward process of converting analog to digital information and using digital technology and digitised information to create and harvest value in new ways (Gobble, 2018). From a practical perspective, digitalisation is proving to be a pervasive, transformative, and enabling technology integrated into both products and processes, as well as social relations and business and production organisations (Ietto-Gillies & Trentini, 2023). Over the past decades, cross-sectoral digitalisation efforts have led to pervasive digital technologies, which have sparked a novel generation of products, services, and platforms (Pershina et al., 2019).

The rise of digitalisation poses new challenges that have significantly transformed different structural components of our society, including the economy, industry, agri-food sector, cities, energy, and governance, among others. In this sense, such emergent phenomena associated with a technological paradigm shift are revolutionising the modus operandi of society as a whole, including its economic, social, cultural, and political organisation (Hilbert, 2020).

Digitalisation has brought new sets of tools that can ensure smart applications and support the green character of innovative solutions towards a quicker and more straightforward approach to building the sustainable society of the future (Mondejar et al., 2021). The latest developments in artificial intelligence, machine learning, and big data are examples of this, demonstrating their massive potential in optimising time-consuming processes such as analysis, interaction, processing, visualisation, and information monitoring. The COVID-19 pandemic has amplified these trends, as even more services and interactions have shifted to digital channels.

The core knowledge surrounding digital transformation is primarily rooted in business and managerial sciences. Recent academic and practical initiatives have led to the emergence of new research fields in this area (Talafidaryani & Asarian, 2024). Within the realm of social sciences, digital transformation has raised several intriguing questions since the early 1990s. These questions range from the cognitive and pedagogical aspects of how digitally mediated knowledge is created, to what learning processes can be encouraged, as well as how digital advancements are reshaping spatial production, compressing time, and ultimately transforming socio-spatial relations (Ash et al., 2018).

From a political and social perspective, scientists have followed the economists' lead, exploring the impact of rapid technological change on public decision making and policy making (van Kersbergen & Vis, 2022). In line with this, it has been demonstrated that digital tools and technologies offer new opportunities for participation in international policies (Hafferty et al., 2024) and related decision-making (Noennig, 2022). Using digital tools in stakeholder participation, including co-creation, co-design, interaction, engagement, and involvement in innovation and decision-making processes, is one of the most recent and practical fields of application as they improve the value creation in projects in a multidimensional way and at different levels (Toukola & Ahola, 2022). Increasing use of digital tools could also be identified in citizen participation, opening new forms of public governance (Shin et al., 2024).

This framework is particularly relevant when intervention scales shift to the complexity of the regions, cities and local territories, where digital tools support cross-sectoral decision-making processes related to governance and policies. Here, decision-makers worldwide have long used digital tools and technology for urban planning and development (Hammond et al., 2023). At these levels, the digital transition is an obligation due to the complexity of spatial planning, which should consider several dimensions, such as space-related processes, interaction among different actors and entities, and resource optimisation and management.

Given this comprehensive framework, exploring how digital tools can support decision making in land use and how they can be developed to this end emerges as a novel and relevant research focus. The novelty of this topic can be found in the lack of previous studies that have systematically reviewed digital tools associated with land-use decisions, disclosing a gap in the knowledge about their ecosystem, functionalities, barriers, limitations and the factors that can affect future uptake.

Understanding and managing land use transformations is an urgent and complex domain that must be addressed in light of changing drivers, multiple actors, and significant impacts on climate, biodiversity, and the environment, among many other processes. Furthermore, the recent rapid changes in land use due to substantial societal development and population growth necessitate the consideration of three critical factors, such as time, intensity, and uncertainty, as new driving forces to be controlled. Due to the need to consider complex dimensions for decision making and the involvement of different stakeholders, it is undeniable that using digital tools can lead to making more informed choices in a shorter time.

This document offers a detailed scientific narrative on digital tools, disclosing their relationship with land use decisions. It culminates in practical, cutting-edge findings that aim to advance knowledge in this field and support the co-development of MOSAIC's digital learning environment.

The document is structured into five main sections that support researchers, practitioners, and non-academic audiences in learning from this research.

Section 1 – Overview, briefly contextualises decision making in a digital era, underlying the main objectives and motivation in studying this topic, relating it to land use and formulating respective research questions.

Section 2 – Systematic Literature Review, describes the overall strategy and methodological approach adopted for the systematic literature review, explaining how studies were identified and selected and where they have been found in line with the PRISMA 2020 statement.

Outputs from the systematic literature review led to a Digital Portfolio presented as a table form in **Section 3 – Results** that collects a detailed description of 55 existing digital tools. This section also describes ten tools selected as interesting references for decision makers looking to learn how to transform land use decisions.

Section 4 – Exploring potentials and limitations of existing digital tools, provides an analysis based on the insights from MOSAIC partners, interviews with developers of existing tools and feedback from a survey realized to the users. Additionally, this section includes ideas generated during a developers' workshop to improve the compatibility and cooperation between the tools and MOSAIC's modelling outputs.

Finally, **Section 5 – Conclusions,** provides co-development recommendations to increase digital tools uptake. It also highlights the contributions of Task 5.1 to the Digital Literacy on Land Use Decision Support Tools, the Digital Learning Environment and lists the answers to the formulated research questions.

1.2 Approaching Digital Tools: objectives, motivations and research questions

Nowadays, approaching digital tools involves exploring a broad and diverse research field, constantly evolving across different sectors. In this context, a fundamental step for guiding and directing the research is establishing clear objectives that define the scope of the study and are associated with relevant motivations that align "with and beyond" the MOSAIC project and Task 5.1, benefiting the academic community and the general public.

The main objective of the present study is to review the potentials and limitations of existing digital tools supporting land use change (e.g. from prior EU projects) to co-develop recommendations for increasing their uptake in decision-making processes.

This comprehensive objective is subdivided into the following two specific objectives associated with the practical key issues to be focused on in Task 5.1, namely:

- To scope existing land use decision support tools developed in recent EU, national, regional or local project efforts, including emerging tools that have not yet been published or released to the public;
- To review the functionalities of these tools to understand:
  - the role of social, economic, regulatory, legal, cultural, environmental and other drivers;
  - their support for decision-makers at different stages of project and policy cycles;
  - key motivations and barriers for uptake.

The motivations that drive the above objectives are scientific, practical and technical. The scientific one is to explore the novel and promising research topic of using digital tools to address land use decisions. The practical one is to examine the potential and limitations of digital tools, developing recommendations for increasing their use in decision making. This could make valuable contributions to research and practice in improving the tools' effectiveness, adoption, and impact. Finally, the technical one is to know whether digital tools can influence drivers and motivations of land use decision makers, integrating concepts such as climate change, biodiversity and sustainability, among others and how the developers tried to anticipate the role these tools may play in decision-making processes. This motivation is directly associated with learning from these insights so MOSAIC can develop its DLE and digital tools/services.

The objectives and motivations framework mentioned above leads to the following set of research questions (RQs) that have been framed to organise the different components of the study and develop a deeper understanding of the topic of digital tools being investigated under the MOSAIC lens.

RQ1 - What is a digital land-use decision support tool?

(Answered in Section 2.1);

RQ2 - What common types of digital land-use decision support tools are available?

(Answered in Section 2.1 and 3.1);

RQ3 - What are the key features and functionalities typically found in digital land-use decision support tools?

(Answered in Section 2.2 and 3.1);

RQ4 - What are the best practices and success factors for developers in designing and deploying practical digital land-use decision support tools?

(Answered in Section 4.2);

RQ5 - How do users perceive the effectiveness and usability of digital land-use decision support tools in real-world decision-making processes?

(Answered in Section 4.2):

RQ6 - What are the benefits, advantages, main challenges, and limitations of using digital land-use decision support tools compared to traditional decision-making methods?

(Answered in Section 4.1 and 5.1).

Answering these questions is crucial for understanding which digital tools are relevant within the MOSAIC scope and how their analysis contributes to advancing new knowledge and supporting the development of the DLE in Task 5.2. The six research questions are structured from a top-down perspective, looking for descriptive (RQ1), exploratory (RQ2-3), reflective (RQ4-5) and interpretive (RQ6) answers.

In this sense, RQ1 begins by narrowing down the definition and conceptualisation of digital land-use decision support tools in the existing literature to provide a broad contextualisation of the topic. RQ2 and RQ3 are exploratory and focus on more specific issues that need investigation within the MOSAIC project, namely, the identification of qualitative and quantitative aspects that characterise the existing digital tools. RQ4 and RQ5 are reflective questions oriented to understanding the perspective of those who develop digital tools, the types of users and their perceptions and opinions, and the contexts in which they have been used until now. The last RQ6 is an interpretative question aiming to provide insights into the advantages and disadvantages of using digital tools compared to traditional methods.

2 SYSTEMATIC LITERATURE REVIEW

2.1 Digital land-use decision support tools

The present section delves into understanding how digital land-use decision support tools are defined and conceptualized in existing literature, answering the **descriptive research question RQ1 “What is a digital land- use decision support tool?**” In this sense, a concise research synthesis has been conducted, shedding light on different definitions and harmonising different concepts on this topic.

Within this discourse, it is essential to note that answering RQ1 is twofold, requiring a clarification of its semantic value. On the one hand, by decomposing the string of research: "digital land-use decision support tool", it is possible to refer that it is associated with the existing and consolidated concepts of Decision Support Tools (DST) and Decision Support System (DSS).

The DST refers to frameworks, methods, guides, techniques, procedures, and analytic approaches targeted at a specific group to inform decision-making (Chazdon & Guariguata, 2018). The DSS is a computer-based system that represents and processes knowledge in ways that allow decision making to be more productive, agile, innovative, and/or reputable (Power, 2008).

Literature on DSTs is extensive and diverse. DSTs have been developed and adopted to aid and inform decision making across scales and various disciplines for problem solving, appraising projects and environmental modelling (Mabhaudhi et al., 2023). In particular, over the last few decades, there has been a rise in DSTs intended to help stakeholders make higher-quality decisions to manage environmental risk (Wong-Parodi et al., 2020) and the broader challenge of sustainable development in different contexts, such as agri-food production (Arulnathan et al., 2020) and agroforestry (Ellis et al., 2004), coastal planning (Barzehkar et al., 2021), urban development (Kapelan et al., 2005).

Unlike the DSTs, the DSSs reflect the advancements of the 21st century. They are intrinsically associated with the progress of the Internet, the Web, and telecommunications technology within an increasingly more global, complex, and connected society (Shim et al., 2002). Current trends in DSS highlight growing interest in using Big Data and web-based technologies (Talari et al., 2022). In this sense, DSSs are developed to address the overflow of information and knowledge, supporting decision-makers in choosing the best compromise (Razmak & Aouni, 2015). One of the most interesting functions of DDS is thus to provide decision makers with analysis, information, recommendations, and environments to test different scenarios (Elkady et al., 2024).

Introducing the "digital" dimension associated with "land use," leads to the focus of the present review on digitalisation and the technologies applied to support decision making in this field. Digital is a crucial concept in defining a digital land-use decision support tool. This definition excludes tools related to methods, instruments, frameworks, or models. It highlights the specific tools that fall under "digital planning." These tools encompass a wide range, from online or social media platforms to apps and gaming devices (Wargent, 2023).

The relevance of shedding scientific light on this topic revolves around its multi-faced and novel nature. This includes designing, deploying and adopting digital tools to provide innovative ways that assist private and public stakeholder groups in understanding changes in urban and rural areas and support their decisions towards determined development goals. Such digital tools help communicate change to all those interested and undertake pilot activities to support better understanding and involvement in planning decision making. In this framework, Shin et al. (2024) reveal how self-organising, community-based, and digital technologies characterise the rapidly changing landscape of citizen participation.

This is the general essence of how and for what digital tools are used, revealing the importance of systematising the knowledge on available technologies to understand which would best suit supporting land-use change decisions, and what the potentials and limitations of existing digital tools are to then co-develop recommendations for increasing their uptake in decision-making processes (Figure 1).

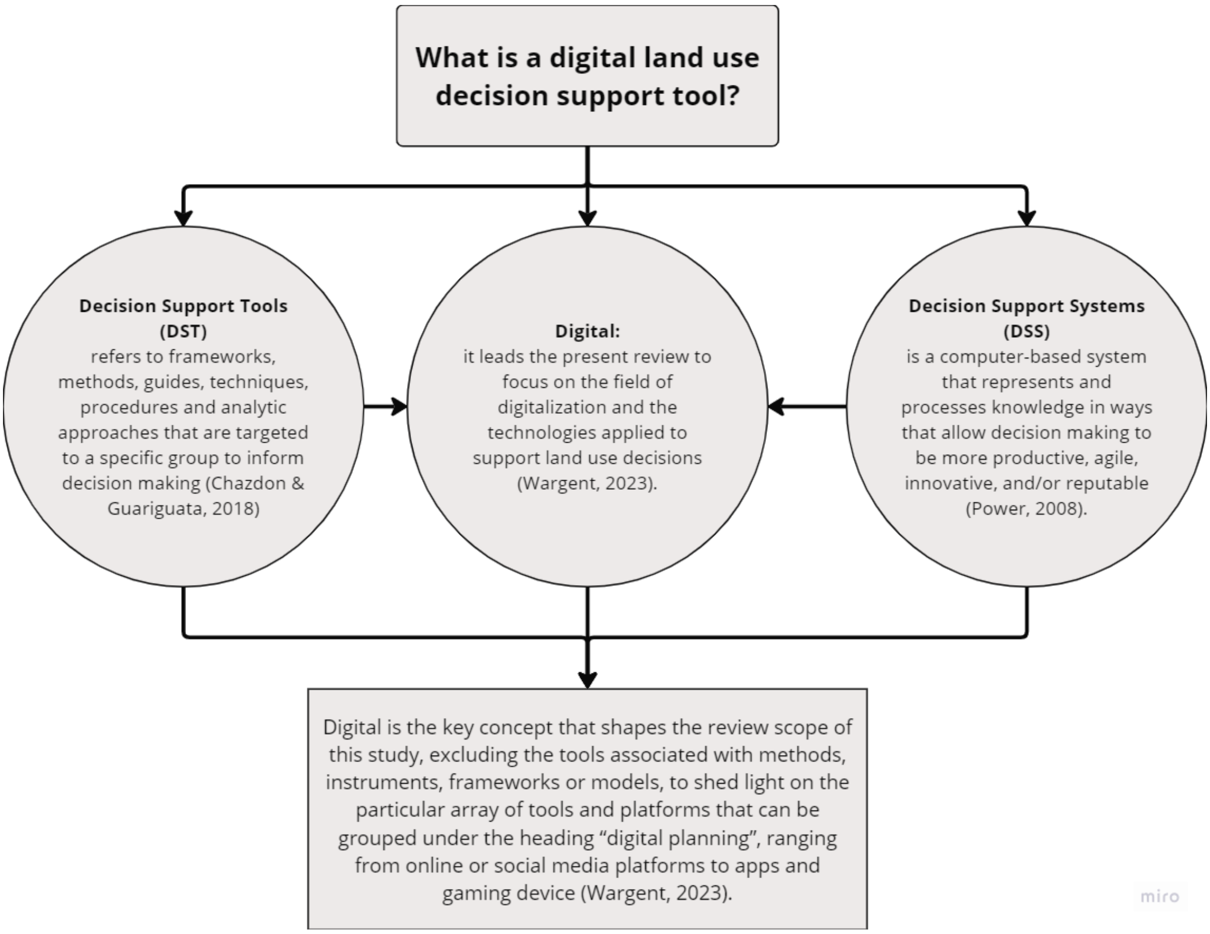


Figure 1: Relational diagram framing answer to RQ1

2.1 Method

After contextualising the topic of digital land-use decision support tools, this section explains the method used to address the **exploratory research questions RQ2 "What common types of digital land-use decision support tools are available?"and RQ3 "What are the key features and functionalities typically found in digital land-use decision support tools?"**, which aim to identify the common types of digital land-use decision support tools and explore the key features and functionalities typically found in these tools.

The systematic literature review (SLR) has been chosen to identify research related to a predetermined topic and provide a transparent, complete, and accurate synthesis of the state of knowledge (Page, McKenzie, et al., 2021).

Among the different methods and techniques to carry out SRL (García-Holgado, Marcos-Pablos, et al., 2020), the present study adopts the PRISMA method - Preferred Reporting Items for Systematic Reviews and Meta-Analyses (Page, McKenzie, et al., 2021). Developed in 2009 to conduct systematic reviews on a broader array of questions for developing clinical practice guidelines, the PRISMA method actually used to cover any systematic review, not just those whose objective it is to summarise the benefits and harms of a healthcare intervention (Moher et al., 2010). Within this framework, the PRISMA method ensures a high-quality research process to collate and synthesise findings of studies that address the RQ2 and RQ3 questions.

The following subsections describe how the present study has addressed the PRISMA method, following the checklist published by Page, Moher, et al. (2021) and the guidelines for performing Systematic Research Projects Reviews by García-Holgado et al. (2020).

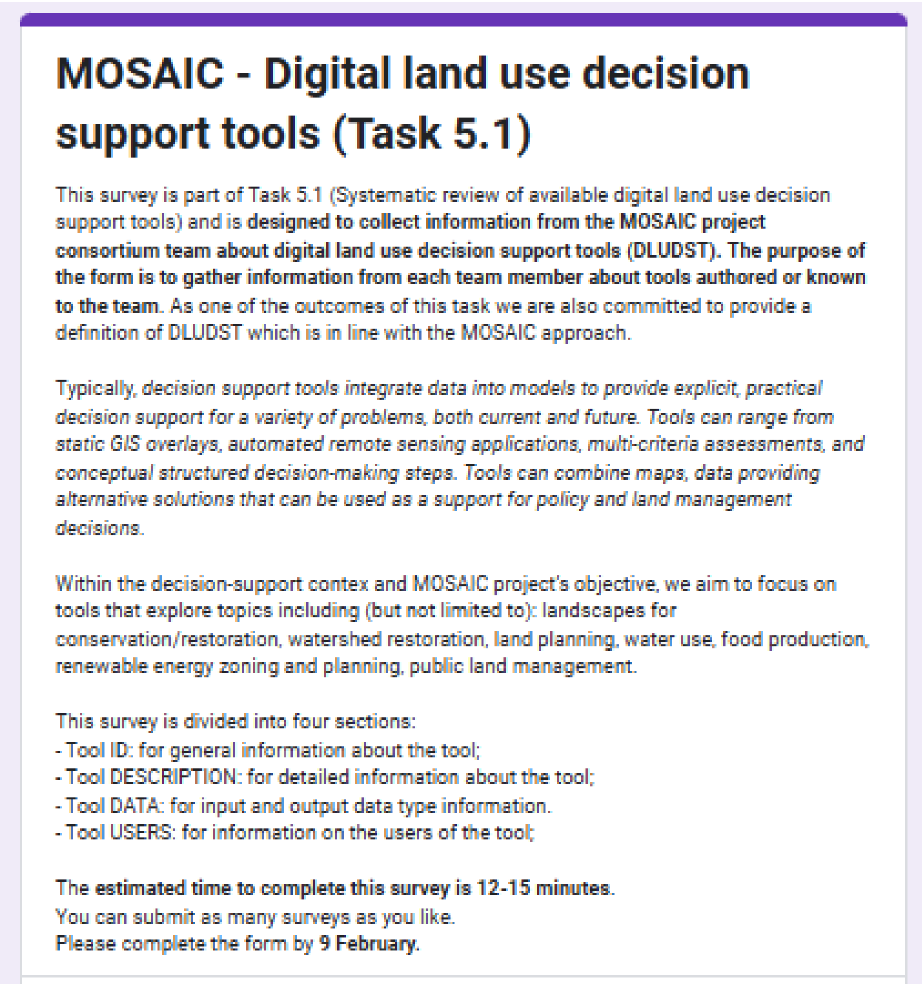
2.1.1 Information Source and Search Strategy

The first step of the present SRL has been to select the databases, registers, websites, organisations, reference lists, and other sources to identify studies. Due to the scientific aims of this review and the relevance of the expected outputs to support the MOSAIC project and WP5, the primary database for searching has been the CORDIS platform - Community Research and Development Information Service (https://cordis.europa.eu). This database is a rich and structured public repository with all the results from the projects funded by the European Union (EU)'s framework programmes for research and innovation.

Including CORDIS in this literature review is relevant for four main reasons. First, MOSAIC aims to gather insights from other EU projects to develop its digital learning environment and digital tools/services, ensuring that any proposal will not duplicate previous work or have an ineffective research design. Second, the results of EU projects are not always available in scientific publications. Third, the specific topic of digital tools has a practical and technological nature beyond pure theory. Accordingly, EU projects make the developed tools available for open access within the CORDIS platform. Finally, it allows the use of search strings similar to those used in scientific databases and provides filters to obtain results within the research scope of this review, with a focus on Europe's geographical context.

That said, to scope digital tools that could be relevant and not associated with any EU research project, other information sources have also complemented the search into CORDIS. In line with this, the Web of Science (WOS) and Scopus electronic databases have been selected for scientific publications. These databases include documents from different publishers, allowing full-length searches or searches only in specific fields of the works, filtering options such as publication year or publication language and using logical expressions or a similar mechanism (García-Holgado, Marcos-Pablos, et al., 2020).

Finally, secondary sources, such as the grey literature (websites, organisations, public and private entities), have been consulted to guarantee a comprehensive review of digital tools and the most complete information for analysis. In line with this, and considering the knowledge and expertise of the MOSAIC consortium in developing and using digital tools to support land-use decision making, an internal survey has been conducted among all the partners. Between January and February 2024, the online survey collected information from the participants responding to the study link using internet-based communication technology (Figure 2).



MOSAIC - Digital land use decision support tools (Task 5.1)

This survey is part of Task 5.1 (Systematic review of available digital land use decision support tools) and is **designed to collect information from the MOSAIC project consortium team about digital land use decision support tools (DLUDST). The purpose of the form is to gather information from each team member about tools authored or known to the team.** As one of the outcomes of this task we are also committed to provide a definition of DLUDST which is in line with the MOSAIC approach.

Typically, *decision support tools integrate data into models to provide explicit, practical decision support for a variety of problems, both current and future. Tools can range from static GIS overlays, automated remote sensing applications, multi-criteria assessments, and conceptual structured decision-making steps. Tools can combine maps, data providing alternative solutions that can be used as a support for policy and land management decisions.*

Within the decision-support contex and MOSAIC project's objective, we aim to focus on tools that explore topics including (but not limited to): landscapes for conservation/restoration, watershed restoration, land planning, water use, food production, renewable energy zoning and planning, public land management.

This survey is divided into four sections:
- Tool ID: for general information about the tool;
- Tool DESCRIPTION: for detailed information about the tool;
- Tool DATA: for input and output data type information.
- Tool USERS: for information on the users of the tool;

The **estimated time to complete this survey is 12-15 minutes.**
You can submit as many surveys as you like.
Please complete the form by **9 February.**

Figure 2: Introduction web page for the Internal Survey

The search strategy adopted for the three databases, CORDIS, WOS and Scopus has been based on the following common criteria and specific filters:

COMMON CRITERIA:

- **Query String:** Digital AND tool AND decision support system AND land-use;
- **Period**: 2000-2023.

SPECIFIC FILTERS:

- **CORDIS - Field of science**: Society, Climate Change and Environment, Energy, Food and Natural Resources (research projects);
- **WOS and Scopus**: Title and Abstract (journal articles).

Four specific keywords have been chosen for the query string to ensure comprehensive and targeted search results. The Boolean operator "AND" has been adopted to find results with information common to the search terms. This approach narrows the relationship between digital tools, decision support systems, and land use. Other tests were performed using the query string "digital AND land-use OR land AND use AND tool OR method OR approach AND decision AND support," but this was excluded as it produced too many irrelevant results.

In this sense, the query integrates “Digital,” “tool,” and “decision support system,” encompassing both DST and DSS related to “land use.”

Finally, the period from 2000 to 2023 has been selected as the most representative of progress in the digitalisation process.

Regarding the specific filters, the search in the CORDIS platform has been focussed on selecting the field of science associated with the MOSAIC project and the scope of this review, while the WOS and Scopus search has been restricted to keywords in the title and abstract.

Using the PRISMA method sequence of steps, Figure 3 shows the synthesis of the relationships from the selected databases and other sources with the first screening process.

In this sense, the common criteria and specific filters applied to the search led to the identification of:

- **109 registers (journal articles)**, including 44 entries from SCOPUS and 65 from WOS;
- **90 registers (research projects)** from CORDIS;
- **29 registers (digital tools)** from the internal survey;
- **14 registers (digital tools)** from the grey literature, using Google to search.

While the results from CORDIS and the other sources are ready to proceed to the screening phase, registers from Scopus and WOS need to pass through a preliminary stage that involves removing duplicate records. In this way,19 journal articles published in both databases have been removed, limiting the number of records for screening to 90.

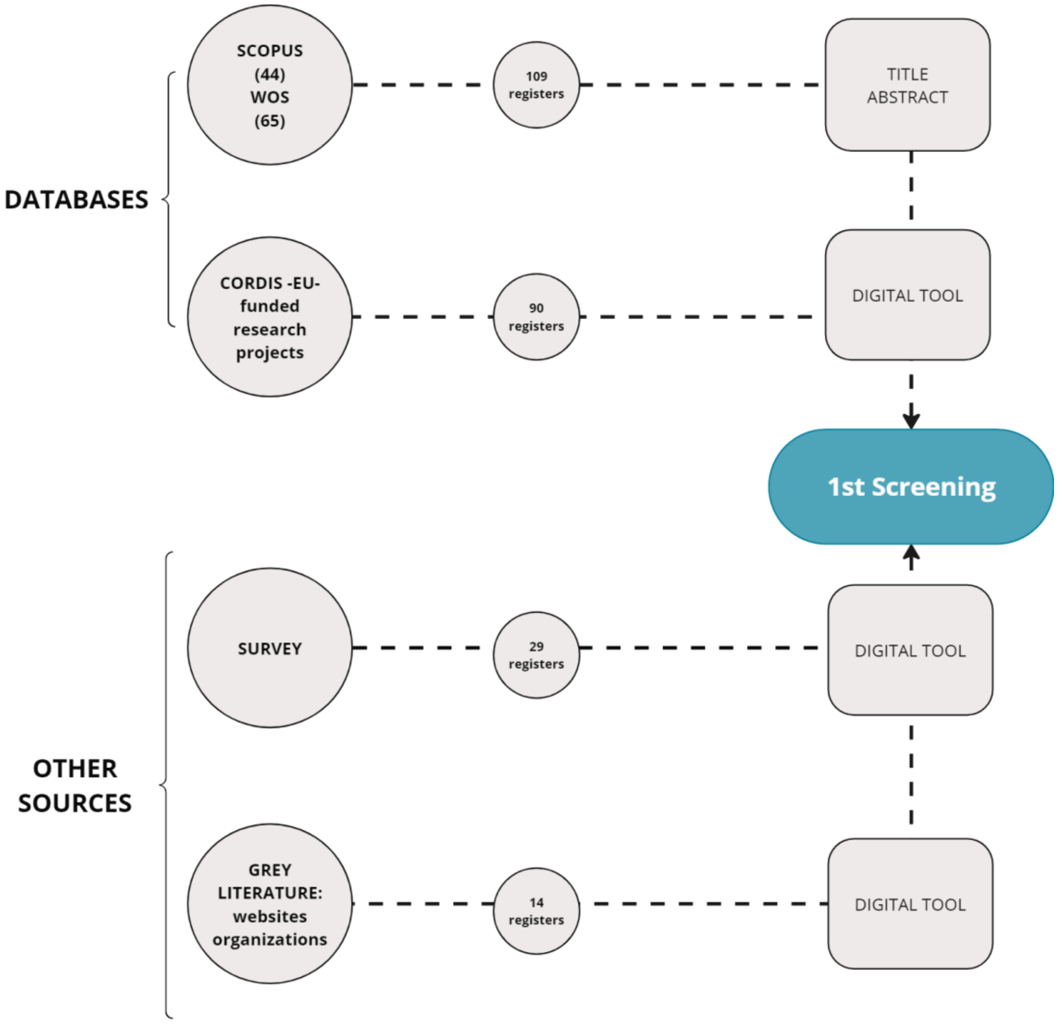


Figure 3: Synthesises the relationships in acquiring records from databases and other sources

2.1.2 Exclusion criteria

The PRISMA method provides a structured approach to conducting systematic reviews, including applying exclusion criteria to be adopted within the screening stage. This process is essential for ensuring the review is comprehensive, unbiased, and relevant to the research questions.

As such, this section describes the exclusion criteria adopted to guarantee that the study has been conducted systematically, transparently, and replicable, according to the key principles of a high-quality systematic review.

Due to the diverse types of records, i.e. research projects, journal articles, survey results and grey literature records, the criteria needed to be adapted to the output of each database. In this sense, some criteria are common to all the records from the four information sources, while others have to be shaped to the nature of the analysed record.

Starting with the description of common exclusion criteria, the first one revolves around the scope. That is, if the record is not related to relevant land-use decisions within the scope of the MOSAIC.

Such **scope-related criteria** method follows the rationale of the pertinence regarding the overall research objectives of the MOSAIC project, focusing on the interpretation and understanding of a diversity of land-use-related challenges, including climate change, renewable energy and biodiversity. From this lens, several records associated with digital tools developed to support decisions in domains indirectly related to land use have been excluded throughout the screening. Some examples of these cases (Figure 4), have been identified, particularly in the records from CORDIS, WOS, and Scopus databases. Despite being relevant areas and influencing land use, the scope is clearly different from the focus of the MOSAIC project.

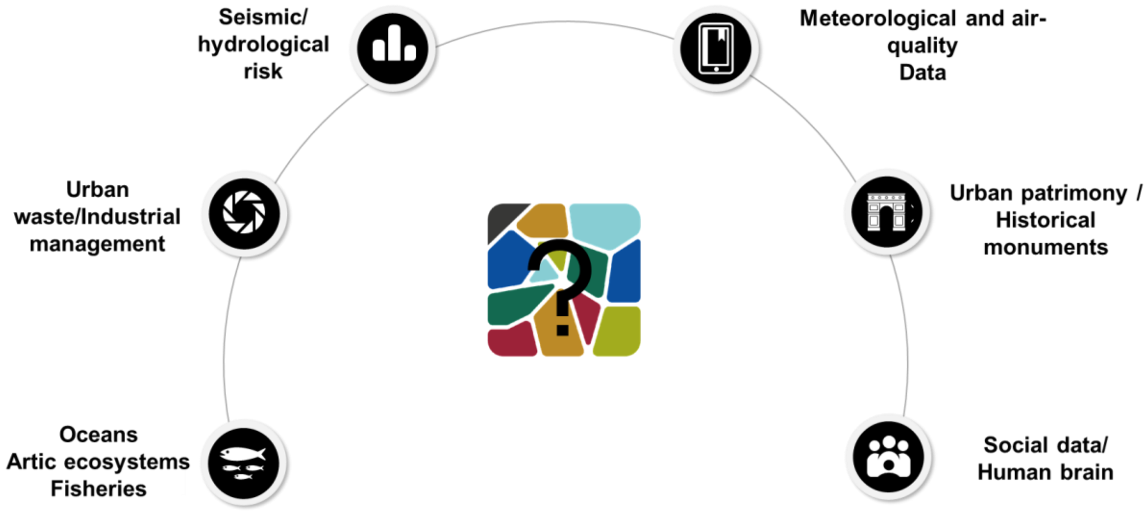


Figure 4: Examples of land use decision frameworks not included within the scope of MOSAIC

The second exclusion condition is related to **technological criteria**: the digital tool must be accessible for analysis and testing; otherwise, it cannot be considered within the review. Such criterion is specific to the nature of digital tools as they are commonly online platforms, desktop applications, software, Web-based systems, mobile apps, and cloud services. In this framework, records associated with digital tools that are no longer in operation/online or that are associated with links redirecting to stolen website domains or applications that are not open access or require payment to be accessed/downloaded have been excluded. Such criterion is fundamental to ensure that the selected digital tools are not outdated, inactive or inaccessible, guaranteeing the consistency and reliability of the final outputs for analysis. It also avoids risks involved with the integrity and security of these tools. In a digital world where links can quickly become obsolete or hijacked, the readers of this study might navigate towards stolen domains or broken links when trying to access tools.

The third condition is a **geographical criterion**, which excludes digital tools not developed for the European context. While this may seem limiting, it is necessary to ensure that the tools are relevant, accessible, tailormade and applicable to the geographical context of interest within the MOSAIC. Imagine a European decision maker trying to test a digital tool developed in Australia to help manage and protect surrounding natural habitats. He stumbled upon a tool that relies heavily on datasets specific to Australian environments, including specific satellite data and land cover classifications. The underlying assumptions and models are tailored to particular landscapes, climate conditions, and regulatory frameworks, vastly different from the challenges faced in Europe. The decision maker quickly realises that the tool, while powerful, would not offer the insights or compatibility needed for their specific European context. This example permits contextualising the main reason for adopting a geographical criterion, selecting digital tools developed in Europe, and enhancing the analysis of tools that incorporate local data, meet regulatory requirements, data privacy and security standards, and are tailored to the unique challenges and priorities of European socio-economic, environmental, political and technological context. Finally, by narrowing the demonstration of their relevance and effectiveness within the European context, the geographical criterion facilitates adapting or replicating these tools for use in other European regions.

The three mentioned criteria - scope-related, technological, and geographical - have been used to exclude records from the four information sources within the initial screening stage of the review.

For WOS and Scopus records, which are associated with journal articles, a second screening stage has been implemented, following two specific exclusion criteria, namely:

- **Manuscript Not Found –** when a manuscript cannot be located even after extensive searching and attempts to contact the authors through email;
- **Manuscript Not in English or Written in Non-Latin Scripts –** when a manuscript is not written in English, especially in languages using non-Latin scripts such as Cyrillic, Arabic, Chinese, or Japanese. The barriers to these manuscripts lie in their translation and interpretation of the contents.

By applying these exclusion criteria, the present systematic review process ensures that only accessible and relevant manuscripts are included, maintaining scientific rigour and quality. Manuscripts that cannot be located despite efforts to contact the authors or those in languages with non-Latin scripts have been excluded to prevent gaps in the review and ensure consistency and comprehensibility.

2.1.3 Screening

The present section focuses on the screening process once the exclusion criteria have been described and justified. This process is designed to systematically select the records to identify studies that are relevant, accessible, and meet the criteria for inclusion in the final digital portfolio.

Within the PRISMA method, screening is typically a multi-stage process in which potentially eligible studies are first identified from screening titles and abstracts, then assessed through a full-text review (Page, Moher, et al., 2021). In this context, it is worth noting that the current review has concentrated on the CORDIS database and the findings of an internal survey regarding research projects, in addition to the traditional databases of Scopus and WOS (journal articles).

From a scientific perspective, this aspect is relevant. It opens one of the main challenges of this review, which has been to address a different screening process between research projects and scientific literature. As García-Holgado, Marcos Pablos, et al. (2020) mention, no established methodology allows for a systematic analysis of the studies and progress made through research projects in a specific area or topic. In this sense, the proposed screening process is novel and could be considered a contribution to the systematic review literature related to the application of the PRISMA method. According to this method, the screening has been divided into two stages.

The first screening adopted the three common exclusion criteria for all the source information (Figure 5). This approach has led to harmonising the records with the data extraction, which excludes some digital tools collected from CORDIS, the internal survey and grey literature. In particular, some of the digital tools suggested in the internal survey overlap with the other two databases, requiring a screening process to eliminate duplicate records. Then, applying the scope-related, technological and geographical criteria led to the selection of 19 digital tools from CORDIS, 18 from the survey and 14 from the grey literature.

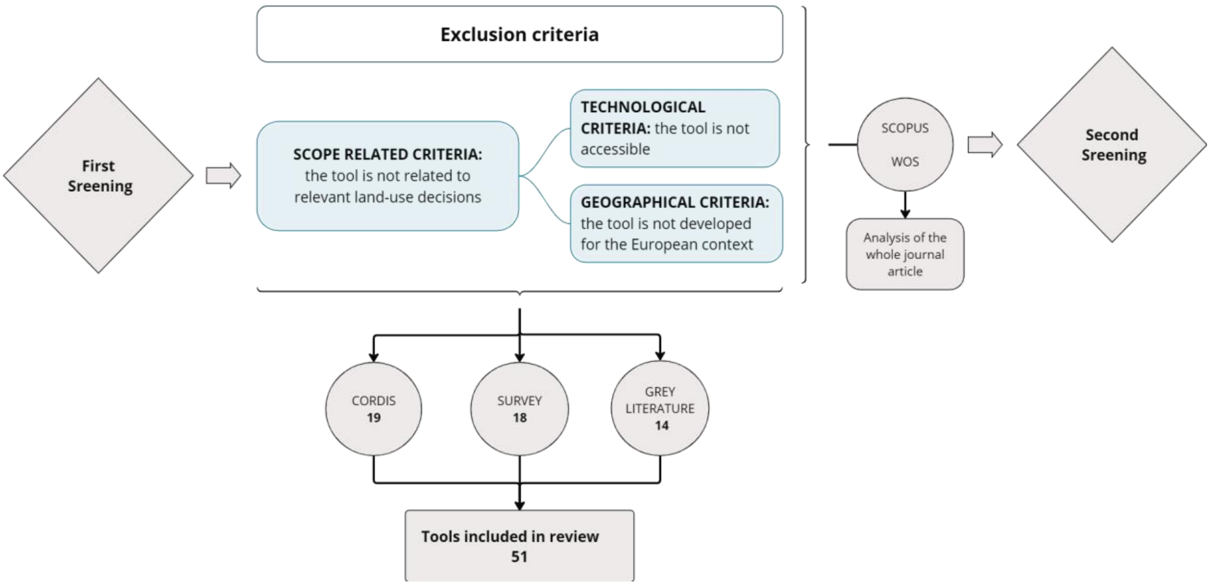


Figure 5: First Screening stage

Some examples of the first screening stage involve excluding digital tools, such as the Walkabilityscore[1] and SaniChoice[2], collected within the internal survey. These tools are not

[1] Avaiable on : https://walkability.marvin.vito.be/?lat=51.037508125715775&lon=4.240722656250001&zoom=10

[2] Available on: https://www.eawag.ch/en/department/sandec/projects/sesp/sanitation-technology-and-system-choice-for-urban-planning-sanichoice/

directly related to land-use decisions but instead focus more on specific issues like the 'walkability score' of neighbourhoods and the sanitation technology and system choice for urban planning.

Other exclusions within the first screening stage are related to records from the grey literature and Scopus and WOS databases. Here, the geographical criteria led to several exclusions because digital tools were developed for non-European contexts, addressing different geographical, social, and environmental challenges.

In this sense, a second screening stage has been necessary due to the nature of the records in Scopus and WOS databases (Figure 6). This has involved applying specific criteria to identify manuscripts that are currently unavailable online , not in English, or written in non-Latin scripts, particularly with journal articles.

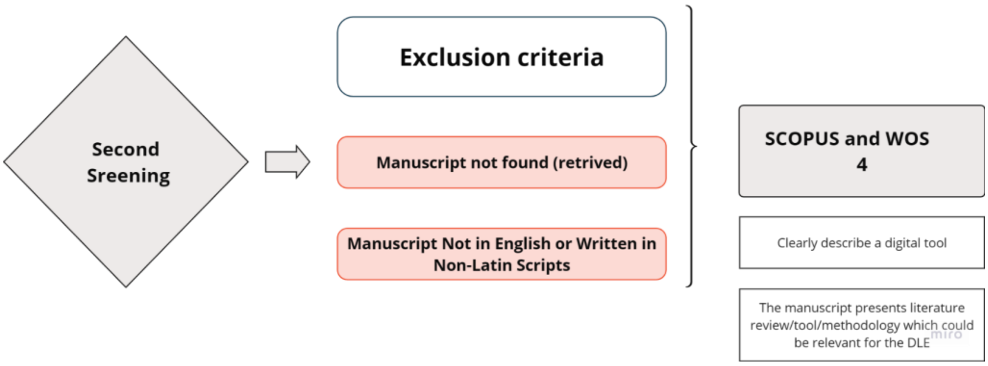


Figure 6: Second screening stage

Screening of records from Scopus and WOS has been more complex due to the inaccuracy of the records when facing the search string. This was demonstrated by the final selection of only four journal articles that described and referenced accessible digital tools.T

In this context, it also refers to the fact that several journal articles have been excluded because they do not refer to or present any digital tools. It is the case, for example, for a "comparison of approaches to regional land-use capability analysis for agricultural land-planning" that describes a comparison of theoretical approaches (Ippolito et al., 2021) or a "conceptual model framework for mapping", analysing and managing supply-demand mismatches of ecosystem services in agricultural landscapes (Shaaban et al., 2021), that describes a conceptual integrated model associated with a combination of three methodological tools. Finally, several records refer to literature reviews or methodologies related to digital tools (Ghavami et al., 2023, Catalano et al., 2023, Obade & Gaya, 2021, Dong et al., 2019, Choi & Lee, 2016, Liu et al., 2016, McRoberts et al., 2007) but do not present any example already developed to be analysed or tested.

From the two screening stages, 55 digital tools related to land use decisions have been selected. These tools are fully operational and open access and will be described and analysed in the next section of this study.

3 RESULTS

3.1 Digital Portfolio

The systematic review has identified previous research projects and studies associated with digital land-use decision support tools. This comprehensive review serves as a robust foundation for the following tasks of WP5. In this sense, the results of this review are a key contribution to the co-design of digital model-based services (Task 5.2), which will be integrated into the digital toolbox of WP6.

This integration will pave the way for the implementation of the digital learning environment and the assessment of its transformative capacities (Task 5.3). The results of the systematic review of digital land-use decision support tools were compiled into a digital portfolio, including 55 digital tools (see Appendix A) developed for improved information organisation.

The results are represented in a static way; however, it is expected to be embedded in the future digital learning environment, with the possibility of selecting tools by queries or other specifications. This table was organised into five major sections (Table 1):

a) **Tool description**: for general information about the tool;
b) **Tool functions**: for more detailed information about the tool;
c) **Tool data**: for input and output data type information;
d) **Tool users**: for information on the users of the tool (if existent);
e) **Tool references**: bibliographic references about the tool for a deeper understanding.

The **tool description section** is a comprehensive resource, offering information about each tool. It includes details such as the source (CORDIS, WOS or Scopus, MOSAIC Internal Survey, Grey literature), tool name, a brief description, an online link, the level of development (Prototype, Under development, Operational), the name of the developer, the type of developer (Public Administration, Academy/Research centre, Enterprise, Other), email contact, and the launching year of the tool and country of origin.

The **tool function section** delves deep into the details, providing a comprehensive understanding of each tool. It covers aspects such as the type of tool (Analysis, Simulation, Stakeholder Engagement, Land use modelling, Scenario modelling, Interaction and visualisation), policy sector (Governance, Spatial planning, Forestry, Agriculture, Rural areas, Protected areas management, Biodiversity, Environment, Climate, Energy, Multiple), main land use domain (Forest Management, Rural Land Development, Natural Resource Management, Ecology, Biodiversity and Conservation, Green Infrastructure, Renewable Energy, Energy Landscapes, Agricultural/Forestry Decision Support Systems, Water Management, Mixed Land Uses), the presence of spatially explicit output, and the scale of tool development (EU, National, Regional, Local).

The **tool data section** includes information about the input and output data used in each tool, namely, general input data type (Qualitative, Quantitative, Both), Detailed input data type (Statistics, Spatial information, Expert knowledge, Field survey data, Dataset), Output data type (Map, Graphics, Texts, Aggregated data), Output timeframe (current, short-medium term, long term).

The **tool user section** covers some information about the users of each tool, whenever the information is available, namely the number of users, the type of users (Citizens, Academy, Policy makers, Land Managers, All, Others) and the time required to use or learn to use the tool (low, medium or high).

The last section – **tool reference** – gathers the bibliographic references about the tool for a deeper understanding.

As represented in Figure 7 and listed in Table 2, 19 tools are from CORDIS, 19 from the MOSAIC internal survey, 13 from grey literature and 4 from the WOS and SCOPUS databases.

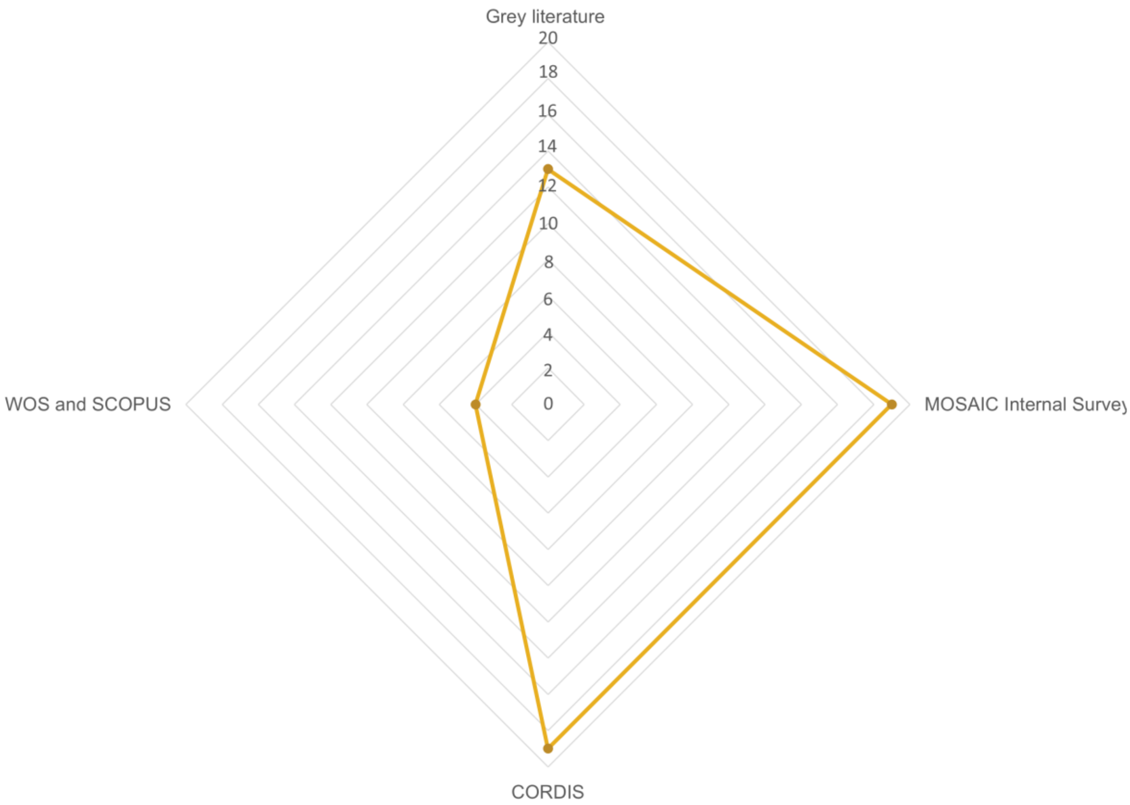


Figure 7: Sources of the 55 digital tools gathered from the systematic literature review

Table 1: Model of the Digital Portfolio

Tool DESCRIPTION											Tool FUNCTIONS					Tool DATA				Tool USERS			Tool REFERENCES
Database of Origin Information Source	**ID**	**Tool name**	**Description**	**Online link**	**Level of development**	**Developer /Publisher**	**Type of Developer**	**Contact**	**Launching Year**	**Country of origin**	**Type of Tool**	**Policy sector**	**Main Land Use Domain**	**Spatially explicit output**	**Scale**	**General input data type**	**Detailed input data type**	**Output data type**	**Output timeframe**	**Users**	**Type of end-users**	**Time requirement**	
Name	nº	Name	75 characters	Link	Prototype Under Development Operational	Name	Public Administration Academy/ Research center Enterprise Other	email	yyyy		Analysis Simulation Stakeholder Engagement Land use modelling Scenario modelling Interaction and visualisation	Governance Spatial planning Forestry Agriculture Rural areas Protected areas Management Biodiversity Environment Climate Energy Multiple	Forest Management Rural Land Development Natural Resource Management Ecology, Biodiversity and Conservation Green Infrastructure Renewable Energy Energy Landscapes Agricultural/Forestry Decision Support Systems Water Management Mixed Land Uses	Yes No	EU National Regional Local	Qualitative Quantitative Both	Statistics Spatial information Expert knowledge Field survey data Dataset	Map Graphics Texts Aggregated data	Current Short-medium term Long term	Number	Citizens Academy Policy makers Land Managers All Others	Low Medium High	Bibliography or web-site

Table 2: List of 55 digital tools, classified by each source.

Source / Data Base	[ID number] Tool Name
CORDIS (TOT 19)	[1] CO-IMPACT [2] ECOPotential view [3] ERA-PLANET [4] GROW [5] GROW GREEN [6] iSQAPER [7] LANDSENSE [8] MIND STEP [9] MySustainableForest [10] NAIAD [11] NATURVATION [12] NBS Simulation Visualisation Tool [13] OPERANDUM [14] RECARE [15] RUBIZMO [16] SCENT [17] SIM4NEXUS [18] SmartCulTour [19] URBAN GreenUP
MOSAIC Internal Survey (TOT 19)	[20] BirdWatch [21] CRAFTY [22] Dynamic Energy Atlas [23] EnBiLA [24] EPIC WebGIS [25] Forest structure and composition maps over Europe [26] IMPACT tool of the Flemish Climate portal [27] INCA tool [28] InVEST® [29] Land-use Planner [30] Nature value explorer [31] NEXUS Learn [32] PANDORA 3.0 plugin [33] Reinvent your street [34] RuimteModel Vlaanderen / Geodynamix [35] TargetEconBES [36] UNBiodiversity Lab [37] Waldsimulator (City-forest simulator) [38] Watch-it-Grow
WOS and SCOPUS (TOT 4)	[39] LandSFACTS [40] MPMAS [41] P@stor-all [42] ZONATION
Grey literature (TOT 13)	[43] AKIS PORTUGAL [44] C.A.F.E (Carbon, Aqua, Fire & Eco-resilience) [45] ClimateMatch [46] CropSAT [47] DAKIS [48] E-Planner [49] Global Forest Watch [50] Land App [51] LANDSUPPORT [52] Land-use Finance Tool [53] MicroLEIS DSS [54] Myforest [55] ViSA - Viability of the social-ecological agroecosystem

To briefly describe the tools, 82% are in operation, whereas five tools are still prototypes, and four are under development (Figure 8). Most tools are developed by universities or research institutes (Figure 9). Of the 46 operational tools, two have no information on the year of launch, and there is a concentration of tools launched after 2013, with a peak of eight tools launched in 2018. The oldest tool recorded is from 1997 (Global Forest Watch - https://www.globalforestwatch.org/), and the most recent is from 2024 (P@stor-all, https://pastorall.supagro.inrae.fr/). Regarding country of origin, EU consortia have developed a significant stake, and eleven single countries have produced digital tools (Figure 11). The results also include three tools developed by entities located outside Europe but with applications in Europe: UNBiodiversity Lab (https://unbiodiversitylab.org/en/), InVEST® (https://naturalcapitalproject.stanford.edu/software/invest), and the already mentioned Global Forest Watch.

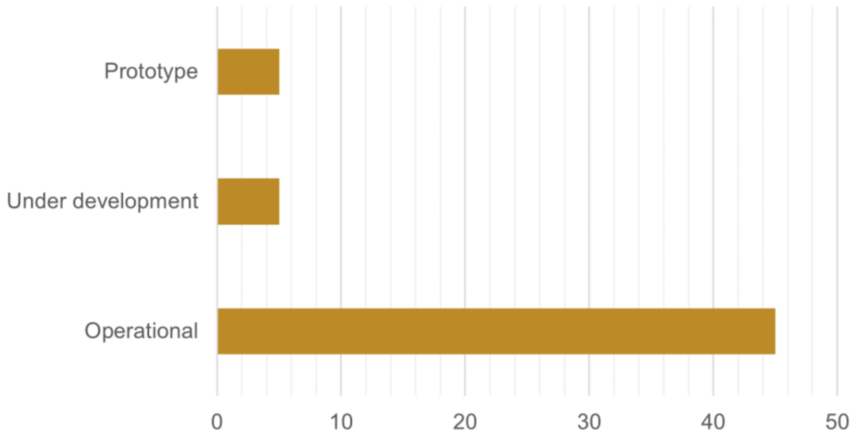


Figure 8: Level of development of the collected tools

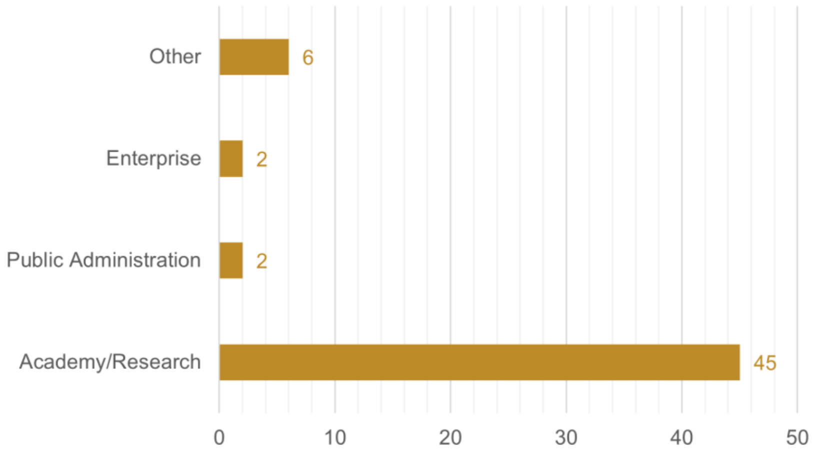


Figure 9: Type of developer of the collected tools

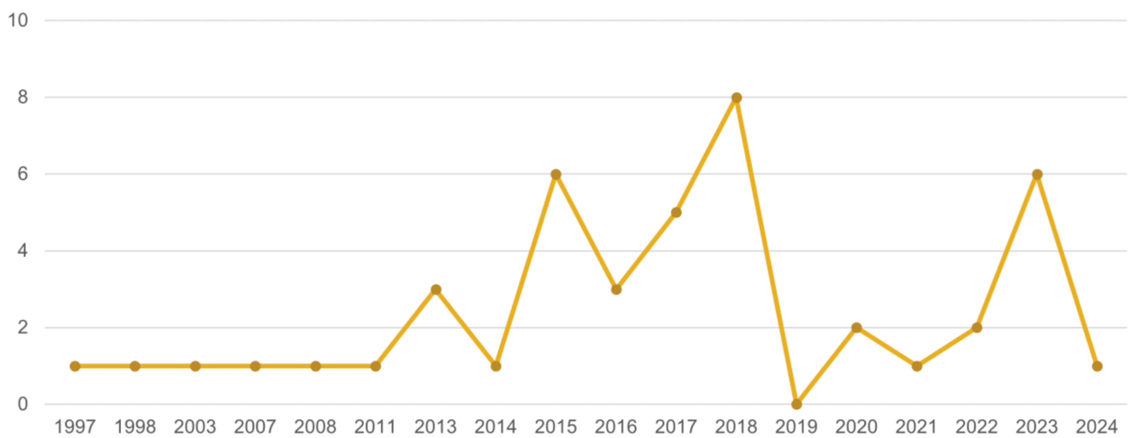


Figure 10: Launching year of the operational tools

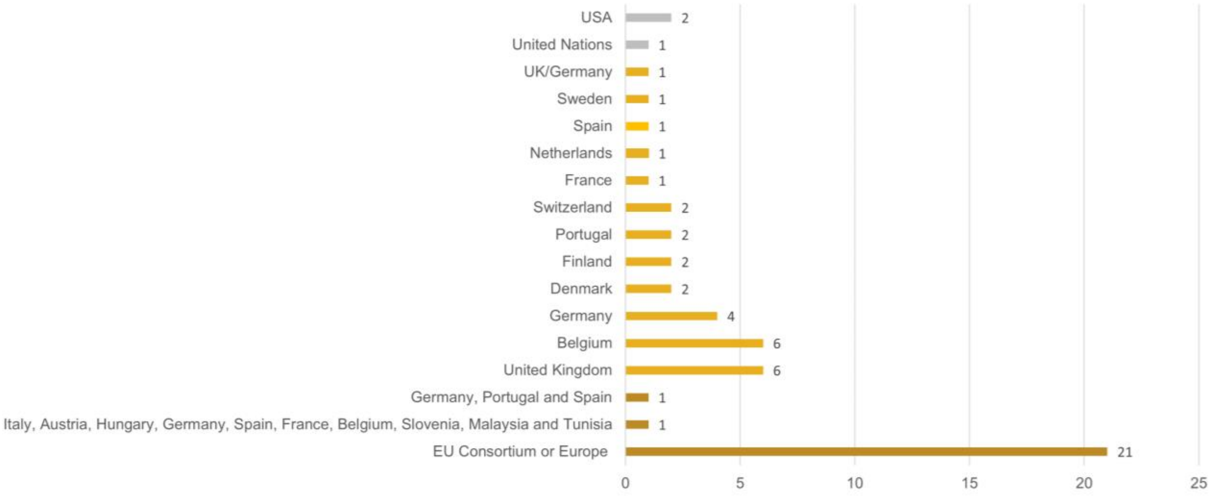


Figure 11: Country(ies) that developed the tool

The main domain of the analysed digital tools is mixed land uses, following agricultural/forestry decision support systems and those related to ecology, biodiversity and conservation (Figure 12). Regarding the type of digital tools (Figure 13), 18 are classified as interaction and visualisation (e.g. EPICWebGIS, SIM4NEXUS, RUBIZMO), 14 with multiple functions (e.g. Dynamic Energy Atlas, CRAFTY, Nature value explorer), nine are dedicated to analysis performance (e.g. OPERANDUM, Land-use finance tools, INCA tool), seven focus on stakeholder engagement (e.g. NAIAD, SmartCulTour, MIND STEP), three on simulations (e.g. NBS Simulation Visualisation Tool, MPMAS), two on scenario modelling (e.g. ViSA, IMPACT tool) and two exclusively on land use modelling (ZONATION, MySustainableForest). Regarding the policy sector (Figure 14) to which the tool is related, the majority are multisectoral, covering several policy sectors (agriculture, spatial planning, forestry, environment, climate, protected areas management, rural development and governance). Second is the agricultural sector followed by spatial planning and forestry. The climate policy sector only has two tools related to it.

Almost 50% of the tools are multiscale, combining European, national, regional or local scales (Figure 15). In the other half, the tools for the local scale are dominant, with 14 cases. Also, 80% of the tools deal with spatially explicit output (Figure 16).

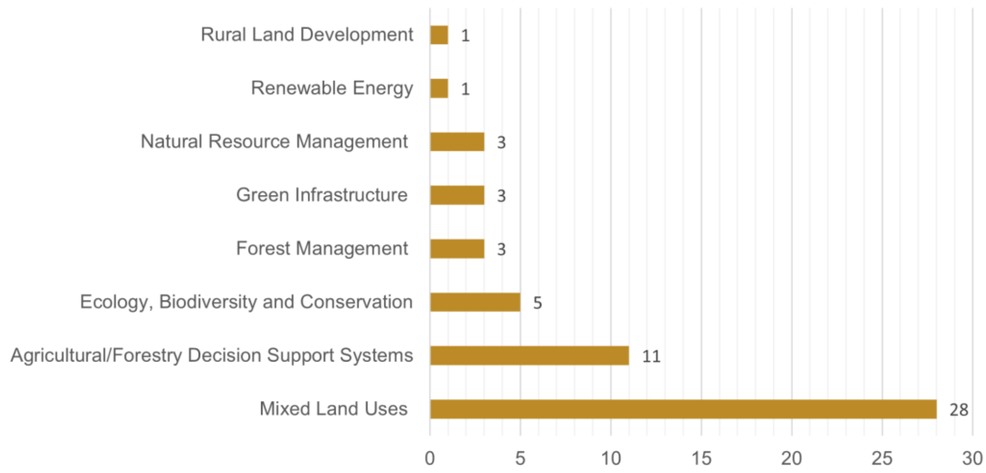


Figure 12: Main land use domain

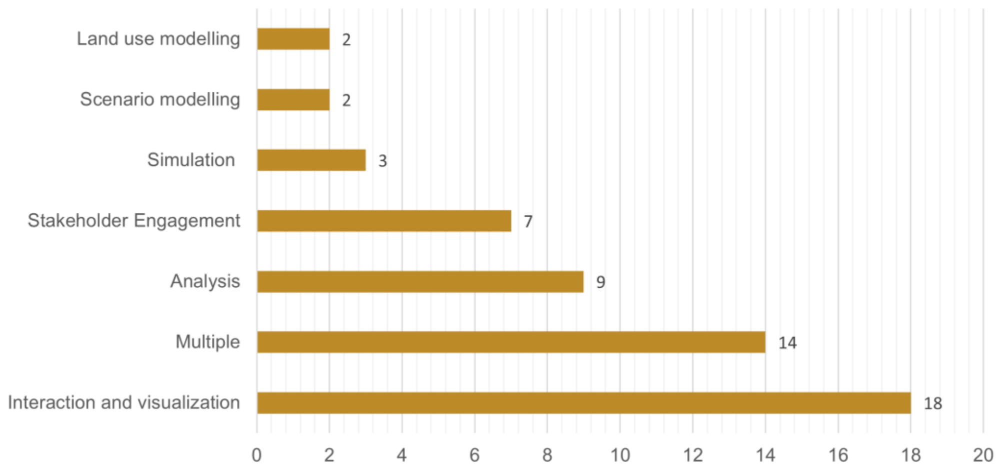


Figure 13: Type of digital tools

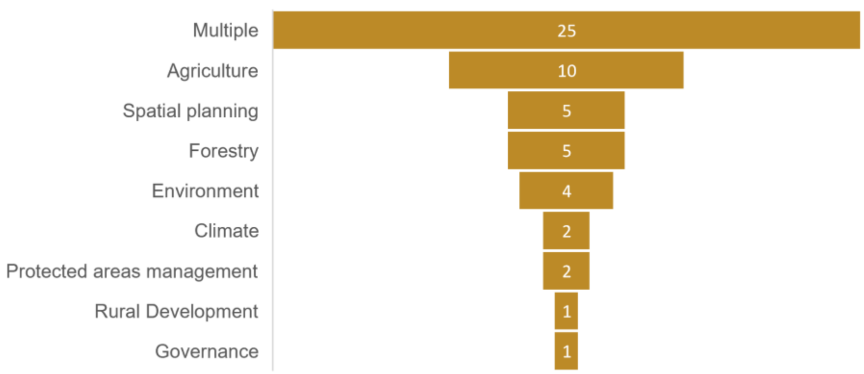


Figure 14: Policy sector related with the tool

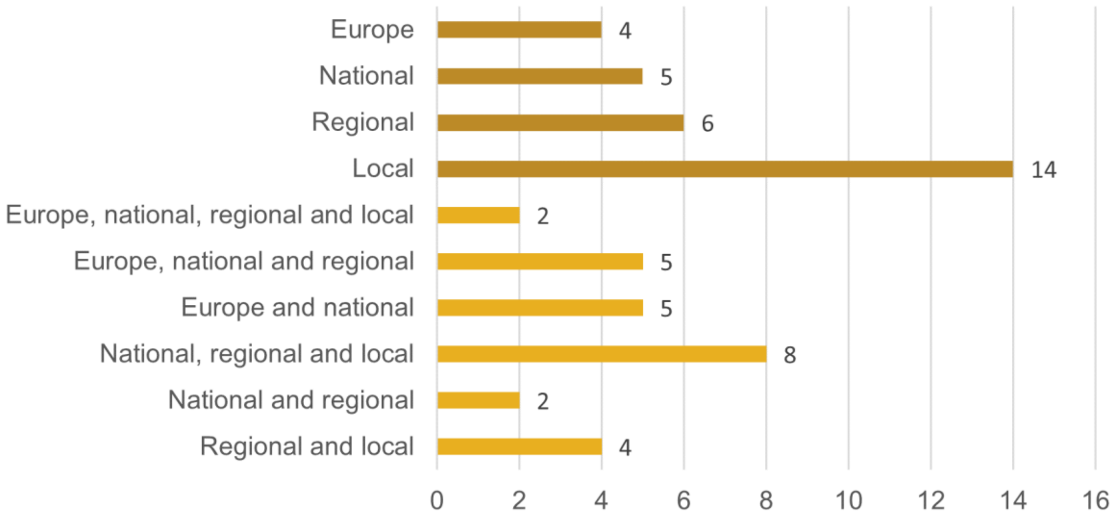


Figure 15: Scale of the tools

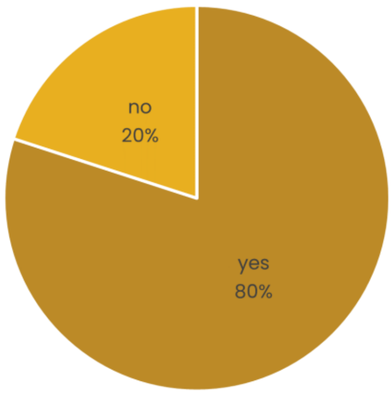


Figure 16: Spatially explicit output

Regarding tool data, most tools use qualitative and quantitative input data (Figure 17). Still, 22% only use quantitative information, and 25% exclusively work with qualitative data. The input data type (Figure 18) is spatial for almost 40% of the tools (21 tools), followed by multiple types (ranging from statistics to spatial) and also those using expert knowledge (7 tools). Despite 80% of the tools being spatial explicit (Figure 16), for 29 tools, the output is aggregated data (Figure 19), meaning it is not exclusively a cartographical output. Regarding the time frame of the output provided by the analysed tools (Figure 20), about 70% deal with the current time frame, 11% short-medium term, and only 7% provide long-term results (e.g. CRAFTY, EnBiLa, IMPACT tool). Six tools cover current to long-term results: Dynamic Energy Atlas, Nature Value Explorer, Land-use planner, InVEST, NEXUS Learn and BirdWatch.

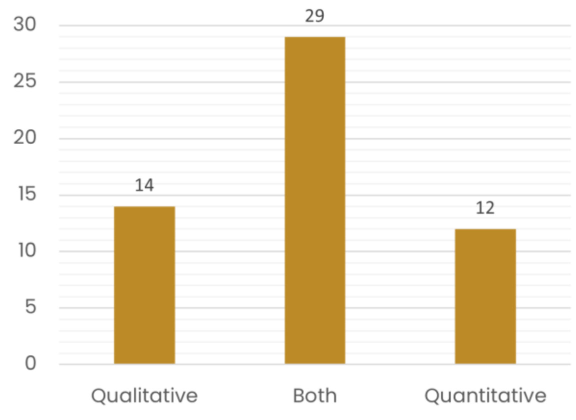


Figure 17: General input data type

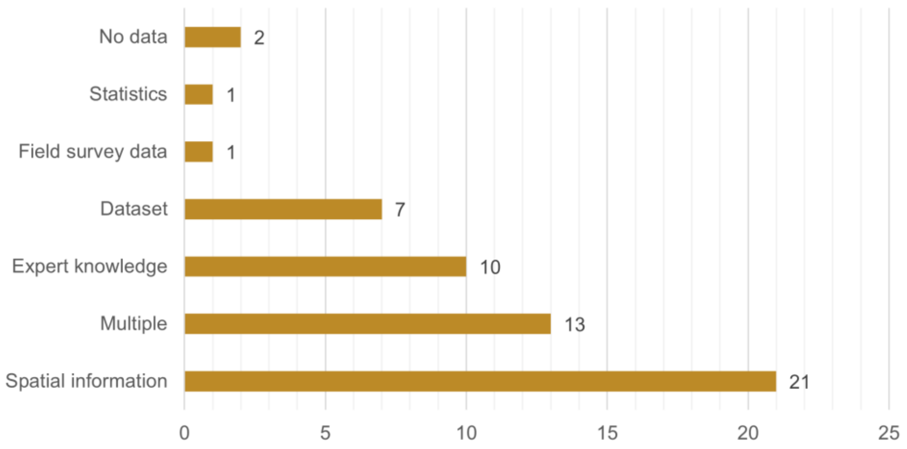


Figure 18: Detailed input data type used in the tool

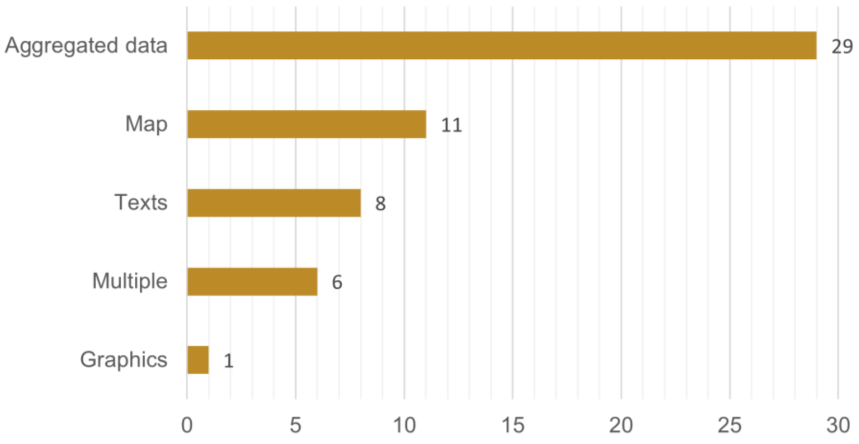


Figure 19: Detailed output data type

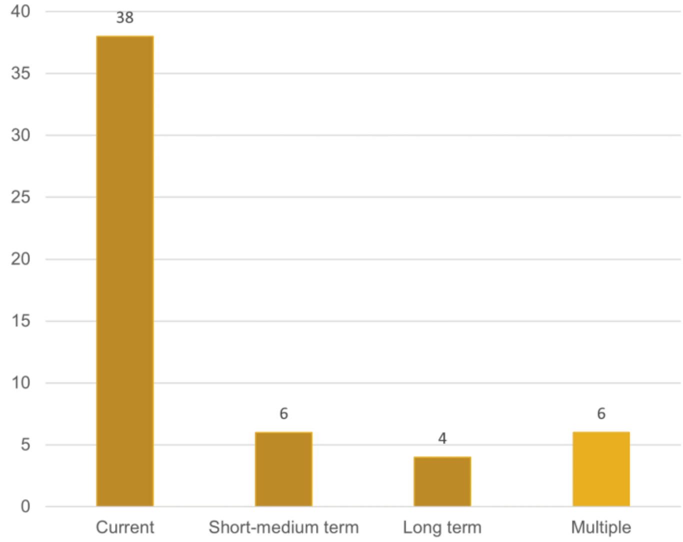


Figure 20: Output timeframe

The information about tool users is scarce, especially concerning the number of users. When analysing the type of end users and considering four categories (Citizens, Academy, Policy-makers, and Land Managers), 25 tools address the full range of end users; only one is aimed solely at citizens, and 10 are directed to land managers (Figure 21).

Only 9% of the tools are considered to have a high time investment requirement, while the rest have low to medium time investment requirements for use or learning to use (Figure 22).

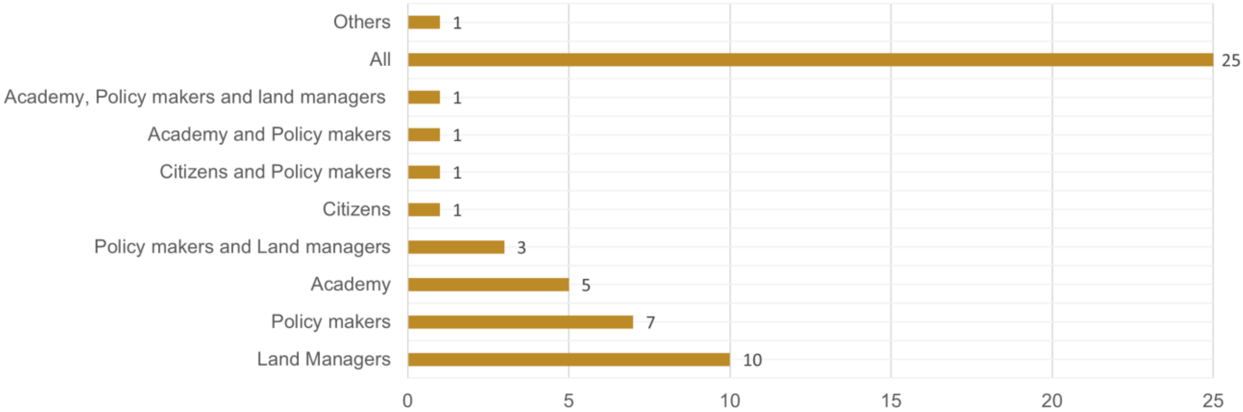


Figure 21: Type of end-user

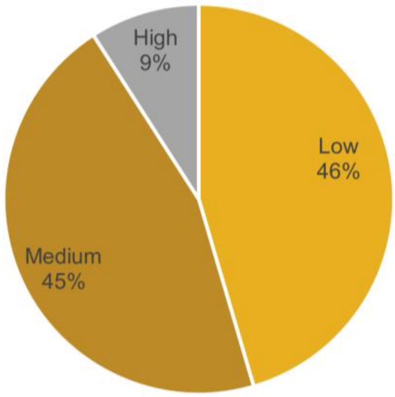


Figure 22: Time requirement for use or learning to use the tool

3.2 Inspiring Digital Tools

This section describes ten inspiring tools selected from the digital portfolio. Due to their scope and functions, these tools are an interesting reference for decision-makers and the co-design of the DLE. In addition, the selection criteria for inspiring tools prioritize a balance between innovation and practicality, aiming to make advanced data and analysis accessible to a broad audience. We have chosen tools that are not only innovative but also practical, aiming to make sophisticated data and analysis available to a broad audience. In this sense, each tool has been selected for its distinct approach to supporting land use decisions and its potential to advance EU policy targets. They also represent examples of applications closely related to MOSAIC scope and its Policy Labs challenges.

Table 3: Inspiring digital tools

TOOL Name	TOOL Type	Link
LANDSUPPORT	GeoSpatial Decision Support System (S-DSS)	https://www.landsupport.eu/
OPERANDUM	Platform for Nature-Based Solutions	https://geoikp.operandum-project.eu/
SIM4NEXUS	SERIOUS GAME	https://seriousgame.sim4nexus.eu/sim4nexus-LoginPage.html
Global Forest Watch	Visualisation and interaction Platform Datasets	https://www.globalforestwatch.org/
UNBiodiversity Lab	Visualisation and interaction Platform Datasets	https://unbiodiversitylab.org/en/
ClimateMatch	Visualisation and interaction Platform Datasets	https://climatematch.org.uk/
Land-use Finance Tool	Guidance and template to map land-use finance	https://landusefinance.org/

TOOL Name	TOOL Type	Link
RUBZIMO	Interaction and visualisation	https://rubizmo.eu/e-learning
C.A.F.E	Interaction and visualisation	https://www.resilientforest.eu/dss-tool/
Land-use planner	Analysis, simulation, land use and scenario modelling	https://landuseplanner.org/

1. LANDSUPPORT

LANDSUPPORT is a free-to-access geospatial decision support digital tool that aims to support forestry and sustainable agricultural practices, assess land-use trade-offs and contribute to developing and implementing land-use policies in Europe. This digital tool is available at different geographical and governance scales, from European to regional/local scale – in Italy, Hungary and Austria – and with two pilot projects in Malaysia and Tunisia, which allows the digital tool to be used in different physical, socio-economic and cultural contexts.

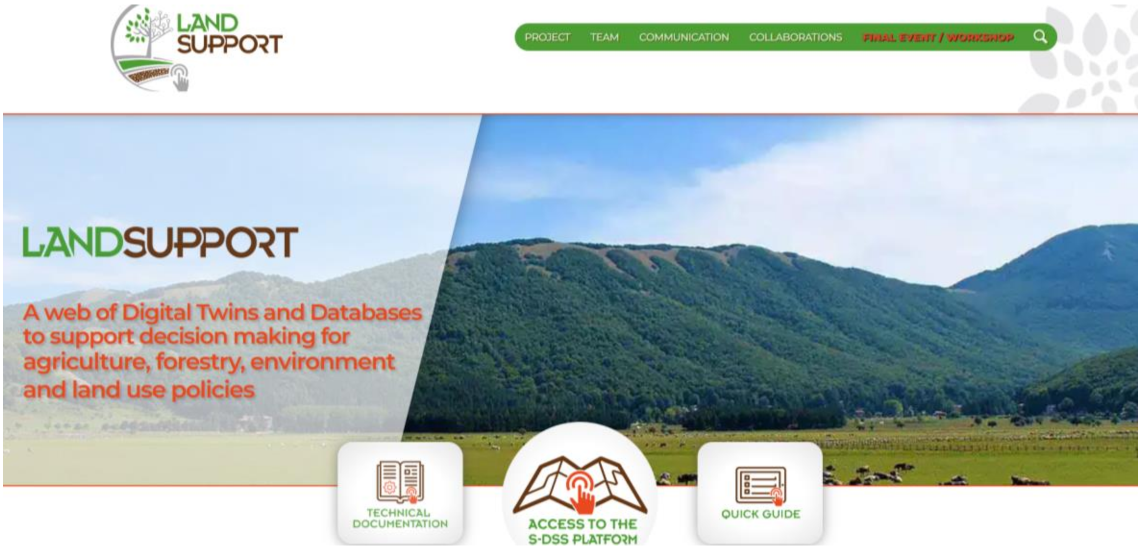


Figure 23: LANDSUPPORT, Web page

2. OPERANDUM

OPERANDUM is a digital, free-access tool that promotes nature-based solutions to increase knowledge about the efficiency in mitigating hydrometeorological risks, supporting technological innovation and adopting practices in national policies. This tool is available worldwide and is structured differently depending on the type of user (Scientist, Business & Investors, Policy-maker, Association, Citizen, News & Media).

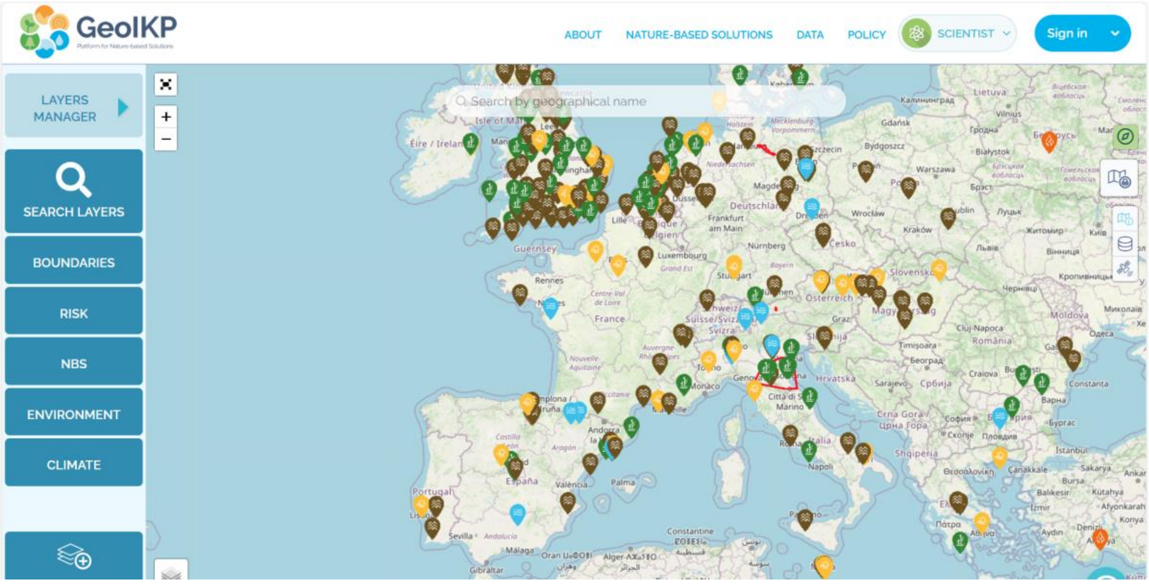


Figure 24: OPERANDUM, Web page

3. SIM4NEXUS

SIM4NEXUS is a digital tool like a "computer game" that aims to contribute to fostering knowledge about the Nexus between the management of land, energy, water and food resources in a climate change scenario. The SIM4NEXUS used the Nexus concept in 12 case studies, applied at global, European, cross-border, national and regional levels, and an interactive page/ map is available that presents the complexity of modelling Nexus relationships.

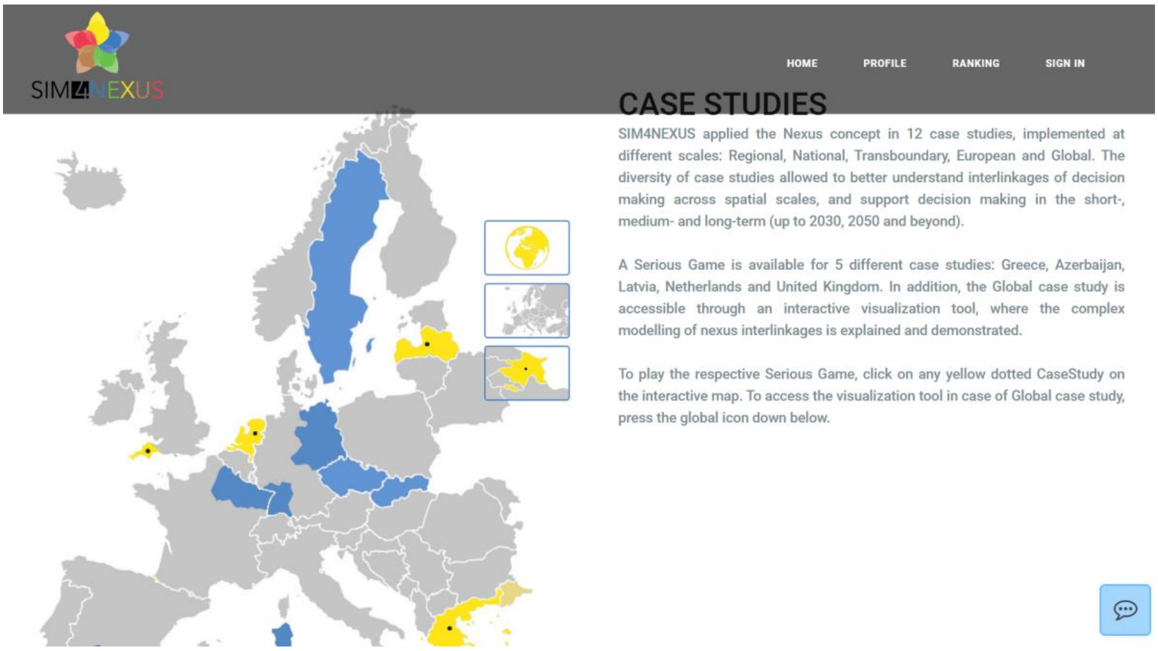


Figure 25: SIM4NEXUS, Web page

4. Global Forest Watch

Global Forest Watch is a free digital tool that makes it possible to monitor forests on a global scale. The digital tool has a map and a control panel, allowing users to search and analyse a set of data, from global to local scale, on the use and conservation of land and forest. This digital tool is designed to demonstrate the current state of conservation of forests globally, to raise awareness about protecting forests.

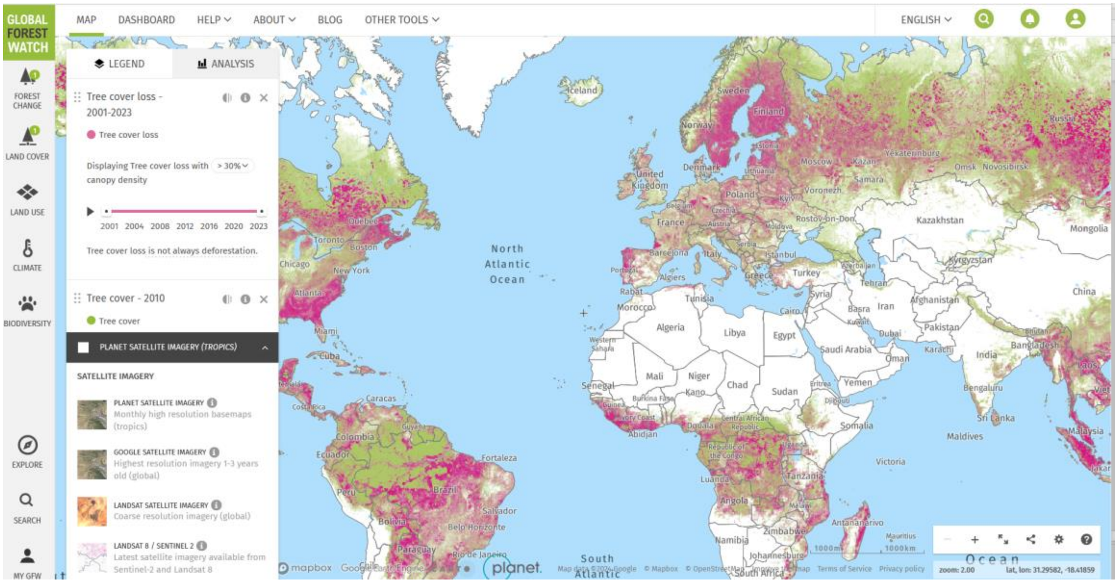


Figure 26: Global Forest Watch, Web page

5. UNBiodiversity Lab

UNBiodiversity Lab is a digital tool, free of charge, whose objectives are to visualise spatial data on a global scale associated with nature and sustainable development practices, set up working groups that promote data sharing and cooperate across different sectors, and use the knowledge sharing of UNBiodiversity Lab partners to develop national strategic plans.

Figure 27: UNBiodiversity Lab, Web page

6. ClimateMatch

ClimateMatch is a free-to-access digital tool that aims to support users in understanding and acting on climate issues. The digital tool connects scientific information with practical solutions, enabling users to make (informed) decisions about the impact of climate change. In addition, it offers an interactive platform that allows the analysis of climate data, identifies specific risks in different sectors and regions, and suggests adaptations or interventions to be carried out in order to address climate challenges.

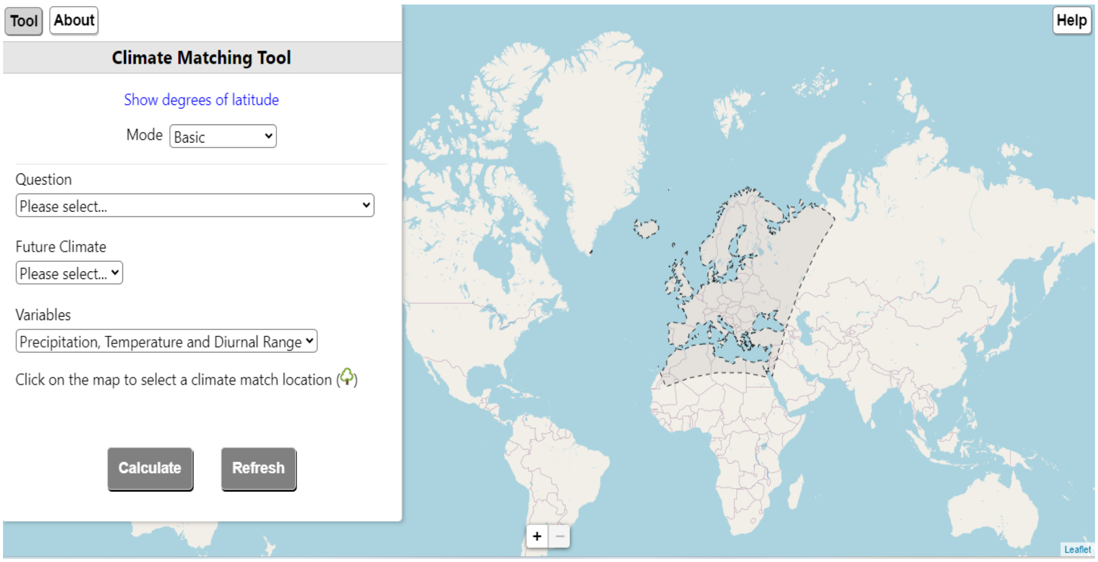


Figure 28: ClimateMatch, Web page

7. Land-use Finance Tool

Land-use Finance Tool is a digital tool that supports the analysis and monitoring, by governments, organisations and financial institutions, of investments related to land use. This tool was developed to facilitate decision-making by clearly showing the relationship between financial investments and environmental practices and goals.

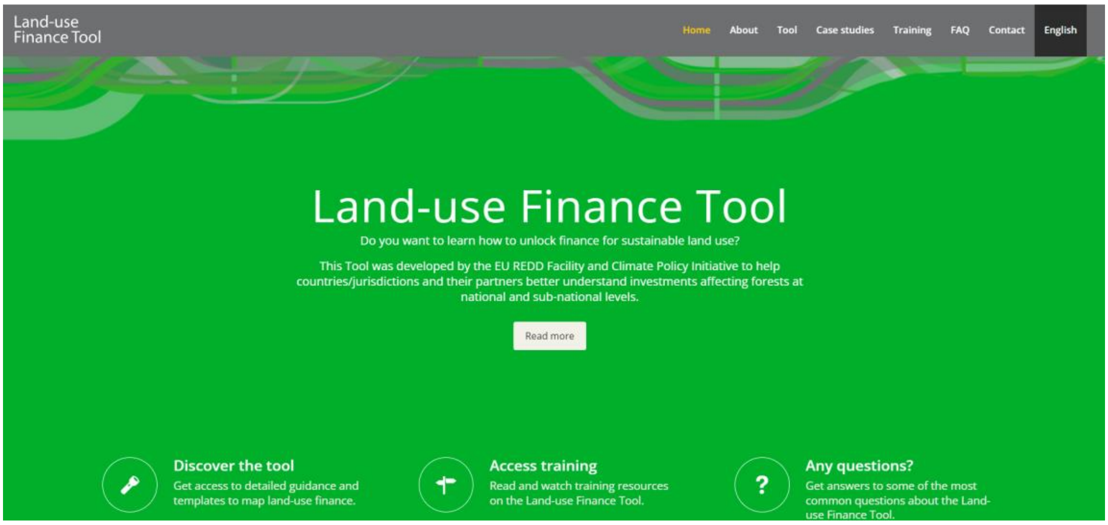


Figure 29: Land-use Finance Tool, Web page

8. RUBZIMO

RUBZIMO is a digital tool that aims to optimise the biomass value chain for sustainable energy and products. This tool offers models and simulations to support farmers, businesses, and policy-makers in making informed decisions about the efficient use of biomass resources. In addition, the platform allows the analysis of productivity, environmental impact, and respective costs, allowing users to maximise efficiency and sustainability throughout the biomass production process.

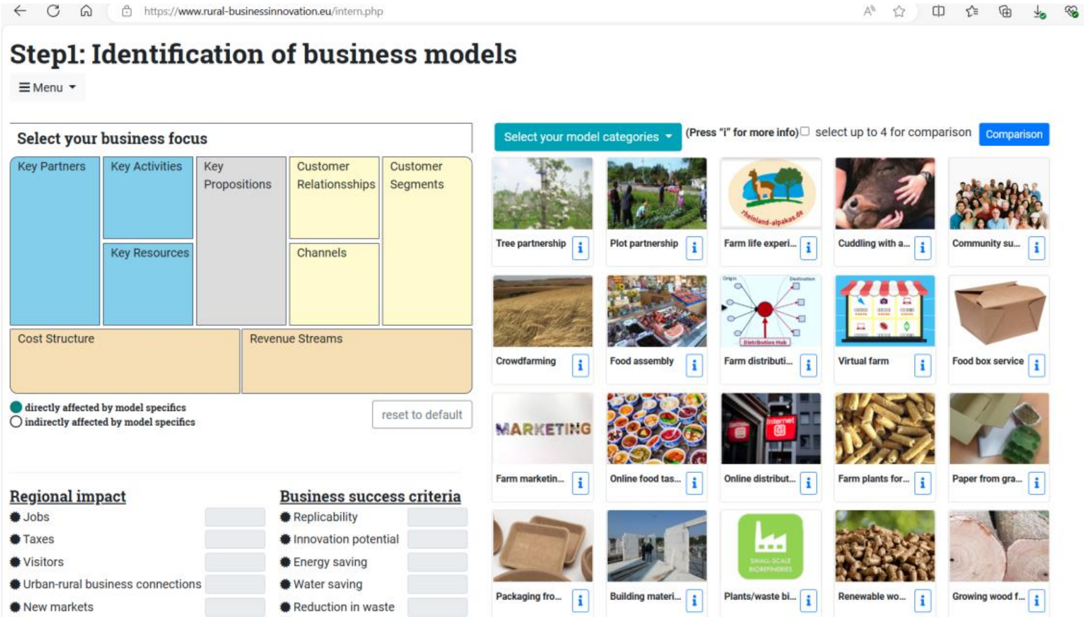


Figure 30: RUBZIMO, Web page

9. C.A.F.E

C.A.F.E. is a digital tool, free of charge, developed to support the integrated management of natural resources. In addition to assessing and monitoring four fundamental factors – carbon, water, fire and ecological resilience – this tool combines environmental data with modelling, which helps decision making considering sustainability and adaptation to climate change.

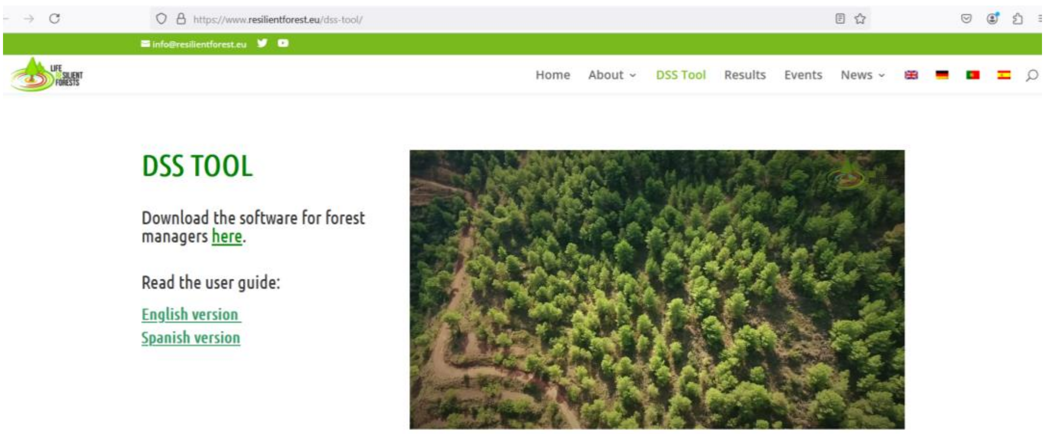


Figure 31: C.A.F.E, Web page

10. Land-use planner

Land-use Planner is a digital tool that helps governments, organisations and citizens to plan sustainable land use through participatory planning. In addition, it facilitates the analysis of different land use scenarios, allowing users to assess the environmental, economic and social impacts of their decisions.

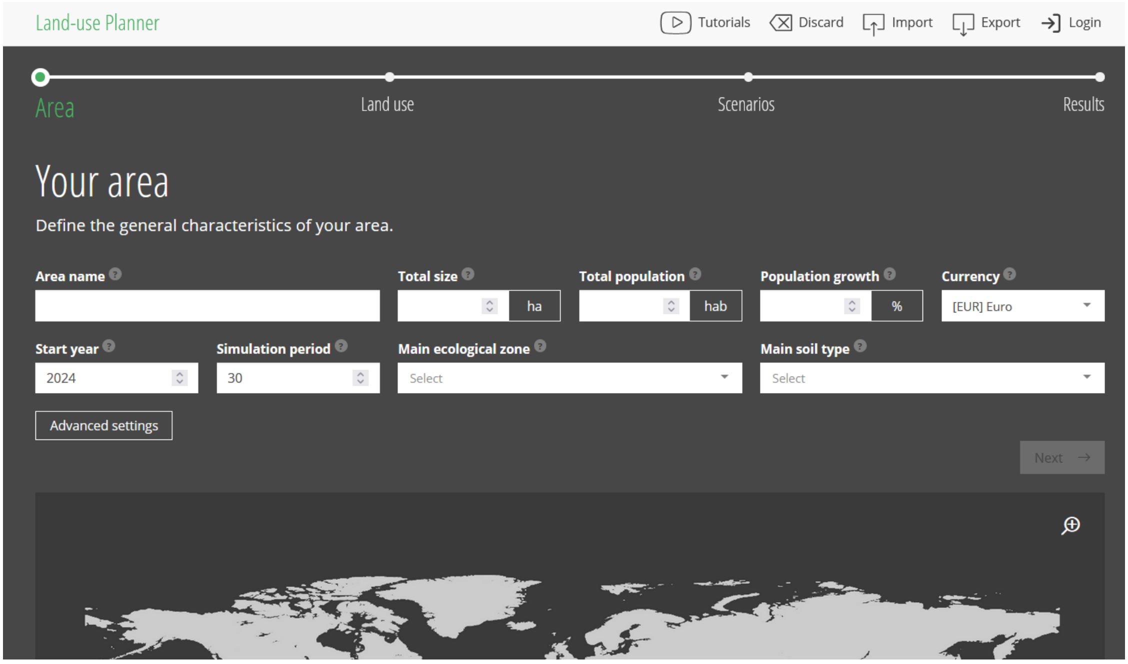


Figure 32: Land-use planner, Web page

4 EXPLORING POTENTIALS AND LIMITATIONS OF EXISTING DIGITAL TOOLS

4.1 Insights from MOSAIC partners

The systematic review shows different types of digital tools with different scopes, scales and contexts, providing a sample of the existing tools with different potential and limitations.

In a broader sense, digital tools have the potential to integrate scientific knowledge and advanced technologies with local contexts and traditional knowledge, supporting decision-making processes. However, digital tools also provide difficulties or barriers to their use, such as accessibility limitations (awareness of the tool's existence, cost and availability or complexity to learn), lack of trust/acceptance of the technology, and adaptability of the tool to solve a need (Bestelmeyer et al., 2024). In specific contexts, such as digital agriculture, more barriers to uptake can be found (Dibbern et al. 2024), such as the farmer's economic and financial condition, the availability of technological infrastructure, the farmer's educational background, and age.

According to Bestelmeyer et al. (2024), integrating digital tools with social networks enhances their relevance and effectiveness. These authors further suggest incorporating these tools into community-based collaborative adaptive management, which emphasizes feedback among monitoring, learning, and management with multiple stakeholders. Dibbern et al. (2024) also highlight the importance of sharing knowledge and resources in a cooperative network to mitigate the digital tool barrier.

In the internal survey conducted with MOSAIC partners (both users and developers), two more questions were included, related to the key motivations and barriers for uptake:

- *What were your main motivations for developing the tool if you were a developer?*

  What are your main motivations for using the tool if you are a user?

- *If you're a developer, what constraints do you identify when developing a tool?*

  What are the main barriers you identify when using this tool if you're a user?

The identified key motivations were categorised into four groups (

Table 4):

1) the possibility of scenario modelling and simulation;
2) to use or provide decision support and visualisation tools;
3) enabling environmental policy and governance;
4) the possibility of using/creating a user-friendly environment.

Table 4: MOSAIC team survey answers organized into four groups of key motivation to use or develop a digital tool

Scenario modelling and simulation	Decision support and visualisation tools	Environmental policy and governance	User-friendly environment
• Get insights into possible future patterns of land use at a regional scale. • To allow modelling of human behaviour within the land system, and feedbacks with ecological systems. • The maps are produced to initialize models that are able to simulate forests (e.g. structure, function, and carbon cycle of forests). • Compare different scenarios. Nice dashboard with scenario results (statistics, graphs, traffic light visual, performance of scenario against targets). • To help policymakers in making scenarios to achieve their climate ambitions. •To understand competition for land and better account for interactions between Biodiversity and ES (regulation and provision).	• Tool developed for a broad audience: develop an interactive map that show complex spatial indicators (map) in a simple way so a broad - non expert public can easily use them. • You can visually represent the territory and make modifications on top of it in order to show a reality. • To alleviate the pressure on environmental services. The digital tool allows local planners to easily look up information and maps on climate impacts. • Visualise the socio-economic value of green-blue areas.	• To help water managers get better insights in the sources of different pollutants in the surface water. • To measure and improve biodiversity using satellite data for monitoring, evaluation and optimization of CAP greening initiatives. • Getting more people inspired with how to adapt to climate change. • "Digital transformation" to support quantitatively support the path to sustainable/regenerative agriculture. • We look for different approaches to solving complex problems using transition science and systemic thinking as a basis.	• Get overview and estimate trade-offs. • User-friendly with access to many datasets. Flexible workspaces for national datasets. • Map viewer with primary forests and tree cover loss (with time sliders).

The main constraints when developing a tool or the main barriers identified by a user were organised into four groups. These groups help to identify different types of obstacles, highlighting the areas that need attention, whether in terms of technical development, data quality and accessibility, governance or communication (Table 5).

Table 5: MOSAIC team survey answers organised into four groups of barriers to the uptake of a digital tool

Technical barriers	**Data barrier**	**Policy and Governance Barriers**	**Communication and Knowledge Dissemination Barriers**
• Too complex model to use by non-modellers, close collaboration between modellers and end users is necessary. • Modelling skills. • It is not an intuitive programme, and requires some training. • Interpretability and flexibility. • Good water quality data, enough time and money to develop the tool conform to the wishes of the users of the tool • for urban lack on data on functioning NBS. Some technical constraints. • Static information, not provides scenario development. • CAPEX costs for data updates, feature requests, marcom/outreach, and governance (many stakeholders). • Availability of field observation data.	• Recent and reliable data on renewable energy. • National data is not available and often of higher quality and better suited for decision-making. • User difficult to get relevant data. • The vulnerability assessment only takes into account the urban factors such as housing and industry. The costs of the impact on nature and agriculture are not in the tool.	• The tool was not used a lot, as the demand for such a tool changed during the course of the project. • Taking about climate change is often difficult as you need to talk about possible scenarios etcetera. The tool was simplified by only showing the high impact scenario, as policy makers very often discarded the high scenario as the 'unlikely' scenario. • The main barrier is a societal focus on reductionist thinking to approach and solve problems. Most processes still focus on a sectoral solution within the silo the problem occurs instead of taking into account all relationships with other siloes/sectors and stakeholders.	• Difficult balance between complex indicators and user-friendliness.

To gain a deeper understanding of the key motivations and challenges, we implemented a multi-step process (Figure 33) that involved (a) exploring the developer's perspective through interviews, (b) capturing the users' viewpoints via surveys, and (c) collaboratively co-developing innovative ideas to enhance synergies between digital tools and Task 5.2, using a dedicated workshop.

Figure 33: Multi-step process to deep key motivations and challenges

4.2 Insights from Developers and Users

The results of the systematic review show that digital tools can help with land use decision-making by providing relevant information to stakeholders and facilitating complex scenario analysis. However, some research challenges of the present study still require more details focusing on the conception and development of digital tools, which is important to advance knowledge in this field and collect valuable information for the co-design of the Digital Learning Environment (DLE)(Task 5.2).

This highlights the need to consider the perspectives of digital tool developers and users more deeply. In this sense, the systematic review has been complemented by an interview study and an online survey, combining qualitative and quantitative methods, to gather insights from digital tools developers and users. This approach aims to answer the **reflective questions RQ4 "What are the best practices and success factors for developers in designing and deploying practical digital land-use decision support tools?" and RQ5 "How do users perceive the effectiveness and usability of digital land-use decision support tools in real-world decision-making processes?",** which are oriented to understanding the perspective of those who developed digital tools, the types of users and their perceptions and opinions, and the contexts in which they have been used until now.

The interview study included five developers selected from MOSAIC consortium partners to collaborate on designing digital model-based services in the Policy Labs embedded into the DLE (Task 5.2). Moreover, the five digital tools are associated with a framework for assessing and managing land use, energy, biodiversity, and ecosystem services, aligning with some of the main research topics of the MOSAIC project.

Interviews were conducted via video conference in September 2024, lasting 45–60 minutes each. The developers were selected by looking into the 55 digital tools collected and matching them with MOSAIC partners. The five developers selected for the interviews correspond to the following digital tools and respective institutions (Table 6):

a) **Competition for Resources between Agent Functional Types (CRAFTY) -** is a land-use modelling tool that simulates how different agents compete for resources and land use, incorporating socio-economic and ecological factors to assess future land-use scenarios and ecosystem services (Calum & Rounsevell, 2014);
b) **Dynamic Energy Atlas (DEA) -** is a spatial analysis tool designed to model and visualise energy consumption, production, and infrastructure across regions. It supports sustainable energy planning and decision-making by providing insights into energy flows and potential energy savings (VITO, 2015);
c) **Energy and Biodiversity Landscape Assessment (EnBiLA)** is a tool used to assess energy projects' impact on landscapes' biodiversity. It integrates biodiversity data with energy infrastructure planning, aiming to support the development of environmentally friendly energy solutions. This tool is still in the prototype stage;
d) **EPIC webGIS** is a Geographic Information System (GIS) platform designed to map and analyse landscapes and ecosystems. It helps users assess ecological indicators, land-use suitability, and biodiversity, supporting sustainable landscape management (ISA & LEAF, 2013);
e) **NATURE VALUE EXPLORER (NVE)** is a decision-support tool that evaluates ecosystems' value and services. It is aimed at helping policy makers and stakeholders understand the economic and ecological benefits of nature conservation and sustainable land management practices (VITO, 2013).

Table 6: References of the five digital tools selected for developers' interviews

Digital Tool	MOSAIC Partner	Country	Online Link	Interviewed Date
Crafty	KIT – Karlshruher Institut Fuer Tecnhologie	Germany	https://landchange.imk-ifu.kit.edu/CRAFTY	September 30, 2024
Dynamic Energy Atlas	VITO – Vlaamse Instelling voor Technologisch Onderzoek	Belgium	https://vito.be/en/news/how-much-renewable-electricity-can-be-generated-within-belgian-borders-dynamic-energy-atlas	September 19, 2024
EnBiLa	ETH Zurick	Switzerland	https://www.energyscape.ethz.ch/index_EN.html (only prototype)	September 20, 2024
EPICWebGIS	ISA – Instituto Superior de Agronomia	Portugal	http://epic-webgis-portugal.isa.ulisboa.pt/	September 23, 2024

Digital Tool	MOSAIC Partner	Country	Online Link	Interviewed Date
Nature Value Explorer	VITO – Vlaamse Instelling voor Technologisch Onderzoek	Belgium	https://www.natuurwaardeverkenner.be/	September 24, 2024

The interview guide has been regraded to gather information about the tool's development, functionalities, impact, and user experiences, including eight open-ended questions and one yes/no question on 11 specific topics (see Appendix B).

The eight questions were selected to collect different perspectives and experiences on:

1. Developer background;
2. roles of each developer in developing the tool;
3. research questions and challenges addressed with the tool;
4. main constraints in its development;
5. stakeholders' involvement in testing and evaluating;
6. embeddedness of the tool in the specific context and the opportunities for generalisation across multiple geographical contexts and different spatial and temporal scales;
7. key motivations and barriers for the uptake;
8. increase the uptake of (existing) tools and co-develop recommendations.

Questions were consistently applied across all interviews, but flexibility in the ensuing dialogue was encouraged to allow the flexibility of each developer's narrative to unfold. The first question in each interview starts with the researcher introducing herself, providing an overview of the background (Figure 34), and obtaining consent from each respondent to participate in the research.

	CRAFTY	DYNAMIC ENERGY	EnBiLA	EPICwebGIS	NATURE VALUE EXPLORER
Background	Physical Geography	Geography	Environmental Sciences	Landscape Architecture	Environmental Economics
Main role as developer	Initiate the design and development of the digital tool Updating of the conceptualization and representation of the process.	Updating the design and representation of the process, through the introduction of improvement actions, additional models, innovation and strategic development.	Responsible for coordinating the digital tool Supports the development of the digital tool by organizing exchange projects with future users.	Coordinate research projects associated with the delimitation of the national ecological structure and a territorial planning proposal for the country.	Responsible for building the conceptual approach and calculating the digital tool Supports communication with users to see what can be modified or if there are problems with the digital tool.

Figure 34: Characterization of the developers (background and role)

The recordings were transcribed using READ AI, and the accuracy of the interview transcripts was reviewed against the interview recordings. The final transcripts were then analysed in INSIGHT7, using systematic coding to extract patterns of words, their frequency, relationships and trends.

This approach has been chosen to support the elaboration of final results with suitable information for easily reporting technical topics, especially for non-academic audiences. In this sense, the content analysis has been systematised according to four main categories of results: **research questions and challenges** (Table 7) **key insights from each digital tool** (Table 8) and **challenging trends for tool developers** (Figure 35).

Table 7: Research questions and challenges

Digital Tool Name	Description
CRAFTY	The research questions behind the development of the digital tool are related to the ambition of **developing a large-scale Earth system model** based on an **agent-based modelling approach** and the need to analyse **how the land system responds to multiple environmental change factors**. This includes changes in the physical environment due to climate change and changes in the socio-economic environment due to changes in social or macroeconomic preferences. In this context, the digital tool allows us to analyse how individual land stakeholders, represented in the model, respond to these changing conditions. In turn, the challenge of developing the digital tool was linked to **constructing a large-scale model based on agents in large geographic areas**.
Dynamic Energy Atlas	The primary goal of the digital tool is to identify **suitable locations for installing renewable energy sources.** By facilitating spatial planning of the Flanders region, the digital tool offers an overview of the **potential for renewable energy productio**n. This contributes to both **energy self-sufficiency and the overall sustainability of the region**.
EnBiLA	One of the research questions that led to the construction of the digital tool is related to the need to create robust **solutions for producing renewable energy**, and **preserving biodiversity** and the **Swiss landscape**. The challenges that the digital tool intends to face are related to the possibility: i) creating a platform with **integrated data for the entire country** (Switzerland) that **all citizens can use**; ii) producing **renewable energy, preserving biodiversity, the ecosystem and the Swiss landscape.**
EPIC WebGIS	The development of the EPIC WebSIG emerged as a response to a **lack of cartography in Portugal that supports spatial planning**. One of the objectives is to save and improve the **understanding of the data** and the

Digital Tool Name	Description
	ecological functioning of the landscape if it were available to everyone. Two research projects were the basis for the construction of this platform. The first project focussed on the **delimitation of the national ecological network**. The methodology adopted for this was based on the cartographical integration of all the areas indispensable to the functioning of ecosystems , starting with typical natural resources, such as soil, water, air circulation and the land morphology. The second project was a **proposal for spatial planning for the country**. We began to integrate data from various components of the landscape system. These were a step forward from the landscape's cartography and have also been widely used.
Nature Value Explorer	Initially, a manual for **cost-benefit analysis** was being made, and all the **effects or the impact on nature** was a question mark. The original research question was, **how can we somehow provide numbers to calculate the impact on nature and open space**? But, then it grows more to what the impact of any land use change is on ecosystem services. That was in the second phase, and the tools also grew because, in the beginning, it was simple Excel. But then, because we saw that people did wrong things, we optimised a bit, and it became a web tool. The **research questions have changed over the years**.

Table 8: Key insights from each digital tool

Digital Tool Name	Description
CRAFTY	**Key motivations:** need to inform political processes, understand how individual decision-making about land use and management contributes to testing theories and improve understanding of the functioning of the Earth system. There is a focus on education and user-friendly interfaces for broader accessibility. **Stakeholder Engagement:** CRAFTY engages diverse stakeholders in land-use decisions. **Geographic scale:** multiple geographical contexts, including several European countries and an ongoing application in Egypt. **User Base:** Run the model: 10-20 users | Use the data: 10 users | Stakeholders: 50 users.

Digital Tool Name	Description
Dynamic Energy Atlas	**Key Motivations:** Manage climate change impacts and assess renewable energy infrastructure. **Barriers:** Difficulty in quantifying data locally, data accuracy issues. **Stakeholder Engagement:** Involves a diverse committee for tool development and implementation. **User Base:** 10 projects > around 30-50 multiple users
EnBiLA	**Key Motivations:** Identifying optimal and visualising renewable energy sites and data download capability. **Geographic scale:** Currently, in the cantons of Switzerland, there is a future expansion to a municipal scale. **Barriers:** Inability for users to upload data. **Stakeholder engagement:** Workshops for feedback and improvement. **Key motivation:** Capacity to engage stakeholders, improve knowledge, and support decision-making across various land-use topics.
EPIC WebGIS	**Key Motivations:** Public service and support for political decision-making drive its development. **Stakeholder Engagement:** The tool effectively engages stakeholders in land-use decisions. **Barriers**: Funding for maintenance and official recognition of data are significant obstacles. **Skills Requirement:** No specific skils to visualize data, but to use the data, users need skills in geographic information systems; no manual exists yet. **User Base**: Approximately 4000 users
Nature Value Explorer	**Key Motivations:** Highlighting the socio-economic benefits of nature restoration and improving cost-benefit analyses **Development Challenges**: Lack of initial data on ecosystem services, need for a user-friendly web interface, and understanding of user demographics. **Stakeholder Engagement**: Involvement of planners, consultants, and educators for feedback and tool adaptation. **User Base:** 3,000 users, with 300-400 regular users.

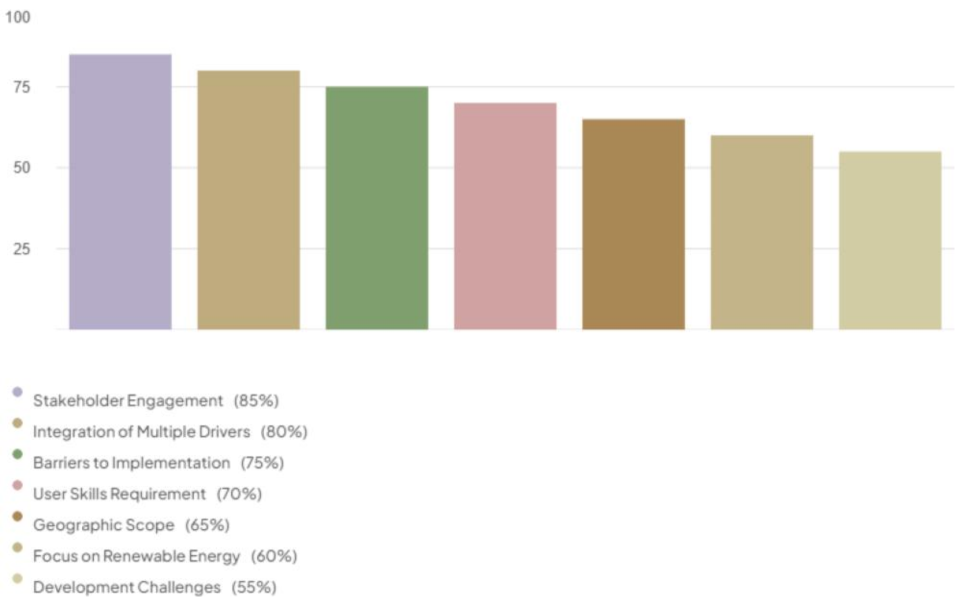


Figure 35: Challenging trends for digital tool developers as identified by the tool developers through the interview (Relative frequency in relation to total responses)

Among the challenging trends for digital tool developers, stakeholder engagement emerges as a crucial aspect for the success of land-use decision tools, with almost all the tools actively involving diverse groups in their development and implementation. Several tools engage diverse stakeholders by integrating multiple drivers (social, economic, environmental) into their algorithms (Table 9).

Table 9: Drivers integrated into the process algorithm of digital tools

Drivers	CRAFTY	Dynamic Energy Atlas	EnBiLA	EPIC WebGIS	Nature Value Explorer
Social	●		●	●	
Economic	●	●	●	●	●
Regulatory	●	●	●	●	
Legal	●	●	●	●	
Cultural	●	●	●	●	●
Environmental	●	●	●	●	●

● Yes

There is also a strong emphasis on the opportunity for stakeholder engagement through workshops and committees to gather feedback and improve tool functionalities.

Table 10: Contextualization of the tool within priority question/criteria (Yes/No question)

Priority question/criteria	CRAFTY	Dynamic Energy Atlas	EnBiLA	EPIC WebGIS	Nature Value Explorer
Capacity of the tool to develop **shared understandings** from the perspectives of **multiple and diversified stakeholders.**	●	●	●	●	●
Capacity of the tool to improve **knowledge or enable learning of stakeholders**, across different topics associated with land-use.	●	●	●	●	●
Capacity of the tool to **engage stakeholders** in land use decisions.	●	●	●	●	●
Capacity of the tool to **engage citizens** in land use decisions.	●	●		●	●
Is any essential or optional **skills development** necessary to use the tool? If yes, does support exist, or is there a manual to ensure its optimal and correct use?	●	●			
Capacity of the tool to **improve spatial understandings** of the flows and interactions of various land uses between competing sectors and at different scales	●	●			●
Capacity of the tool to inform or support decision-makers at different **stages of a project and/or policy cycles**.	●	●	●	●	●

● Yes

While there are common themes in motivations and engagement strategies, the specific focus, challenges, and target audiences differ significantly among the five digital tools. Each developer faced unique challenges related to their specific tool's focus area, such as data availability, technical integration, or user adoption. The target audience varies, with some tools aimed at politicians and planners, while others target broader user bases, including researchers and the general public.

Regarding the challenges faced, some of the most relevant quotes from the developers' interviews indicate that:

> *"Two of the biggest constraints linked to the development of the digital tool are related to data and financial costs";*
>
> *"The diversity of data that made the model parameterization and processing capacity difficult, due to the existence of many processes";*
>
> *"Finding people with the right skills to work with modelling was a challenge to support the development of the tool";*
>
> *"Based on user feedback, a significant obstacle to adopting this digital tool is the challenge of theoretically quantifying data within specific geographic contexts";*
>
> *"One of the main constraints of the digital tool is that it is not possible to quantify everything on a regional scale, and sometimes it becomes difficult to use the digital tool to support implementation";*
>
> *"One of the main barriers to adherence is related to the impossibility of uploading data (from users) to the platform".*

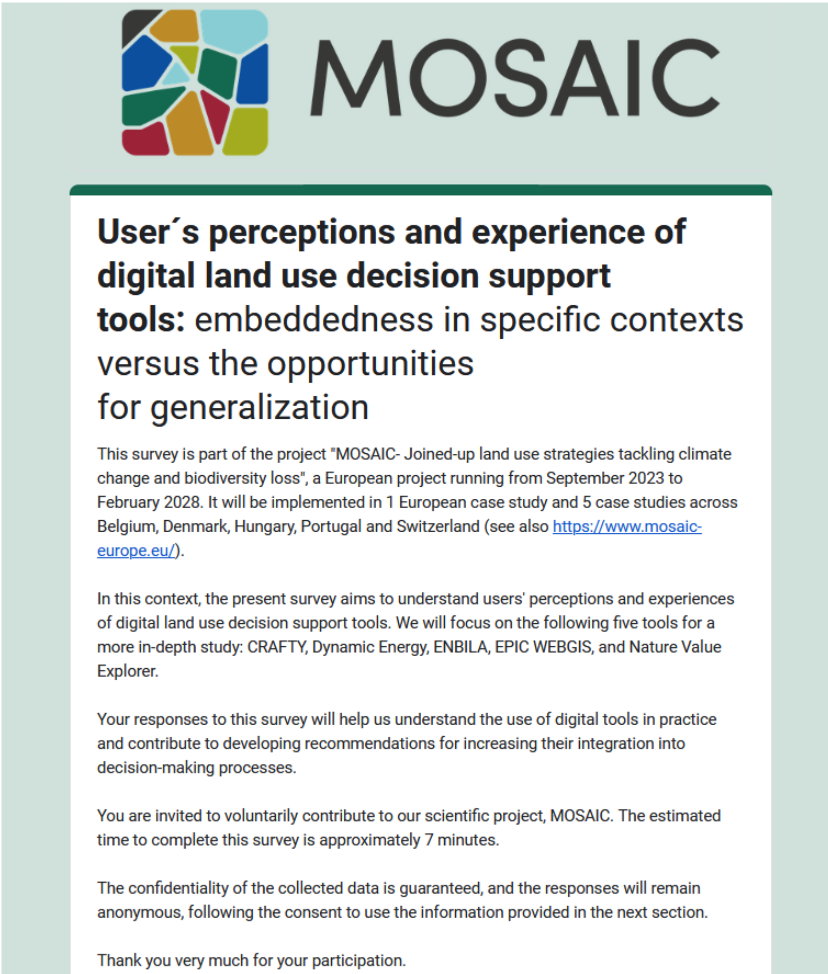
At this point, it is important to refer to some limitations of this part of the study associated with interviewing only five developers, namely:

- **Limited Representativeness:** A small sample size of five developers may not adequately capture the wide range of perspectives and experiences across the broader community of digital tool developers. This could lead to biased or incomplete findings, potentially overlooking important insights from those not interviewed.
- **Potential for Bias:** The selection process for the five developers is crucial. If the chosen developers have similar backgrounds, work on similar types of tools, or operate in similar geographical contexts, the study might suffer from selection bias, limiting the generalizability of the results.
- **Lack of Depth in Specific Areas:** This point is associated with the multi-faceted nature of digital tools, which encompass various aspects such as stakeholder engagement, data types, policy sectors, and user experiences. Interviewing only five developers might restrict the study's ability to explore these areas in detail, especially if the chosen developers do not represent the full spectrum of tool types and functionalities.
- **Difficulty in Identifying Common Trends:** The sources aim to identify best practices, success factors, and recommendations for increasing the uptake of digital tools. A small sample size may make it challenging to discern meaningful patterns or trends that can be reliably generalised to other developers or contexts.
- **Reduced Statistical Power:** The study may lack the statistical power to draw robust conclusions or make strong inferences about the broader population of digital tool developers. The limited sample size may increase the margin of error, making it harder to confidently generalise findings to other developers.

To address these limitations and align the results with the scope of the DLE co-design (Task 5.2), three additional strategies have been implemented to provide more comprehensive and reliable insights into the world of digital tool development and its implications for supporting sustainable land use decisions within the DLE:

- An online survey to the selected digital tools users;
- A workshop with the developers;
- A focus-oriented study on digital tools in decision making concerning biodiversity and ecosystem services (which include climate-related services).

Regarding the survey, each developer provided contact details of the digital tools user(s) or served as an intermediary to the users. The **users' survey** was created using *Google Forms* (Figure 36), distributed on October 15, and remained open until November 8, 2024.



MOSAIC

User´s perceptions and experience of digital land use decision support tools: embeddedness in specific contexts versus the opportunities for generalization

This survey is part of the project "MOSAIC- Joined-up land use strategies tackling climate change and biodiversity loss", a European project running from September 2023 to February 2028. It will be implemented in 1 European case study and 5 case studies across Belgium, Denmark, Hungary, Portugal and Switzerland (see also https://www.mosaic-europe.eu/).

In this context, the present survey aims to understand users' perceptions and experiences of digital land use decision support tools. We will focus on the following five tools for a more in-depth study: CRAFTY, Dynamic Energy, ENBILA, EPIC WEBGIS, and Nature Value Explorer.

Your responses to this survey will help us understand the use of digital tools in practice and contribute to developing recommendations for increasing their integration into decision-making processes.

You are invited to voluntarily contribute to our scientific project, MOSAIC. The estimated time to complete this survey is approximately 7 minutes.

The confidentiality of the collected data is guaranteed, and the responses will remain anonymous, following the consent to use the information provided in the next section.

Thank you very much for your participation.

Figure 36: Introduction web page for the user's survey

The survey comprises twelve questions (see Appendix C) structured to gather information about: user demographics, experience with specific tools (CRAFTY, Dynamic Energy Atlas, EnBiLA, EPIC WebGIS, Nature Value Explorer), and reasons for using them. In this sense, it delves into topics such as using the tool within policy cycles and/or project phases and explores perceived barriers to their adoption. The survey also investigates the potential of these tools to address biodiversity and climate change challenges and their effectiveness in improving land use decisions. Finally, it asks respondents to share any comments or recommendations for tool improvement.

The survey results gather insights from 17 tool users. This sample comprised a majority of people from the public sector, but academy, private sector and civil society organisations were also represented (Figure 37). Most of the users were researchers, followed by engineers (Figure 38). Of these, 59% are women and 41% are men. (Figure 39).

1. What sector do you work in?

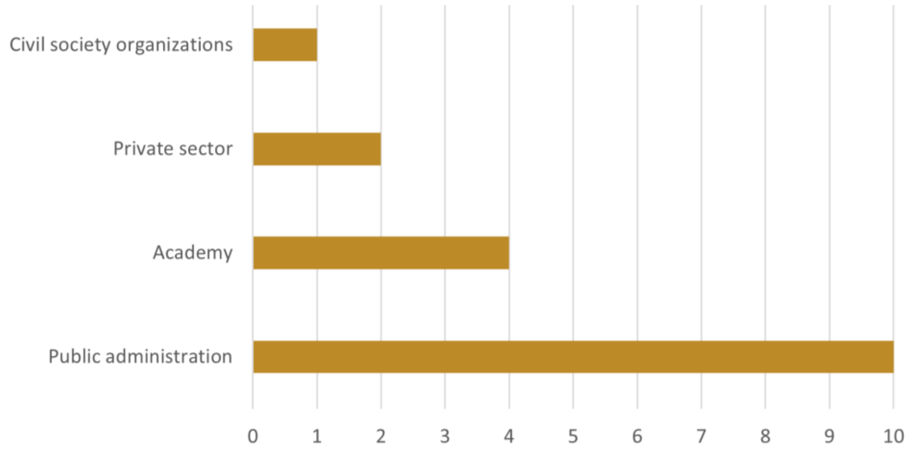


Figure 37: Characterization of users by work sector (x-axis: number of answers)

2. What is your current profession?

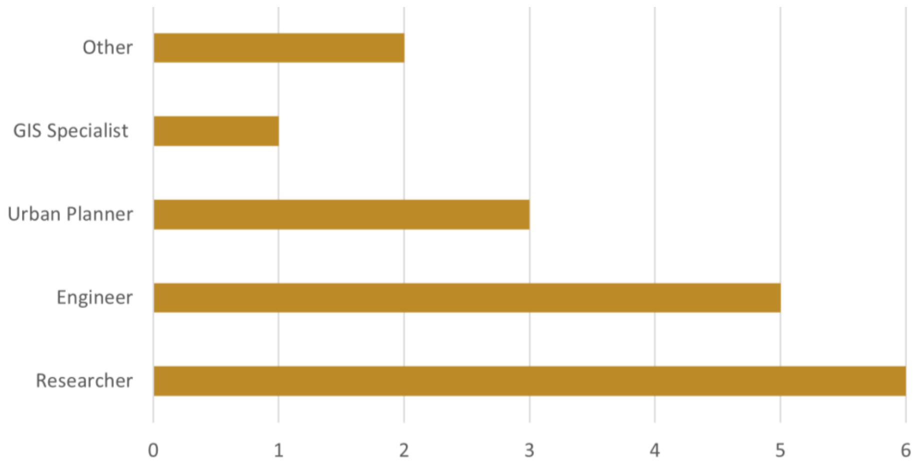


Figure 38: Characterization of users by profession x-axis: number of answers)

3. What is your gender?

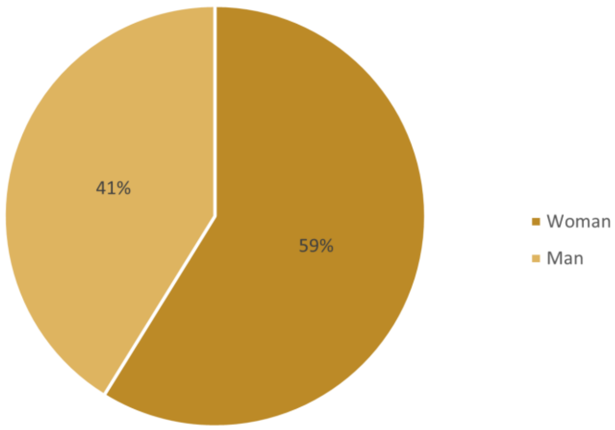


Figure 39: Characterization of users by gender

Regarding users, nine are EPIC WebGIS tool users, four are CRAFTY users, two are Nature Value Explorer users, and two are Dynamic Energy Atlas (Figure 40). There are no EnBILa users, as this tool is still in the prototype stage.

4. Which of the following digital tools do you have experience with?

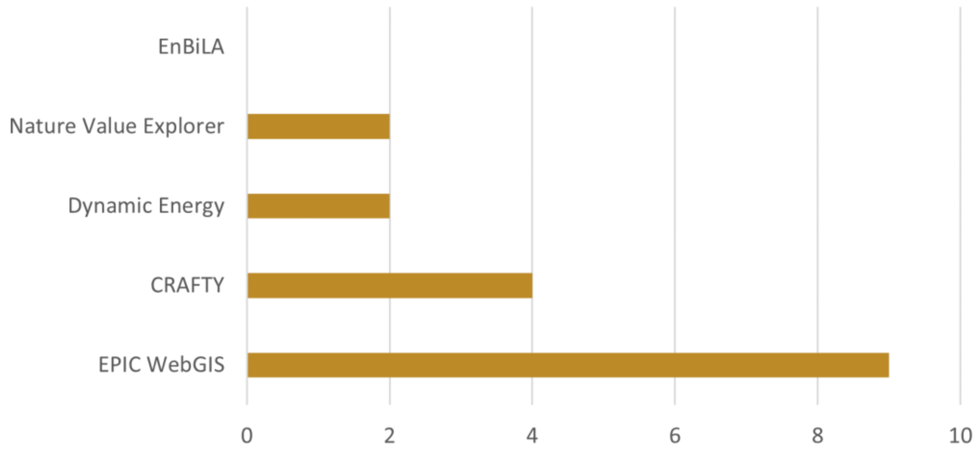


Figure 40: Experience of users in the digital tool (x-axis: number of answers)

The following questions, from 5 to 12, were related to the digital tool selected by each user. Most users found the tools through an institution (Figure 41).

Regarding the policy cycle, digital tools are commonly used in policy evaluation followed by formulation, and decision making (Figure 42). They are used in all stages of the project phase, with more incidences in the planning and conception phases (Figure 43).

5. How did you find out about the digital tool?

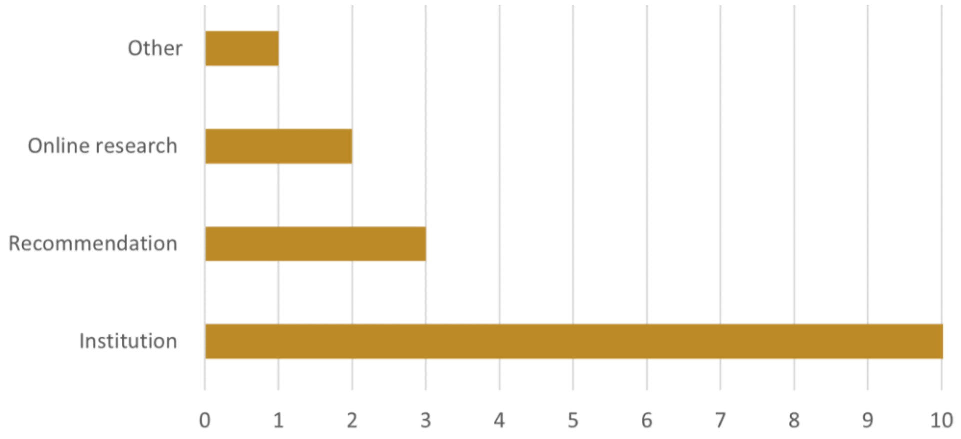


Figure 41: How the user discovered the tool (x-axis: number of answers)

6. At what stage, or stages, of the policy cycle do you use the tool?

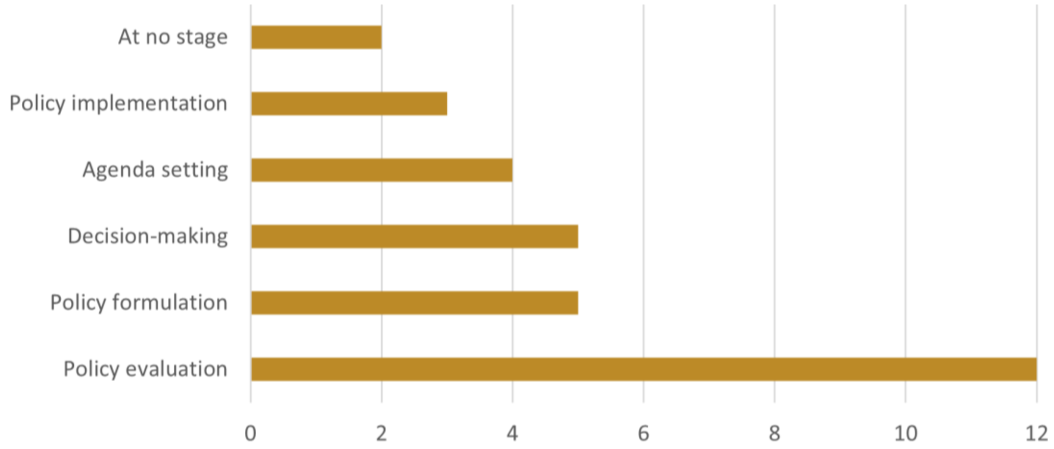


Figure 42: Phase of the policy cycle where the tool is most used (x-axis: number of answers)

7. At what phase, or phases, of the project stages do you use the tool?

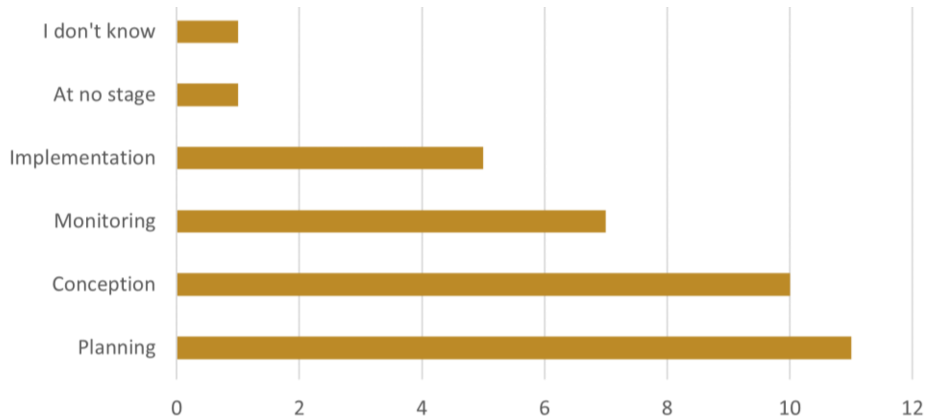


Figure 43: Phase of the project stage where the tool is most used (x-axis: number of answers)

The following Figure 44 presents a set of bar charts organized in an overarching chart of key motivations of the different users to use the tools and four individual charts corresponding to the specific tools analysed. The overarching chart underscores the importance of improving decision-making and supporting policy development as central motivations for using these tools. Other notable motivations include “to learn and/or to have knowledge” and “to save time and resources”.

8. What is/are your key motivation for using the tool?

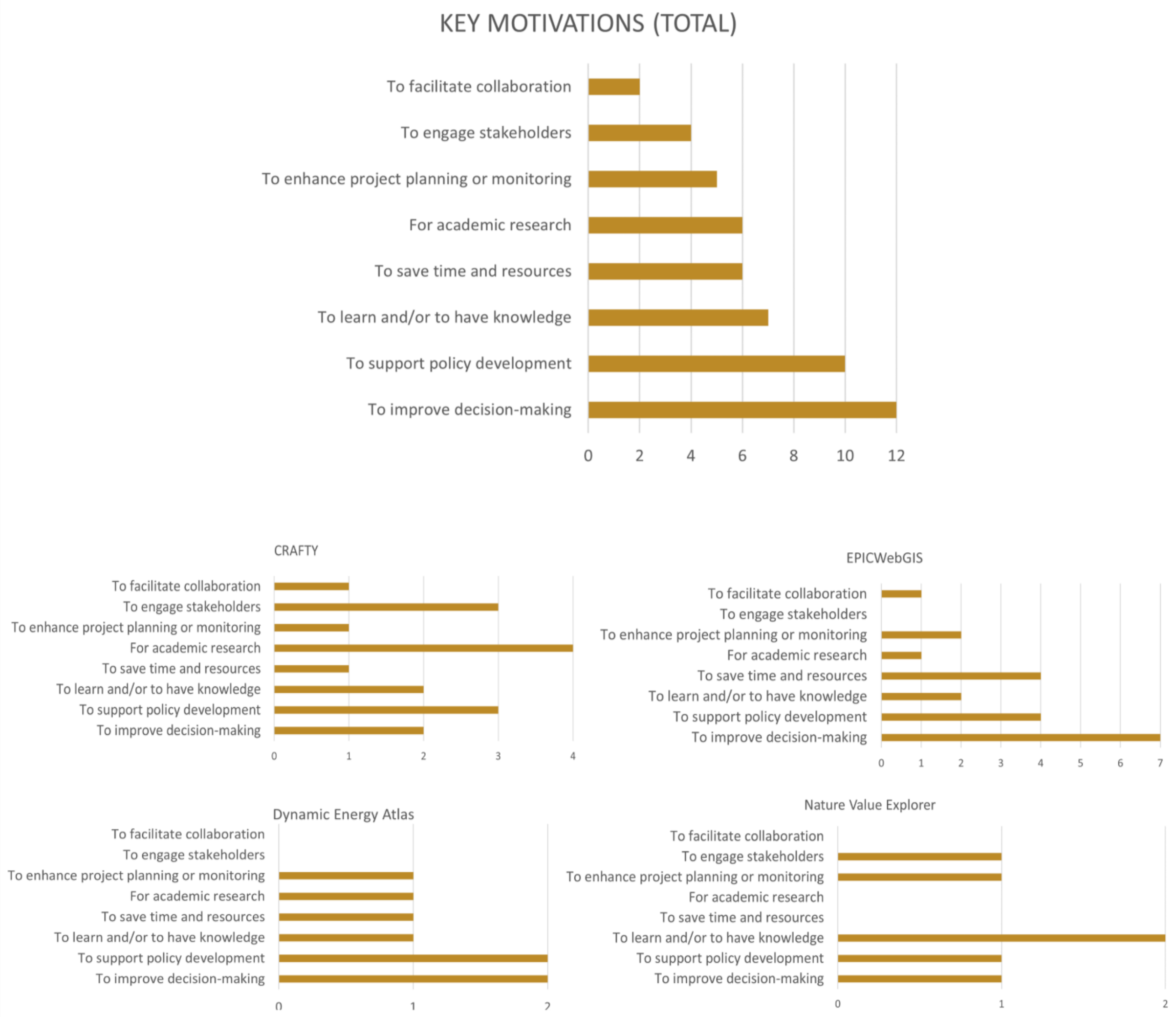


Figure 44: Key barriers of tool users, total and for each tool (x-axis: number of answers)

Each chart highlights the motivations associated with a specific tool. CRAFTY focuses on the motivation of using “for academic research”, followed by “to support policy development” and “to engage stakeholders”.

EPICWebGIS users strongly emphasize “to improve decision-making”, following “to support policy development” and “to save time and resources”. Dynamic Energy Atlas displays a balanced distribution, with “to support policy development" and “to improve decision making” standing out. The Nature Value Explorer tool users highlight the key motivations for “learning and/or to have knowledge”.

The barrier to uptake summarizes the challenges in adopting digital tools. The overall chart (Figure 45) indicates usability issues, technical challenges, and data limitations as primary obstacles to tool adoption.

9. What do you perceive as the barriers to uptake to the adoption and effective use of digital tool in land use decision-making?

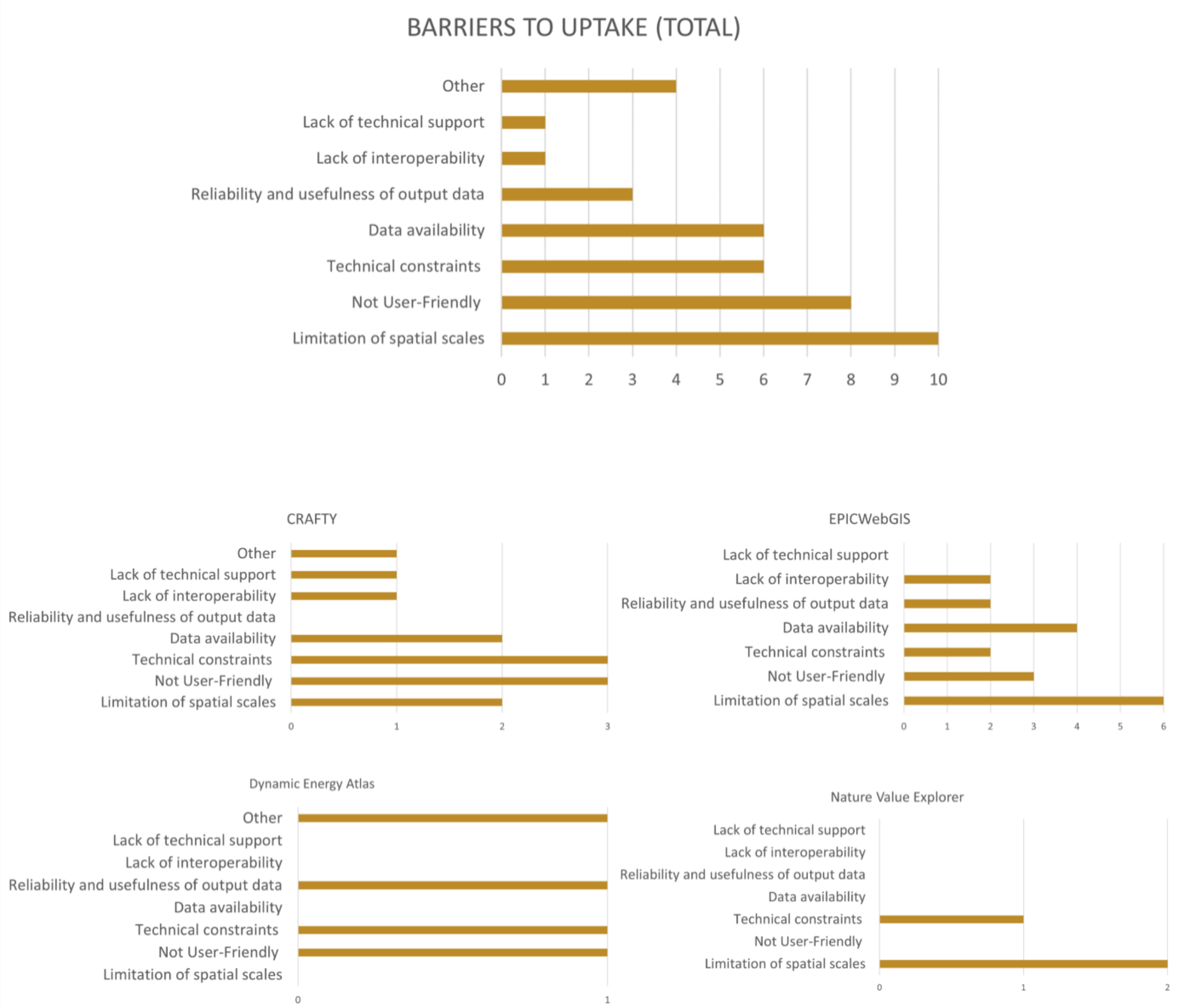


Figure 45: Key barriers of tool users, total and for each tool (x-axis: number of answers)

The most prominent barriers regard “limitation of spatial scales” and also significant are “Not User-Friendly” and “Technical constraints”. Minor barriers include “Lack of technical support” and “Lack of interoperability”. The “other” options include “Coupling of different models in terms of feedbacking” and “Lack of quality of input data”.

Each chart highlights barriers associated with a specific tool. The CRAFTY users emphasise the “Technical constraints” and “not-user friendly” as barriers. The challenges related to “Limitation of spatial scales” and “Data availability” are also mentioned.

The EPICWebGIS shows “limitations of spatial scales” as the most prominent barrier, probably because most data is at the national scale, followed by the “data availability”. The Dynamic Energy Atlas users highlight, at the same level of importance, four barriers: “Technical constraints”, “Not user friendly”, “reliability and usefulness of output data”, and “Lack of quality of input data” (as other). The Nature Value Explorer focuses on "Limitations of spatial scales" and "Technical constraints" as significant barriers.

Regarding future challenges, question 10 aimed to understand users' perceptions about the utility of the digital tool in addressing challenges related to biodiversity, climate targets or other policies and targets related to the Green Deal. Most users agreed that the tools could help fulfil targets related to biodiversity (Figure 46). Three users added the following: “could be useful for the first three options”; “biodiversity, climate and Green Deal, but of course with limitations”; and “evaluate the competition for space between nature, agriculture and energy”.

In an exercise of evaluating the tool's utility in improving the land use decisions, most tools evaluated are considered “helpful” (Figure 47).

10. Do you think the tool could be helpful/useful in addressing challenges related to?

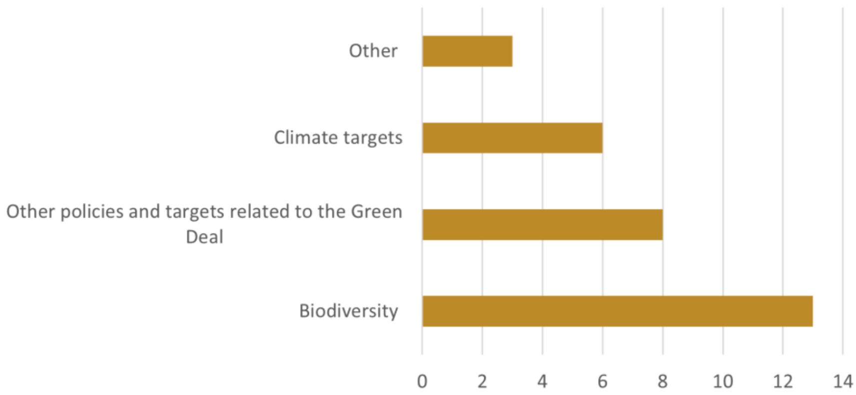


Figure 46: Future challenges (x-axis: number of answers)

11. Has the digital tool helped you to improve land use decisions?

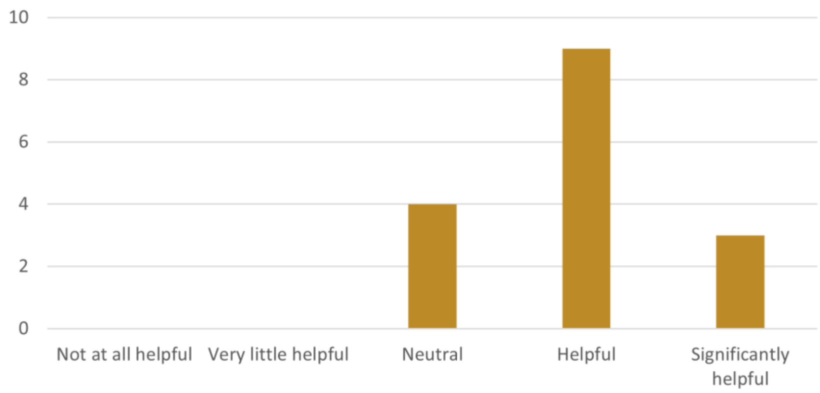


Figure 47: Improvement of land use decision using Digital tools (x-axis: number of answers)

The last question asked for comments or recommendations to improve the tool for which they are users. We gathered five contributions:

- “Model can be transformed into an executable, easy to get to everyone who would want to work on and also becomes user friendly.” (CRAFTY)
- “Make stakeholder involvement a frequent and normal practice in these tools, at all stages, i.e. not only to share the results with them, but also engage them in the design and parameterization” (CRAFTY)
- “Congratulations for the EPIC WebGIS portal that includes WMS services freely available to the public and allows the maps for download” (EPIC WebGIS)
- “Now we only have the regional level of data and not national” (Nature Value Explorer)
- “More users. Continued development of user interface, potentially online” (CRAFTY).

After the interviews and survey stages had been completed, an online **workshop** was held **with the developers** and also other MOSAIC team members, such as those involved in the DLE co-design process (task 5.2 from WP5) and the WP2 leaders. This workshop aimed to validate the reviews and generate new ideas to improve the compatibility and collaboration between the tools and the modelling outputs of MOSAIC (Task 5.2).

The workshop via Zoom on November 13, 2024, marks a significant milestone. This event aimed to promote active participation, knowledge and experience exchange, and collaborative ideas among participants, aligning closely with the task's overarching goals and the following main objectives:

1. **Present systematic review results** – First, we shared comprehensive findings from the systematic review of available digital land-use decision support tools. These findings provided participants with valuable insights into current trends, challenges, and opportunities within the scope of MOSAIC project. The presentation set the foundation for informed discussions and ensured that all participants had a shared understanding, facilitating cohesive and productive collaboration.

2. **Engage developers and MOSAIC team members –** promote the sharing of expertise and hands-on experience of developers and MOSAIC team members, whose insights are essential for improving learning on digital tools. The session was enriched by the interdisciplinary backgrounds of participants, including experts in environmental science, geography, and landscape architecture. The following developers contributed with specific backgrounds:

    - **Inge Liekens** (VITO, Belgium) has a background in Environmental Economics. She is a developer of the **Nature Value Explorer**, with a focus on scenario modelling and tool customization.

    - **Karolien Vermeiren** (VITO, Belgium) has a background in Geography. She is a developer of the **Dynamic Energy Atlas**, with a focus on managing process design and introducing strategic indicators.

- **Jonas Schwaab** (ETH Zurich, Switzerland) has a background in Environmental Sciences. He is a developer of the **Energy and Biodiversity Landscape Assessment** (EnBiLa), with a focus on coordinating tool development and fostering user exchanges.
- **Manuela Magalhães** (ISA, Portugal), represented by **Natália Cunha (ISA, Portugal),** has a Landscape Architecture background. She is a developer of the **EPICwebGIS**, with a focus on national ecological network, green infrastructure and landscape planning.
- **Mark Rounsevell** (KIT, Germany) has a background in Physical Geography. He is a developer of **CRAFTY**, with a focus on overseeing the digital tool's initial design and conceptual framework.
- MOSAIC Team members: **Francesca Poggi** (UNL), **Selma Pena** (ISA), **Ana Muller** (ISA) and **Beatriz Romão** (UNL) leads of Task 5.1, **Anna Verhoeve** (ILVO), lead of WP2 (Policy Labs), **Dieter Mortelmans** (INBO) co-lead of Task 5.2 (DLE).

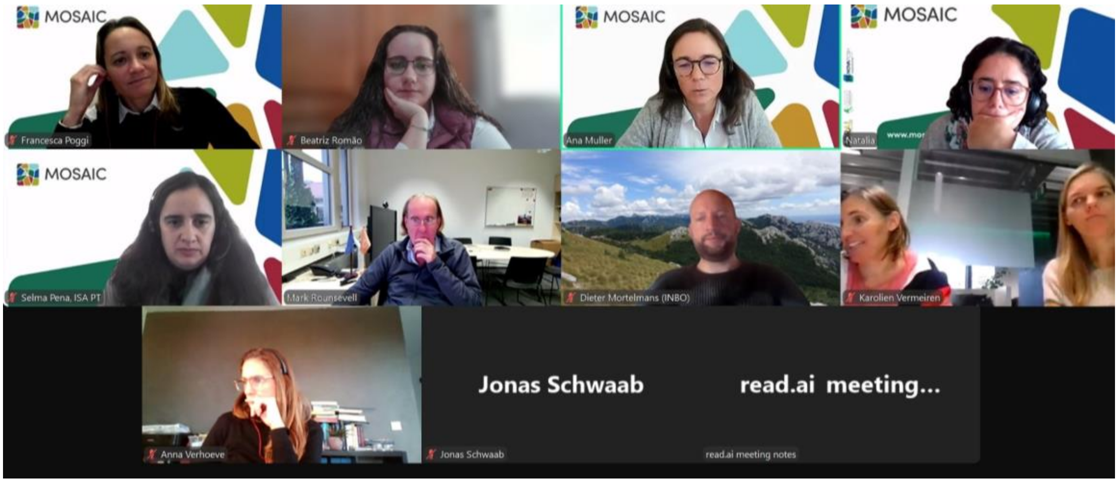


Figure 48: Participants of the Developers' Workshop

3. **Co-develop innovative ideas** - In this part of the workshop, participants worked together in the online collaborative platform Miro to brainstorm and generate ideas to enhance the interoperability and synergies between MOSAIC's existing tools and modelling outputs.

Following these three objectives, the interactions within the workshop has been structured according to five different sequential moments (Figure 49): the presentation of the Digital Tools Portfolio, the sharing of reflections on the main outputs from the developers interviews and users survey, the presentation of the DLE concept and finally, a co-development moment to promote brainstorming on potential functionalities for the future DLE-learning module on digital tools to be developed within Task 5.2 (Figure 49 and Figure 50).

Figure 49: Structure of the interactions model in Miro

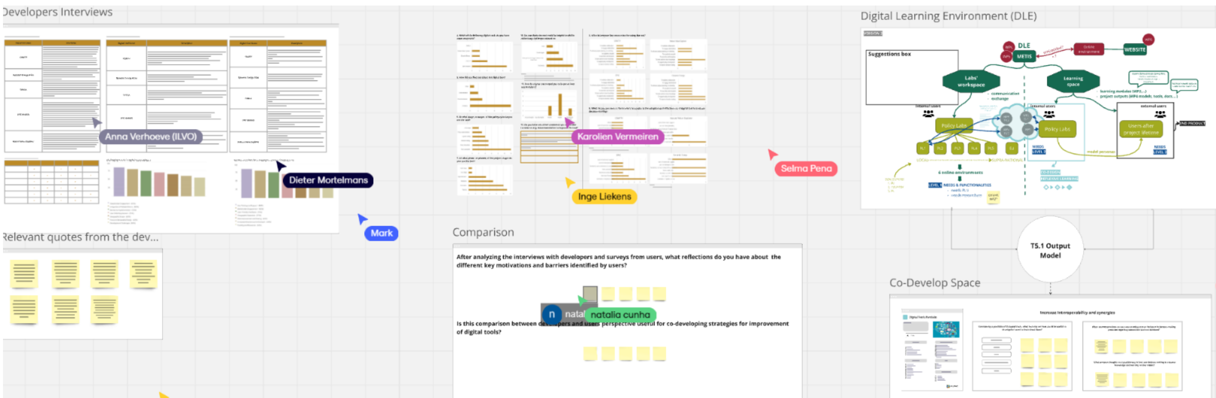


Figure 50: Global view of the Miro board used in the workshop

The sharing of reflections and the brainstorming moments were divided into two panels in Miro according to the following framework of questions:

Panel A – Comparison between the outputs from the interviews with developers and surveys from users:

A.1 After analyzing the interviews with developers and users surveys, what reflections do you have about the different key motivations and barriers identified by users?

The developers identified several motivations and barriers that influence user experience with digital tools, namely:

EPICWebGIS developer highlighted that users are motivated by free access, time-saving, and innovation, but encounter barriers such as complexity, and lack of user-friendliness. This presents a challenge to developers to balance usability with the technical robustness of the tool. Non-existent or insufficient data can significantly limit the tool’s effectiveness. The frequency of updates is essential to keep the tool engaging and to ensure that it continues to provide clear value, otherwise users may perceive it as lacking value and ultimately abandon it.

Both **Nature Value Explorer (NVE)** and **Dynamic Energy Atlas (DEA) developers** indicated that feedback from users of their respective digital tools was generally as expected and in line with known challenges/issues that the developers had anticipated. The DEA developer also noted that the challenges faced by users were not uniform, given the different backgrounds, roles or contexts and expectations, with the diversity of users playing an important role in determining specific barriers. For example, a researcher using the tool directly found it complex and not very user-friendly, whereas policymakers using the outputs appreciated the functionality but struggled with the complexity and lack of insight from the data, suggesting that the tool needs to balance complexity with clarity to make it useful for decision-making.

The **developer of CRAFTY** noted that technical barriers are a significant challenge, particularly for research tools. While useful, these tools are often not designed with usability in mind, making them difficult to use. They are designed only to handle complex tasks, which limits their wider usability/utility unless usability is considered in the tool's design.

A.2 Is this comparison between developers' and users' perspectives useful for co-developing strategies for the improvement of digital tools?

The responses to this question provided reflections on improving digital tools, highlighting several key points:

- User engagement in the development process is crucial to ensure the tool meets its objectives and enhances usability.
- The diversity of users means that the tool must address varying needs and requirements. Additionally, it must manage expectations, making users' experiences and developers' perspectives particularly valuable.
- User input is essential for refining the tool's interface design, making it more intuitive and user-friendly, and improving the overall user experience.
- Beyond building the tool, providing adequate technical support and ensuring proper training is essential to maximize its effectiveness.

Panel B - Co-develop space to increase interoperability and synergies for the development of a learning module on digital tools in the DLE.

B.1 Considering the portfolio of 55 digital tools, what learning services could be useful to develop for users to learn from them?

The responses suggest several learning services to enhance user interaction with the portfolio of 55 digital tools. These included an AI-based tool to query tools or their outputs; a tool finder with upload and update options; to provide an overview of each tool’s characteristics and potential outputs; Story maps and online interactive maps providing spatial model outputs and a mobile app for monitoring land use.

B.2 What recommendations can be made to enhance their inclusion in decision-making processes regarding sustainable land-use decisions?

Several recommendations were made to enhance the inclusion of digital tools in decision-making processes related to sustainable land use. First, Artificial Intelligence (AI) should be included with a multifaceted approach that addresses factors such as accessibility, education, data quality, and community engagement. Additionally, promoting the digital tools through the use of videos addressing their usefulness and potential uses, as well as other available tools. Linking tools to policies was another important recommendation. Finally, providing tangible examples of how the tools can be applied in real-world scenarios.

B.3 What are your thoughts on digital literacy in land-use decision making to enhance knowledge and learning on this subject?

Digital literacy plays a critical role in enhancing knowledge and participation among stakeholders such as community members, policymakers, students, and land use professionals, by improving access to better resources for understanding, evaluating, and making informed decisions about land-use practices. The responses to this question highlight several key points.

Embracing digital literacy is seen as a beneficial and forward-thinking approach, though it’s important to acknowledge the limitations and uncertainties of digital tools to build trust. It facilitates information consolidation, communication among stakeholders and transparency in decision making. However, for digital literacy to be effective, the insights provided must be practical and tangible, such as through maps and concrete/real-world results.

A side-project arose following a request to the MOSAIC consortium to investigate the role of digital tools in supporting the Swiss Biodiversity Action Plan (FOEN, 2017). In this side-project, the factors that hinder or facilitate the implementation of digital tools in decision making, specifically concerning biodiversity and ecosystem services, was explored. Through interviews with planning practitioners across four case studies (urban, tourism, water, and agriculture), we examined the applicability and use of various digital tools identified in an extensive literature review (Klein et al., 2024a, Klein et al., 2024b). The results show that practitioners do not know or use decision-support tools (like InVEST or Zonation). Even though they are rated as interesting, and there is some interest in learning more about the tools, they are rarely applicable to actual decision-making. Key barriers include (1) a lack of or incomplete constraints to use such tools, (2) the personal motivation of decision makers (only those who are personally inclined to take action), and (3) insufficient knowledge about ecosystem services, their value, and the tools available. Additional hindering factors include the difficulty in quantifying ecosystem services in economic terms and the financial costs associated with learning and applying these tools.

5 CONCLUSIONS

5.1 Co-development recommendations for increasing uptake

Focussing on the advantages and disadvantages of using digital tools compared to traditional methods, this section addresses the last **interpretive research question RQ6 (“What are the benefits, advantages, main challenges, and limitations of using digital land-use decision support tools compared to traditional decision-making methods?”)**, providing set of recommendations for increasing the uptake of digital tools based on co-developing recommendations. This approach interprets the systematic review results, including specific insights from the interviews, users survey, and the workshop's outcome.

In recent years, digital tools have emerged as powerful assets in decision making, especially in fields requiring integrating scientific knowledge with local contexts, such as sustainable land-use decisions. In this context, digital land-use decision support tools offer innovative ways to visualize changes, helping stakeholders understand the impact of their choices on land use. This capability fosters better understanding and facilitates informed actions aligned with policy targets, development goals, and the different stakeholders involved in decision making.

One of the other most significant advantages of digital land-use decision support tools is their efficiency, as they can optimize otherwise “complex spatial scales” and “time-consuming” processes like data analysis, visualization, and monitoring. This efficiency is vital for time-sensitive projects aimed at climate change adaptation or mitigation and reducing biodiversity loss, where accelerating decision making is essential.

Digital tools also enhance communication across different sectors, making conveying complex changes to various stakeholders easier and engaging them in different stages of the policy cycle or project phases. This aspect, often challenging to execute with traditional methods, helps deepen understanding of how new policies or projects will impact land use and communities, ultimately promoting more significant involvement in the planning process.

Digital tools also enable access to broader networks and higher levels of decision making and increase cross-sectoral collaboration, particularly in governance and sustainable development areas. In this context, digital tools are evolving to devise innovative solutions to complex challenges related to land use decisions that could address climate change, biodiversity loss, and renewable energy, thereby helping society take quicker steps toward the urgent ecological transition and sustainable development.

However, despite these advantages, the uptake of these tools is not without challenges and requires careful consideration of the potentials and limitations, as described in section 4.1 of the present study.

Accessibility remains a significant barrier, and the tools are costly, complex, or simply unknown to potential users. This lack of awareness limits the potential reach of digital land use decision support tools, and even when people are aware, they may not trust or fully accept the technology, questioning its reliability or applicability. Furthermore, adaptability is an issue.

While these tools may excel in specific scenarios, they often struggle to address unique local needs without extensive customization, which can be complex and expensive.

From a technical perspective, there are additional barriers. Many digital tools require advanced modelling skills and are not intuitive, which hinders accessibility for non-experts. In cases where the tools are complex, interpretability becomes a challenge, with users finding it difficult to extract meaningful insights without specialized training. Likewise, data barriers persist, as high-quality, up-to-date information is often needed to leverage digital tools fully. Data development costs, particularly for field observation data, can be prohibitively high, and available data may not always represent the current situation, reducing the accuracy of models and projections.

Insights from the developers' interviews confirm that this framework opens a specific range of recommendations for increasing the uptake of existing tools (Figure 51). One of the most challenging trends for tool developers is overcoming barriers associated with skills to use the tools and the lack of user-friendly manuals.

Other common barriers include data accuracy issues, funding for maintenance, and challenges in quantifying local data. In this sense, Table 11 presents the main recommendations provided by developers for increasing the uptake of digital tools.

Table 11: Recommendations for increasing uptake of digital tools

Digital Tool Name	Description
CRAFTY	**User Training:** Enhance user training and support to improve tool usability. **Increase engagement:** Promote stakeholder engagement to gather diverse perspectives. **Enhance functionality:** Develop user-friendly interfaces to attract non-expert users. **Expand Functionality:** Expand the tool's application to additional regions for broader impact.
Dynamic Energy Atlas	**Increase Local Partnerships**: Collaborate with local stakeholders for insights. **Policy Support:** Engage policymakers for tool adoption and implementation. **User Training**: Provide manuals and support for optimal tool use. **Data Improvement:** Focus on enhancing data accuracy and availability.

Digital Tool Name	Description
EnBiLA	**Increase user engagement:** Conduct workshops to demonstrate the tool and gather feedback. **Enhance functionality:** Address the data upload barrier to improve user experience. **Broaden outreach:** Expand the tool's geographic application to attract more users. **Stakeholder collaboration:** Continue involving stakeholders in the development process for better insights.
EPIC WebGIS	**Enhance Training:** Develop training programs for users to improve skills in geographic information systems. **Create Documentation:** Produce a user manual to facilitate optimal tool usage. **Increase Funding**: Seek continuous funding sources for tool maintenance and data integration. **Promote Data Sharing:** Advocate for official recognition and integration of the tool's data with governmental entities. **User Feedback:** Conduct user interviews to gather insights for further tool improvements.
Nature Value Explorer	**Increase Awareness**: Promote the tool through seminars, articles, and user stories to enhance visibility. **User Feedback:** Conduct regular surveys and workshops to gather user insights for continuous improvement. **Expand Functionality:** Develop input maps for other countries to broaden the tool's applicability. **Training Resources:** Create instructional materials, such as manuals and videos, to assist users in effectively utilising the tool.

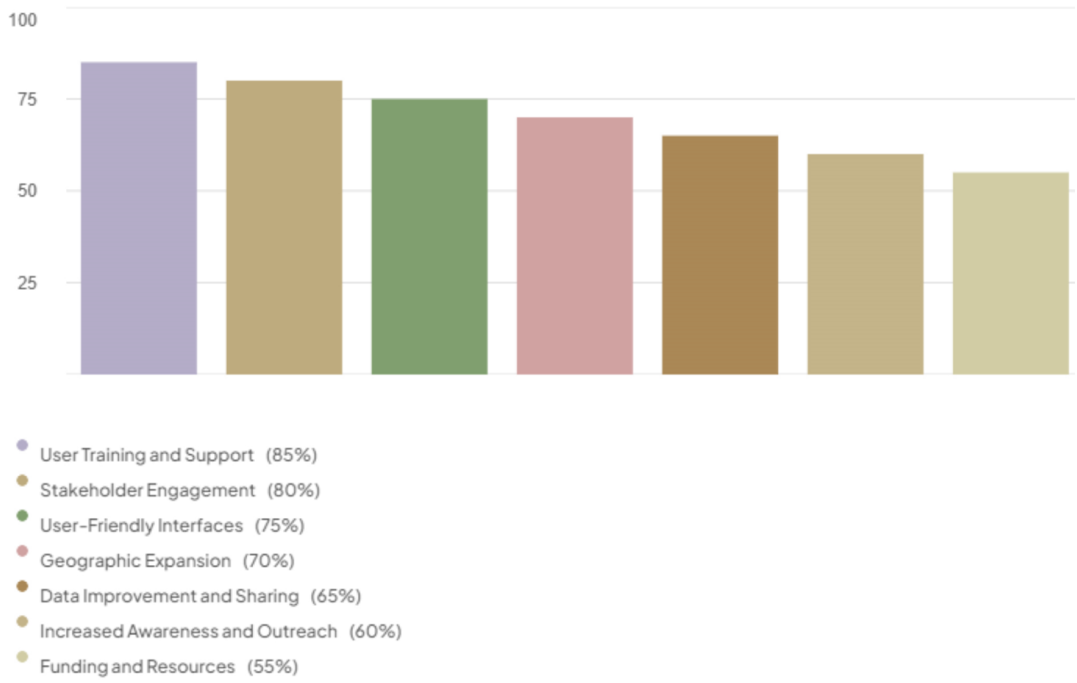


Figure 51: Recommendations for increasing the uptake of existing tools

(Relative frequency in relation to total responses)

The main recommendation to uptake referred to by the developers revolves around **"user training and support"**, meaning an effort to provide comprehensive learning tutorials/workshops and manuals to empower users, leading to effective adoption of the tool and reducing barriers related to technical skills.

"Engaging stakeholders" is the second main recommendation identified by the developers for the successful uptake of digital tools, mainly when dealing with complex, cross-sectoral decision-making processes. Deep engagement fosters trust, adaptability, and a shared understanding of how digital tools can drive meaningful, sustainable change.

Developing **"user-friendly interfaces**" and **"geographical expansion**" is another core recommendation that can increase accessibility and encourage adoption by a broader range of users and contexts. The latter aspect led to **"Data considerations,"** which are also critical for ensuring the relevance and applicability of digital tools in decision-making. Addressing data accuracy, availability, and integration can build trust in the tool's outputs and increase user value.

Finally, **"funding and resources"** form the backbone of uptaking digital tools due to the costs associated with developing and maintaining digital tools that vary widely depending on their complexity, functionality, target audience, and geographical scope. By fostering public-private partnerships, adopting transparent reporting practices, and tapping into in-kind resources, organizations can build digital tools that are accessible, impactful, and sustainable over the long term.

5.2 Contributions to Digital Literacy on Land-Use Decision Support Tools

This study reveals a vast and rapidly evolving landscape of digital tools for sustainable land-use decision-making developed in recent EU, national, regional, and local project efforts.

The results from the systematic review, complemented by insights from digital tools developers and users, highlight the importance of promoting Digital Literacy among stakeholders. This literacy will enable them to effectively access information about available digital tools and understand their potential benefits in supporting sustainable land use decisions and their limitations.

This topic is particularly relevant as it revolves around decision making for sustainable land use transformations, which represent one of the most crucial drivers of society's future development, especially considering the impacts of climate change and biodiversity loss.

The contributions of this study are both theoretical and practical, introducing a new concept of Digital Literacy in Land Use Decision Support Tools, which unlocks novel and actionable knowledge and co-developing recommendations for increasing their uptake in decision-making processes. This conceptual vision of literacy will be precisely formalized through the Digital Learning Environment in Task 5.2 of the WP5.

Figure 52: Conceptual Vision of Digital Literacy in Land Use Decision Support Tools

(AI Image generated using ChatGPT)

In line with these final remarks, the six research questions addressed in this document lead to the following conclusive answers:

RQ1 - What is a digital land use decision support tool?

- Answer based on insight from section 2.1:

A digital land-use decision support tool is an interactive, computer-based system designed to assist decision-makers in analyzing, planning, and managing land-use changes. These tools integrate the functionality of traditional Decision Support Tools (DSTs), which provide structured methods and frameworks for project assessment and decision support across various scales and disciplines, with the enhanced data processing, accessibility, and scenario-testing capabilities of Decision Support Systems (DSSs).

RQ2 - What common types of digital land-use decision support tools are available?

- Answer based on insights from sections 2.2 and 3.1:

From the analysis of the 55 digital tools that resulted from the systematic review, it is possible to conclude that the most common types are "**interaction and visualization tools"**, with 18 tools, followed by **"tools with multiple functions",** encompassing 14 tools.

RQ3 - What are the key features and functionalities typically found in digital land-use decision support tools?

- Answer based on insights from sections 2.2 and 3.1:

Deepening the previous RQ2, the analysis of the 55 digital tools found that "interaction and visualization tools" are designed to make complex information more accessible and engaging for users by leveraging visual aids such as maps, charts, and interactive elements.

In addition, "tools with multiple functions" reflect a more versatile nature, combining other functionalities to offer a more comprehensive land-use analysis and decision-making approach. When examining the specific functionalities of the tools, the review identified the following features:

- **Spatially Explicit Output:** 80% of the tools provide spatially explicit output, predominantly maps. This capability allows users to visualize the spatial distribution of data and assess the potential consequences of different land-use choices.
- **Multiple Data Inputs:** The tools accommodate various input data types, including qualitative and quantitative information, spatial data, statistics, expert knowledge, and field survey data. This highlights the multi-faceted nature of land-use decisions, requiring consideration of a wide array of factors.

- **Output Timeframe:** Most tools prioritize the current timeframe, with approximately 70% designed to support immediate decision making. However, a subset of the tools also offer projections for the short, medium or long-term.
- **Wide Range of Users:** The target audience for these tools is diverse, often encompassing a broad spectrum of users such as citizens, academics, policymakers, and land managers.

RQ4 - What are the best practices and success factors for developers in designing and deploying practical digital land-use decision support tools?

- Answer based on insight from section 4.2:

Analysing the perspective of the developers in the interviews and the workshop, the best practices and success factors are:

- **Prioritise user needs** by developing user-friendly interfaces, creating intuitive and accessible interfaces, providing comprehensive training, and considering skills requirements;
- **Engage Stakeholders** by fostering collaborative development, seeking diverse perspectives and facilitating communication;
- **Address Data Considerations** by ensuring data accuracy, enhancing data availability, and integrating multiple data sources.

RQ5 - How do users perceive the effectiveness and usability of digital land-use decision support tools in real-world decision-making processes?

- Answer based on insight from section 4.2:

Analysing the perspective of the users in the survey, it is possible to conclude that they found them helpful in real-world decision-making processes, but there are some barriers to uptake, primarily related to usability and data limitations. Addressing these barriers, such as **improving user interfaces, expanding data availability, and providing better technical support**, will be crucial for increasing the uptake and effectiveness of these tools in real-world applications.

RQ6 - What are the benefits, advantages, main challenges, and limitations of using digital land-use decision support tools compared to traditional decision-making methods?

- Answer based on insight from sections 4.1 and 5.1:

The analysis of systematic review results, including specific insights from the interviews, user survey, and the workshop's outcome, reveals that the **benefits and advantages** of digital tools compared to traditional decision-making methods are:

- **Efficiency:** digital tools can streamline complex and time-consuming processes, such as data analysis, visualisation, and monitoring. This efficiency is crucial for addressing time-sensitive sustainability challenges like climate change adaptation and biodiversity loss.
- **Enhanced Communication:** digital tools can effectively convey complex information to diverse stakeholders, fostering a shared understanding of land-use changes and their potential impacts.
- **Informed Decision-Making:** By providing access to a broader range of data, analytical capabilities, and scenario modelling, digital tools enable more informed, evidence-based decisions.
- **Increased Stakeholder Engagement: i**nteractive platforms and user-friendly interfaces encourage broader participation and collaboration among stakeholders, promoting a more inclusive decision-making process.
- **Spatial Analysis:** digital tools excel in spatial analysis, allowing users to visualise the spatial distribution of data, understand the interconnectedness of land uses, and assess the potential consequences of different choices.
- **Cross-Sectoral Collaboration:** Digital tools can facilitate collaboration across different sectors, including government, industry, and research, promoting a more integrated approach to land-use planning and management.

On the other hand, the main challenges and limitations can be summarized as:

- **Accessibility:** Cost, complexity, lack of awareness, and limited access to technology can hinder the adoption of digital tools, particularly in under-resourced communities.
- **Trust and Acceptance**: Some stakeholders may not trust or fully accept the outputs of digital tools, questioning their reliability or applicability, particularly when data accuracy is uncertain.
- **Adaptability:** While digital tools may excel in specific scenarios, adapting them to unique local needs can require extensive customisation, which can be costly and complex.
- **Technical Expertise:** Some tools demand advanced modelling skills and technical expertise, limiting their accessibility for non-experts. In these cases, providing comprehensive training and user-friendly interfaces is crucial.
- **Data Limitations:** Data accuracy, availability, and integration pose ongoing challenges. High-quality, up-to-date data is essential; acquiring such data can be expensive and time-consuming.
- **Maintenance and Funding:** Sustaining digital tools requires ongoing maintenance, updates, and user support, necessitating long-term funding and resources.

The insights gained from analyzing existing digital land-use decision support tools permit us to highlight the importance of creating accessible, user-friendly, and adaptable systems that support diverse stakeholders in making informed land-use decisions. As the need for such tools becomes increasingly evident, MOSAIC is committed to creating a lasting impact by developing a Digital Learning Environment designed to evolve beyond the project's lifespan. Through a co-design process within Task 5.2, the DLE will offer tailored functionalities to meet the needs of stakeholders in policy labs and those involved in land use decisions. As the DLE aims to facilitate learning between academia and practice, the present study's contributions will be integrated into a learning module related to the Digital Portfolio presented in this document.

In this sense, integrating the Digital Portfolio of 55 digital tools (Appendix A) in the DLE can support land use decision processes through a list of keywords for a search function. Based on these keywords, users should be able to navigate easily to the tools that may interest them and increase the uptake of digital tools. This navigation approach is the only one used for the time being and does not preclude any other navigation approaches that might be developed during the development of DLE.

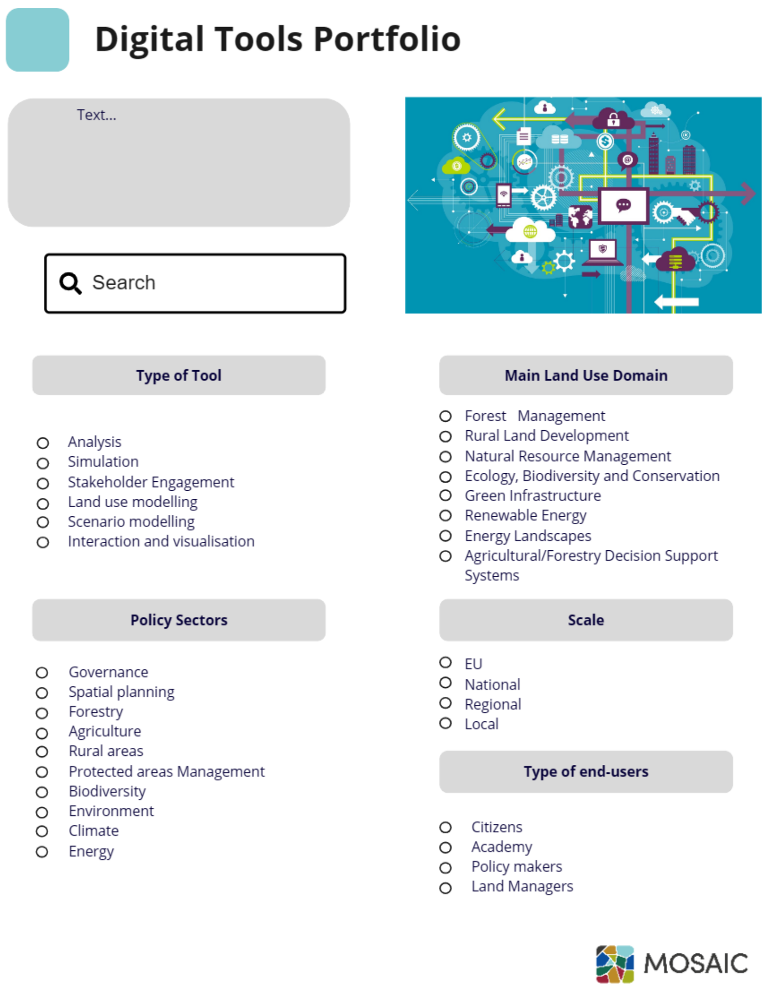


Figure 53: Product vision for the integration of the Digital Portfolio into the DLE

From the workshop with the developers, other learning services have been suggested as future components of the learning module on digital tools, representing a valuable framework to be considered within the co-designing phase of the DLE (Task 5.2).

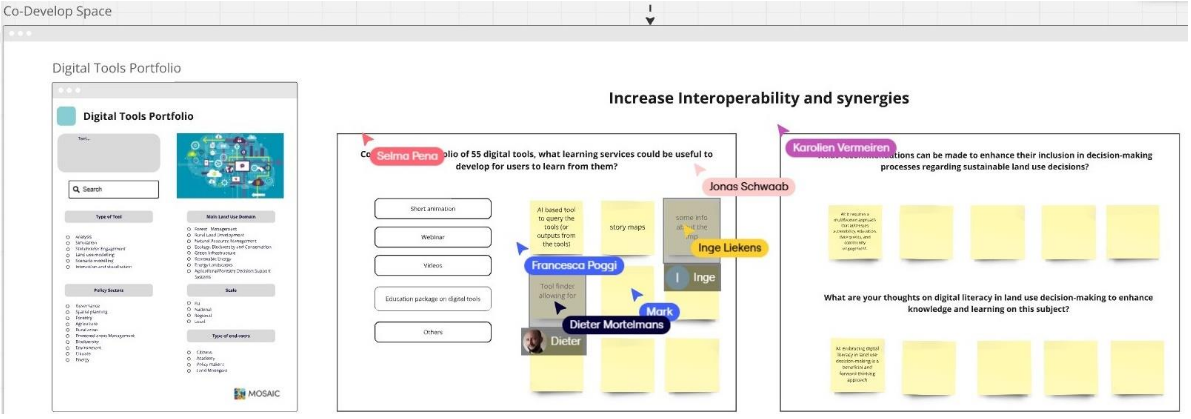


Figure 54: Miro board to co-develop ideas during the developers´ workshop

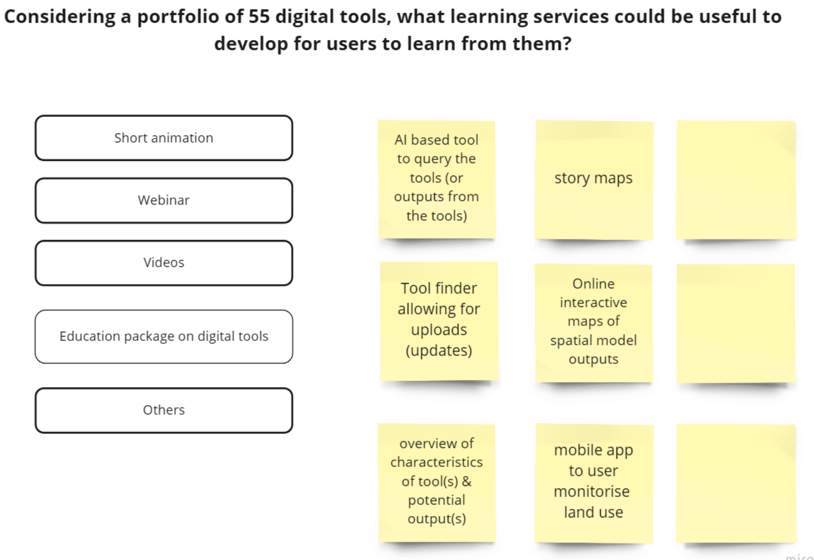


Figure 55: Learning services for the DLE suggested by the developers

In this way, the co-designed DLE, complemented by the Digital Portfolio of 55 tools and the outputs from this study, will enable learning services to promote stakeholders' access to tailored resources, fostering uptake and widespread adoption and impactful application of digital solutions in sustainable land use decision-making.

The integrative approach developed in this study places digital tools as a key driver in supporting informed, equitable, and sustainable land-use transformations within the MOSAIC project, its Policy Labs, and broader stakeholder networks. These networks include policymakers, researchers, land managers, and local communities, emphasizing the importance of co-designing a digital learning environment that fosters actionable and impactful knowledge on integrating digital tools into sustainable land use planning across diverse stakeholders, contexts and regions.

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APPENDIX

Appendix A – Digital Portfolio – ideally to be consulted digitally

Appendix B – Developers interview

Appendix C – Users survey

Project Partners

vito

WSL

ELO European Landowners' Organization

ESSRG Environmental Social Science Research Group

ETH Eidgenössische Technische Hochschule Zürich Swiss Federal Institute of Technology Zurich

Eurosite

ILVO Flanders Research Institute for Agriculture, Fisheries and Food

INRAE

KIT Karlsruher Institut für Technologie

KLIMASKOV FONDEN

NOVA FCSH FACULDADE DE CIÊNCIAS SOCIAIS E HUMANAS UNIVERSIDADE NOVA DE LISBOA

UNIVERSITY OF AMSTERDAM

UNIVERSITY OF COPENHAGEN

THE UNIVERSITY OF EDINBURGH

U LISBOA UNIVERSIDADE DE LISBOA | INSTITUTO SUPERIOR DE AGRONOMIA

ADRAL AGÊNCIA DE DESENVOLVIMENTO REGIONAL DO ALENTEJO

VLAAMSE LAND MAATSCHAPPIJ

RESEARCH INSTITUTE NATURE AND FOREST

WWF

oppla

MOSAIC

MOSAIC is an EU-funded project working to understand and influence how land-use across Europe is managed.

www.mosaic-europe.eu

www.linkedin.com/company/mosaiclanduse

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Federal Department of Economic Affairs, Education and Research EAER
State Secretariat for Education, Research and Innovation SERI

T5.1 MOSAIC DIGITAL PORTFOLIO

Tool DESCRIPTION											Tool FUNCTIONS					Tool DATA				Tool USERS			Tool REFERENCES
Database of Origin/Information Source	ID	Tool name	Description	Online link	Level of development	Developer /Publisher	Type of Developer	Contact	Launching Year	Country of origin	Type of Tool	Policy sector	Main Land Use Domain	Spatially explicit output	Scale	General input data type	Detailed input data type	Output data type	Output timeframe	Users	Type of end-users	Time requirement	
Name	n°	Name	75 characters	Link	Prototype Under development Operational	Name	Public Administration Academy/Research center Enterprise Other	email	yyyy		Analysis Simulation Stakeholder Engagement Land use modelling Scenario modelling Interaction and visualization	Governance Spatial planning Forestry Agriculture Rural areas Protected areas management Biodiversity Environment Climate Energy Multiple	Forest Management Rural Land Development Natural Resource Management Ecology, Biodiversity and Conservation Green Infrastructure Renewable Energy Energy Landscapes Agricultural/Forestry Decision Support Systems Water Management Mixed Land Uses	Yes, No	EU National Regional Local	Qualitative Quantitative Both	Statistics Spatial information Expert knowledge Field survey data Dataset	Map Graphics Texts Aggregated data	Current Short-medium term Long term	Number	Citizens Academy Policy makers Land Managers All Others	Low Medium High	Bibliography or web-site
CORDIS (TOT 19)	1	CO-IMPACT	Developed within the Connecting Nature Project, CO-IMPACT is a decision-support tool allowing officers and cities to create impact assessment plans for their NBS/projects. The main objective is to make the process of building a baseline and impact assessment plan straight forward and simple for anyone who wishes to do so, with the final report providing advice around suitable methodologies based on scale and project characteristics	https://co-impact.app/	Operational	University of Coruña	Academy/Research Center	ana.dumitru@udc.es;david.tome.lourido@ud	2021	EU Consortium (Spain Coordinator)	Analysis	Multiple	Green Infrastructure	no	Local	Qualitative,	Expert knowledge	Texts	Current	no data	All	Low	https://cordis.europa.eu/project/id/730222
	2	ECOPotential view	ECOPotential is a project funded by the European Union, focused on research and monitoring of protected ecosystems. This project uses satellite data and other Earth observation technologies to analyze and model ecosystem dynamics, with the aim of supporting the conservation and sustainable management of protected areas.	https://maps.ecopotential-project.eu/	Operational	CONSIGLIO NAZIONALE DELLE RICERCHE; UNIVERSITA DEL SALENTO;	Academy/Research Center	antonello.provenzale@cnr.it	2015	EU Consortium (United Kingdom Coordinator)	Interaction and visualization	Protected areas management	Mixed Land Uses	yes	EU, national and regional	Qualitative,	Expert knowledge	Map	Current	no data	Land managers	Medium	https://cordis.europa.eu/project/id/641762
	3	ERA-PLANET	European Union-funded research program that aims to coordinate and integrate environmental observation infrastructure in Europe. This program is part of the Horizon 2020 initiative and involves several countries and research institutions.	http://www.era-planet.eu/index.php	Operational	CONSIGLIO NAZIONALE DELLE RICERCHE	Academy/Research Center	pirrone@iia.cnr.it	2015	EU Consortium (Italy coordinator)	Stakeholder Engagement	Environment	Mixed Land Uses	no	EU and national	Qualitative,		Texts	Current	no data	Land managers	Medium	https://cordis.europa.eu/project/id/689443
	4	GROW	The GROW Observatory will create a sustainable citizen platform and community to generate, share and utilise information on land, soil and water resource at a resolution hitherto not previously considered. The vision is to underpin smart and sustainable custodianship of land and soil, whilst meeting the demands of food production, and to answer a long-standing challenge for space science, namely the validation of soil moisture detection from satellites.	https://growobservatory.org/about/	Operational	UNIVERSITY OF DUNDEE	Academy/Research Center	hello@growobservatory.org	2016	EU Consortium (United Kingdom Coordinator)	Interaction and visualization	Multiple	Mixed Land Uses	yes	National and regional	Both	Spatial information	Aggregated data	Current	7.8M People reached	Citizens	Low	https://cordis.europa.eu/project/id/690199
	5	GROW GREEN	GROW GREEN will provide the platform for a step change in the way that NBS are embedded in the long-term planning, development, operation and management of cities around the world. The NBS Business Models search engine offers a first orientation and inspiration to decision-makers on the type of interventions using Natural Based Solutions may be most appropriate for them, considering the specific problems they want to solve in their cities or companies, or the objectives they intend to achieve	https://growgreenproject.eu/	Operational	MANCHESTER CITY COUNCIL	Public administration	michelle.oddy@manchester.gov	2017	EU Consortium (United Kingdom Coordinator)	Interaction and visualization	Environment	Green Infrastructure	no	Local	Quantitative	Dataset	Aggregated data	Current	no data	All	Low	https://cordis.europa.eu/project/id/730283
	6	iSQAPER	Knowledge regarding the complex interplay between agricultural land use and management and soil quality and function is fragmented and incomplete, in particular with regard to underlying principles and regulating mechanisms. The main aim of iSQAPER is to develop an interactive soil quality assessment tool (SQAPP) for agricultural land users that integrates newly derived process understanding and accounts for the impact of agricultural land use and management on soil properties and functions, and related ecosystem services	Home (isqaper-project.eu)	Operational	WAGENINGEN UNIVERSITY	Academy/Research Center	harm.gooren@wur.nl ; klaas.oostindie@wur.nl	2015	EU Consortium (Spain Coordinator)	Interaction and visualization	Agriculture	Agricultural/Forestry Decision Support Systems	yes	Local	Both	Spatial information	Aggregated data	Current	119118	All	Low	https://cordis.europa.eu/project/id/635750
	7	LANDSENSE	Currently within the EU's Earth Observation (EO) monitoring framework, there is a need for low-cost methods for acquiring high quality in-situ data to create accurate and well-validated environmental monitoring products. The aim of the LandSense project is to build a far reaching citizen observatory for Land Use and Land Cover (LULC) monitoring that will also function as a technology innovation marketplace.	https://landsense.eu/	Operational	International Institute of Applied Sytems Analysis	Academy/Research Center	moorthy@iiasa.ac.at	2016	EU Consortium (Austria Coordinator)	Interaction and visualization	Multiple	Mixed Land Uses	yes	Local	Quantitative	Spatial information	Aggregated data	Current	no data	All	Low	https://cordis.europa.eu/project/id/689812
	8	MIND STEP	The EU-funded MIND STEP project will make use of agricultural and biophysical data and include individual decision making (IDM) unity in new and existing policy models for impact assessments. Using agricultural statistics and big datasets, the new IDM models will be estimated and calibrated, drawing on established economic and evolving machine learning techniques. The MIND STEP project creates a modelling toolbox that offers policy-makers timely and relevant evidence of the impact of agricultural policies and different outcomes in environmental and socio-economic areas	https://mind-step.eu/	Prototype	STICHTING WAGENINGEN RESEARCH	Academy/Research Center	mindstep@wur.nl	2019	EU Consortium (Netherlands Coordinator)	Stakeholder Engagement	Agriculture	Agricultural/Forestry Decision Support Systems	yes	EU	Both	Dataset	Aggregated data	Current	no data	Policy makers	Medium	https://cordis.europa.eu/project/id/817566
	9	MySustainableForest	MySustainableForest aims at developing a pre-commercial service platform for forest stakeholders, compliant with open and standard interfaces, which integrates Earth Observation data into the forest stakeholders' decision making processes and operations.	https://mysustainableforest.com/project/description/	Operational	GMV Aerospace and Defence S.A.U.	Enterprise	info@mysustainableforest.com	2018	EU Consortium (Spain Coordinator)	Land Use modelling	Forestry	Forest Management	yes	EU and national	Both	Spatial information	Aggregated data	Current	no data	All	Medium	https://cordis.europa.eu/project/id/776045
	10	NAIAD	Focus on assessing and demonstrating the insurance value of nature. NAIAD's primary objective is to develop and test nature-based solutions (NBS) to reduce water-related risks, such as floods and droughts, and demonstrate how these ecological services can be integrated into risk management and insurance strategies.	https://naiad2020.eu/	Operational	ICATALIST	Academy/Research Center	zdravko.kozinc@iskriva.net; lvay@icatalist.eu	2016	EU Consortium (Spain coordinator)	Stakeholder Engagement	Multiple	Natural Resource Management	yes	Regional	Qualitative,	Spatial information	Texts	Current	no data	Policy makers	Low	https://cordis.europa.eu/project/id/730497
	11	NATURVATION	Focuses on promoting nature-based solutions (NBS) in urban environments to address social, environmental and economic challenges.	https://naturvation-navigator.com/	Operational	Durham University	Academy/Research Center	h.a.bulkeley@durham.ac.uk; naturvation@ceu.edu	2017	EU Consortium (United Kingdom coordinator)	Analysis	Multiple	Mixed Land Uses	no	EU, national and regional	Qualitative,		Texts	Current	no data	Policy makers	Low	https://cordis.europa.eu/project/id/730243
	12	NBS Simulation Visualisation Tool	The Nature-Based Solutions Simulation Visualization Tool (NBS) is an advanced platform intended to support the implementation of nature-based solutions (NBS) to address urban environmental challenges such as climate change, water management and loss of biodiversity. This tool allows users to visualize and analyze the impacts of NBS in urban settings, facilitating informed decision-making by urban planners, engineers and policymakers.	https://unalab.eng.it/nbssvt_v4/home.jsp?city=genova&scale=local&year=2030&indicator=default&impact=default&scenario=00&prevision2=10	Operational	Smith School of Environment and Enterprise	Enterprise	info@unalab.eu info@ecopotential-project.eu	2017	EU Consortium (Italy Coordinator)	Simulation	Multiple	Ecology, Biodiversity and Conservation	yes	Local	Qualitative,	Spatial information	Map	Short-medium term	no data	All	Medium	https://cordis.europa.eu/project/id/730052
	13	OPERANDUM	Severe hydro-meteorological phenomena are having a high impact in European territories and are of global concern. The science behind these phenomena is complex and advancement in knowledge proceeds with progress in data acquisition and forecasting useful for real-scenario interventions	OPERANDUM | OPEn-air laboRAtories for Nature baseD solUtions to Manage hydro-meteo risks (operandum-project.eu)	Operational	ALMA MATER STUDIORUM - UNIVERSITA DI BOLOGNA	Academy/Research Center	info@operandum-project.eu	2018	EU Consortium (Italy Coordinator)	Analysis	Climate	Mixed Land Uses	no	National, regional and local	Both	Expert knowledge	Texts	Current	no data	All	Low	https://cordis.europa.eu/project/id/776848
	14	RECARE	The RECARE project is a European initiative focused on the prevention and remediation of soil degradation in Europe. The aim of the Stakeholders Platform is to enable interaction between all those people who are interested in the RECARE project activities in a particular Case Study area.	https://www.recare-hub.eu/stakeholder-platforms	Operational	Wageningen University	Academy/Research Center	coen.ritsema@wur.nl	2013	EU Consortium (Netherlands Coordinator)	Stakeholder Engagement	Agriculture	Agricultural/Forestry Decision Support Systems	yes	EU and national	Both	Spatial information	Texts	Current	no data	All	Low	https://cordis.europa.eu/project/id/603498
	15	RUBIZMO	Rural entrepreneurs in the bioeconomy find it difficult to access funding, skilled employees and innovation support networks. The EU-funded RUBIZMO project will identify innovative business models (developed or identified in projects under the Seventh Framework Programme, Horizon 2020, Interreg, Central Europe, etc.) with significant potential to support modernisation and sustainable growth in rural economies. These will also be relevant to the food sector, bio-based value chains and ecosystem services. The selection and classification of models will be deployed for the creation of a virtual library of business cases, the drafting of guidelines for public authorities and policymakers, a cooperation toolkit for efficient networking and a transformation support tool for novice entrepreneurs.	https://rubizmo.eu/e-learning	Operational	RISE RESEARCH INSTITUTES OF SWEDEN AB	Academy/Research Center	justin.casimir@ri.se	2018	EU Consortium (Sweeden Coordinator)	Interaction and visualization	Rural Development	Rural Land Development	no	Regional	Qualitative,	Expert knowledge	Aggregated data	Current	no data	Land managers	Low	https://cordis.europa.eu/project/id/773621
	16	SCENT	SCENT - Smart Toolbox for Engaging Citizens into a People-Centric Observation Web - The project designed, developed and implemented a people-centric observation web, formulated on the basis of using low-cost, portable sensors and innovative applications. The SCENT toolbox offers various capabilities involving crowdsourcing and serious gaming mechanisms towards enabling, incentivising and increasing the involvement of citizens as individuals and/or citizen groups/associations in the process of environmental monitoring. By using their smartphones and portable sensors, citizens can take images of land cover / land use while walking around in their city or the countryside, report events that may affect floods (e.g. river obstacles) and measure water level, flow velocity and soil moisture, without complex or bulky equipment. They are doing this in a playful manner, through a game of catching animated animals in their surroundings and collecting points.	https://scent-project.eu/	Operational	National Technical University of Athens	Academy/Research Center	hello@scent-project.eu getinvolved@scent-project.eu	2016	EU Consortium (Greece Coordinator)	Analysis	Environment	Natural Resource Management	yes	Local	Both	Spatial information	Aggregated data	Long term	no data	All	Medium	https://cordis.europa.eu/project/id/688930
	17	SIM4NEXUS	SIM4NEXUS has developed a Serious Game. The Serious Game is a computer game that aids learning about the Nexus by helping users to understand and explore the interactions between water, energy, land and food resources management under a climate change context, divides the problem into manageable interventions, and allows participants to learn by doing. The ultimate goal of game development is to create a fun and interactive capacity-building tool to be used in research, educational settings and management.	https://seriousgame.sim4nexus.eu/sim4nexus-MainPage.html?id=250e65f5-a592-4985-aabf-38e8099350e5#world_map	Under development	Wageningen University & Research (WUR)	Academy/Research Center	sim4nexus@wur.nl	2016	EU Consortium (Netherlands Coordinator)	Interaction and visualization	Multiple	Mixed Land Uses	yes	EU and national	Qualitative,	Spatial information	Map	Current	no data	Policy makers	Low	https://cordis.europa.eu/project/id/689150
	18	SmartCulTour	The SmartCulTour Game is an integral part of a set of intervention toolkits for the six SmartCulTour Living Labs. With its playful approach to policy making, the game aims to engage stakeholders to learn about cultural tourism and interventions to make cultural tourism more sustainable for communities, the environment, and creative businesses. The game was developed in 2021 by the Research & Development Lab 'Cradle' of Breda University of Applied Sciences. Drawing on insights and outputs of previous WPs such as the 'state of the art of cultural interventions' or the 'Future of cultural tourism for urban and regional destinations', concepts have been translated into a workshop with playable interactions.	http://www.smartcultour.eu/smartcultour-platform/	Operational	Breda University of Applied Sciences	Academy/Research Center	weber.j@buas.nl	2023	EU Consortium (Netherlands Coordinator)	Stakeholder Engagement	Governance	Mixed Land Uses	no	Regional	Qualitative,	Expert knowledge	Aggregated data	Current	no data	All	Low	https://cordis.europa.eu/project/id/870706
	19	URBAN GreenUP	Urban GreenUp objective is the development, applicantio and replicantion of Renaturing Urban Plans in a number of European and Non-European partner cities with the aim to mitigate the effects of climate change	https://www.cartif.es/en/urban-greenup-en/	Operational	CARTIF Technology Centre	Academy/Research Center	rausan@cartif.es	2017	EU Consortium (Netherlands Coordinator)	Stakeholder Engagement	Environment	Mixed Land Uses	yes	Regional and local	Both	Spatial information	Texts		no data	All	Medium	https://cordis.europa.eu/project/id/730426
MOSAIC Internal Survey (TOT 19)	20	BirdWatch	BirdWatch is a service to measure and improve biodiversity using satellite data for monitoring, evaluation and optimization of CAP greening initiatives. Agricultural biodiversity has dramatically declined in recent years, especially due to the intensification of land use and mowing activities, an increase in the application of pesticides and manure, of indoor keeping of livestock, in the drainage of wetlands, in the loss in structural elements, such as hedges or fallow land, and a decreasing variability in crop types.	Not published yet	Under development	LUP/VITO	Academy/Research Center	rik.hendrix@vito.be	planned by 2025	Germany	Land Use modelling;habitat optimisation	Agriculture;Protected areas management;Biodiversity;Climate	Ecology, Biodiversity and Conservation;Green Infrastructure;Agricultural/Forestry Decision Support Systems	yes	Europe	Both	Spatial information;Field survey data;Dataset	Spatially explicit;Map	Current;Short-medium term	no data	All	Low	Not published yet
	21	CRAFTY	Agent-based modelling framework for application primarily at large spatial scales (national-continental), in the land system. Model applications are usually cross-sectoral and exploratory, analysing land system dynamics under global change. As an agent-based framework, a focus is on the decision-making processes of land managers, and their role in social-ecological systems.	https://landchange.earth/CRAFTY	Operational	Various	Academy/Research Center	calum.brown@kit.edu	2014	UK/Germany	Simulation;Land Use modelling;Scenario modelling	Forestry;Agriculture;Protected areas management;Biodiversity;Environment;Climate	Forest Management;Ecology, Biodiversity and Conservation;Renewable Energy;Mixed Land Uses	yes	Europe;National	Both	Statistics;Spatial information;Expert knowledge;Field survey data;Dataset	Aggregated data	Long term	no data	Academy	Medium	collected at
	22	Dynamic Energy Atlas	The Dynamic Energy Atlas enables to address the spatial dimension of the energy system in its full complexity. It supports mapping, monitoring, trend and scenario analysis in a quest for (new) suitable locations for energy production taking into consideration energy demand as well as technological, spatial planning land use and environmental constraints and concerns. The tool tackles possible locations for PV, residual heat exchange, wind turbines, hydropower, geothermal energy, biomass energy installations, riothermia, ...	DOI: 10.4229/EUPVSEC20202020-7DO.9.1	Operational	VITO	Academy/Research Center	karolien.vermeiren@vito.be	2015	Belgium	Analysis;Simulation;Scenario modelling;Interaction and visualization	Spatial planning;Energy	Renewable Energy;Energy Landscapes	yes	National;Regional	Quantitative	Statistics;Spatial information;Expert knowledge;Dataset	Spatially explicit;Map;Graphics;Aggregated data	Current;Short-medium term;Long term	no data	Policy makers	Medium	Meuris, M., Vanoirbeek, E., Catthoor, F., Menke-Hubeny, F., Uljee, I., Lemmens, J., Horváth, I.T., Duchêne, F., Clymans, W., & Schils, A. (2020). Towards Country Scale Photovoltaic Energy Yield Modelling.
	23	EcHiLA	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Simulation Stakeholder Engagement Scenario modelling Interaction and visualization	Spatial planning Climate Energy Multiple	Rural Land Development;Ecology, Biodiversity and Conservation;Renewable Energy;Energy Landscapes	yes	National;Regional;Local	Qualitative	Spatial information Dataset	Map	Long term	no data	All	Medium	Not published yet
	24	EPIC WebGIS	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Portugal	Interaction and visualization	Spatial planning	Mixed Land Uses	Yes	National, regional and local	Both	Spatial information	Map	Current	no data	All	Low	Magalhães, M.R., Pena, S.B., Müller, A., Cunha, N.S., Silva, J.S., Cardoso, A.S., Barata, L.T., Franco, L., 2018. EPIC WebGIS - A partilha de conhecimento como ferramenta de integração da paisagem nas políticas de ordenamento do território. Revista Cartográfica Nº 96. Instituto Panamericano de Geografia e História. DOI: 10.35424/rcarto.i96.193 (ISSN 0080-2085 (Print) 2663-3981 (Online))
	25	Forest structure and composition maps over Europe	[illegible]	Not published yet	Under development	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Interaction and visualization	Forestry	Forest Management;Agricultural/Forestry Decision Support Systems	yes	Europe	Quantitative	Spatial information;Dataset	Map	Current	no data	Academy	Medium	Not published yet
	26	IMPACT tool of the Flemish Climate portal	[illegible]	[illegible]	Operational	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Scenario modelling	Spatial planning;Climate	Green Infrastructure;Water Management	yes	Regional	Quantitative	Statistics;Dataset;Makes use of statistical modelling of possible future climates + existing geodatasets of Flanders	Map	Long term	no data	Policy makers;Land managers	Low	https://www.vmm.be/publicaties/klimaatportaal-vlaanderen (in Dutch)
	27	INCAtool	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	EU	Analysis	Governance;Economics, accounting	Mixed Land Uses;All land	yes	Europe	Quantitative	Statistics	Aggregated data	Current	no data	Policy makers	Medium	Vallecillo, S., La Notte, A., Ferrini, S., & Maes, J. (2019). How ecosystem services are changing: An accounting application at the EU level. Ecosystem Services, 40, 101044. https://doi.org/10.1016/j.ecoser.2019.101044
	28	InVEST	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	USA	Analysis;Simulation;Interaction and visualization	Spatial planning;Forestry;Agriculture;Rural Development;Protected areas management;Biodiversity	Forest Management;Rural Land Development;Ecology, Biodiversity and Conservation;Mixed Land Uses	yes	Europe;National;Regional;Local	Quantitative	Spatial information;Expert knowledge;Field survey data;Dataset	Spatially explicit;Map;Graphics;Aggregated data	Current;Short-medium term;Long term	no data	All	Medium	https://naturalcapitalproject.stanford.edu/software/invest
	29	LandCare Planner	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Finland	Analysis;Simulation;Stakeholder Engagement;Land Use modelling;Scenario modelling;Interaction and visualization	Governance;Spatial planning;Forestry;Agriculture;Rural Development;Biodiversity;Environment	Forest Management;Rural Land Development;Ecology, Biodiversity and Conservation;Agricultural/Forestry Decision Support Systems	yes	National;Regional;Local	Quantitative	Statistics;Expert knowledge;Dataset	Graphics;Texts;Aggregated data	Short-medium term;Long term	no data	Policy makers;Land managers	Medium	Not available
	30	Nature value explorer	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Belgium	Analysis;Interaction and visualization;assessment	Spatial planning;Forestry;Agriculture;Rural Development;Protected areas management;Climate	Forest Management;Rural Land Development;Natural Resource Management;Green Infrastructure;Mixed Land Uses	yes	National	Both	Spatial information	Aggregated data	Current;Short-medium term	no data	Academy;Policy makers;Land managers	Low	Steven Broekx, Inge Liekens, Wim Peelaerts, Leo De Nocker, Dries Landuyt, Jan Staes, Patrick Meire, Marije Schaafsma, Wouter Van Reeth, Olivier Van den Kerckhove, Tanya Cerulus, A web application to support the quantification and valuation of ecosystem services, Environmental Impact Assessment Review, Volume 40, 2013, Pages 65-74, ISSN 0195-9255, https://doi.org/10.1016/j.eiar.2013.01.003
	31	NEXUS Lean	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Belgium	Stakeholder Engagement;Interaction and visualization	Governance;the tools can be applied to any sector	applicable to many situations	yes	Europe;National;Regional;Local	Qualitative	Spatial information;Expert knowledge;Field survey data;stakeholder input through co-creation	Aggregated data	Current;Short-medium term;Long term	no data	All	Medium	Not available
	32	PANDORA 3.0 plugin	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Italy	Analysis;Simulation	Spatial planning	Green Infrastructure	yes	National	Qualitative	Dataset	Aggregated data	Current	no data	Land managers	High	Pelorosso, R., Gobattoni, F., Geri, F., Leone, A. PANDORA 3.0 plugin: A new biodiversity ecosystem service assessment tool for urban green infrastructure connectivity planning. Ecosystem Services, Volume 26, Part B, 2017, Pages 476-482, ISSN 2212-0416, https://doi.org/10.1016/j.ecoser.2017.05.016. http://dx.doi.org/10.1016/j.ecolind.2015.01.016"http://dx.doi.org/10.1016/j.ecolind.2015.01.016
	33	Reinvent your street	[illegible]	[illegible]	Operational	[illegible]	Other	[illegible]	[illegible]	Netherlands	Simulation;Stakeholder Engagement;Interaction and visualization	Spatial planning	Mixed Land Uses;Urban	no	Local	Both	Spatial information	Aggregated data	Current	no data	Citizens;Policy makers	Low	Not available
	34	RuimteModel Vlaanderen / SimLandUse	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Belgium	Analysis;Simulation;Land Use modelling;Scenario modelling	Spatial planning;Forestry;Agriculture	Mixed Land Uses	yes	Regional	Quantitative	Expert knowledge	Map	Current	no data	Policy makers	High	White, R., Engelen, G. and Uljee, I., 2015. Modeling Cities and Regions as Complex Systems From Theory to Planning Applications. ISBN: 9780262029568
	35	TargetBoreal85	[illegible]	Not available	Prototype	[illegible]	[illegible]	[illegible]	[illegible]	Denmark	Land Use modelling;Scenario modelling	Spatial planning;Forestry;Agriculture;Biodiversity;Environment;Climate;Water quality and Recreation	Forest Management;Natural Resource Management;Ecology, Biodiversity and Conservation;Agricultural/Forestry Decision Support Systems;Water Management;Mixed Land Uses	yes	National	Quantitative	Spatial information;Expert knowledge;Dataset	Aggregated data	Current	no data	Academy;Policy makers	High	Termansen, M., Hasler, B., Levin, G., Filippelli, R., Lundhede, T., Strange, N., Nainggolan, D., Bladt, J & Zandersen, M 2023, National arealforvaltningsmodel for vand, klima, biodiversitet og friluftsliv. IFRO Udredning, nr. 2023/09, Institut for FÃ¸devare- og RessourceÃ¸konomi, KÃ¸benhavns Universitet.
	36	UNBiodiversity Lab	[illegible]	[illegible]	Operational	[illegible]	[illegible]	[illegible]	[illegible]	UN	Interaction and visualization	Governance;Spatial planning;Biodiversity;Environment	Ecology, Biodiversity and Conservation	yes	Europe;National;Regional	Quantitative	Spatial information;Dataset	Map	Current	no data	Policy makers;Land managers	Low	https://unbiodiversitylab.org/wp-content/uploads/2023/05/UNBL-2022-Annual-Report-FNL.pdf
	37	Waldentwicklung	[illegible]	Not published yet	Under development	[illegible]	[illegible]	[illegible]	[illegible]	Switzerland	Simulation;Stakeholder Engagement;Land Use modelling;Scenario modelling;Interaction and visualization	Spatial planning;Forestry;Biodiversity;Environment	Forest Management;Ecology, Biodiversity and Conservation;Green Infrastructure;Urban	no	Local	Both	Spatial information;Expert knowledge;Field survey data	Graphics	Current	no data	All	Low	Not published yet
	38	Watch-It-Grow	[illegible]	[illegible]	[illegible]	VITO	[illegible]	[illegible]	[illegible]	Belgium	Analysis;Simulation;Stakeholder Engagement;Land Use modelling;Scenario modelling;Interaction and visualization	Governance;Agriculture;Rural Development;Protected areas management;Biodiversity;Environment;Climate	Rural Land Development;Natural Resource Management;Ecology, Biodiversity and Conservation;Agricultural/Forestry Decision Support Systems	yes	Regional	Both	Statistics;Spatial information;Expert knowledge;Field survey data;Dataset;remote sensing (satellite and airborne derived)	Spatially explicit;Map	Short-medium term	no data	All	Medium	https://blog.vito.be/remotesensing/watchitgrow-connects
WOS and SCOPUS (TOT 4)	39	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	United Kingdom	Interaction and visualization	Spatial planning	Mixed Land Uses	yes	Local	Both	Dataset	Aggregated data	Short-medium term	no data	All	Medium	Wang, C., Miller, D., Brown, I., Jiang, Y., & Castellazzi, M. (2016). Visualisation techniques to support public interpretation of future climate change and land-use choices: A case study from N-E Scotland. International Journal of Digital Earth, 9(6), 586–605. https://doi.org/10.1080/17538947.2015.1111949
	40	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Germany	Simulation	Agriculture	Agricultural/Forestry Decision Support Systems	yes	Regional and local	Both	Dataset	Aggregated data	Short-medium term	no data	Academy	High	Mössinger, J., Troost, C., & Berger, T. (2022). Bridging the gap between models and users: A lightweight mobile interface for optimized farming decisions in interactive modeling sessions. Agricultural Systems, 195, 103315. https://doi.org/10.1016/j.agsy.2021.103315
	41	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	France	Analysis	Agriculture	Agricultural/Forestry Decision Support Systems	yes	Local	Both	Spatial information	Aggregated data	Current	no data	Land managers	Medium	Kalenga Tshingomba, U., Djibo, B., Seulot, L., Teixeira, M., & Jouven, M. (2022). A spatialised information system to support decisions regarding grazing management in mountainous and Mediterranean rangelands. Computers and Electronics in Agriculture, 198, 107100. https://doi.org/10.1016/j.compag.2022.107100
	42	ZONATION	[illegible]	[illegible]	[illegible]	University of Helsinki	Academy/Research Center	[illegible]	[illegible]	Finland	Land Use modelling	Multiple	Ecology, Biodiversity and Conservation	yes	National, regional and local	Both	Spatial information	Spatially explicit;Map	Short-medium term	no data	Academy	Medium	Moilanen, A., Lehtinen, P., Kohonen, I., Jalkanen, J., Virtanen, E. A., & Kujala, H. (2022). Novel methods for spatial prioritization with applications in conservation, land use planning and ecological impact avoidance. Methods in Ecology and Evolution, 13(5), 1062–1072. https://doi.org/10.1111/2041-210X.13819
Grey literature (TOT 13)	43	AKIS PORTUGAL	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Portugal	Stakeholder Engagement	Agriculture	Agricultural/Forestry Decision Support Systems	no	National	Both	Expert knowledge	Aggregated data	Current	no data	All	Low	Rui Almeida e Francisca Vicente. 2020. AKIS and advisory services in Portugal. Report for the AKIS inventory (Task 1.2) of the i2connect project. (Project funded under the Horizon 2020 Research and Innovation Programme under Grant Agreement 863039)
	44	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Interaction and visualization	Forestry	Agricultural/Forestry Decision Support Systems	yes	Local	Both	Dataset	Map	Current	no data	Land managers	Medium	https://www.resilientforest.eu/wp-content/uploads/2020/05/DSS-TOOL-.pdf
	45	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	United Kingdom	Simulation	Climate	Natural Resource Management	yes	National, regional and local	Both	Expert knowledge	Aggregated data	Current	no data	All	Low	Broadmeadow, M. S. J., Ray, D., & Samuel, C. J. A. (2005). Climate change and the future for broadleaved tree species in Britain. Forestry: An International Journal of Forest Research, 78(2), 145–161. https://doi.org/10.1093/forestry/cpi014
	46	CropSAT	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Sweden	Analysis	Agriculture	Ecology, Biodiversity and Conservation	yes	Local	Qualitative,	Spatial information	Aggregated data	Current	no data	All	Low	Alshihabi, O., Piikki, K., & Söderström, M. (2020). CropSAT – A Decision Support System for Practical Use of Satellite Images in Precision Agriculture. In A. El Moussati, K. Kpalma, M. Ghaouth Belkasmi, M. Saber, & S. Guégan (Eds.), Advances in Smart Technologies Applications and Case Studies (pp. 415–421). Springer International Publishing. https://doi.org/10.1007/978-3-030-53187-4_45
	47	DAKIS	[illegible]	[illegible]	Prototype	[illegible]	[illegible]	[illegible]	[illegible]	Germany	Interaction and visualization	Agriculture	Agricultural/Forestry Decision Support Systems	yes	Local	Both	Field survey data	Aggregated data	Current	no data	Land managers	Medium	Mouratiadou, I., Lemke, N., Chen, C., Wartenberg, A., Bloch, R., Donat, M., Gaiser, T., Basavegowda, D. H., Helming, K., Hosseini Yekani, S. A., Krull, M., Lingemann, K., Macpherson, J., Melzer, M., Nendel, C., Piorr, A., Shaaban, M., Zander, P., Weltzien, C., & Bellingrath-Kimura, S. D. (2023). The Digital Agricultural Knowledge and Information System (DAKIS): Employing digitalisation to encourage diversified and multifunctional agricultural systems. Environmental Science and Ecotechnology, 16, https://doi.org/10.1016/j.ese.2023.100274
	48	E-Planner	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	United Kingdom	Interaction and visualization	Agriculture	Agricultural/Forestry Decision Support Systems	yes	National, regional and local	Both	Spatial information	Aggregated data	Current	no data	All	Low	Redhead, J. W., Burkmar, R., Brown, M., & Pywell, R. F. (2022). E-Planner: A web-based tool for planning environmental enhancement on British agricultural land. Environmental Modelling & Software, 155, 105437. https://doi.org/10.1016/j.envsoft.2022.105437
	49	Global Forest Watch	[illegible]	[illegible]	[illegible]	World Resources Institute (WRI)	[illegible]	[illegible]	[illegible]	USA	Interaction and visualization	Multiple	Mixed Land Uses	yes	EU, national and regional	Qualitative,	Expert knowledge	Aggregated data	Current	no data	All	Low	Estoque, R. C., Johnson, B. A., Dasgupta, R., Gao, Y., Matsuura, T., Toma, T., Hirata, Y., & Lasco, R. D. (2022). Rethinking forest monitoring for more meaningful global forest landscape change assessments. Journal of Environmental Management, 317, 115478. https://doi.org/10.1016/j.jenvman.2022.115478
	50	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Interaction and visualization	Protected areas management	Ecology, Biodiversity and Conservation	yes	Local	Both	Spatial information	Aggregated data	Current	no data	Land managers	Low	Not available
	51	LANDSUPPORT	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Interaction and visualization	Multiple	Agricultural/Forestry Decision Support Systems	yes	EU, national and regional	Qualitative,	Spatial information	Map	Current	no data	All	Medium	Terribile, F., Acutis, M., Agrillo, A., Anzalone, E., Azam-Ali, S., Bancheri, M., Baumann, P., Birli, B., Bonfante, A., Botta, M., Cavallaro, F., Colandrea, M., D'Antonio, A., de Mascellis, R., de Michele, C., de Paoli, G., Monica, C. della, di Leginio, M., Ferlan, M., ... Basile, A. (2023). The LANDSUPPORT geospatial decision support system (S-DSS) vision: Operational tools to implement sustainability policies in land planning and management. Land Degradation & Development. https://doi.org/10.1002/LDR.4954
	52	Land-use Finance Tool	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	United Kingdom	Analysis	Forestry	Forest Management	no	National	Both	Expert knowledge	Texts	Current	no data	Others	Medium	https://climatepolicyinitiative.org/wp-content/uploads/2019/02/Land-Use-Finance-Tool.pdf
	53	MicroLEIS DSS	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Spain	Analysis	Agriculture	Agricultural/Forestry Decision Support Systems	yes	Regional and local	Both	Dataset	Aggregated data	Current	no data	Land managers	Medium	de La Rosa, D., Mayol, F., Diaz-Pereira, E., Fernandez, M., & de La Rosa, D. (2004). A land evaluation decision support system (MicroLEIS DSS) for agricultural soil protection: With special reference to the Mediterranean region. Environmental Modelling & Software, 19(10), 929–942. https://doi.org/10.1016/J.ENVSOFT.2003.10.006
	54	MyForest	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	United Kingdom	Interaction and visualization	Forestry	Forest Management	yes	National, regional and local	Both	Spatial information	Aggregated data	Current	no data	Land managers	Medium	Not available
	55	VISA - Viability of the social-ecological agroecosystem	[illegible]	[illegible]	Prototype	[illegible]	[illegible]	[illegible]	[illegible]	Germany	Scenario modelling	Spatial planning	Mixed Land Uses	yes	Regional and local	Both	Spatial information	Aggregated data	Short-medium term	no data	Academy	High	Sheaden, M. (2023). Viability of the social-ecological agroecosystem (VISA). SoftwareX 22, 101360. https://doi.org/10.1016/j.softx.2023.101360

MOSAIC

Short interview with tool developer

Name of the Digital Tool	
1. What is your **background**?	
2. What is your **role as developer** of the digital tool?	
3. What were your **research questions or challenges** to answer that led to developing the digital tool?	
4. What were the **main constraints** you identify when developing the digital tool?	
5. Had you worked with relevant **stakeholders** on this tool regarding its development, **testing, and/or evaluation**? If yes, please describe what type of stakeholders and the main pertinent insights that you have collected.	
6. How have the **digital tool embedded within your specific context**/s and what are the opportunities for **generalization across multiple geographical contexts** and **different spatial and temporal scales**?	

7. Could you describe the **key motivations and barriers for the uptake** of your digital tool?
8. How could be **increased the uptake of (existing) tools and co-develop recommendations**, also with the end-user?
9. Explain how the tool can be situated within the following priority questions/criteria that arose in this scoping interview.

Priority question/criteria	**Does your tool address/implement this question/criteria? If yes, please explain how**	
	YES	NO
Capacity of the tool to develop **shared understandings** from the perspectives of **multiple and diversified stakeholders.**		
Capacity of the tool to improve **knowledge or enable learning of stakeholders**, across different topics associated with land-use.		
Capacity of the tool to **engage stakeholders and/or citizens** in land use decisions.		
Extent to which the tool integrates social, economic, regulatory, legal, cultural, environmental and other (energy, bioenergy, PV, recreation ECSY, infrastructures, employment) **drivers in process algorithms.**		
Is any essential or optional **skills development** necessary to use the tool? If yes, does exist support exist or a manual to ensure the optimal and correct use of it?		
Capacity of the tool to **improve spatial understandings** of the flows and interactions of various land uses between competing sectors and at different scales		

<table>
<tr><td>Capacity of the tool to informs or support decision-makers at different stages of a project and/or policy cycles.</td><td></td><td></td></tr>
<tr><td rowspan="2">Would you be available to attend an online workshop in the second week of October 2024 to validate the reviews and to co-develop innovative ideas to increase the interoperability and synergies between the tools and MOSAIC’s modelling outputs?</td><td>YES</td><td>NO</td></tr>
<tr><td></td><td></td></tr>
<tr><td>How many users does your digital tool have?</td><td colspan="2"></td></tr>
<tr><td>Could you please provide us with the contact details of 1/2 users so we can interview them?
Note that you should not feel obliged to answer questions about the users’ contacts.
We would organize interviews with users to understand their perceptions/experience about the use of the tool, in this sense the transfer of personal data aim to provide a certain benefit for the project and also for the user him/herself. However, the fact that data can be shared must then be communicated transparently to the user.</td><td colspan="2"></td></tr>
<tr><td>Do you, as a developer, have any specific questions that you would like to ask the users of your tool? If so, please provide the information to include in the user interview. The developers will receive the analysis of the user interviews during the workshop.</td><td colspan="2"></td></tr>
</table>

User´s perceptions and experience of digital land use decision support tools: embeddedness in specific contexts versus the opportunities for generalization

This survey is part of the project "MOSAIC- Joined-up land use strategies tackling climate change and biodiversity loss", a European project running from September 2023 to February 2028. It will be implemented in 1 European case study and 5 case studies across Belgium, Denmark, Hungary, Portugal and Switzerland (see also https://www.mosaic-europe.eu/).

In this context, the present survey aims to understand users' perceptions and experiences of digital land use decision support tools. We will focus on the following five tools for a more in-depth study: CRAFTY, Dynamic Energy, ENBILA, EPIC WEBGIS, and Nature Value Explorer.

Your responses to this survey will help us understand the use of digital tools in practice and contribute to developing recommendations for increasing their integration into decision-making processes.

You are invited to voluntarily contribute to our scientific project, MOSAIC. The estimated time to complete this survey is approximately 7 minutes

The confidentiality of the collected data is guaranteed, and the responses will remain anonymous, following the consent to use the information provided in the next section.

Thank you very much for your participation.

Consent to use the information provided

We value your participation in the research. To proceed with data collection and analysis, we need your consent to use the information you provide.

For further information, please contact VITO Data Protection Officer Charlotte Vanhoof at the following email address: assist-dpo@vito.be and the National Commission of Data Protection (CNPD) at geral@cnpd.pt.

You agree to the following:

1. The data you provide is confidential and will only be used for scientific research within the scope of MOSAIC.
2. You have the right to withdraw your consent at any time. If you choose to participate, you also have the right to access, correct, or remove your data, in whole or in part, from the study.
3. Personal data will be processed to ensure your anonymity, so that you cannot be directly or indirectly identified through published results.

Do you agree with the terms above and are you willing to participate in the research by providing elements for the MOSAIC project?

Yes

No

1. What sector do you work in?

Public administration

Academy

Civil society organizations

Private sector

I don't know

I don't want to answer

Other: __________

2. What is your current profession?

Researcher

Policymaker

Urban Planner

Landscape Architect

GIS Specialist (Geographic Information Systems)

Engineer

Consultant

Other: __________

3. What is your gender?

Man

Woman

I don't want to answer

4. Which of the following digital tools do you have experience with? (Select the applicable option)

Note: The following questions are related to the selected digital tool.

CRAFTY

Dynamic Energy

EnBiLA

EPIC WebGIS

Nature Value Explorer

5. How did you find out about the digital tool?

Recommendation (e.g., from a colleague or friend)

Online research (e.g., website, fórum)

Institution (e.g., university, research centre, company or government organisation)

I don't know

I don't want to answer

Other: __________

6. At what stage, or stages, of the policy cycle do you use the tool? (Checkbox, allows you to select multiple)

Agenda setting

Policy formulation

Decision-making

Policy implementation

Policy evaluation

At no stage

I don't know

I don't want to answer

7. At what phase, or phases, of the project stages do you use the tool? (Checkbox, allows you to select multiple)

Conception

Planning

Implementation

Monitoring

At no stage

I don't know

I don't want to answer

8. What is/are your key motivation for using the tool? (Checkbox, allows you to select multiple)

To improve decision-making

To save time and resources

To support policy development

To enhance project planning or monitoring

For academic research

To facilitate collaboration

To engage stakeholders

To learn and/or to have knowledge

Other: _________

9. What do you perceive as the barriers to uptake to the adoption and effective use of digital tool in land use decision-making? (Checkbox, allows you to select multiple)

Not User-Friendly (modelling skills, require training, ...)

Lack of interoperability (data exchange in different systems/platforms)

Technical constraints (time requirement of software performances, offline functions, ...)

Data availability

Limitation of spatial scales (only national, only regional, ...)

Reliability and usefulness of output data

Lack of technical support

Other: _________

10. Do you think the tool could be helpful/useful in addressing challenges related to:

Biodiversity (e.g. Nature Restoration Law, 2030 Biodiversity Strategy, Farm-to-Fork strategy)

Climate targets (e.g. 2030 Climate target plan)

Other policies and targets related to the Green Deal

I don't know

I don't want to answer

Other: _________

11. Has the digital tool helped you to improve land use decisions?

1 - Not at all helpful, 2 - Very little helpful, 3 - Neutral, 4 - Helpful, 5 - Significantly helpful

12. Do you have any other comments you would like to make or any recommendation to improve the tool?