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Review article

A review on the role of living labs in advancing sustainable practices in rural areas: Insights from agriculture, forestry, and agroforestry systems

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ABSTRACT

Transforming food systems to ensure adequate and nutritious food while minimising negative environmental and societal impacts requires direct stakeholder involvement in developing nature-based solutions (NbS) for sustainable rural development. The Living Labs (LLs) approach, characterised by open innovation and user-centred design, is gaining attraction as a collaborative space where users co-create, test, and evaluate innovations in real-world settings. While LLs are well established in various fields, their application in agriculture, particularly in forestry and agroforestry, is relatively new. This review highlights, for the first time, the implementation of LLs across agriculture, forestry, and agroforestry sectors. It addresses key concepts of LLs and examines their implementation, benefits, and challenges. Notably, we illustrate and discuss findings from case studies such as REFOREST and SALAM-MED LLs, with the objectives to 1) demonstrate how, in some study cases, LLs can foster stakeholder engagement and co-create knowledge to develop innovative solutions for ecosystem restoration and economic resilience; 2) evaluate the effectiveness of LLs in promoting sustainable practices and propose guidelines for their better implementation; and 3) carry out a comparative analysis to highlight the differences in terms of methodologies, stakeholder involvement, and outcomes between European and North American LL models. While the comparative analysis indicates the need for further investigation, particularly in the economic evaluation of these approaches, this review underscores, in general, the necessity for continued research to optimise the role of LLs in promoting sustainable innovation and collaboration among diverse stakeholders. It aims to enhance understanding of how LLs can improve sustainability in land-use practices while guiding future research and policy development.

1. Introduction

Rural areas in Europe encompass diverse landscapes with varying levels of forests, agriculture, and agroforestry, capable of providing multiple ecosystem services (Rolo et al., 2021). Rural areas comprise almost 50 % of the European Union's land area and are home to around a fifth of its population (Cascone et al., 2024). However, these areas are still facing challenges such as inadequate infrastructure, ageing demographics, depopulation, and various barriers to economic activity (Kalantaryan et al., 2021). Despite the importance of these areas, farmers in many rural areas face considerable vulnerability due to their heavy dependence on natural resources, inadequate infrastructure, unpredictable weather patterns, and limited access to financial resources. These factors collectively pose significant challenges to achieving food security in rural communities (Aryal et al., 2020). Although both forests and agricultural land are important land uses globally, agroforestry systems have recently emerged as a new model aimed at integrating and improving the sustainability of both food systems in response to the challenges of climate change. While agriculture focuses on crop production and livestock, forestry involves the management of forest resources for timber, biodiversity, and ecosystem services. Agroforestry integrates trees and crops/shrubs into agricultural systems, enhancing biodiversity, improving soil health, and increasing resilience against climate change.

In Europe, there seems to be a gap between the exploration and exploitation of knowledge, which is known as the 'European paradox' (Schuurman, 2014). The European Commission has proposed Living Labs (LLs) as a solution to overcome this paradox by promoting this innovative approach, which started with the establishment of the European Network of Living Labs (ENoLL) in 2006. Despite that, LLs have

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not yet fully realised their potential, and a more detailed conceptualisation and a better understanding of the mechanisms of LLs are still in progress (Schuurman, 2014). This review provides insights into the potential of LLs as open innovation systems that facilitate various knowledge transfers among stakeholders using a participatory-based approach.

Living labs are user-centred, open innovation ecosystems that operate in real-life environments and integrate stakeholders (users, businesses, government entities, and scientists) through a systematic co-creation approach (Alonso et al., 2021). This partnership enables users to actively participate in the research, development, and innovation process (Compagnucci et al., 2021) since LLs are an innovative form of open innovation that offers numerous benefits to various stakeholders. Magalhães et al. (2020) defined LLs as 'laboratories of public action' in which local problematic situations can be identified, interpreted, understood, and addressed, generating possibilities for democratic experimentalism. Therefore, they serve as a vital research infrastructure for the next decade of user-system interaction research. In the following subsections, we provide a brief description of the history of LLs and their emergence.

The term "Living Labs" has a long history, with early references dating back to 1749 when Knight described a "living laboratory" in the context of experimental environments (Fulgencio et al., 2012). The term "living laboratories" can be used interchangeably with "living labs," but it may also refer to experimental environments where real-world conditions are simulated only for research purposes. Unlike LLs, which focus on co-creation and user involvement, living laboratories may not always prioritise stakeholder engagement in the same collaborative manner. The participatory approach, on the other hand, is an essential component of LLs. The terms "participatory approach" and "living labs" are distinct concepts where the participatory approach is fundamental to the functioning of LLs, as they are designed to engage different stakeholders. Therefore, the participatory approach is a critical component of LLs, rather than an interchangeable term (Collins and Ison, 2009). The concept gained traction in the 1990s (Lakatos et al., 2024), particularly attributed to Prof. William Mitchell at MIT, who emphasised user-centric research methodologies for prototyping and validating solutions in real-life contexts (Bergvall-Kåreborn et al., 2009). Initial definitions varied, with Moffat (1990) viewing LLs as environments for monitoring lifestyle impacts on health, while Bajgier et al. (1991) proposed them as educational spaces for real-life problem-solving. In Europe, the formal establishment of LLs began in 2006 with the creation of ENoLL, aimed at enhancing citizen participation and addressing societal challenges (Hossain et al., 2019; Mastelic et al., 2015). Since then, LLs have evolved into diverse sustainability-oriented labs, including Urban Living Labs and Transformation Labs, each engaging users and stakeholders in different ways throughout the innovation cycle (McCrory et al., 2020; Jarzebski et al., 2023). Despite the growing interest and scholarly output on LLs, Leminen et al. (2017) noted a limited understanding of their historical evolution. For better understanding, it is opportune to note that the terms "living lab," "living laboratory," and "living labbing" have been used interchangeably in the literature, and there are two distinct approaches to living labs: the North American view and the European view (Hossain et al., 2019). The early North American approach and the more recent European approach both involve users in innovation activities in real environments. However, the North American approach sees LLs as demo homes, home labs, or houses of the future, while the European approach sees them as a platform to study users' everyday habits.

In this work, we conducted a literature search to explore studies implementing the LLs concept across the interconnected sectors of agriculture, forestry, and agroforestry, which dominate most rural areas. In fact, in recent years, there has been a rapid growth in the number of LLs studies in rural agricultural areas, but there has also been a rather high attrition rate indicating the challenges faced by this mostly practice-based concept. To the best of the authors' knowledge, while the implementation of the LLs concept is widely adopted in agriculture, there have not been many experiences regarding the implementation of the LLs concept in the forestry and agroforestry sectors. Moreover, we provide insights on the implementation of the LLs concept within the agriculture, forestry and agroforestry sectors to respond to important questions such as 1) What are the key concepts of LLs in the three contexts and how are they being implemented; 2) What are key features of LLs approaches in the North America and Europe; and 3) What are the specific benefits and challenges faced by the LLs concept in the three sectors?

2. Research methodology

Today, as ENoLL has grown, the number of academic papers on LLs has also increased, leading to a wider implementation of the various aspects related to the LLs concept in agriculture, and to a lesser extent in the forestry and agroforestry sectors. We conducted a literature review of articles published in official literature and open-source databases to enhance future research and identify gaps in implementing the concept of LLs in these three contexts. Previous literature review studies have utilised different approaches to identify relevant documents for analysis (Hossain et al., 2019). Some authors searched for articles in a single database such as the Web of Science (WoS) (Dahlander and Gann, 2010) or Scopus (Ceseracciu et al., 2023), while others used multiple databases and selected a final set of articles after removing duplicated and irrelevant documents (Hossain, 2016). Similarly, Ceseracciu et al. (2023) highlighted that there has been a gap in publications regarding LLs, while recently, the number of publications has expanded. In this review, we adopted an approach between these methods, as was done by Van Der Have and Rubalcaba (2016), and searched for documents in the WoS and Scopus databases. In addition, open sources on the Internet were also used to assess LL experiences, especially in agroforestry at the European level. Most of the research on open sources has led to several informational reports and newsletters from European, Mediterranean and global project websites where a network of LLs has been established and research studies on implementing the LLs concept in agroforestry are still ongoing. In detail, a bibliometric analysis was conducted using a set of keywords ("Living Labs" and "participatory approach") to look for articles within the context of agriculture, forestry, and agroforestry. The analysis indicated that publications on LLs started to appear in the last two decades, while the term "participatory approach" has been used since the beginning of the 19th century. For this reason, the analysis considered the period between 2008 and 2024 for better comparative results. When using the two databases, we found that most papers were indexed on both platforms; however, the results on Scopus were more consistent and responded correctly to our search objective. Moreover, when searching on the PubMed platform, no results or only a limited number of documents (2 − 3) were found when using the principle keywords ("living labs" and "participatory approach" in agriculture, forestry or agroforestry). Therefore, only Scopus's results are illustrated in this paper. When using only "Living Labs" as a keyword in the three sectors, the result from WoS yielded 93 articles in agriculture, 17 in forestry and 2 in agroforestry. When combining the results, a total of 95 documents were obtained. Similarly, when using only "Living Labs" as a keyword in Scopus, the results yielded 80 articles in agriculture, 19 in forestry and 3 in agroforestry, and when combining the results, the research yielded 81 papers. The combined results were passed to the next step by applying the Scopus filters to avoid double counting and overlapping of studies that have used the same keywords (document type "articles and conference papers", period "from 2008 to 2024", Language "English" and source type "Journal and Conference proceeding"). Then, a tree was built using the VOSviewer software (version 1.6.20; Leiden University, Leiden, Netherlands) for visualising scientific landscapes and bibliometric illustrations. The selection criteria were based on English language documents (Research articles, review papers, books and book chapters) published during the period from 2008 to 2024, while references in other languages were excluded. We should mention that the exported bibliography was used to show the importance of the subject and that no extensive work has been done in this area that needs more focus. The software offers a wide range of data visualisation functionalities that help with screening. When downloading metadata from Scopus or WoS, it extracts all the necessary information to create maps based on the important keywords selected by the user. Three visualization modes are available: Network Visualization presents a map of interlinkages between the chosen keywords, illustrating direct and indirect connections with varying thicknesses which represent the degree of importance. Overlay Visualisation displays the same map but uses different colours to indicate the evolution of concepts or keywords over a specific period. Density Visualisation highlights the density of each keyword within the entire set, where areas coloured in yellow indicate higher density and significance within the research framework.

Following the same methodology as outlined above, the keyword "Participatory approach" was searched within three sectors on the WoS platform. This search yielded 453 articles in agriculture, 104 in forestry, and 36 in agroforestry. When these results were combined using the same filters, a total of 500 documents were obtained. Similarly, the search on Scopus revealed 1081 articles in agriculture, 652 in forestry, and 128 in agroforestry, while the combined results from Scopus resulted in 1547 documents. The final step involved creating a bibliometric illustration using the same software. Fig. 1 below summarises the search methodology on Scopus highlighting the important results for more clarity.

3. Results and discussion

3.1. Bibliometric analysis

For the bibliometric analysis, Fig. 2 below represents a general overview of all indexed keywords related to the LLs within the agriculture, forestry and agroforestry sectors. Fig. 3 shows that in the last two decades, studies were focused primarily on LLs within the agriculture sector, and to a lesser extent within forestry. On the contrary, LLs were not linked directly to agroforestry indicating an important gap in this direction. Therefore, one of the objectives of this study is to highlight this research gap that can create more opportunities for future research in this direction with the involvement of stakeholders.

On the other hand, Fig. 3 illustrates that the keyword "Participatory approach" is directly associated with agriculture, while its connection to forestry is indirect. Notably, no direct or indirect links were found between the terms "Participatory approach" and “agroforestry”. This preliminary bibliometric analysis highlights a significant research gap regarding the participatory approach in agroforestry, suggesting that further exploration and investigation into this area are needed. In this study, this software was used to clarify and to show the gap in this research field, and the possible potential of implementing LLs in the three sectors. The findings indicate a contrast in research focus across the sectors, with agriculture receiving more attention. This could reflect future trends in research priorities or funding allocation within these sectors. The absence of literature on participatory approaches in agroforestry highlighted a potential gap and emphasised the need for targeted studies that could enhance stakeholder engagement and improve outcomes within this sector. By addressing this gap, future research could contribute to more sustainable practices and policies that integrate participatory approaches effectively across all three sectors.

It is widely accepted that individual users are considered one of the most valuable external sources of knowledge and a key factor for the success of open innovation (Jespersen, 2010). Today, despite extensive implementation and studies on LLs, there is no consensus on the definition of the term in the literature. Mbatha and Musango (2022) analysed 35 papers and summarised 12 definitions of the term ‘living lab’. The authors highlighted three main components of a LL; a component that focuses on experimentation, which is built on everyday practices in a real-time environment (Sovacool et al., 2020), a component that focuses on innovation processes and the development of new products, services, and societal infrastructures (Giannouli et al., 2018), and a component focused on the importance of collaboration between those living in the lab and multiple stakeholders from different sectors in co-creation (Eon et al., 2017). Collectively, LLs can be defined as one of the more recent approaches to managing open innovation processes, where individual users are involved in co-creating, testing, and evaluating innovation in open, collaborative, multi-contextual, and real-world settings (Bergvall-Kåreborn et al., 2009; Ståhlbröst, 2008). A major principle within the LL research consists of capturing the real-life context in which an innovation is utilised by end users through a multi-method approach (Schuurman, 2015). In the LL setting, a field test is a user study in which the interaction of a set of users with innovation in the context of use is tested and evaluated (Georges et al., 2016). Involving individual users in the process of systems development is a key dimension of open innovation

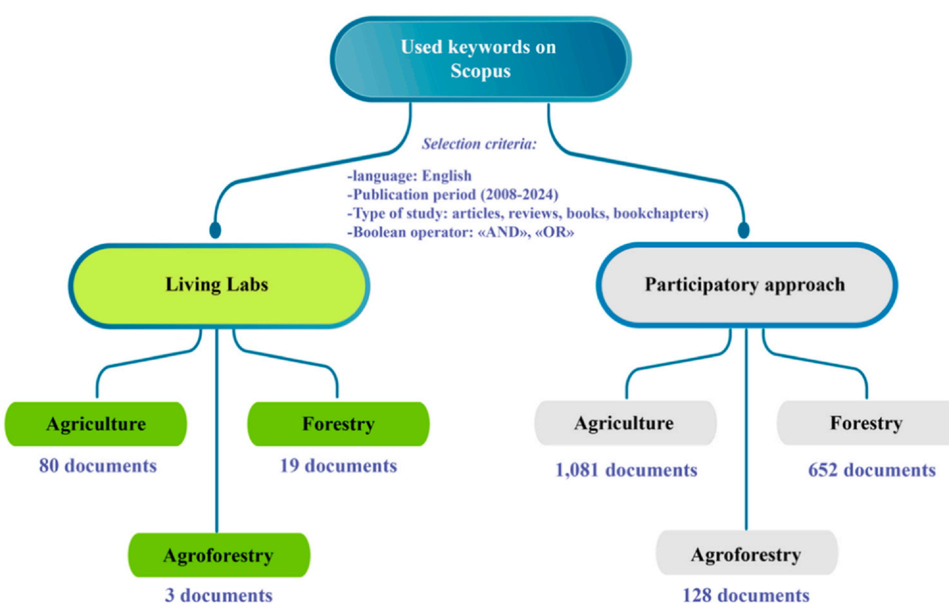

Fig. 1. Overview of the research methodology process on Scopus.

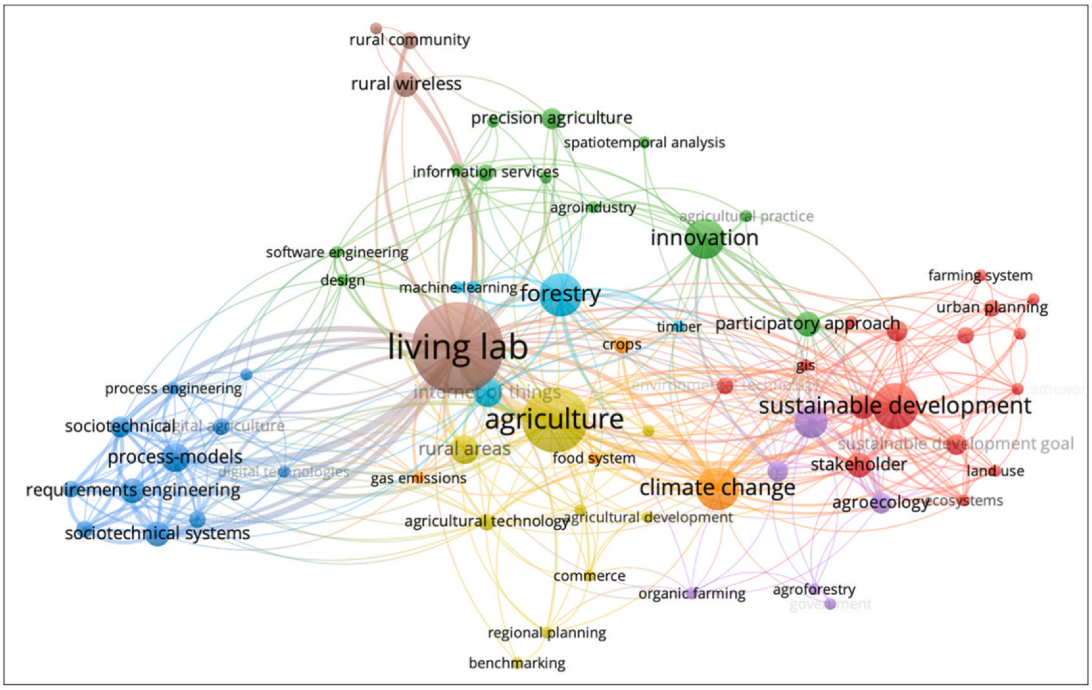

Fig. 2. Bibliometric illustration showing the interlinkages between the keyword "Living Labs" and the three main sectors (agriculture, forestry and agroforestry).

that contributes positively to new innovations as well as system success, system acceptance, and user satisfaction (Bano and Zowghi, 2015; Leonardi et al., 2014; Lin and Shao, 2000). However, when it comes to testing an innovation, previous studies show that the users' motivation in an open innovation environment such as LLs, especially at the beginning of the test, is higher than for the rest of the activity (Ley et al., 2015; Ogonowski et al., 2013; Ståhlbröst and Bergvall-Kåreborn, 2013). Consequently, the users tend to drop out of field tests before the project or activity has ended, as their motivations and expectations change over time (Georges et al., 2016). This drop-out might be due to the participant's decision to stop the activity or external environmental factors that caused them to terminate their engagement before completing the assigned tasks (O'Brien and Toms, 2008). The drop-out occurs in all phases of the innovation process, from contextualization to testing and evaluation (Habibipour et al., 2016).

The term "living lab" has been applied to many different types of innovation activities; however, even within a unique definition proposed in the literature, there can be various types of LLs. According to Leminen et al. (2012), LLs can be classified into four different types of networks characterised by open innovation: utilizer-driven, enabler-driven, provider-driven, and user-driven (or user-community-driven) LLs. A detailed characteristics of the different types of LLs are shown in the supplementary materials file (Table SM1). As 'LLs' is an upper-level

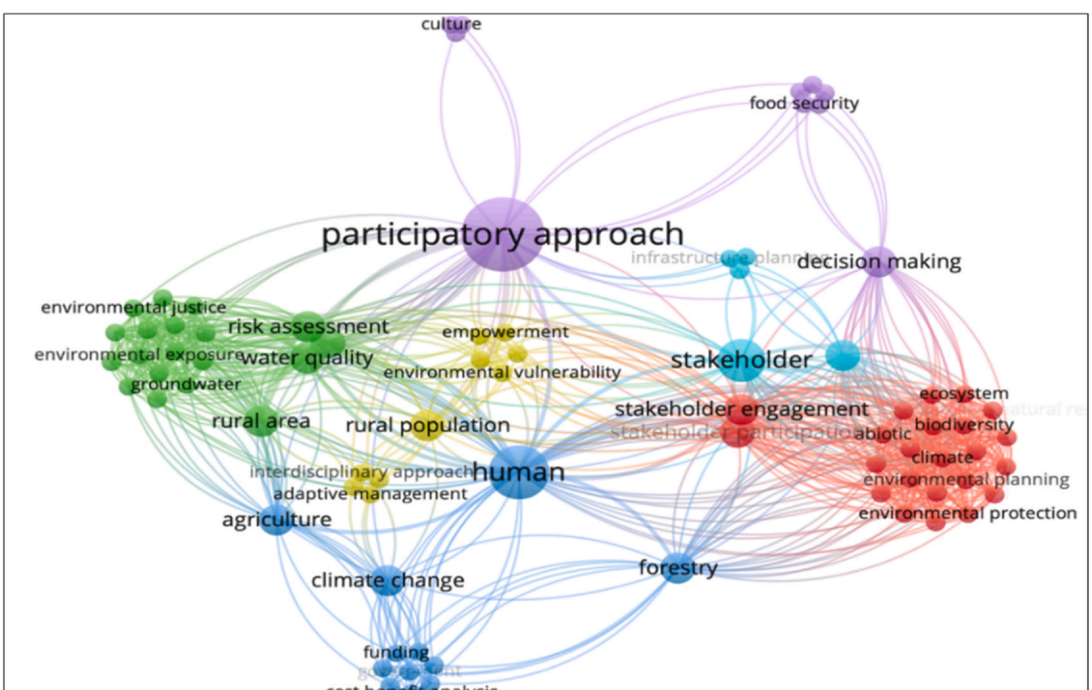

Fig. 3. Bibliometric illustration showing the interlinkages between the keyword "Participatory approach" and the forest, agriculture and agroforestry sectors.

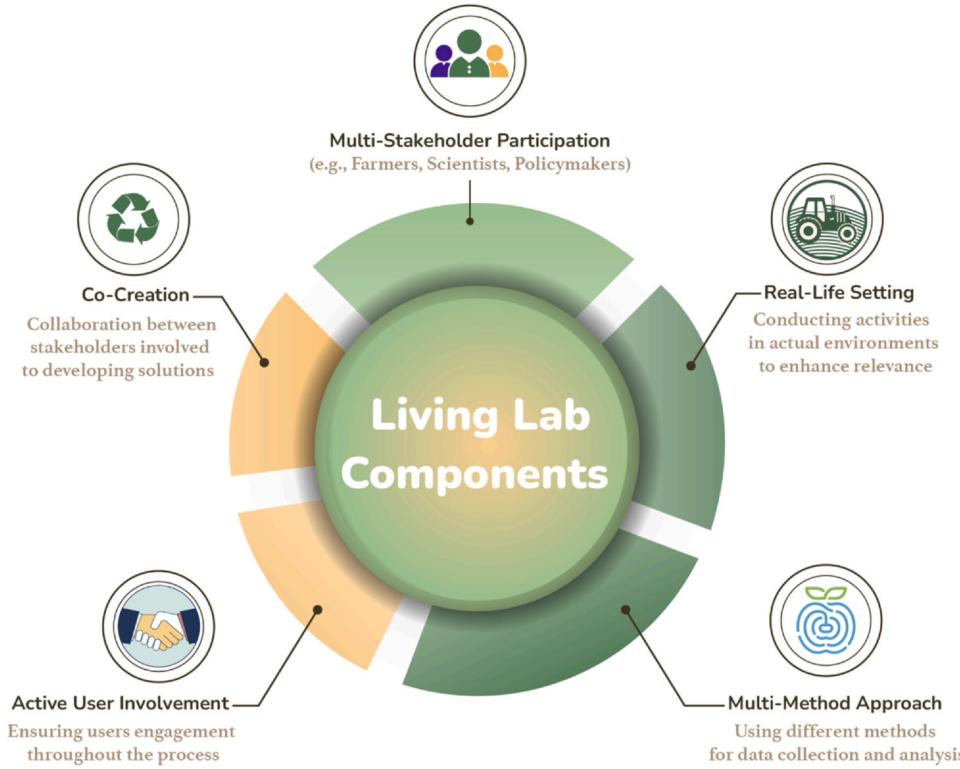

Fig. 4. The main components of Living Lab as introduced by ENoLL.

term that covers multiple topics, its key characteristics have been discussed from various perspectives (Hossain et al., 2019). Key characteristic elements of LLs found in the literature (e.g. Mulder, 2007; Leminen, 2015; Leminen and Westerlund, 2016; Hossain et al., 2019) can be seen in the supplementary materials file Table SM2. Based on our interpretation, several studies have reported different key characteristic elements of LLs. A study by Følstad (2008), for example, identifies context (e.g. context research, familiar context, real-world context), users (involving users as co-creators), activity (e.g. co-creation, technical testing, evaluation), challenges (discovery), and innovative outcomes (e.g. large-scale solutions) as the main characteristics of LLs. In contrast, Mulder (2007) propose six elements of LLs, including user involvement, service creation, infrastructure, governance, innovative outcomes, methods and tools. They emphasize the importance of methods and tools, arguing that the ENoLL has been recognized in Europe as a primary source for the methods and tools applied in LLs. Fig. 4 illustrates the different components of LLs according to ENoLL. Bergvall-Kåreborn et al. (2009) shared similar views to the previous scholars and pointed out five key components including information and communications technology (ICT) and infrastructure, management, partners and users, research, and approaches. Leminen and Westerlund (2016) identify four key aspects in nine identified research avenues for LLs, namely (1) systems (networks and ecosystems), (2) milieu (real-life environments) and approach, (3) user and public involvement, and (4) the activity, project, or management tool. Finally, Voytenko et al. (2016) list geographical embeddedness, experimentation, learning, participation, user involvement, leadership, ownership, evaluation, and refinement as key characteristics of LLs, aligning with most of the previously identified key characteristics of LLs.

3.2. Living Labs as a participatory-based approach to innovations in agriculture, forestry and agroforestry

Generally, agricultural, forestry and agroforestry systems are framed as socioecological systems that necessitate socio-technical innovation to face different challenges. Socio-ecological systems are defined as integrated systems of biophysical and social components that interact dynamically and resiliently across various scales, emphasising the interlinkages between human and ecological components (Berkes and Folke, 1998; Redman et al., 2004). Socio-technical innovation, on the other hand, refers to the collaborative processes that include social and technological advancements that aim at improving sustainability in these three sectors (Moraine et al., 2017). This perspective is important for understanding how agricultural practices can be sustainably managed while considering both ecological health and social equity. Moreover, the integration of socio-technical innovations is crucial for addressing the threats of climate change and other challenges, which require the involvement of different stakeholders (Nassauer and Opdam, 2008). Therefore, framing agricultural systems within the socioecological systems paradigm highlights the importance of socio-technical innovations in fostering resilience and sustainability in response to evolving environmental challenges.

Living Labs are open-innovation networks facilitating user-driven innovation that can be effective in promoting solutions to challenges in the agriculture, forestry and agroforestry sectors. By engaging diverse stakeholders, LLs enable experimentation in real-life environments. This collaborative approach fosters the development of solutions that align with users' needs, allowing for rapid scaling of successful innovations to broader markets (van der Walt et al., 2009; Leminen et al., 2012). Understanding the dynamics within LLs is essential for stakeholders to identify key drivers of innovation and anticipate outcomes. This is particularly important in sectors like agriculture and forestry, where the fragmented nature of research can complicate the innovation process (Dekkers, 2011). Effective stakeholder engagement is crucial because misidentifying stakeholders can lead to mismanagement and outcome limitations (Freeman, 2010; Bratteteig and Wagner, 2012). Living Labs emphasises active user involvement from the early design and implementation stages, distinguishing them from traditional participatory approaches. This is vital in agriculture and forestry, where local knowledge and practices play a significant role in successful innovation (Manzini and Eduardo, 2013; Cascone et al., 2024). As the global economy shifts toward knowledge-intensive models, innovation has become a key driver of economic and social growth in these sectors (Gray et al., 2014). The adoption of the 17 Sustainable Development Goals (SDGs) further highlights the importance of collaboration among various stakeholders (companies, governments, NGOs, and scientists) to address sustainability challenges in agriculture and forestry (Hossain et al., 2019; UN General Assembly, 2015). Moreover, sustainable development can promote innovation when pursued through a multi and transdisciplinary approach that integrates different perspectives (Fourati-Jamoussi et al., 2019). Living Labs play a pivotal role by fostering user involvement in value co-creation processes that contribute to economic, social, and environmental outcomes within agriculture, forestry and agroforestry (Compagnucci et al., 2021; Nyström et al., 2014). Successful networks must establish diverse stakeholder relationships to enhance innovation capacity in these sectors. The open innovation model facilitates broader participation compared to traditional methods, yielding benefits such as cost savings and improved performance (Calia et al., 2007; Chesbrough, 2006; Nyström et al., 2014). Practitioners must strategically plan for user participation to enhance co-creation while developing methodologies to effectively manage the complexities of long-term engagement in agricultural settings (Akasaka et al., 2022). The growing interest in stakeholder theory has led to frameworks (Fig. 4) that categorise engagement practices essential for managing innovation processes effectively within LLs (Freeman, 2010; Edlmann and Grobbelaar, 2021). The authors identified three categories of themes (see Fig. 5) crucial for the management of the formation and innovation process. These themes are interconnected, meaning that the performance of one theme affects the others, and consequently impacts engagement throughout the process.

According to the references analysed above, it can be emphasised that the integration of LLs into agriculture, forestry, and agroforestry presents several advantages, but also some critical challenges. One significant benefit is the ability of LLs to foster collaboration among diverse stakeholders, which can lead to more context-specific solutions better suited to local conditions with different socio-economic and sociocultural factors. The participatory approach encourages knowledge sharing and innovation diffusion across sectors, which is particularly vital in addressing complex issues such as climate change and resource depletion. However, the effectiveness of LLs can be limited by various factors. First, the success of these initiatives relies heavily on the active participation of all stakeholders. If certain groups or marginalized communities are not adequately represented or involved, it can lead to imbalances in power dynamics and result in innovations that do not meet the needs of all users. Furthermore, while LLs aim for inclusivity, there might be inherent biases in stakeholder selection processes that favour certain voices over others. Additionally, while LLs have a demonstrated potential for enhancing sustainability in agriculture and forestry practices, there is a risk that they may inadvertently reinforce existing inequalities within these sectors if not carefully managed. For instance, larger agricultural enterprises may dominate discussions at the expense of smallholder farmers or indigenous knowledge systems. This could undermine the very principles of co-creation that LLs seek to promote.

In conclusion, LLs represent a promising participatory-based approach to fostering innovation in agriculture, forestry, and agroforestry. By engaging diverse stakeholders in collaborative experimentation and knowledge sharing, LLs can drive sustainable practices that align with local needs while addressing broader environmental challenges. However, for these initiatives to achieve their full potential, it is essential to ensure equitable stakeholder engagement and representation throughout the innovation process. Addressing these challenges will not only enhance the effectiveness of LLs but also contribute to more resilient agricultural systems capable of adapting to future uncertainties. As global priorities shift towards sustainability and resilience in food systems and natural resource management, LLs will play a pivotal role in shaping innovative solutions that benefit both people and the planet.

3.3. The role of LLs in advancing sustainable practices in rural areas

Agriculture, forestry, and agroforestry all play pivotal roles in the global food supply chain, with each contributing to food security, environmental sustainability, and economic stability, particularly in rural areas. A mixture of these systems (e.g. forest and agroforestry) has proven to alleviate trade-offs between ecosystem services in European rural landscapes (Rolo et al., 2021). Today, there is a growing consensus that agriculture, forestry, and agroforestry systems could assist in combating food insecurity by expediting the transition towards sustainability (Datta et al., 2024). Even though changes in land use (e.g. forest-agriculture landscapes) present both threats and opportunities to forests, people and the climate, innovative interventions based on institutions, incentives and/or information can facilitate the knowledge

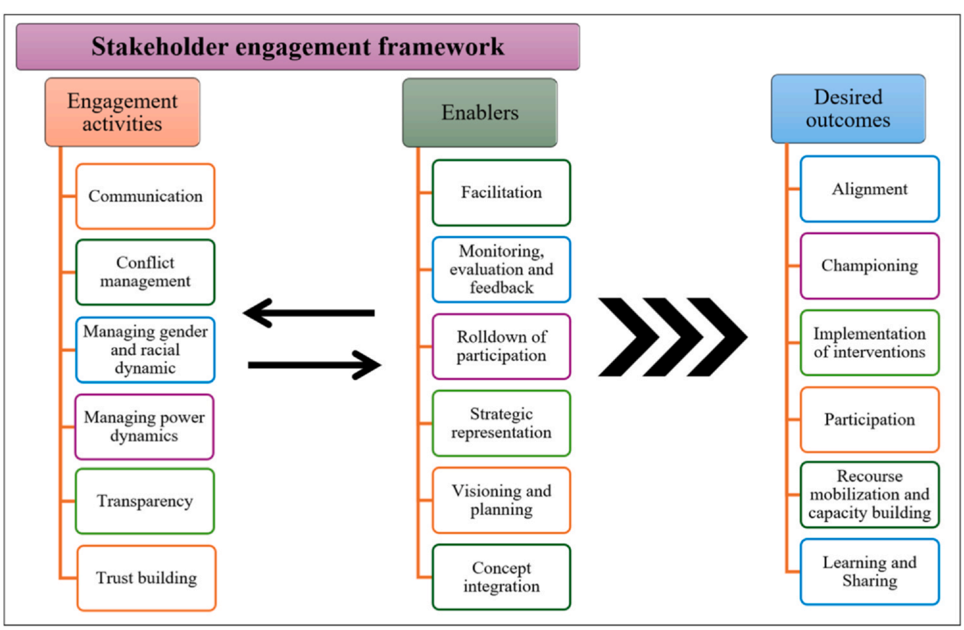

Fig. 5. Stakeholder engagement framework
(reproduced from Edlmann and Grobbelaar, 2021).

of how and where commodity agriculture occurs in relation to forests, leading to improved outcomes (Newton et al., 2013). Comparative assessments of different interventions in agriculture, forestry, and agroforestry through LLs are essential for advancing sustainable practices in rural areas (Ballon and Schuurman, 2015). Living Labs approach creates innovative ecosystems that enhance productivity, promote biodiversity, and empower rural communities to tackle specific challenges while ensuring economic viability (Olawumi and Chan, 2019). They serve as dynamic platforms for stakeholders—such as farmers, researchers, and local communities—to co-create and test innovative solutions in real-world settings (Krammer, 2014). By fostering experimentation and knowledge exchange, LLs are particularly relevant for addressing complex challenges in these sectors. Implementing the LL concept in agriculture, forestry, and agroforestry offers interconnected benefits, including a collaborative co-creation process, user-centric approaches, technology testing platforms, and tools for informing policy decisions (Mishenin et al., 2024).

3.3.1. The implementation of the LLs concept in agriculture

In the shift to agroecological practices, networking and innovation play a crucial role in the implementation of LLs. Agricultural LLs are a new and promising initiative aimed at revitalising rural social networks and driving innovation (Toffolini et al., 2021). The European Commission (EC) defines innovation in agriculture as a new idea, product, practice, service, production process, or even a new way of organising things that proves successful in practice. This innovation can be technological, non-technological, organizational, or social, and can be based on new or traditional practices. However, it only becomes an innovation when widely adopted and proves its usefulness in practice. In agriculture, the magnitude of environmental challenges we face today requires the involvement of diverse stakeholders and collaborators to develop socially, culturally, and economically robust sustainability practices (Beaudoin et al., 2022). Innovation in the agriculture and agri-food sectors typically involves multi-actor approaches. The LLs approach stimulates the development of user-centric solutions for complex environmental issues by exploring, co-creating, testing, and evaluating innovations within real-world contexts (Kim et al., 2019). The LLs model, as an innovation platform, has been studied in relation to sustainability and users (Compagnucci et al., 2021). The main objective of the approach is to maximize the use of existing knowledge and data, building upon foundations laid by previous projects. They also aim to establish a stakeholder and actor engagement platform to enable knowledge transfer, training, and innovation.

Agricultural LLs, similar to urban and rural LLs, are guided by three common principles: sustainability, complexity, and context-based locality (McPhee et al., 2021). However, their integration and operation within agri-food systems offers a unique perspective for efficient implementation and management. This includes consideration of seasonal cycles, quantities, and the diversity of the stakeholders involved (Cascone et al., 2024). Therefore, in agriculture, it is essential to develop innovations within local socio-technical networks (Lamine, 2011). Agricultural systems are socio-ecological systems (Urruty et al., 2016), wherein control is distributed among a network of farmers, advisors, agri-food industry actors, local and national authorities, and scientists, all of whom play a role in determining innovation (Touzard et al., 2015; Bourne et al., 2017). It is important to remember that every region and agricultural system has unique features that require adaptable LL approaches to meet local needs. This highlights the importance of focusing on collaborative efforts and the active involvement of all stakeholders, including farmers, researchers, institutions, and local communities (McPhee et al., 2021). Despite being relatively new, the LL approach in the agricultural sector is gaining increased attention as a response to environmental, economic, and social challenges (Bergvall-Kåreborn et al., 2009). In recent years, there has been an increasing number of scientific papers about this approach in agriculture (Cascone et al., 2024). The rise in publications indicates a growing interest and recognition of the crucial role of engaging critical stakeholders in agricultural innovation (Bronson et al., 2021). However, it is essential to carefully assess whether this increase results in significant real-world consequences, and if the LL approach effectively translates innovative ideas into practical measures to improve rural areas. Based on the information in the literature, the following table (Table 1) summarises the key benefits and challenges due to the implementation of the LLs concept in the agriculture sector.

3.3.2. The implementation of the LLs concept in forestry

Forest land can provide valuable benefits such as essential ecosystem services. In recent decades, there have been significant changes in society's views and expectations regarding forests (Ranacher et al., 2017). For instance, increased environmental awareness and a growing interest in recreation have shifted the public's perception of forests beyond their traditional role as sources of raw materials. Additionally, the push to transition toward “sustainable,” “green,” and “bio-based” economies has led to a heightened demand for raw materials. This demand is not only for more advanced bio-based products but also for generating renewable energy. For that, research into innovation in the forest sector is expanding, with increasing focus on the institutional, policy, and societal dimensions (Weiss et al., 2021). This attention is particularly relevant for understanding how to foster innovation within

Table 1
Key benefits and challenges of LLs application in agriculture found in the literature.

Benefits		Challenges		Ref.
Key Benefit	**Definition/Remarks**	**Key Challenge**	**Definition/Remarks**	
Innovation Testing	LLs provide a space for farmers and researchers to test new agricultural practices and technologies in real-world conditions, leading to more effective solutions tailored to local needs	Funding and Resources	Securing adequate funding and resources for long-term projects can be difficult, often relying on external grants or governmental support	(Potters et al., 2022)
Stakeholder Engagement	LLs foster collaboration among various stakeholders—farmers, scientists, policymakers, and NGOs—enhancing knowledge sharing and community involvement	Scalability	Solutions developed in LLs may be hard to scale beyond the local context due to varying regional conditions and constraints	(McPhee et al., 2021)
Sustainability Promotion	Many LLs focus on sustainable practices, such as organic farming, agroecology, and resource-efficient methods, which help reduce environmental impact.	Resistance to Change	Some farmers may be hesitant to adopt new practices, preferring traditional methods, which can limit the impact of LLs	(McPhee et al., 2021)
Capacity Building	LLs offer training and education opportunities, empowering farmers with skills and knowledge to implement sustainable practices effectively	Monitoring and Evaluation	Measuring the success and impact of LLs can be complex, as results may take time to materialise and require ongoing assessment	(Potters et al., 2022)
Economic Viability	By improving productivity and resource management, LLs can help increase the economic resilience of rural communities	Integration with Policies	Ensuring that the innovations and practices developed in LLs align with broader agricultural policies can be a challenge, requiring advocacy and negotiation	(Potters et al., 2022; Moruzzo et al., 2024)

the sector. Recent decades have seen a major shift in the planning and development of ecosystems and forest management, especially in Europe (Pretzsch et al., 2007). The forest-based sector, by providing bio-based products, contributes to the development of the bioeconomy which represents the European Union's responses to different ecological, energy, food and climate challenges, reducing society's dependence on fossil fuels (Pelli et al., 2017). Nevertheless, forest management practices and the development of sustainable forest policy involve a complex interplay of technical, scientific, social, and political issues such as rural development, biodiversity conservation and carbon sinks (Nagasaka et al., 2016). It is crucial therefore to integrate all these elements to effectively address these issues. This integration relies on fostering collaborative partnerships between scientists and policymakers. Currently, there is no comprehensive understanding of public perceptions or expectations regarding the sustainability of the forest sector. In fact, the stakeholder system of the European forest sector consists of various groups, each interacting with different levels of sustainability that hold significant societal importance (Lähtinen et al., 2017). A successful forest policy depends not only on how responsible people are but also on how the stakeholders effectively communicate (Dragoi et al., 2011). Bridging the communication gaps between the various stakeholders is essential for creating and maintaining sustainable forest management strategies and expressing their full potential and multi-functionality (Ugolini et al., 2015). Therefore, the improvement of stakeholder communication to promote sustainability and acceptance within the forest sector becomes of great importance. Despite current efforts, Lähtinen et al. (2017) indicate a lack of specific information on how to effectively communicate and shape the forest sector's image in the eyes of different stakeholders. It is believed that the forest sector's contribution to sustainable development and societal well-being relies on effective stakeholder management and communication to understand the needs of various stakeholders. To cope with this challenge, Smudde and Courtright (2011) emphasize that effective stakeholder management must involve three key tasks: (1) identifying important stakeholders, the topics that matter to them, and suitable communication methods; (2) maintaining relationships with these stakeholders; and (3) enhancing those relationships. By addressing these tasks, organizations can ensure sustainable communication with stakeholders, ultimately contributing to improved sustainability in the sector. Today, innovations based on stakeholder involvement have become a distinct research field in the forestry and timber industry (Weiss et al., 2020). Among the methods meant to improve communication and innovation in the forest sector could be the LLs approach as an innovative method that fosters collaboration among stakeholders. The essence of LLs lies in their capacity to facilitate experimentation and iterative learning, making them particularly suited for complex fields like forestry where ecological, economic and social factors intertwine. Similar to agriculture, LLs in the forestry sectors serve several key purposes. On the one hand, they allow for testing new technologies, practices and policies in a context that reflects the complexities of forest ecosystems and management systems. On the other hand, by involving a diverse range of stakeholders—such as local communities, forest managers, private forest owners, policymakers, and researchers—LLs foster dialogue and shared understanding, which is critical for addressing current challenges such as climate change, biodiversity loss, and sustainable resource management. Numerous efforts have been undertaken to provide policymakers and practitioners with answers to the key issues and challenges facing the forest-based sector (Weiss et al., 2020; Lovrić et al., 2020). These efforts include developing the bioeconomy, adapting to and mitigating climate change, forest renewal, and meeting citizens' expectations of forests while reconciling ecosystem services. However, exploring more innovative approaches such as LLs has not been applied to address these challenges effectively. Despite the wide application of this approach in other sectors, LLs-based studies in the forestry sector are rare (Weiss et al., 2020). Only a few case studies are found in the literature where the LLs approach has been effectively applied. Arnould et al. (2022) developed a methodological reference framework based on the LLs approach to pilot innovation in complex forest contexts that involve multiple actors and scales, both in time and space, while being grounded in specific territories. By using the action research methodology defined by Coenen et al. (2015), Arnould et al. (2022) sought to provide scientific insights for designing innovative forest management and wood systems by carrying out practical projects in LLs. The authors focused on integrating local knowledge into forest management strategies, exploring sustainable timber production, and developing ecosystem services. These initiatives have shown that the LLs approach improves collaboration between forest sector stakeholders, drives innovation in the forestry sector and can help rethink the development and implementation of forest policies, demonstrating the effectiveness of this approach in guiding innovation processes within a multi-stakeholder, multi-functional, and uncertain forestry environment. Their findings indicated that stakeholder engagement significantly improved decision-making processes, fostered innovation, and led to greater social acceptance of forestry practices. Moreover, in another study, Arnould et al. (2020) organised community workshops with the involvement of all stakeholders and the local inhabitants to initiate a citizen-participatory approach to deal with the community forest projects related to forest management and timber harvesting. The authors highlighted that the vision and organization of LLs appears well-suited to tackle forest challenges by employing co-creation, user-centred processes, collective intelligence, and multi-stakeholder approaches. They incorporate both short-term and long-term perspectives and participatory actions, highlighting the need to strengthen policy engagement, research, development and innovation in the forestry sector to provide long-term support for the actions implemented.

In Italy, interesting results based on the participatory approach, the key characteristic of LLs, come from Ugolini et al. (2015) and Ugolini et al. (2018) which have shown good experiences using this approach in the urban forestry sector. An important aspect highlighted by the authors was the importance of knowledge transfer as a key to achieving a common interest of the different stakeholders in the sector, indicating that the LLs approach has great application potential in the forestry sector. These study cases also showed the importance of revealing the unexploited potential to improve knowledge transfer and narrow the communication gaps between stakeholders in the forestry sector (Ugolini et al., 2015). As a result, the stakeholder network can be strengthened based on a prominent role in temporal considerations of the ecosystem services that the sector can provide (Ugolini et al., 2018). Similarly, Ciliberti et al. (2022) indicated that Italy is an interesting case study as it is the world's largest importer of wood-energy biomass where, each year, tons of fuelwood are imported without clear traceability, and the enforcement of the European Timber Regulation (EUTR) remains inadequate. To address this issue, the authors emphasised that comprehensive evaluations using the LLs approach are necessary to create a viable digital ecosystem in this sector, which would help clarify the impacts of ongoing digitalization within the industry. With reference to the previously mentioned experience, LLs in the forestry sector could also be of scientific value since they provide a unique setting for collective innovation in the context of societal challenges involving heterogeneous stakeholders such as citizens, customers, policy-makers, researchers, educators, businesses and universities to significantly contribute to the development of sustainable public policy Kalinauskaite et al. (2021). In the following table (Table 2), we provided key benefits and challenges of the LLs implementation in the forestry sector.

Overall, the LLs approach presents a transformative opportunity for the forestry sector, promoting sustainable practices through collaborative innovation and real-world experimentation. Information in the literature indicates that the LLs model contributes to the concept of adaptive management, which is essential in the forest sector due to the inherent uncertainties in ecological systems. Furthermore, by facilitating ongoing feedback loops among stakeholders, LLs can help refine

Table 2
Key benefits and challenges of LLs application in forestry found in the literature.

Benefits		Challenges		Ref.
Key Benefit	**Definition/Remarks**	**Key Challenge**	**Definition/Remarks**	
Collaborative Innovation	LLs foster collaboration among researchers, industry stakeholders, and local communities, leading to innovative solutions tailored to specific local needs	Complexity of Stakeholder Involvement	Managing diverse interests and expectations from various stakeholders can be challenging and may lead to conflicts	(Witteveen el al, 2023)
Real-World Testing	LLs provide a platform for testing new forestry practices and technologies in real-world environments, enabling more practical and applicable results	Resource Intensity	Implementing LLs can be resource-intensive, requiring significant time, funding, and expertise to coordinate effectively	(Lakatos et al., 2023)
Enhanced Sustainability	By involving various stakeholders, LLs can promote sustainable forestry practices that balance ecological, economic, and social needs	Scalability Issues	Solutions developed in LLs may be difficult to scale or replicate in different contexts due to unique local conditions	(Martin et al., 2021)
Knowledge Sharing	LLs facilitate the exchange of knowledge and best practices among participants, helping to build capacity and improve outcomes	Measurement of Impact	Assessing the effectiveness and impact of LLs can be complex, making it challenging to demonstrate value and secure ongoing support	(Potters et al., 2022)
Community Engagement	LLs encourage local community involvement, ensuring that the voices of those affected by forestry practices are heard and integrated into decision-making	Regulatory Barriers	Navigating existing regulations and policies can hinder the implementation of innovative practices explored within LLs	(Moruzzo et al., 2024)

practices and policies in response to changing environmental conditions and community needs. As the challenges facing forests become increasingly complex, this approach may prove crucial in driving forward effective and inclusive forestry management strategies. However, effectively tailoring communication in the forest sector and enhancing its image involves crafting clear messages that target specific audiences. This important issue should be explored further through future research projects as well as practical communication efforts within the sector.

3.3.3. *The implementation of the LLs concept in agroforestry*

The traditional agroforestry systems in Europe are often seen as successful models that effectively combine food production, biodiversity conservation, and cultural values. Rolo et al. (2021) showed highly differentiated ecosystem service profiles for landscapes associated with a specific land cover, with agroforestry generally providing higher cultural ecosystem services than forest and agriculture. However, the slow process of uptake and the failure of these systems in some parts of the world is mainly due to a lack of understanding of the perspectives of local stakeholders on the production, management, socio-economic, and environmental aspects of these systems. To address this gap, Yousefi and Ewert (2023) highlighted that agroforestry systems have to be studied following an open, participatory-based approach in LLs. In their study, Rolo et al. (2020) showed the results of participatory research conducted with ten stakeholder groups across Europe to find solutions for improving the economic and ecological sustainability of High Nature and Cultural Value agroforestry systems. The findings show that the solutions often did not align well with the identified challenges (Fig. 6). While some challenges were common across countries, the solutions to address them were more specific to each case. Therefore, the authors highlighted that the successful implementation of these solutions requires a deep understanding of the diverse socio-cultural and natural contexts of agroforestry systems. They also emphasized the need to develop bottom-up proposals and collective actions based on this understanding.

From a sustainability point of view, Rolo et al. (2021) combined biophysical and sociocultural approaches to assess how different landscapes (forest, agriculture or agroforestry) and landscape characteristics drive spatial associations of ecosystem services. Their findings suggest

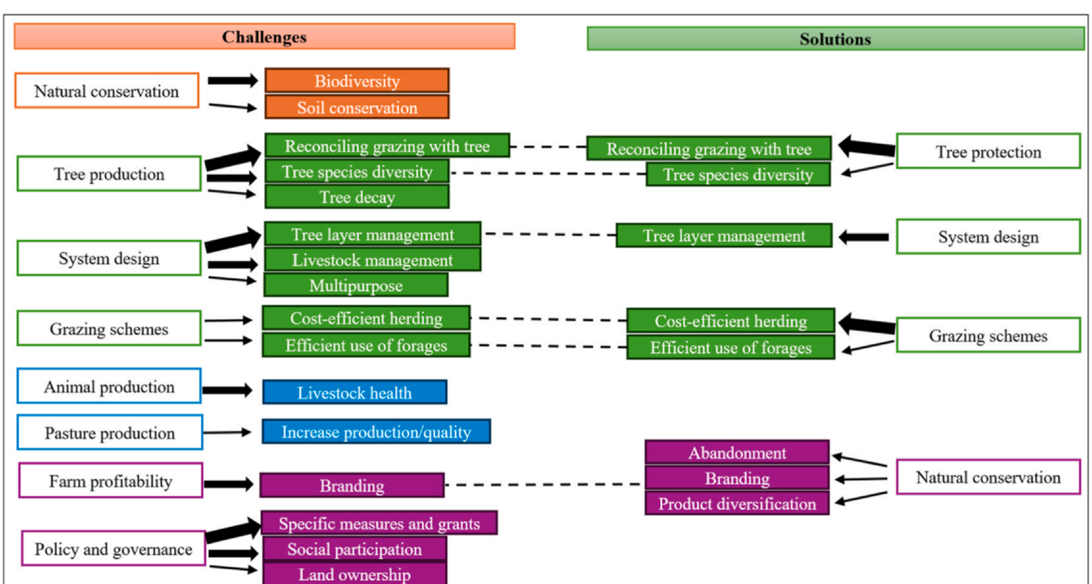

Fig. 6. Match-finding between challenges and solutions identified by stakeholders on a participatory approach basis. The arrow width represents the relative importance of the challenge (where identified) and the proposed solutions (whenever applicable)
(reproduced from Rolo et al., 2020).

Table 3
Key benefits and challenges of LLs application in agroforestry found in the literature.

Benefits		Challenges		Ref.
Key Benefit	**Definition/Remarks**	**Key Challenge**	**Definition/Remarks**	
Integrated Approaches	LLs promote the integration of agriculture and forestry practices, leading to more sustainable land use and improved ecosystem services	Diverse Stakeholder Interests	Balancing the varying interests and needs of stakeholders can be complex and may lead to conflicts	(Potters et al., 2022)
Stakeholder Collaboration	LLs facilitate collaboration among farmers, researchers, and policymakers, fostering shared learning and co-creation of solutions tailored to local contexts	Resource Constraints	Establishing and maintaining LLs requires significant investment in time, money, and expertise, which can be a barrier for some regions	(McPhee et al., 2021)
Practical Innovation	LLs enable real-world testing of agroforestry techniques, allowing for adjustments based on direct feedback from practitioners and the environment	Variable Outcomes	The effectiveness of practices tested in LLs may not be consistent across different environmental or social contexts, complicating scalability	(Lakatos et al., 2024)
Increased Resilience	By promoting diverse practices, LLs can enhance the resilience of agroecosystems to climate change and market fluctuations	Measurement Challenges	Quantifying the impact of LLs on agroforestry practices and ecosystems can be difficult, hindering efforts to demonstrate success	(Moruzzo et al., 2024)
Capacity Building	LLs provide training and knowledge transfer, empowering local communities to adopt sustainable agroforestry practices	Regulatory Challenges	Navigating agricultural and forestry regulations can pose obstacles to implementing innovative practices identified within LLs	(Witteveen et al., 2023)

that agroforestry should be prioritised over other land covers as it delivers a suite of multiple ecosystem services. In the following table (Table 3), we summarize the benefits of LLs in agroforestry based on the information found in the literature. Using a combined literature review, interviews, focus groups and participatory observation, Tubenchlak (2019) analysed the potential of agroforestry systems for upscaling landscape restoration, considering Forest Transition theory and pathways (Wilson et al., 2017). Results from both studies indicated that the main benefits of agroforestry systems, according to the stakeholders, include quality and diversification of food production, soil recovery and the sense of reconnection with nature, while the challenges include access to knowledge and labour, inputs and markets, as well as legal insecurity in managing forests and land tenure. It is opportune however to understand that both benefits and challenges are site-, regional- and/or national-specific due to variations in conditions.

Despite the shortage of studies within the literature, there has been a growing number of projects funded by the EU to study the effectiveness of LLs as an open innovation approach to bring together different stakeholders for the co-creation of economic and social values and to encourage the uptake of agroforestry systems in recent years. The collected case studies in the supplementary materials file provide essential lessons about exploring LLs in agroforestry. This approach emphasizes integrating ecological, economic, and social values for sustainable land use, particularly in Europe. These LLs demonstrate the effectiveness of participatory research involving diverse stakeholders such as farmers, policymakers, and researchers. In addition, collaboration among stakeholders in these LLs helps bridge critical research gaps and promotes the adoption of the best agroforestry practices to enhance biodiversity and resilience in the face of climate change. In fact, the recent LLs projects (REFOREST, LIVINGAGRO, SALAM-MED, etc.) within the Circular Bioeconomy Alliance (CBA) and other partnerships, aim to foster a sustainable transition towards a circular bioeconomy that harmonises with nature. More details and examples are reported in Table SM3 and Table SM4 showcasing the potential of LLs to restore ecosystems and create new economic opportunities for local communities, aligning with the concept of a circular economy. With support from the European Commission under Horizon Europe, PRIMA projects, and other funding programs, these LLs can facilitate the transition to agroecological systems. The support from the European Commission under Horizon Europe, alongside the PRIMA program, has been pivotal in enabling these LLs to transition towards agroecological systems. Horizon Europe provides substantial funding for research and innovation projects aimed at addressing climate change and promoting sustainable agriculture, while PRIMA focuses on fostering research and innovation in the Mediterranean region. Through ongoing innovation and knowledge exchange, LLs will play a crucial role in co-creating sustainable solutions to address new challenges.

4. Concluding remarks and future directions

This review highlights the pivotal role of LLs in promoting sustainable agricultural systems by fostering collaboration among stakeholders in the agriculture, forestry, and agroforestry sectors. Living Labs represents a transformative approach to innovation and sustainability, enabling participants to address complex challenges related to ecosystem services in rural areas. The findings of the bibliographic analysis indicate that integrating these systems can mitigate trade-offs between ecosystem services, thereby enhancing sustainability in various contexts. The novelty of this work lies in its comparative analysis of LL models used in European and North American approaches, providing insights into their effectiveness in advancing sustainable practices and evaluating the current situation of LLs within agriculture, forestry and agroforestry sectors. This understanding is crucial for practitioners and policymakers aiming to implement LLs effectively. Future research should focus on several key areas to reduce the identified gaps:

- Benefits and Challenges: While this review emphasises the benefits of LLs in agriculture, it is essential to explore the challenges faced by these initiatives, including barriers to stakeholder engagement and resource allocation.
- Empirical Research: There is a need for more empirical studies examining the long-term impacts of LLs on innovation processes within agricultural systems. Research should evaluate the effectiveness of different LL models related to sustainability outcomes.
- Integration of Values: Future studies should consider the socio-cultural values, emphasising the social, cultural, environmental, and economic impacts of LLs on sustainable practices in agriculture and agroforestry.
- Adaptation to climate change: The perspectives on LLs must adapt to emerging global challenges such as climate change. This requires inclusive participation from all actors involved to ensure relevance and effectiveness in promoting sustainable practices.
- User Engagement Strategies: Developing new strategies that enhance user engagement throughout the innovation process is crucial. This includes exploring co-creation, testing, and evaluating innovations within real-world contexts, particularly when supported by digital technologies.
- Interdisciplinary Collaborations: Effective implementation of LLs should be guided by principles of sustainability, complexity, and

context-based locality through horizontal interdisciplinary partnerships and knowledge exchange.

In summary, LLs have significant potential to drive sustainable agricultural practices by facilitating collaborative innovation. Addressing the highlighted areas for future research will further enhance their effectiveness and relevance in promoting resilience within agriculture systems.

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CRediT authorship contribution statement

Tallou Anas: Writing – review & editing, Writing – original draft, Supervision, Methodology, Conceptualization. **Alhajj Ali Salem:** Writing – review & editing, Writing – original draft, Supervision, Software, Methodology, Conceptualization. **Sanesi Giovanni:** Writing – review & editing, Validation, Supervision, Methodology, Funding acquisition, Conceptualization. **Vogiatzakis Ioannis Nikolaou:** Validation. **Camposeo Salvatore:** Writing – review & editing, Supervision. **Vivaldi Gaetano Alessandro:** Writing – review & editing, Validation, Supervision. **Lopriore Giuseppe:** Writing – review & editing, Writing – original draft, Supervision, Methodology, Conceptualization.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.ijagro.2025.100033.

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