Exploring agroforestry limiting factors and digitalization perspectives: insights from a european multi-actor appraisal

Margherita Tranchina, Paul Burgess, Fabrizio Giuseppe Cella, Laura Cumplido-Marin, Marie Gosme, Michael den Herder, Sonja Kay, Gerry Lawson, Bohdan Lojka, João Palma, et al.

Agroforest Syst
https://doi.org/10.1007/s10457-024-01047-x

Exploring agroforestry limiting factors and digitalization perspectives: insights from a european multi-actor appraisal

Margherita Tranchina · Paul Burgess · Fabrizio Giuseppe Cella · Laura Cumplido-Marin · Marie Gosme · Michael den Herder · Sonja Kay · Gerry Lawson · Bohdan Lojka · João Palma · Paul Pardon · Linda Reissig · Bert Reubens · Evert Prins · Jari Vandendriessche · Alberto Mantino

Received: 26 March 2024 / Accepted: 24 July 2024

Abstract Despite its potential for fostering farm sustainability, the adoption of agroforestry faces context-dependent challenges, among which the (perceived) shortage of decision-supporting tools and barriers hindering the assessment of economic, environmental, and social benefits. The process of digitalization offers significant opportunities to enhance sustainability, but it remains crucial to foster a human-centric, fair, and sustainable approach. In the context of the DigitAF Horizon Europe project, we present the results of a multi-stakeholder questionnaire aimed at understanding the perceptions of stakeholders regarding agroforestry and digitalization, as well as the needs of these stakeholders for a successful implementation of this agricultural practice. In the questionnaire, there was a specific focus on the need for and the conditions for the use of digital tools and models, such as generalized digital tools,

M. Tranchina
Institute of Management, Sant'Anna School of Advanced Studies, Pisa, Italy

M. Tranchina
University School for Advanced Studies IUSS, Pavia, Italy

P. Burgess · L. Cumplido-Marin
Cranfield University, Cranfield, Bedfordshire, UK

F. G. Cella · A. Mantino (✉)
Department of Agriculture, Food and Environment, University of Pisa, Pisa, Italy
e-mail: alberto.mantino@unipi.it

M. Gosme
ABSys, Univ Montpellier, CIHEAM–IAMM, CIRAD, INRAE, Institut Agro, Montpellier, France

M. den Herder
European Forest Institute, Joensuu, Finland

S. Kay
Agricultural Landscapes and Biodiversity, Zurich, Switzerland

G. Lawson
European Agroforestry Federation, Montpellier, France

B. Lojka
Faculty of Tropical AgriSciences, Czech University of Life Sciences Prague, Prague, Czech Republic

J. Palma
MVARC, Mértola, Portugal

P. Pardon · B. Reubens
Flanders Research Institute for Agriculture, Fisheries and Food (ILVO), Merelbeke, Belgium

L. Reissig
Agroscope, Socioeconomics, Ettenhausen, Switzerland

E. Prins
Louis Bolk Institute, Bunnik, Netherlands

J. Vandendriessche
Department of Environment, Ghent University, Melle-Gontrode, Oost-Vlaanderen, Belgium

Published online: 03 August 2024

applications and mapping, climate and weather forecasting and recording, farm management and decision support, and agroforestry and environmental tools. The purpose of this survey was to provide insights to inform agroforestry actors and to foster collaborative initiatives that enhance the potential of digital tools to support the design, implementation, and maintenance of effective and sustainable agroforestry in the European context. Our questionnaire was completed by stakeholders from seven European countries, including farmers, academics, policy actors, farm advisors, and actors in the value chain with an interest in agroforestry. Stakeholders from six living labs, representing Czechia, Finland, Germany, Italy, the Netherlands, and the UK, were involved in the appraisal, along with a multi-stakeholder group from Belgium. Respondents used data and digital tools for various purposes in farming systems and were interested in their potential to improve agroforestry including animal, tree, and crop performance, management guidance, system design, and tree species selection. Our survey revealed that the perceived usefulness of digital tools for agroforestry was substantially higher than stakeholders' awareness of existing tools, indicating a need for better promotion and development of user-friendly, accessible solutions. Additionally, significant obstacles to agroforestry adoption, such as large up-front investments, administrative burdens, and fear of reduced CAP support, were identified, emphasizing the necessity for targeted support and policy improvements. Moving forward, efforts should focus on developing targeted solutions to promote agroforestry according to stakeholder perception, and user-friendly digital tools tailored to the needs and preferences expressed by stakeholders, while also increasing knowledge sharing and capacity building among practitioners and researchers.

Keywords Stakeholder perception · Participatory research · Actor-oriented research · Sustainable agriculture · Tools · Survey

Introduction

In the past decade European Union policies have emphasized the need to move towards more sustainable and resilient economies and food systems, reaching net-zero emissions by 2050, and reversing environmental degradation (EC 2018). Simultaneously, the process of digitalization is radically transforming both societies and economies, and the European Union aims to leverage digital technologies to promote sustainability and economic well-being (EC 2021a). This Digital and Green Twin Transition framework acknowledges that digital solutions can play a pivotal role in enhancing the efficiency and sustainability of food production (Muench et al. 2022). Nevertheless, it should be acknowledged that the acceleration of digitalization can be accompanied by negative effects on the environment and societies (Zanizdra et al. 2021), therefore requiring careful context-based considerations and risk assessment. In line with the Digital Decade Policy Programme 2030 (EP 2022), the aim of this work is to contribute to making digital transformation inclusive and human-centric, placing agroforestry stakeholders at the heart of innovations in digital tools and models for agriculture.

In the framework of urgently mitigating and adapting to climate change, agroforestry is a recognized practice to reduce greenhouse gas emissions (IPCC 2023). In addition, it can address the growing societal demand for high-quality, safe, and nutritious food produced in a sustainable way (EC 2021b). Agroforestry can be defined as the practice of deliberately integrating woody vegetation with crop and/or animal systems to benefit from the resulting ecological and economic interactions (Burgess and Rosati 2018).

Agroforestry systems (Fig. 1) have been categorized not only based on their structure but also based on their productive or protective function as well as their environmental adaptability (Nair 1985). A suggested categorization for agroforestry systems in Europe is presented in Table 1.

According to 2012 LUCAS Land Use and Land Cover data, agroforestry is present on 15.4 million ha in the EU27, equivalent to about 3.6% of the territorial area and 8.8% of the utilized agricultural area (den Herder et al. 2017).

It is estimated that implementing agroforestry on only 10% of Europe's farmland, in the area with the highest number of accumulated environmental pressures, could lead to carbon sequestration between 8 and 2355 million Mg CO_{2eq} per year depending on the type of agroforestry (Kay et al. 2019b). Additionally, agroforestry might enhance biodiversity levels (Edo et al. 2023; Torralba et al. 2016), pollination

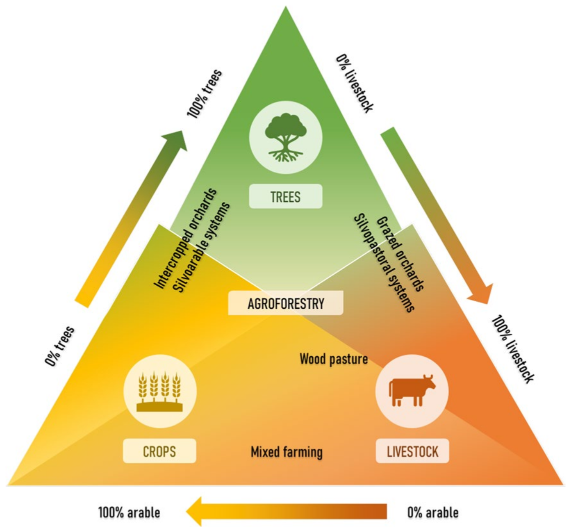


Fig. 1 Agroforestry components, modified from den Herder et al. (2015)

(Varah et al. 2020), and related ecosystem services (Kletty et al. 2023; Staton et al. 2019), and has proven to boost soil fertility, mitigate soil erosion and reduce nutrient leaching (Palma et al. 2007). In addition, agroforestry landscapes were also found to result in an overall higher economic gain compared to business-as-usual agricultural practices (Kay et al. 2019a).

Despite its proven potential, the adoption of agroforestry faces context-dependent challenges, including the perceived lack of decision-supporting tools and limited assessment of economic, environmental, and social costs and benefits. Past works examined current advances in agroforestry research, providing insight into reasons for adoption and innovation testing (Burgess and Rosati 2018), perceived challenges and proposed solutions (Rois-Díaz et al. 2018; Tsonkova et al. 2018; García de Jalón et al. 2018; Rolo et al. 2020), as well as farmers' knowledge and limited awareness of the costs and benefits of agroforestry as a practice (Rois-Díaz et al. 2018).

Agroforestry measures within the Common Agricultural Policy 2014–2022 have had limited success (Lawson 2016b). In the new CAP programming period (2023–2027), Member States were called to provide a definition of agroforestry (Lawson 2023), being allowed to define permanent grassland to "include other species such as trees and/or shrubs which produce animal feed" (Bertomeu and Lawson 2024). This flexibility for Member States could allow farmers who practice agroforestry to be eligible for CAP-Pillar-I Basic Income Support for Sustainability (BISS), but in contrast, member states have often implemented complicated eligibility criteria during past CAP programming periods.

Based on our knowledge, there are no previous studies that discuss the perception of a range of stakeholders regarding digital tools in agroforestry systems at the European level. Here, we present the results of a multi-stakeholder questionnaire aimed at understanding the perceptions of stakeholders regarding agroforestry, in addition to their needs regarding this agricultural practice and digital tools. Our questionnaire was completed by farmers, academics, policymakers, farm advisors, and actors in the value chain with an interest in agroforestry from seven European countries. These

Table 1 Suggested typology for agroforestry systems in Europe, in relation to agricultural, biodiversity, and climate legislator framework and to national Land Parcel Identification Systems (LPIS). Modified from Lawson (2016a)

Tree location	Agroforestry system	Land use classification	
		Forest land	Agricultural land
Trees within parcels	Silvopastoral	Forest grazing	Wood pasture
			Orchard grazing
	Silvoarable	Forest farming	Alley cropping
			Alley coppice
			Orchard intercropping
	Agrosilvopastoral	Sequential mixtures of silvoarable and silvopastoral systems	
Trees between parcels	Linear agroforestry	Forest strips	Shelterbelt networks
			Wooded edges
			Riparian tree strips

"pioneer" stakeholders from six DigitAF living labs, representing Czechia, Finland, Germany, Italy, the Netherlands, and the UK, answered the questionnaire, along with a similar multi-stakeholder group from Flanders, Belgium.

For the purpose of this study, we define agroforestry pioneers as actors that lead the way in the adoption, promotion, and advancement of agroforestry practices within their national context and were therefore included in the living labs or in the selected group from Belgium. This is supported by the self-assessment results, where respondents indicated possessing a good to very good understanding of agroforestry (~75%). Furthermore, we defined digital models as computer-based simulations or representations of processes or systems and digital tools as solutions involving the use of both data and models (e.g. generalized digital tools, applications and mapping, climate and weather forecasting and recording, farm management and decision support, and agroforestry and environmental tools). We defined data as information such as facts and numbers used to conduct analysis or make decisions.

By highlighting the needs and perceptions of these pioneers regarding agroforestry and digital tools, this research aims to provide insights to inform agroforestry actors and foster collaborative initiatives that harness the potential of digitalization for sustainable agroforestry in the European context.

Methodology

The DigitAF project (2022 to 2026, www.digitaf.eu) aims to co-develop digital tools tailored to the needs of diverse agroforestry stakeholders by adopting an end-user-centred multi-actor approach, including the establishment of and working with Living Labs. The development and improvement of open-source tools is at the core of DigitAF's strategy, utilizing practical knowledge, scientific evidence, and models.

Living Labs (LLs) description

To ensure the tools align with real-world needs, the DigitAF project established six Living Labs (LL) located in Czechia, Finland, Germany, Italy, the Netherlands, and the United Kingdom. Living Labs are collaborative platforms where representatives from diverse groups identify needs and gaps in agroforestry practices. Through LLs, insights are formalized into models, guiding the development of user-centric digital tools tailored to empower actors in adopting agroforestry. LLs also serve as test beds for new technologies and facilitate the dissemination of tools to a broader audience, fostering widespread engagement in the agroforestry community. The LLs included stakeholders working on agroforestry policy, practitioners implementing agroforestry on the ground, and other actors in agroforestry value chains including distributors and NGOs.

In the **Netherlands**, agroforestry is a recent bottom-up phenomenon. The most widespread systems include silvopasture, alley cropping, and food forests (EURAF 2023d). The LL in The Netherlands operates nationally, and it was established by directly reaching out to farmers, policymakers, and other beneficiaries.

Germany has a number of long-established agroforestry systems such as meadow orchards, windbreaks, forest farming, and hedgerows (DeFAF 2023). Some unique German landscapes include the "Knicks" in Schleswig–Holstein and the "Hag"-landscapes in Bavaria (EURAF 2023b). The LL in Germany comprises experienced practitioners in the agroforestry scene in Brandenburg.

Italy claims the fourth-largest agroforestry area in Europe, encompassing approximately 1.4 million ha, with a significant portion dedicated to silvopastoral systems (EURAF 2023c). The Italian LL is based in Tuscany, a region where field hedgerows, silvopastoralism for cattle, sheep, and goats are widespread agroforestry activities. The Italian LL evolved from a pre-existing network established during the EIP-AGRI OG NEWTON project (Baronti et al. 2023).

The United Kingdom LL was specifically created for the DigitAF project and brought together agroforestry policymakers, practitioners, and actors in the value chain in the East Midlands and Eastern England. Traditional agroforestry practices in the UK include hedgerows, shelterbelts, grazed orchards, wood pastures, and parklands (Burgess 2017).

The LL In **Czechia** is comprised of stakeholders located predominantly in Central Bohemia and South Moravia. Despite Czech agroforestry nearly disappearing with the intensification of agriculture, silvopastoral systems remain in mountainous sites. Home gardens also remain a very common practice (IUAF 2021).

Finland has a rich tradition of agroforestry with practices including reindeer husbandry, collection of non-wood forest products, and grazing of forests and wood pastures. While reindeer husbandry and the collection of non-wood forest products are still widely applied in northern Finland, there was a decline in forest grazing and management of traditional wood pastures, mainly in southern Finland (EURAF 2023a). The LL was initiated based on active stakeholders in the AFINET project (GA ID: 727,872) and the Finnish Agroforestry Network. It centers around two regions: Uusimaa, focusing on silvoarable agroforestry, and North Karelia, focusing on silvopastoral agroforestry.

In addition, a multi-stakeholder group from Flanders, Belgium was selected by local project partners. This group, connected to agroforestry-related exchange programs for quite some time, can be considered as a kind of Living Lab as well, although not officially defined like that in the context of the DigitAF project. In Belgium, a wide range of agroforestry systems can be found, including particularly alley cropping, silvopastoral systems, hedgerows, and traditional fruit orchards.

The estimated extent of agroforestry in all seven countries is shown in Table 2.

Table 2 Extent and distribution of agroforestry in Europe based on LUCAS data combining arable agroforestry, livestock agroforestry, and High-value tree agroforestry. Modified from (den Herder et al. 2017)

Country	Utilized agricultural area (UAA)	Agroforestry	Estimated proportion of UAA
	1000 ha	1000 ha	%
Belgium	1358	43.7	3.2
Czech Republic	3484	45.8	1.3
Finland	2291	158.1	6.9
Germany	16,704	263.5	1.6
Italy	12,856	1403.9	10.9
Netherlands	1872	27.8	1.5
United Kingdom	16,882	551.7	3.3
EU-27 total	174,499	15,421	8.8

Survey conceptualization, structure, and administration

The complete questionnaire can be accessed online on the DigitAF website (https://digitaf.eu/). Section 1 collected the general characteristics of the respondents. Section 2 consisted of four questions in which all respondents were asked about their current use of tools and data in farming systems. Section 3 consisting of six questions, looked at agroforestry knowledge and the use of digital tools in agroforestry systems. A detailed set of questions on agroforestry and digital models and tools was presented in Sect. 4 divided into policy-related (13 questions), technical, economic, and administrative issues (6 questions), and tree, crop, and animal interactions (21 questions).

The structured questionnaire was designed to be self-administered online via Google Forms. The survey was initially designed in English and then translated by LL coordinators into the native languages used by the LLs with minor modifications, to adapt to the local context. This resulted in separate databases for each country and language used. The results were subsequently re-translated into English using language consistent with the initial version to allow for database merging and analysis. The survey was made specific to different actors as illustrated in Table 3, by using conditional logic in Google Forms. This resulted in variations in completion time depending on the stakeholder type. Due to the length of the survey, users also had the option to skip some sections by stating they were not interested in a specific topic. Before administering, the survey was pre-tested and shortened or modified when needed. The final survey had an estimated total time for completion of around 1–1.5 h. All LLs conducted initial briefings or meetings introducing the contents and methodologies for completing the survey between December 2022 and March 2023. The survey took place between March and June 2023. In total, 92 stakeholders completed the questionnaire, although the number answering individual questions varied by section depending on relevance and the willingness to respond. The final number of respondents per section is shown in Table 3.

Table 3 Survey structure and number of respondents for each section

Section	Topic	Stakeholder type	Number of respondents
1	General characteristics of respondents	All	92
2	Experience of digital tools in farming systems	All	92
3	Agroforestry knowledge and perception and digital tools in agroforestry systems	All	92
4	Detailed questions on agroforestry and digital tools and models:		
	a. Policy-related questions	Farmers & policymakers	53
	b. Technical, economic and administrative issues	All	89
	c. Tree, crop and animal interactions questions	All	74

Data analysis

Data was analyzed and summarized using Excel pivot tables and Power Query functions. To present the results in an effective manner, we calculated a Weighted Average Likert Score for questions in the sections regarding technical, economic, and administrative issues (4.b) and tree, crop, and animal interactions (4.c). We assigned weights to the Likert scale responses based on their perceived importance or severity and then calculated a weighted average to represent the overall sentiment or perception for each issue by considering the frequency with which each response was selected (Likert 1932).

The assigned weights (w_i) for section 4b were as follows: not relevant = 0, not problematic at all = 1, slightly problematic = 2, problematic = 3, very problematic = 4, extremely problematic = 5. The assigned weights (w_i) in section4c are as follows: 1 (not useful at all) = 1, 2 = 2, 3 = 3, 4 = 4, 5 (extremely useful) = 5.

$$WALS = \frac{\sum_{i=1}^{n} (w_i \times f_i)}{\sum_{i=1}^{n} f_i}$$

where *WALS* is the Weighted Average Likert Score, n is the total number of responses, w_i is the weight assigned to the Likert scale response for the i-th response, and f_i is the Likert scale score for the i-th response, meaning the number of times an answer was selected by respondents.

Results

General characteristics of respondents

The agroforestry "pioneers" that completed the questionnaires were from the Czech Republic (30), Finland (8), Germany (13), Italy (12), Netherlands (14), United Kingdom (8), and Belgium (7). Among the 92 respondents, there were 40 farmers or landowners, 15 academics, 14 policymakers, 13 farm advisors, and 10 other stakeholders in the value chain.

Detailed demographic information is available in Table 4.

A vast majority of farmers (74%) and farm advisors (69%), work directly with agroforestry, either on their own farms or on the farms they advise.

Experience of digital data and tools in farming systems

Stakeholders used digital tools for decision support (75%), research (37%), and training (23%). As shown in Table 5, data is also used in a wide range of thematic areas, including policy or subsidies (57%), tree and crop species selection (47%), economy or market (46%), and soil and nutrients (41%). Digital models are mostly used in technical or managerial aspects (40%).

Table 4 General characteristics of respondents include stakeholder type, country, gender, age, and educational background

Category		Frequency (n°)	Frequency (%)
Stakeholder type	Academic	15	16.30
	Farm advisor	13	14.13
	Farmer or landowner	40	43.48
	Other stakeholder in the value chain	10	10.87
	Policymaker	14	15.22
	Total	92	100
Country	Belgium	7.0	7.61
	Czech Republic	30.0	32.61
	Finland	8.0	8.70
	Germany	13.0	14.13
	Italy	12.0	13.04
	Netherlands	14.0	15.22
	United Kindgdom	8.0	8.70
	Total	92	100
Gender	Male	53	57.61
	Female	38	41.30
	Prefer not to say	1	1.09
	Total	92	100
Age	18–35 years old	28	30.43
	36–50 years old	34	36.96
	51–65 years old	28	30.43
	66 +	2	2.17
	Total	92	100
Educational background	Secondary school	1	1.09
	High school	9	9.78
	Bachelor's degree	14	15.22
	Master's degree	43	46.74
	Doctoral or above	24	26.09
	Prefer not to say	1	1.09
	Total	92	100

Some concrete examples of digital tools used by respondents include but are not limited to:

- Versatile digital tools (Excel, Google sheets, YouTube, Google Scholar, CAD),
- GIS applications and mapping tools (QGIS, Google Earth, LPIS, Sollumis, ruimtelijkeplannen.nl),
- Climate and weather tools (Met Office, SunCalc, Meteoblue, ČHMU, klimatickazmena.cz),
- Farm management and decision support tools (FarmOS, Farm Carbon Calculator, Geofolia),
- Agroforestry and Environmental tools (Yield Safe/Farm Safe, LandIS, Metsään.fi, Food forests calculation model HAS, Ecological Site Classification ESC).

Around 65% of respondents openly stated that the ideal tool should be simple, clear, intuitive, and user-friendly.

Respondents' expectations and relevant take-home messages regarding the usability and interface design of tools in farming systems are as follows:

- Simplicity and clarity: respondents emphasize the importance of simple and clear controls, intuitive operation, and a structure separating basic and advanced functions. Tools should be

Table 5 Stakeholder usage of data and digital models per thematic area

Proportion of respondents (%)				
Data usage per thematic areas	Not used before	Used before	Currently using	Not applicable
Animal nutrition and welfare	30.4	15.2	22.8	31.5
Biodiversity (e.g. wild species)	29.4	22.8	33.7	14.1
Economy / market (e.g. prices)	18.5	18.5	45.7	17.4
Energy and GHGs emissions (CO2 eq)	35.9	18.5	19.6	26.1
Policy (e.g. subsidies)	12.0	22.8	56.5	8.7
Soil and nutrients (e.g. fertilization plans)	18.5	21.7	41.3	18.5
Tree/ crop species selection	25.0	15.2	46.7	13.0
Digital model usage per thematic area				
Economy (including financial and labour)	30.4	12.0	26.1	31.5
Policy (including subsidies)	32.6	14.1	31.5	21.7
Technical (agronomic and managerial aspects)	26.1	13.0	40.2	20.7

easily accessible either free of charge or at an accessible fee.

- Intuitive interface: a recurring theme is the need for an intuitive graphical interface that minimizes the learning curve for users. Respondents emphasize the importance of tools being easy to understand and navigate, allowing individuals to quickly grasp its functionalities and apply it effectively.
- On-site accessibility: tools should be readily accessible on-site or in the field, enabling users to consult and utilize them in real-time. Clear and updated information enhances the relevance and practicality of digital solutions in diverse environments.
- Ease of use and reliability: ease of use is central, with respondents highlighting the importance of smooth operation, and reliable performance. A clear graphical user interface, simple data entry, and intuitive controls contribute to a positive user experience.
- Compatibility and flexibility: tools should be compatible with other applications, allowing seamless integration among them and data transfer. Flexibility in adjusting parameters and customization options is deemed to enhance usability across different contexts.
- Clear outputs and practicality: users expect tools to provide clear, understandable outputs and recommendations that are relevant to their work. Practicality, usefulness, and time-saving features are essential considerations in tool design and implementation.

Agroforestry knowledge and use of digital tools in agroforestry systems

Most of the stakeholders indicated they had a good or very good level of knowledge, with 74 indicating "good knowledge" or more on the five-point Likert scale. Respondents associate the following practices with agroforestry systems: silvopastoral system (89%); wood pasture (86%); silvoarable system (82%); shelterbelts and windbreaks (66%); and alley cropping (61%).

Stakeholders expressed their perception regarding the potential usefulness of new or enhanced digital tools or models in agroforestry. Results shown in Fig. 2, indicate that over 90% of all stakeholders stated that a new digital tool or model could be either useful or very useful in all thematic areas. Moreover, most stakeholders would rather use laptops and desktops (75%), followed by smartphones (56%), and tablets (33%).

Policy-related aspects

Most farmers were interested in tree-planting schemes within the Common Agricultural Policy (CAP) 2014–2022 (62%), while the rest were not or were not familiar with subsidies. As far as the new agroforestry and carbon farming in the Common Agricultural Policy (CAP) 2023–2027, most of the farmers expressed their interest (86%). Regarding tree landscape features (hedges, isolated trees, lines of trees, groups of trees) on their farm in accordance with the

CAP 2023–2027, 66% of respondents had identified them, while the rest had not (10%), or they were not familiar with the concept (12%). Most of the farmers stated they will be planting more tree landscape features (hedges, isolated trees, lines of trees, groups of trees) on their land (76%), as well as implementing new agroforestry systems (74%).

Farmers proved to be skeptical about the possible application of a voluntary carbon farming scheme, with 64% indicating that it would depend on the details and 7% saying they would not. Respondents mentioned the main obstacles they face regarding the voluntary carbon farming scheme as the lack of details or lack of information in their native language. Only 57% of farmers declared their willingness to apply for a (potential) agroforestry scheme, while the rest were negative about the rigid settings of the subsidy program, limiting eligibility criteria, or lack of knowledge of the local agricultural intervention fund workers. One farmer expressed his skepticism as follows: *"I don't know about subsidies, and I don't feel like studying it. I find it complicated and incomprehensible". (CZ).*

When farmers were asked how data collection by the European Land Parcel Identification System (IACS/LPIS) in their country could be improved, they suggested enhancing accountability, reducing disparities in subsidy allocation, incorporating a stronger emphasis on agroforestry, and validating identification systems through field observations. They also suggested simplifying the LPIS interface and optimizing data entry processes and ensuring accurate registration of tree elements within LPIS.

> "I don't know what to improve on the data. But when working with the application, I could imagine an AI chatbot that knows the system and can find/show/mediate/explain what I need." (CZ)

Regarding tree-planting schemes under the CAP 2014–2022, policymakers identified erosion protection, microclimate improvement, and biodiversity increase as advantages. As challenges, they cited: the limited integration of farming and forestry, a perceived inconsistency in EU rule interpretation across countries, a high investment threshold for agroforestry projects, limited tree planting options within specific schemes, lack of recognition of agroforestry within CAP, and overall administrative complexities.

> "The CAP 2014–2022 did not recognize agroforestry as an agricultural form and allowed a limited number of trees per hectare in combination with grassland or arable land." (NL)

There were mixed responses regarding whether the new agroforestry carbon farming in CAP 2023–2027 meets national needs: some believe it meets needs due to its focus on climate mitigation and tree planting, while others express uncertainty or dissatisfaction with the inclusion of agroforestry in the CAP or the effectiveness of the subsidy rates. Suggestions for improvement include simplifying parcel registration, recognizing agroforestry as a distinct system, and questioning the appropriateness of the eco-scheme for all agroforestry forms.

> "Some improvements have been made (recognition of agroforestry as an agricultural method, basic premium for non-productive landscape elements, eco-scheme where a number of agroforestry systems can score points), but there is still room for improvement." (NL).

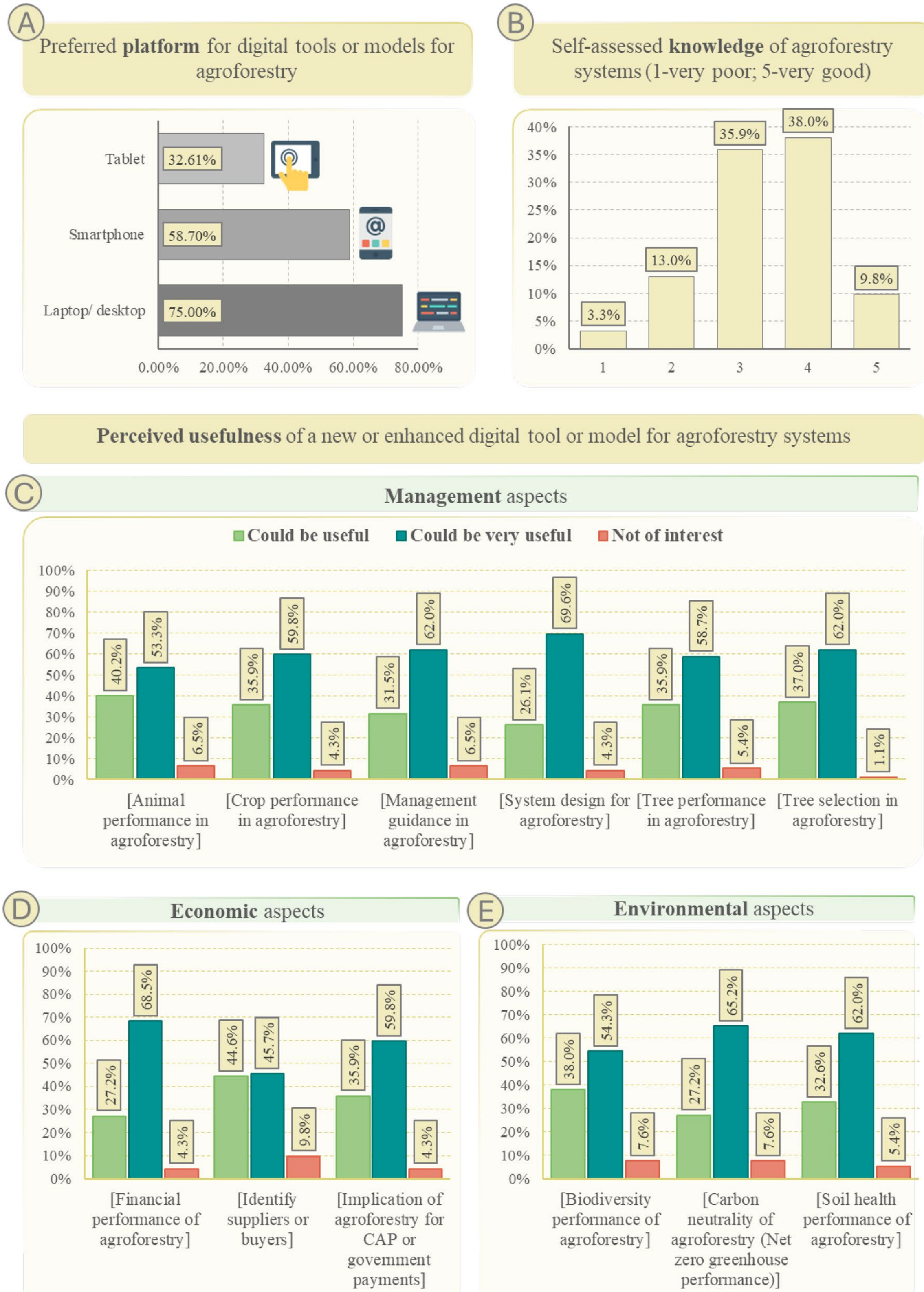
Policymakers' responses demonstrate a positive attitude towards the proposed EU Framework on Carbon Removals, although some called for transparency to prevent greenwashing and were skeptical towards carbon capture, and concerned about potential administrative costs.

> "Agroforestry can contribute to the storage and retention of carbon. A reward for this service would be appropriate." (NL)

Some policymakers express unfamiliarity or uncertainty regarding LPIS/IACS data. Many highlight the need to make improvements to this system and make parcel registration easier for agroforestry farmers. Suggestions regarding their simplified use include recognizing and registering agroforestry systems as cohesive entities instead of separate rows with existing crop codes, and monitoring agroforestry as a whole, indicating a desire for more comprehensive tracking and analysis.

Technical, economic, and administrative issues

This section referred to potential technical, economic, and administrative issues relating to the application


A
Preferred platform for digital tools or models for agroforestry
Tablet 32.61%
Smartphone 58.70%
Laptop/ desktop 75.00%
0.00% 20.00% 40.00% 60.00% 80.00%
B
Self-assessed knowledge of agroforestry systems (1-very poor; 5-very good)
1 3.3%
2 13.0%
3 35.9%
4 38.0%
5 9.8%
Perceived usefulness of a new or enhanced digital tool or model for agroforestry systems
C
Management aspects
Could be useful
Could be very useful
Not of interest
[Animal performance in agroforestry] 40.2% 53.3% 6.5%
[Crop performance in agroforestry] 35.9% 59.8% 4.3%
[Management guidance in agroforestry] 31.5% 62.0% 6.5%
[System design for agroforestry] 26.1% 69.6% 4.3%
[Tree performance in agroforestry] 35.9% 58.7% 5.4%
[Tree selection in agroforestry] 37.0% 62.0% 1.1%
D
Economic aspects
[Financial performance of agroforestry] 27.2% 68.5% 4.3%
[Identify suppliers or buyers] 44.6% 45.7% 9.8%
[Implication of agroforestry for CAP or government payments] 35.9% 59.8% 4.3%
E
Environmental aspects
[Biodiversity performance of agroforestry] 38.0% 54.3% 7.6%
[Carbon neutrality of agroforestry (Net zero greenhouse performance)] 27.2% 65.2% 7.6%
[Soil health performance of agroforestry] 32.6% 62.0% 5.4%

◂**Fig. 2** Results regarding the preferred platform for digital tools or models for agroforestry (**a**), self-assessed knowledge of agroforestry systems on a scale from 1-very poor to 5-very good (**b**), perceived usefulness of a new or enhanced digital tool or model for agroforestry systems regarding management (**c**), economic (**d**), or environmental (**e**) aspects

of agroforestry, using a scale from "not relevant" to "extremely problematic".

The categories with the highest WALS were the necessity of large investments to set up agroforestry systems, the fear that an increased number of trees/ha would result in losing CAP support, the administrative burden when implementing AF systems, the technical knowledge of agricultural workers, the management costs of agroforestry systems, and the level of knowledge regarding the management of trees on farmland (Table 6).

We asked stakeholders if they perceived certain aspects of agricultural management to become more/less or equally complex when implementing agroforestry systems. Crop harvesting operations (78% of respondents), crop species selection (56% of respondents), and soil tillage practices (50% of respondents) were perceived as becoming more complicated. On the contrary, the reduction in pesticide use (50% of respondents), and the management of pests and diseases (46% of respondents) were mentioned as becoming less complicated. The respondents openly highlighted additional technical challenges, including long-term planning, resource availability and support, machinery accessibility, wildlife interaction, mechanization post-planting, growth maintenance, weed management, lack of advisory and peer support, local tree sourcing, crop herbicide application, market route identification, integration into training and studies, availability of harvest machinery, and phytosanitary treatments. *"It is impossible to quickly adapt the agroforestry system to new conditions." (CZ).*

Respondents express a wide range of preferences for information, tools, and support regarding agricultural management aspects related to agroforestry. Desired resources include estimated crop harvest dates, links to informative websites, information on the effects of herbicides and pesticides on woody plants and fruit quality, as well as nutrient monitoring, planning online tools for establishing agroforestry systems, and biological weed control methods. Furthermore, they expressed a need for practical guidance and technical advice such as support for crop, plant, and tree selection based on soil and landscape aesthetics; tools for optimal area design and harvesting efficiency, as well as experienced advisors, websites, and directories with examples.

Respondents expressed their views on further economic challenges, mentioning implementation issues such as high investment costs, lack of locally based data on cost/benefit analysis of different agroforestry systems, considerations of long-term benefits and diversification complexity, profitability, the need for loans, uncertainty of subsidy reimbursement; market-related issues such as the difficulty in finding species with assured markets and profitable investment, the uncertainty of markets for new products and difficulty in evaluating future sales, challenges in small-scale distribution issues in finding buyers for special wood products; and management related issues such as the lack of manpower, and machinery cost for agroforestry.

> "The conditions for subsidies for agroforestry are too restrictive." (BE)

Administrative and policy-related obstacles identified by respondents include policy and legal constraints, ignorance of local administration, lack of political support, policy issues regarding harvesting and tenancy, complex application for CAP funds, challenges in parcel registration combined with other administrative tasks, potential replanting obligations, and the perception that local support rules do not encourage agroforestry systems. Stakeholders remain concerned about the limitations of the number of trees per hectare to remain eligible for subsidies.

There is *"bloated bureaucracy" (CZ)* and *"little recognition of the benefits of agroforestry on the environment, climate, and landscape." (BE).*

Tools for tree, crop, and animal interactions

We asked respondents to rank the need for and usefulness of a digital model or tool by selecting a score from a 1–5 (not useful at all to extremely useful) Likert scale and expressing whether they knew of any tool or model within this topic. Following the process described in the methodology section, we calculated a Weighted Average Likert Score. Results are shown in Table 7.

Table 6 Information regarding the list of obstacles that were presented to the stakeholders alongside the corresponding Weighted Average Likert Score

	Category: Technical: T, E: Economic, P: policy-administrative	Full table obstacles	Weighted Average Likert Score
1	E	Necessity of large investments to set up AF systems	3.20
2	P	Fear that an increased number of trees/ ha would result in losing CAP support	3.13
3	P	Administrative burden when implementing AF systems	3.08
4	T	Technical knowledge of agricultural workers (employees)	3.04
5	E	Management cost of agroforestry systems	3.03
6	T	Level of knowledge regarding the management of trees on farmland	3.03
7	T	Changes in agro-mechanical operations	2.96
8	P	Entity of support of Common Agricultural Policy measures	2.90
9	E	Insufficient future revenue to manage the AF systems	2.88
10	E	Access to financing	2.86
11	P	Issues related to permits for removing trees	2.85
12	T	Availability of resources regarding the management of AF systems	2.84
13	T	Presence of a network of knowledge regarding technical issues related to AF systems	2.82
14	T	Increased complexity of AF systems	2.76
15	P	Issues related to land ownership	2.76
16	T	Water provision of young trees	2.75
17	P	Issues related to permits for planting trees	2.70
18	E	Diminished income related to the primary crops	2.63
19	T	Effect on the yields of the main crop	2.58
20	T	Harvesting fruits/ nuts from the trees	2.49
21	T	Pruning of the trees	2.37
22	T	Interaction with livestock	2.37
23	P	Issues related to permits for agroforestry-related infrastructure	2.35
24	P	Issues related to accountancy	2.23
25	T	Availability of cereal and fodder species adequate to be grown in AF systems	2.18
26	P	Issues related to food safety	1.70

Table 7 Results of the tree-crop-animal interaction section; perceived usefulness of a digital tool or model expressed via the Weighted Average Likert Score (WALS, 1 (not useful at all) to 5 (extremely useful), as well as the proportion of people who did not know of an existing tool (%)

Category of interest	Perceived usefulness of a digital tool or model (WALS)	Proportion who did NOT know of an existing tool (%)
Tree species or variety selection	4.28	84
Agroforestry system design (ex. species selection, architecture of the system, etc.)	4.05	74
Predicting crop and/or tree performance to support decision-making	3.92	86
Tree management	3.74	91
Animal performance to support decision-making	3.49	96

Tree species or variety selection had the highest score of 4.28 indicating high perceived usefulness. However, it is noteworthy that 84% of respondents reported not having knowledge of any existing digital models or tools in this category. This overall result was the same in all categories: agroforestry system design (*WALS* 4.05, 74% no tool knowledge); prediction of plant and/or tree performance (*WALS* 3.92, 86%), tree management (*WALS* 3.74, 91%) and animal performance (*WALS* 3.49, 96%). Results show that while stakeholders perceived potential digital tools or models to be extremely useful, they had a very scarce knowledge of existing ones.

We asked which parameters they would like to see incorporated further in digital models or tools. Stakeholders showed a high level of interest, being particularly interested in hydrology for system design (71.6%), climate requirements for tree species selection (85.1%), nutrient availability for crop and tree performance (75.7%), and animal health and animal performance tools (71.6%).

Around 76% of respondents would like additional user-friendliness, followed by improved visualization (32%), scale (27%), and language (13%). These results confirm what already emerged in Section 2 (Table 3), indicating that respondents value greatly the user-friendliness and simplicity of tools.

Respondents expressed various perspectives on the usefulness of a decision-support digital model or tool for agroforestry system design, with a range of explanations provided. Some include the simplification of work, better monitoring of parameters, the ability to process complex data quickly through a decision support system (DSS), clear implementation and long-term projection of agroforestry systems, better clarity in future planting planning and landscape design, assistance in balancing management requirements and costs, help with tree selection and system simulation. Other responses include the enhancement of existing design tools with specific functions for agroforestry, support for grant applications and subsidy submissions, the adaptation to local conditions, and the filling of expertise gaps.

> "A decision support digital model or tool for agroforestry system design would be useful for me to relate the different components of an agroforestry system, analyzed individually and then correlated together to result in a multifunctional management of the system." (IT).

Discussion

Our results offer valuable insights into the perceptions and needs of diverse stakeholders regarding digital tools for agroforestry. While acknowledging the non-random sampling method and inherent bias in the respondent pool, it's essential to recognize the valuable perspectives shared by informed stakeholders deeply engaged in agroforestry practices. As compared to the overall statistics for the entire EU farming population, the respondents were typically younger and we had a higher proportion of female respondents in our survey population (Eurostat 2018).

In general, the use of data by the respondents was greater than their use of tools. The proportion of respondents citing that they were using tools for research (37%) can partly be explained by the fact that 26% of respondents had obtained a PhD degree, indicating that research was likely to be a part of their day-to-day work.

The survey highlighted that the perceived usefulness of digital tools related to agroforestry was substantially higher than the knowledge of existing digital tools. While stakeholders expressed high perceived usefulness across various categories, a substantial percentage reported a lack of awareness of the existence and availability of such tools. This could be a result of a lack of awareness or a result of the fact that existing digital tools for agroforestry are not fit for purpose or not easily accessible. If the issue is the first, then this can be addressed by raising awareness, through better promotion of these tools and through education initiatives. As reported by Giannitsopoulos et al. (2023) in a study on a grassland tool, respondents commonly request for tools to be simpler and to incorporate more features. Additional features included hydrology, climate requirements, nutrient availability, and animal health. However, stakeholders' preference for enhanced user-friendliness also emphasizes the importance of simplicity and accessibility in digital tools. One way of resolving this tension is through improved visualization and documentation so that the tools can effectively convey complex information to a diverse audience (Giannitsopoulos et al. 2023).

We also analyzed technical, administrative, and economic obstacles to the application of agroforestry. Beyond the technical obstacles, our findings indicated that other major obstacles to widespread agroforestry adoption were the necessity of large investments to set up agroforestry systems, the fear that an increased number of trees per hectare would result in losing CAP support, and the administrative burden and management costs when implementing agroforestry systems. These results are consistent with those from previous research, indicating that low profitability was a key preoccupation of stakeholders despite their positive valuation of the natural and cultural dimensions of agroforestry (Rolo et al. 2020). A recent systematic literature review highlighted the occurrence of perceived issues from participatory research. It identified some recurring issues in Europe being the necessity of large upfront investment, the lack of knowledge, the increased costs, administrative burden as well as the faulty design of policy and subsidy measures (Tranchina et al. 2024).

These results also match those of previous research with European stakeholders working with agroforestry, in which it emerged that the main negative perceptions of agroforestry included increased labor, the complexity of work, management costs, and administrative burden (García de Jalón et al. 2018). Camilli et al. (2018), focusing on stakeholders in Italy, also highlighted that the bureaucratic complexity of the CAP discourages farmers from applying for grants: farmers perceived that trees in fields could be obstacles because they caused the reduction of CAP payments. In 2017, a study investigating farmers' reasoning behind the uptake of agroforestry found that they are often influenced by their awareness of successful existing systems and that limited awareness of the term "agroforestry" results in misconceptions. In fact, farmers expressed willingness to adopt agroforestry if provided with knowledge on profitability and practical aspects (Rois-Díaz et al. 2018). In 2018, a study on agroforestry stakeholder perception involving 183 farmers suggested that the current legal framework and low financial rewards from ecological benefits are the major barriers to the uptake and maintenance of agroforestry in Germany, despite farmers recognizing the non-market benefits of agroforestry (Tsonkova et al. 2018). Qualitative interviews held in north-eastern Germany report results that also align with our findings, indicating that administrative barriers and high start-up costs currently impede the transition from conventional agriculture to agroforestry systems (Litschel et al. 2023). Past studies showed that farmers in Mediterranean areas perceived the main drawbacks of silvoarable systems to be intercrop yield decline, whereas farmers in Northern Europe tended to highlight the general complexity of work and difficulties with mechanization (Graves et al. 2017). Results from research carried out in the context of the SAFE (2001–2005) project showed that the main concern of farmers in Spain, France, England, Italy, Greece, Germany, and the Netherlands in relation to silvoarable systems was the yield and quality of crops, followed by work complexity, mechanization and project feasibility (Liagre 2005). In our study, mechanization issues were also deemed as very challenging, ranking seventh overall and third among the technical issues, preceded only by knowledge-related technical challenges.

Conclusions

The questionnaire results provide valuable insights into the current landscape of digital tool utilization, data preferences, and stakeholder perceptions on economic, technical, and administrative issues in agroforestry. The identified gaps between perceived usefulness and knowledge of existing tools highlight the importance of targeted efforts to bridge these gaps. Moving forward, addressing the specific needs and preferences expressed by stakeholders will be essential in developing effective, user-friendly digital tools that can contribute to the advancement of sustainable and efficient agroforestry. Compared to previous studies, our stakeholders' responses highlight concerns about the financial investment required to establish and maintain agroforestry systems. Together with pressing administrative and policy issues, they remain key constraints to the advancement of agroforestry. Conversely, pioneering stakeholders identified knowledge-related constraints as key barriers. Based on our findings, further initiatives should focus on improving and developing agroforestry tools, simplifying and standardizing the legal status of agroforestry in the CAP and other related policy frameworks, and increasing, sharing, and co-developing knowledge among practitioners, advisors, and scientists.

Author contributions All authors played a key role in designing the survey, contributing ideas and drafting topic-relevant questions in the iterative process that led to its final version after multiple meetings. Paul Burgess, Laura Cumplido-Marin contributed to the shortening, finalization and language proofing of the original version of the survey. Great effort was made by all LL coordinators and country referents in testing and administering the survey, liaising with stakeholders when issues emerged, as well as translating both the survey and its results through a unified framework. Margherita Tranchina significantly contributed with coordination efforts and led the efforts in database management, manuscript drafting, and data elaboration under the guidance of Alberto Mantino. All authors have contributed significantly to the conception, design, acquisition of data, analysis, and interpretation of the work. They have been involved in drafting the manuscript or revising it critically for important intellectual content.

Funding Open access funding provided by Università di Pisa within the CRUI-CARE Agreement. This study was funded by the DigitAF Horizon Europe project (GA N°101059794). The contribution of Margherita Tranchina in this paper and related research have been conducted during and with the support of the Italian inter-university PhD course in sustainable development and climate change (link:www.phd-sdc.it).

Data availability It is hereby declared that no personal data has been stored in the course of this scientific research. The data utilized in this study exclusively consists of anonymized or aggregated information, ensuring the privacy and confidentiality of individuals involved. Respondents gave informed consent on data collection, storage, and utilization in compliance with the GDPR framework. No datasets were generated or analysed during the current study.

Declarations

Conflicts of interest All authors certify that they have no affiliations with or involvement in any organization or entity with any financial interest or non-financial interest in the subject matter or materials discussed in this manuscript. The authors declare no competing interests.

References

Baronti S, Brunori A, Camilli F, Chiarabaglio P, Maienza A, Manetti MC, Marini F, Mantino A, Mele M, Nigro F, Pacini A, Ripamonti A, Sabbatini T, Tranchina M, Tozzini C, Ugolini F (2023) Ps Go Newton - Network Per L'agroforestazione In Toscana.

MBertomeuGLawson2024Permanent Grassland Definitions in the EU10.5281/zenodo.10449117Bertomeu M, Lawson G (2024). Permanent Grassland Definitions in the EU. https://doi.org/10.5281/zenodo.10449117

Burgess P (2017) Agroforestry in the UK. Q J for 111(2):111–116

Burgess PJ, Rosati A (2018) Advances in European agroforestry: results from the AGFORWARD project. Agrofor Syst 92(4):801–810. https://doi.org/10.1007/s10457-018-0261-3

Camilli F, Pisanelli A, Seddaiu G, Franca A, Bondesan V, Rosati A, Moreno GM, Pantera A, Hermansen JE, Burgess PJ (2018) How local stakeholders perceive agroforestry systems: an Italian perspective. Agrofor Syst 92(4):849–862. https://doi.org/10.1007/s10457-017-0127-0

DeFAF (2023) Agroforst Landkarte. Deutschen Fachverbandes für Agroforstwirtschaft (DeFAF). https://agroforstkarte.agroforst-info.de/. Accessed 4 May 2024

den Herder M, Moreno G, Mosquera-Losada RM, Palma JHN, Sidiropoulou A, Santiago Freijanes JJ, Crous-Duran J, Paulo JA, Tomé M, Pantera A, Papanastasis VP, Mantzanas K, Pachana P, Papadopoulos A, Plieninger T, Burgess PJ (2017) Current extent and stratification of agroforestry in the European Union. Agr Ecosyst Environ 241:121–132. https://doi.org/10.1016/j.agee.2017.03.005

EC (2018) Communication from the commission to the european parliament, the european council, the council, the european economic and social committee, the committee of the regions and the european investment bank a clean planet for all a european strategic long-term vision for a prosperous, modern, competitive and climate neutral economy

EC (2021a) Communication from the commission to the european parliament, the council, the european economic and social committee and the committee of the regions 2030 digital compass: the european way for the digital decade, COM/2021/118 final

EC (2021b) Regulation (Eu) 2021/2115 of the european parliament and of the council establishing rules on support for strategic plans to be drawn up by member states under the common agricultural policy (CAP Strategic Plans) and financed by the european agricultural guarantee fund (EAGF) and by the european agricultural fund for rural development (EAFRD) and repealing regulations (EU) No 1305/2013 and (EU) No 1307/2013

Edo M, Entling MH, Rösch V (2023) Agroforestry supports high bird diversity in European farmland. Agron Sustain Dev 44(1):1. https://doi.org/10.1007/s13593-023-00936-2

EP E (2022) DECISION (EU) 2022/2481 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 14 December 2022 establishing the Digital Decade Policy Programme 2030. Official Journal of the European Union

EURAF (2023a) Agroforestry in Finland. European Agroforestry Federation (EURAF). https://euraf.net/2023/01/20/finland/. Accessed 4 May 2024

EURAF (2023b) Agroforestry in Germany. European Agroforestry Federation (EURAF). https://euraf.net/2023/01/20/germany/. Accessed 4 May 2024

EURAF (2023c) Agroforestry in Italy. European Agroforestry Federation. https://euraf.net/2023/01/20/italy/. Accessed 4 May 2024

EURAF (2023d) Agroforestry in the Netherlands. European Agroforestry Federation. https://euraf.net/2023/01/20/netherlands/. Accessed 4 May 2024

Eurostat (2018) Farm Structure Survey 2016.

García de Jalón S, Burgess PJ, Graves A, Moreno G, McAdam J, Pottier E, Novak S, Bondesan V, Mosquera-Losada R, Crous-Durán J, Palma JHN, Paulo JA, Oliveira TS, Cirou E, Hannachi Y, Pantera A, Wartelle R, Kay S, Malignier N, Van Lerberghe P, Tsonkova P, Mirck J, Rois M, Kongsted AG, Thenail C, Luske B, Berg S, Gosme M, Vityi A (2018) How is agroforestry perceived in Europe? an assessment of positive and negative aspects by stakeholders. Agrofor Syst 92(4):829–848. https://doi.org/10.1007/s10457-017-0116-3

Giannitsopoulos ML, Burgess PJ, Bell MJ, Richter GM, Topp CFE, Ingram J, Takahashi T (2023) Translating and applying a simulation model to enhance understanding of grassland management. Grass Forage Sci 78(1):50–63. https://doi.org/10.1111/gfs.12584

Graves AR, Burgess PJ, Liagre F, Dupraz C (2017) Farmer perception of benefits, constraints and opportunities for silvoarable systems: preliminary insights from Bedfordshire. England Outlook Agric 46(1):74–83. https://doi.org/10.1177/0030727017691173

Herder M, Burgess P, Mosquera-Losada MR, Herzog F, Hartel T, Upson M, Viholainen I, Rosati A (2015) Preliminary stratification and quantification of agroforestry in Europe. Milestone Report. https://doi.org/10.13140/RG.2.1.4258.4482

IPCC (2023) Summary for Policymakers. In: Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change IPCC, Geneva, Switzerland. https://doi.org/10.59327/IPCC/AR6-9789291691647.001

IUAF (2021) Agroforestry in the Czech Republic. International Union For Agroforestry. https://iuaf.org/czech-republic/. 2024

Kay S, Graves A, Palma JHN, Moreno G, Roces-Díaz JV, Aviron S, Chouvardas D, Crous-Duran J, Ferreiro-Domínguez N, García de Jalón S, Măcicăşan V, Mosquera-Losada MR, Pantera A, Santiago-Freijanes JJ, Szerencsits E, Torralba M, Burgess PJ, Herzog F (2019a) Agroforestry is paying off—Economic evaluation of ecosystem services in European landscapes with and without agroforestry systems. Ecosyst Serv 36:100896. https://doi.org/10.1016/j.ecoser.2019.100896

Kay S, Rega C, Moreno G, den Herder M, Palma JHN, Borek R, Crous-Duran J, Freese D, Giannitsopoulos M, Graves A, Jäger M, Lamersdorf N, Memedemin D, Mosquera-Losada R, Pantera A, Paracchini ML, Paris P, Roces-Díaz JV, Rolo V, Rosati A, Sandor M, Smith J, Szerencsits E, Varga A, Viaud V, Wawer R, Burgess PJ, Herzog F (2019b) Agroforestry creates carbon sinks whilst enhancing the environment in agricultural landscapes in Europe. Land Use Policy 83:581–593. https://doi.org/10.1016/j.landusepol.2019.02.025

Kletty F, Rozan A, Habold C (2023) Biodiversity in temperate silvoarable systems: a systematic review. Agr Ecosyst Environ 351:108480. https://doi.org/10.1016/j.agee.2023.108480

GLawson2023Agroforestry definitions in the new CAP (Version 1)Zenodo10.5281/zenodo.7828435Lawson G (2023) Agroforestry definitions in the new CAP (Version 1). Zenodo. https://doi.org/10.5281/zenodo.7828435

Lawson G Sustainable management criteria for agroforestry in the European Union. In: 3rd european agroforestry conference montpellier, 23–25 May 2016, 2016a. EURAF

Lawson GJ (2016b) Options for agroforestry in the CAP 2014–2020. Paper presented at the EURAF—Actas de Conferências

Liagre FPA, Moreno G, Bellido M, Mayus M, Postma M, Schindler B, Graves A, Mantzanas K, Dupraz C (2005) Survey of farmers' reaction to modern silvoarable systems. Deliverable 2.3 of the Silvoarable Agroforestry For Europe (SAFE) project, European Research contract QLK5-CT-2001–00560

Likert R (1932) A technique for the measurement of attitudes. Arch Psychol 22(140):55–55

Litschel J, Berendt F, Wagner H, Heidenreich S, Bauer D, Welp M, Cremer T (2023) Key actors's perspectives on agroforestry's potential in North Eastern Germany. Land 12(2):458

Muench S, Stoermer E, Jensen K, Asikainen T, Salvi M, Scapolo F (2022) Towards a green & digital future. Luxembourg (luxembourg). https://doi.org/10.2760/977331

Nair PKR (1985) Classification of agroforestry systems. Agrofor Syst 3(2):97–128. https://doi.org/10.1007/BF00122638

Palma JHN, Graves AR, Bunce RGH, Burgess PJ, de Filippi R, Keesman KJ, van Keulen H, Liagre F, Mayus M, Moreno G, Reisner Y, Herzog F (2007) Modeling environmental benefits of silvoarable agroforestry in Europe. Agr Ecosyst Environ 119(3):320–334. https://doi.org/10.1016/j.agee.2006.07.021

Rois-Díaz M, Lovric N, Lovric M, Ferreiro-Domínguez N, Mosquera-Losada MR, den Herder M, Graves A, Palma JHN, Paulo JA, Pisanelli A, Smith J, Moreno G, García S, Varga A, Pantera A, Mirck J, Burgess P (2018) Farmers' reasoning behind the uptake of agroforestry practices: evidence from multiple case-studies across Europe. Agrofor Syst 92(4):811–828. https://doi.org/10.1007/s10457-017-0139-9

Rolo V, Hartel T, Aviron S, Berg S, Crous-Duran J, Franca A, Mirck J, Palma JHN, Pantera A, Paulo JA, Pulido FJ, Seddaiu G, Thenail C, Varga A, Viaud V, Burgess PJ, Moreno G (2020) Challenges and innovations for improving the sustainability of European agroforestry systems of high nature and cultural value: stakeholder perspectives.

Sustain Sci 15(5):1301–1315. https://doi.org/10.1007/s11625-020-00826-6

Staton T, Walters RJ, Smith J, Girling RD (2019) Evaluating the effects of integrating trees into temperate arable systems on pest control and pollination. Agric Syst 176:102676. https://doi.org/10.1016/j.agsy.2019.102676

Torralba M, Fagerholm N, Burgess PJ, Moreno G, Plieninger T (2016) Do European agroforestry systems enhance biodiversity and ecosystem services? a meta-analysis. Agr Ecosyst Environ 230:150–161. https://doi.org/10.1016/j.agee.2016.06.002

Tranchina M, Reubens B, Frey M, Mele M, Mantino A (2024) What challenges impede the adoption of agroforestry practices? A global perspective through a systematic literature review. Agrofor Syst. https://doi.org/10.1007/s10457-024-00993-w

Tsonkova P, Mirck J, Böhm C, Fütz B (2018) Addressing farmer-perceptions and legal constraints to promote agroforestry in Germany. Agrofor Syst 92(4):1091–1103. https://doi.org/10.1007/s10457-018-0228-4

Varah A, Jones H, Smith J, Potts SG (2020) Temperate agroforestry systems provide greater pollination service than monoculture. Agr Ecosyst Environ 301:107031. https://doi.org/10.1016/j.agee.2020.107031

Zanizdra M, Harkushenko OM, Vishnevsky V, Kniaziev SI (2021) Digital and green economy: common grounds and contradictions. Sci Innov 17:14–27. https://doi.org/10.15407/scine17.03.014