UNIVERSITÀ DEGLI STUDI DI PADOVA

Administrative unit: **University of Padova**

Department: **Land, Environment, Agriculture and Forestry (LEAF)**

PhD Program: **Land, Environment, Resources and Health (LERH)**

Batch: XXXIV

Innovation in Forest Ecosystem Services provision and enhancement in Europe by investigating economic, social, and policy approaches

Dissertation financially supported by the Horizon 2020 project SINCERE, grant number 773702

PhD Program Coordinator: Prof. Marco Borga

Supervisor: Prof. Paola Gatto

Co-Supervisor: Prof. Davide Pettenella

PhD candidate: Giorgia Bottaro

Evaluators:
Prof. Davide Marino, Department of bioscience and territory, University of Molise

Dr. Elena Gorríz, Centro de Ciencia y Tecnología Forestal de Cataluña (CTFC)

UNIVERSITÀ
DEGLI STUDI
DI PADOVA

Sede Amministrativa: Università degli Studi di Padova

Dipartimento Territorio e Sistemi Agro-Forestali (TESAF)

CORSO DI DOTTORATO DI RICERCA: **Land, Environment, Resources, Health (LERH)**

Ciclo: XXXIV

Analisi degli approcci economici, sociali e politici innovativi per il miglioramento e la fornitura dei Servizi Ecosistemici Forestali

Tesi redatta con il contributo finanziario del progetto europeo Horizon 2020: SINCERE. Numero di finanziamento 773702

Coordinatore: Prof. Marco Borga

Supervisore: Prof. Paola Gatto

Co-Supervisore: Prof. Davide Pettenella

Dottorando: Giorgia Bottaro

Valutatori:

Prof. Davide Marino, Dipartimento di Bioscienze e Territorio, Università degli Studi del Molise

Dr. Elena Gorríz, Centro de Ciencia y Tecnología Forestal de Cataluña (CTFC)

d

Table of contents

List of figures

List of tables

List of abbreviations and Acronyms

AFP	Plain Forest Association
BaU	Business as Usual
CEPF	Confederation of European Forest Owners
CNPF	Centre National de la Propriété Forestière
FES	Forest Ecosystem Services
EU	European Union
EUSTAFOR	European State Forest Association
IM	Innovative Mechanisms
MBIs	Market Based Instruments
MCA	Multiple Correspondence Analysis
MS	Member States
n-MBIs	non-Market Based Instruments
NRRPs	National Recovery and Resilience Plans
RDP	Rural Development Programme
SME	small and medium enterprises

Summary

Current global changes are negatively affecting the capability of forest ecosystems to provide forest ecosystem services (FES). In contrast, they are also stimulating an increase in the demand for natural products and services. This is expanding the gap between the demand and supply of forest ecosystem services. Different instruments have been already implemented to try to cope with this challenge, but without finding effective solutions. This dissertation explores European innovative economic, social, and policy approaches to support the provision of forest ecosystem services that will allow meeting their societal demand.

The analysis of the economic approach has been implemented compiling an inventory of European innovative experiences implemented to support FES provision and enhancement. The inventory has been analysed through a specific framework developed for the purpose. Moreover, the specific innovation types introduced have been further investigated through a specific framework. Descriptive and frequency analyses have been computed, jointly with the implementation of the Multiple Correspondence Analysis (MCA). The results underline the high variability of economic instruments used within the innovative mechanisms targeting a high variability of forest ecosystem services. The analysis reveals also the presence of instruments that do not belong to the defined categories but are characterised by the establishment of new social organisations. The outcomes of the MCA depict two different dimensions. The first one describes the positive relations between the presence of new social organisations and the provision of bundled FES. Differently, the second one describes the importance of command & control instruments to support the provision of those FES characterised by difficult excludability.

The analysis of the social approaches has been computed considering the Italian national context. An analysis of the national and regional regulatory background sustaining the presence of associative models have been done. The final analysis allowed to establish a categorisation of the existing experiences. Within this classification, the most innovative models result in community cooperatives. Indeed, they are aimed to benefit the whole community in which they were constituted, and not only the member of the association. Moreover, a lack of coordination among policies and experiences have been detected. The latter could have a positive impact through the sharing of best practices and the knowledge gained.

Finally, the analysis of the policy approach consists in analysing the role of the forestry sector within one of the most recent EU regulations and financing sources: the National Recovery and Resilience Plan. The plans of the 26 member states have been analysed through keywords. Descriptive analysis and cluster analysis have been computed. The results of the cluster analysis reveal the presence of three different clusters characterised by the presence or absence of forest-related themes. The first cluster is characterised by more traditional and conservative countries with an inward-looking orientation. The second cluster is characterised by innovative countries supporting a more traditional forestry sector oriented to wood and wood-based products. Finally, the last cluster is characterised by innovative countries supporting forest multifunctionality and having a more global perspective.

The conclusion highlights the theoretical contribution of this dissertation that introduced two analytical frameworks to investigate innovative mechanisms and innovation types of those experiences supporting FES provision and enhancement. Finally, policy recommendations have been provided.

Sommario

I cambiamenti globali a cui stiamo assistendo negli ultimi decenni, se da un lato stanno riducendo la capacità degli ecosistemi forestali di fornire servizi ecosistemici forestali (SEF), dall'altro stanno stimolando una crescita della domanda di questi servizi e prodotti. In questo modo, il divario esistente tra la domanda e l'offerta dei servizi ecosistemici forestali sta aumentando sempre più. Per cercare di ridurre tale divario, negli anni sono stati sviluppati e introdotti diversi strumenti politici ed economici, che però non sempre sono stati efficaci nel supportare la fornitura di tali SEF. Questo lavoro di tesi ha come obiettivo quello di esplorare quegli approcci innovativi economici, ma anche sociali e politici in grado di stimolare una gestione forestale capace di fornire i SEF richiesti della società.

La prima parte dello studio ha riguardato la creazione di un inventario di meccanismi innovativi implementati in Europa a sostegno della fornitura dei SEF. Essi sono poi stati analizzati attraverso un framework sviluppato per evidenziarne le caratteristiche principali, tra cui vi è l'indicazione riguardante il tipo di innovazione introdotta. Un secondo framework è stato sviluppato appositamente per questa analisi specifica. I dati raccolti sono stati poi analizzati attraverso analisi statistiche descrittive e l'implementazione dell'analisi delle corrispondenze multiple (ACM). Le prime elaborazioni rivelano un'alta variabilità rispetto agli strumenti economici presenti e ai servizi ecosistemici forestali presi in considerazione dai meccanismi innovativi. In alcuni casi sono stati identificati alcuni strumenti non appartenenti a nessuna delle categorie predefinite ma che sono caratterizzati dalla costituzione di nuove organizzazioni sociali. I risultati dell'ACM rivelano la presenza di due dimensioni principali in grado di descrivere parte della variabilità presente all'interno dei casi dell'inventario. La prima dimensione raccoglie quei casi caratterizzati dalla presenza di nuove organizzazioni sociali e dalla fornitura di una pluralità di SEF, mentre la seconda è caratterizzata dalla presenza di strumenti di commando e controllo a sostegno della fornitura di quei beni e servizi forestali caratterizzati da una bassa escludibilità.

Nella seconda parte della tesi viene esplorato il contesto dell'associazionismo forestale italiano attraverso l'analisi del quadro normativo nazionale e dei quadri normativi regionali e attraverso lo studio di alcune esperienze presenti nel territorio nazionale. Tali analisi hanno permesso una categorizzazione dei modelli associativi individuati, che comprendono anche quelle forme associative più innovative, ovvero le cooperative di comunità, il quale obiettivo

non è quello di generare impatti positivi solo all'interno dei membri della cooperativa, ma di estenderli all'intera comunità di cui fanno parte. Tali analisi hanno permesso di individuare una forte mancanza di coordinazione tra i regolamenti, ma anche tra le esperienze stesse, andando ad inficiare sulla capacità di condivisione di buone pratiche.

L'ultima parte della tesi infine, è focalizzata allo studio del ruolo del settore forestale all'interno di una delle più recenti e innovative normative e fonti di finanziamento comunitario: il Piano Nazionale di Risanamento e Resilienza (PNRR). Ventisei PNRR sono stati analizzati attraverso l'utilizzo di diverse parole chiave, di analisi statistiche descrittive e attraverso l'analisi dei gruppi, ("cluster analysis"). I risultati di quest'ultimo studio rivelano la presenza di tre diversi clusters definiti in base alle tematiche, legate al settore forestale, presenti o meno all'interno dei singoli PNRR. Il primo cluster è caratterizzato da stati più tradizionali e conservatori che, attraverso il PNRR, intendono promuovere azioni mirate ad una gestione forestale a sostegno del settore stesso con un focus prettamente nazionale. Il secondo cluster è caratterizzato da paesi più innovativi volti a promuovere la filiera dei prodotti legnosi. Infine, anche l'ultimo cluster è caratterizzato da stati più innovativi, dove però questa spinta è indirizzata alla promozione della multifunzionalità delle foreste.

La conclusione evidenzia il contributo teorico apportato dal lavoro di ricerca svolto, le limitazioni incontrate e indicazioni su possibili indirizzi di ricerca futuri. Infine sono state formulate alcune raccomandazioni di indirizzo politico.

Acknowledgments

I would like to start expressing my gratitude to Paola Gatto and Davide Pettenella, whom supervised my research work in these three years. Thanks to Paola Gatto for her support and the great trust she gave me, and to Davide Pettenella for his constant presence and advice.

This research would not have been possible without the Horizon 2020 project SINCERE, funded by the European Union. I would like to acknowledge the possibility I had to collaborate with an European consortium of researchers and professionals devoted to the topic of ecosystem services and their valorisation. My gratitude goes to Sven Wunder with whom I had the pleasure to collaborate and that made himself available as host for the short-term scientific visit I should have done in EFIMed. Many thanks also to the other scholars and practitioners within the SINCERE consortium: Georg Winkle, Marko Lovrić. Mario Torralba, Tobias Plieninger, Nathalie Pipart, Sarah Adams, Irina Prokofieva, Andreas Bernasconi, the collegues from Etifor, and all the other partners.

I had the chance to collaborate also with others colleagues working on other European projects. I would like to thank the colleagues from the InnoForEst project and from the Nobel project. I'm furthermore grateful to the Eurac Research team for our collaboration in organising the international IUFRO conference.

An additional thanks to Ludwig Liagre and Nicola Andrighetto with whom I had the possibility to deeply collaborate. It has been important for me to work together with them.

Lastly, thank you very much to the two reviewers that accepted to review the present manuscript, Davide Marino and Elena Gorríz. I hope that you found the reading interesting.

A very final thanks to the colleagues of the department with whom I shared not only academic moments, the whole research group of forest policy and economics, and the colleagues of the administrative office.

It would have been impossible to achieve this without the support of my parents, my brother Diego, who revised my English in this last stage, my partner, Sara, my closest friends, and last but not least, my resilience.

"Never get so busy making a living that you forget to make a life" *(Dolly Parton)*

Part I: Body of Dissertation

1. Introduction

This chapter introduces the research background and the problem statement. It then presents the objectives and the structure of the study, elucidating the leading thread among the different parts.

1.1. Research background and problem statement

Forests in Europe cover 35% of the total land area (Korhonen and Stahl, 2020) and provide a high variety of goods and services (García-Nieto et al., 2013; Orsi et al., 2020), which are indispensable to the well-being of people living in proximity to forested lands and to society as a whole (MEA, 2005; IPBES 2018). These goods and services are known as forest ecosystem services (FES) (Haines-Young and Potschin, 2018).

In the last decades, the gap between demand and supply of FES has increased, also in connection to the expanding of global issues. Global warming (IPCC, 2021) and population growth (Roser et al., 2013) are increasing the pressure on forest resources (Hanewinkel et al., 2013; Maja and Ayano, 2021). On the one hand, population growth and the higher importance attributed to forests in facing current environmental and climatic challenges (EC 2019; EC 2021) are leading to a rise in FES demand (Sauter et al., 2019). The Covid-19 pandemic has intensified these needs and triggered new ones, providing new possibilities for some FES (mainly cultural ones) that were less valued before the pandemic (Grima et al., 2020; Ugolini et al., 2020). On the other hand, global warming is leading to forests degradation, decreasing forests resilience and making forests more susceptible to external agents such as pest infestations, wildfires, and windstorms (Chirici et al., 2019; Ferrara et al., 2019; Forzieri et al., 2021), impacting negatively on their capability in providing FES (Mina et al., 2017).

Mountain forests ecosystems are vulnerable and sensitive to temperature and precipitation variations (Beniston, 2003), hence they represent appropriate cases to assess the impacts of climate change on forests capability to provide FES (Ding et al., 2016). Bottaro et al. (2022) conducted a literature review to assess the European trends on FES provided by mountain forest ecosystems connected to climate changes. Only the papers describing the effects of climate changes on mountain forests have been taken into consideration by the authors. Papers based on modelling climate changes effects have been excluded. The results of the study showed that for the majority of mountain FES the trend is negative (Figure 1.1), with

some exceptions in the boreal region (Scandinavian countries and Island), due mainly to the lengthening of the growing season due to temperature increase.

Forest Ecosystem Services	ES category	forest ES sub-category	Boreal	Temperate Oceanic	Temperate Continental	Mediterranean	Alpine
Provisioning services	Bioenergy production						
	Timber production						
	Non-wood forest products						
Regulating Services	Climate regulation	forests carbon stocks					
		Soil carbon stocks					
		Albedo					
	Pest control						
	Natural hazard regulation	Forest fires/ wildfires					
		Erosion, avalanche, landslide					
		Flooding					
	Water quality regulation						
	Biodiversity						
Cultural Services	Recreation (fishing, nature enjoyment)	Hunting					
		NWFP picking					
	Tourism (skiing)						
	Aesthetic / heritage (landscape character, cultural landscapes)						

	TREND	CONFIDENCE LEVEL
	increasing	well established
		established but incomplete
	stable	established but incomplete
	decreasing	established but incomplete
		well established
	mixed	unresolved
	NA	not enough data

Figure 1.1. Impacts of climate change on FES provided by mountain forest ecosystems according to European climatic regions. From Bottaro et al. (2022)

Given that climate change is going to drastically impact the natural ecosystems in the close future, strengthening the capability of forests to provide FES is essential to meet the societal demand of FES. Traditionally, European forest management, especially in northern and central Europe, has been targeted to boost the delivery of provisioning ecosystem services, mainly wood and wooden-related products, the priority of which is still predominantly on forest-related policies (Primmer et al., 2021). However, a multifunctional and sustainable approach to forest management is needed and required to face current environmental and social challenges and to meet the increased demand of regulating and cultural FES (Benz et al., 2020). Although at the European level and in some European countries specific forest policies spurring multifunctional and sustainable forest management are already applied (EC 2013; Messier et al., 2019), higher efforts are needed, both in policy and economic terms.

Scholars in environmental policy already proposed and analysed several economic instruments to support the provision of ecosystem services, e.g. Sterner and Coria (2013), which have been implemented from a local to the international scale. These instruments are usually divided in two different categories: Market Based Instruments (MBIs) (e.g. Stavins, 2003; Pirard, 2012; Boisvert et al., 2013; Gómez-Baggethun and Muradian, 2015; Lapeyre et al., 2015) and non-Market Based Instruments (n-MBIs) (e.g. Lapeyre et al., 2015). n-MBIs refer to policy instruments with no direct link with the market – e.g. command and control approach, regulations, monitoring and penalties, etc. (Lapeyre et al., 2015). MBIs, conversely, refer to the suite of instruments that promote behaviours through market signals (Stavins, 2003) such as tax rebates and subsidies, payment of ecosystem services, biodiversity offset, certifications. Even if they have been the most applied instruments for environmental conservation and enhancement of ecosystem services worldwide (Pirard and Lapeyre, 2014), a common definition and understanding of them is still far. Indeed, a plethora of different instruments are described as MBIs, even when they tentative definitions not overlap (Pirard, 2012),. Moreover, despite the existing classifications of MBIs (e.g. Stavins, 2003; Windle et al., 2005; Prokofieva and Wunder, 2014), a common understanding and classification of them is still missing (Froger et al., 2015). Whether the majority of economic instruments are suitable in supporting the provision of marketable FES, challenges rise for FES with a public good or common-pool resources nature (Farley and Costanza, 2010). The provision of goods and services that are external to the market and characterised by difficult excludability is

sometime believed to be governments' responsibility (Daly and Farley, 2004). This is true also in those forests, often owned by private actors, where the potentiality of providing FES is high. Because the existing instruments are not always capable of addressing forest management to spur the provision of distinct FES, forest owners struggle in aligning FES provision with the increasing societal demand (Ezzine-de-Blas et al., 2016; EU Horizon 2020).

Because several FES are common or public goods, it is fundamental to foster scholars and policy-makers to design and implement innovative policies instruments that can effectively encourage landowners in FES provision (Kemkes et al., 2010). One of the main policies supporting agricultural and forest ecosystems is the Rural Development Programmes. Being the main source of funding to support forests in Europe, its measures are thoroughly monitored and studied (e.g. Alliance Environment, 2017). However, forestry in Europe is shaped also by several other policies dealing directly or indirectly with the forestry sector, such as climate and environment conservation, agriculture, and energy policies (Winkel and Sotirov, 2016), where the role given to forestry sector is not equally known. This generates a lack of knowledge regarding the role of forestry sector within the European regulations in general. These and other topics issues were considered within the pillars around which the Next Generation EU programme of the European Union (EU) has been structured. Through the Next Generation EU programme, the EU will support the member states to recover from the covid-19 pandemic providing them with a precise path to innovate by being greener, more digital, and healthier. To understand the role of forestry sector within one of the main components of the Next Generation EU – i.e., the National Recovery and Resilience Plans (NRRPs) – is fundamental for providing indications about the direction towards which the forestry sector is led within one of the most innovative and recent EU policies.

According to Forest Europe (2020), the majority of the European countries share the issue of having small forest properties average sizes, with plots often far from each other. This brings about land fragmentation and land abandonment, making it difficult the implementation of effective forest management (Hatcher et al., 2013). The creation of social organisations such as forest associations and cooperatives and the coordination among forest owners, forest managers, local administrations, harvesting companies, and other key stakeholders is among the most often proposed strategies to encourage forest owners in actively managing their forests (Jylhä, 2007; Živojinović et al., 2015). Kittdredge (2005) deeply analysed the benefits,

and consequently the reasons, that stimulate forest owners to become part of a forest association The principal reasons are the facilitation in accessing to financial measures, the organisation of joint economic activities and events, the sharing of professional services, the increase of the contractual power, and the possibility to develop labels, brands or standards to promote specific products.

Against this complex background, the importance emerges of finding innovative approaches capable to support the provision and enhancement of FES. More specifically, there is the need of finding: new approaches, capable to support from an economic perspective the provision of those FES not yet properly addressed by the existing instruments; new social approaches capable to stimulate effective forest management when forest land ownership is fragmented; new policy frameworks capable of properly supporting the forestry sector. These three needs are at the core of the present dissertation, where they have been analysed at different scales and with different methodological approaches.

1.2. Dissertation objectives and structure

The overarching objective of this research is to identify and analyse innovative approaches capable to support forest management for FES provision and enhancement. This general objective has been broken down into three specific objectives:

1. to provide an insight into economic approaches to spur FES provision;
2. to explore how the occurrence of social practices can support forest management addressed to FES provision, and how they are characterised;
3. to analyse the role of forestry sector in one of the most recent EU policies and to investigate in which direction it addresses innovation within the sector.

This dissertation is organised as a compilation of papers and is divided into two parts.

Part I is the body of the dissertation. Beside Chapter 1, it includes Chapters 2, 3 and 4., which correspond respectively to Paper **I**, Paper **II**, and Paper **III**. These three papers accomplish the three specific objectives of the dissertation (Figure 1.2). In them, I had responsibility as main author. They have been included in the dissertation in their original version, i.e., respectively:

Ch. 2 – Paper **I**. *Innovative mechanisms to support forest ecosystem services provision and enhancement. An overview at the European level*. Under submission to Forests.

The paper aims to investigate Innovative Mechanisms (IM). Those are new approaches implemented at the European level capable to support landowners in providing FES (specific objective 1). We compiled an inventory of these experiences and analysed them through two different frameworks, the first one analysing IM features, the second one focusing on the analysis of their innovativeness. Descriptive statistical analysis and frequency analysis have been computed to describe the inventory and to identify the presence of specific trends. Furthermore, Multiple Correspondence Analysis (MCA) have been computed to identify those features that tend to be jointly implemented within the innovative mechanisms.

Ch. 3 – Paper **II**. *The Italian Forest Management Associations: Innovation and Challenges*. Submitted to iForest.

The paper represents an initial attempt to understand the role and to characterize forest associations and cooperatives in Italy (specific objective 2). Moreover, it explores the legal national and regional frameworks and the availability of public funds for establishing forest associations. A classification of the existing models has been carried out according to the described regulatory system and to the outcome of the analysis of the experiences implemented at the national level.

Ch. 4 – Paper **III**. *The role of the forestry sector in the National Recovery and Resilience Plans: a comparative analysis*. To be submitted to a peer-reviewed journal.

The Paper analysed the National Recovery and Resilience Plans (NRRPs) of the EU member states. The analysis aimed to understand the role of forestry sector within the plans and whether NRRPs were capable to boost innovation within the forestry sector of the member states (specific objective 3). Initially, the analysis of the text was implemented through the use of keywords. Later, a Cluster Analysis has been computed to group and

characterise the member states according to presence or absence of specific forest-related themes within their plans.

Finally, Chapter 5 reports the concluding remarks and recommendations.

Part II comprises two papers (paper **IV** and paper **V**) written collectively with the colleagues of the H2020 projects SINCERE (grant agreement ID: 773702) and InnoForESt (grant agreement ID: 763899). These papers are more linked to the third specific objective. Even if they have been not specifically designed to address the specific dissertation objectives, these papers integrate and enlarge its outcomes.

Figure 1.2, developed through an open-source visual collaboration platform called Miro[1], describes the interlinkages amongst the main objective, the specific objectives and the outcomes of the research. It also explains how the specific objectives have been addressed by the different papers by using different arrows widths, representing the relevance of the specific objectives within each paper.

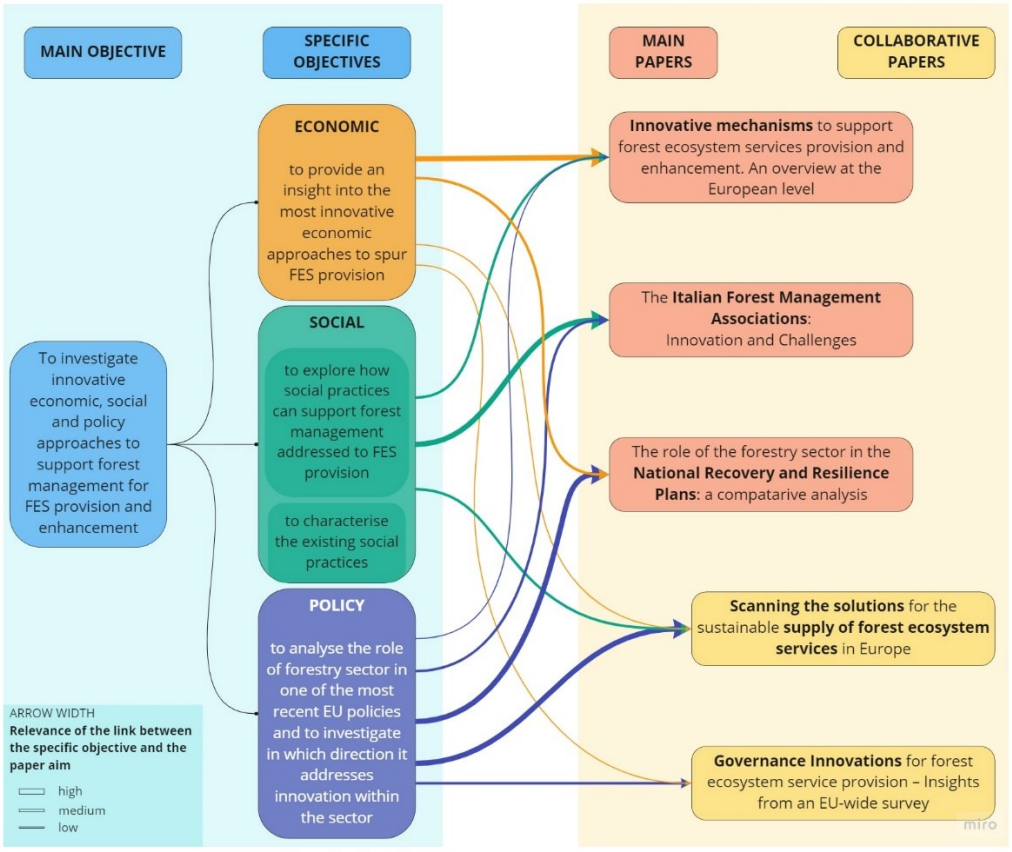


Figure 1.2. Relations among the main and specific objectives of the dissertation and the papers produced

[1] https://miro.com/app/dashboard/

The contribution of the main authors of the papers are described in Table 1.1.

Table 1.1. Contributions of the main authors for the development of the dissertation's papers

	Main papers			Collaborative papers	
Responsibility/ task	Paper **I**	Paper **II**	Paper **III**	Paper **IV**	Paper **V**
Overall responsibility	**G.B.**	**G.B.**	**G.B.**, L.L.	M.T., M.HM.	C.M.
Conception and design	**G.B.**, P.G., D.P.	**G.B.**, N.A., D.P.	**G.B.**, L.L., D.P.	M.T., M.HM., C.M., T.P.	C.M., C.G., M.L.
Methodology design	**G.B.**, P.G., D.P.	**G.B.**, N.A., D.P.	**G.B.**, L.L., D.P.	M.T., M.HM.	C.M., M.T., M.L., C.G.
Data collection	**G.B.**	**G.B.**, N.A.	**G.B.**, L.L.	**all the authors**	M.T., M.L.
Data analysis	**G.B.**, P.G.	**G.B.**, N.A.	**G.B.**, L.L.	**all the authors**	E.D., **G.B.,** C.G.
Results interpretation	**G.B.**, P.G., D.P.	**G.B.**, N.A., D.P.	**G.B.**, L.L., D.P.	M.T., M.HM.	**all the authors**
Manuscript writing	**G.B.**	**G.B.**, N.A.	**G.B.**, L.L.	M.T., M.HM.	**all the authors**
Revision	P.G., D.P.	D.P., P.G.	D.P.	**all the authors**	**all the authors**

Giorgia Bottaro (G.B.), *Davide Pettenella* (D.P.), *Paola Gatto* (P.G.), *Nicola Andrighetto* (N.A.), *Ludwig Liagre* (L.L.), *Mario Torralba* (M.T.), *Mónica Hernández-Morcillo* (M.HM.), *Tobias Plieninger* (T.P.), *Marko Lovrić* (M.L.), *Carsten Mann* (C.M.), *Carol Großmann* (C.G.), *Ewelina Dobrowolska* (E.D.)

1.3. References

Alliance Environment (2017). Evaluation of the CAP forest measures. Available at: https://ec.europa.eu/info/sites/default/files/food-farming-fisheries/forestry/documents/eval-cap-forestry-measures-leaflet_en.pdf

Beniston M (2003) Climatic change in mountain regions: a review of possible impacts, pp 5–31. https://doi.org/10.1007/978-94-015-1252-7_2

Benz, J.P., Chen, S., Dang, S., et al. (2020). Multifunctionality of forests: A white paper on challenges and opportunities in China and Germany. Forests 11:266. doi: 10.3390/f11030266

Boisvert, V., Méral, P., Froger G. (2013). Market-based instruments for ecosystem services: institutional innovation or renovation? Society and Natural Resources, 26 (10), pp. 1122-1136

Bottaro, G., Gatto, P., Pettenella, D. (2021) Assessing the Economic Impacts of Climate Change on Mountain Forests: A Literature Review. In: Managing Forest Ecosystems, Vol. 40, Tognetti, R., Smith, M., Panzacchi, P. (Eds): Climate-Smart Forestry in Mountain Regions. Springer Nature, Switzerland, AG

Chirici G, Giannetti F, Travaglini D, Nocentini S, Francini S, D'Amico G, Calvo E, Fasolini D, Broll M, Maistrelli F et al. (2019). Forest damage inventory after the "Vaia" storm in Italy. For. Riv. Selvic. Ed. Ecol. For. 16, 3–9.

Daly, H. E., Farley, J. (2004). Ecological Economics: Principles And Applications. Edited by USA. Island Press: Washington, DC. Ecological Economics. Vol. 55. https://doi.org/10.1016/j.ecolecon.2005.08.005.

Ding H, Chiabai A, Silvestri S, Nunes PALD (2016) Valuing climate change impacts on European forest ecosystems. Ecosyst Serv 18:141–153. https://doi.org/10.1016/j.ecoser.2016.02.039

EC (2013) A new EU Forest Strategy: for forests and the forest-based sector

EC (2021). New EU Forest Strategy for 2030 (2021/572/EC). Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. Available on: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52021DC0572

EC (2019). European Commission. The European Green Deal (2019/640/EC). Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2019%3A640%3AFIN

EU Horizon 2020: SINCERE (Spurring INnovations for Forest ECosystem SERvices in Europe). Project Proposal, 2018-2022.

Ezzine-de-Blas et al. (2016) Innovative mechanisms for financing biodiversity conservation: an exchange of experiences between Europe and Mexico. Summary of the key insights for CBD COP13 side event (16 December 2016), Cancun, Mexico.

Farley J. and Costanza R. (2010). Payments for ecosystem services: from global to local. Ecological Economics 69: 2060-2068

Ferrara C, Salvati L, Corona P, Romano R, Marchi M (2019). The background context matters: Local-scale socioeconomic conditions and the spatial distribution of wildfires in Italy, Science of The Total Environment. 654, 43-52. ISSN 0048-9697, https://doi.org/10.1016/j.scitotenv.2018.11.049.

Forest Europe (2020). State of Europe's Forests 2020. Ministerial Conference on the Protection of Forests in Europe - Liaison Unit Bratislava

Forzieri G, Girardello M, Ceccherini G, et al (2021) Emergent vulnerability to climate-driven disturbances in European forests. Nat Commun 12:1–12. doi: 10.1038/s41467-021-21399-7

Froger, G., Boisvert, V., Méral, P., Le Coq, J, F., Caron, A., Aznar, O. (2015). "Market-Based Instruments for Ecosystem Services between Discourse and Reality: An Economic and Narrative Analysis." Sustainability (Switzerland) 7 (9): 11595–611. https://doi.org/10.3390/su70911595.

García-Nieto, A. P., García-Llorente, M., Iniesta-Arandia, I., & Martín-López, B. (2013). Mapping forest ecosystem services: from providing units to beneficiaries. Ecosystem Services, 4, 126-138

Gómez-Baggethun, E., Muradian, R., 2015. In markets we trust? Setting the boundaries of market-based instruments in ecosystem services governance. Ecological Economics, 117: 217-224.

Grima, N., Corcoran, W., Hill-James, C., Langton, B., Sommer, H., Fisher, B. (2020). The importance of urban natural areas and urban ecosystem services during the COVID-19 pandemic. PLoS ONE 15(12): e0243344. Doi: https://doi.org/10.1371/journal.pone.0243344

Haines-Young, R. and M.B., Potschin (2018): Common International Classification of Ecosystem Services (CICES) V5.1 and Guidance on the Application of the Revised Structure

Hanewinkel, M., Cullmann, D.A., Schelhaas, M.J., Nabuurs, G.J., Zimmermann, N.E. (2013). Climate change may cause severe loss in the economic value of European forest land. Nat. Clim. Chang. 3, 203-207

Hatcher, J., Straka, T., Greene, J. (2013). The Size of Forest Holding/Parcelization Problem in Forestry: A Literature Review. Resources, 2, 39–57

IPBES (2018).The regional assessment report on biodiversity and ecosystem services for Europe and Central Asia of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. M. Fischer, M. Rounsevell, A. Torre-Marin Rando, A. Mader, A. Church, M. Elbakidze, V. Elias, T. Hahn, P.A. Harrison, J. Hauck, B. Martín-López, I. Ring, C. Sandström, I. Sousa Pinto, P. Visconti, N.E. Zimmermann and M. Christie (eds.). IPBES secretariat, Bonn, Germany. 48

IPCC (2021): Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S. L. Connors, C.

Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M. I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T. K. Maycock, T. Waterfield, O. Yelekçi, R. Yu and B. Zhou (eds.)]. Cambridge University Press. In Press.

IPCC, (2021): Summary for Policymakers. In: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S. L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M. I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T. K. Maycock, T. Waterfield, O. Yelekçi, R. Yu and B. Zhou (eds.)]. Cambridge University Press. In Press.

Jylhä L (2007). Forest Management Associations - value from cooperation for forest owners Unasylva, 58, 44-47

Kemkes, R. J., Farley, J., Koliba, C. J. (2010). "Determining When Payments Are an Effective Policy Approach to Ecosystem Service Provision." Ecological Economics 69 (11): 2069–74. https://doi.org/10.1016/j.ecolecon.2009.11.032.

Kittdredge DB (2005). The cooperation of private forest owners on scales larger than one individual property: international examples and potential application in the United States. Forest Policy and Economics, 7(4), 671-688

Korhonen, K. and Stahl, G. (2020). Maintenance and Appropriate Enhancement of Forest Resources and their Contribution to Global Carbon Cycles. In FOREST EUROPE, 2020: State of Europe's Forests 2020

Lapeyre, R., Froger, G., Hrabanski, M. (2015). "Biodiversity Offsets as Market-Based Instruments for Ecosystem Services? From Discourses to Practices." Ecosystem Services 15: 125–33. https://doi.org/10.1016/j.ecoser.2014.10.010

Maja, M.M., Ayano, S.F. (2021). The Impact of Population Growth on Natural Resources and Farmers' Capacity to Adapt to Climate Change in Low-Income Countries. Earth Syst Environ 5, 271–283. https://doi.org/10.1007/s41748-021-00209-6

Roser, M., Ritchie, H., Ortiz-Ospina, E. (2013). World Population Growth. Published online at OurWorldInData.org. Retrieved from: 'https://ourworldindata.org/world-population-growth' [Online Resource]

MEA. 2(005.) Millenium Ecosystem Assessment: Ecosystems and Human Well-Being

Messier, C., Bauhus, J., Doyon, F., Maure, F., Sousa-Silva, R., Nolet, P., Mina, M., Aquilué, N., Fortin, M.-J., Puettmann, K. (2019). The functional complex network approach to foster forest resilience to global changes. Forest Ecosystems, 6:21 https://doi.org/10.1186/s40663-019-0166-2

Mina, M., Bugmann, H., Cordonnier, T., Irauschek, F., Klopcic, M., Pardos, M., Cailleret, M. (2017) Future ecosystem services from European mountain forests under climate change. Journal of Applied Ecology, 54 (2), pp. 389-401.

Orsi, F., Ciolli, M., Primmer, E., Varumo, L., Geneletti, D. (2020). Mapping hotspots and bundles of forest ecosystem services across the European Union. Land Use Policy 99, 104840

Pirard, R. (2012). "Market-Based Instruments for Biodiversity and Ecosystem Services: A Lexicon." Environmental Science and Policy 19–20: 59–68. https://doi.org/10.1016/j.envsci.2012.02.001

Pirard, R. and Lapeyre, R. (2014). "Classifying Market-Based Instruments for Ecosystem Services: A Guide to the Literature Jungle." Ecosystem Services 9: 106–14. https://doi.org/10.1016/j.ecoser.2014.06.005

Primmer, E., Varumo, L., Krause, T., et al. (2021). Mapping Europe's institutional landscape for forest ecosystem service provision, innovations and governance. Ecosyst Serv 47:101225. doi: 10.1016/j.ecoser.2020.101225

Prokofieva, I., Wunder S. (2014). Designing Economic Instruments for Ecosystem Service Provision. In: Jellesmark Thorsen B., Mavsar R., Tyrväinen L., Prokofieva I., Wunder S. (eds) The Provision of Forest Ecosystem Services. Vol II Assessing Costs of Provision and Designing Economic Instruments for Ecosystem Services. EFI Series What Science Can Tell Us (5). Joensuu: European Forest Institute.

Sauter, I., Kienast, F., Bolliger, J., Winter, B., Pazúr, R. (2019). Changes in demand and supply of ecosystem services under scenarios of future land use in Vorarlberg, Austria. Journal of Mountain Science, 16 (12), pp. 2793-2809

Stavins, R. N. (2003). Experience with Market-Based Environmental Policy Instruments. Handbook of Environmental Economics. Vol. 1. Elsevier Masson SAS. https://doi.org/10.1016/S1574-0099(03)01014-3.

Sterner, T. and Coria, J. (2011). Policy Instruments for Environmental and Natural Resource Management (2nd ed.). Routledge. https://doi.org/10.4324/9781315780894

Ugolini, F., Massetti, M., Calaza-Martínez, P., Cariñanos, P., Dobbs, C., Krajter Ostoić, S., Marin, A.M., Pearlmutter, D., Saaroni, H., Šaulienė, I., Simoneti, M., Verlič, A., Vuletić, D., Sanesi, G. (2020). Effects of the COVID-19 pandemic on the use and perceptions of urban green space: An international exploratory study, Urban Forestry & Urban Greening, Volume 56, 126888, ISSN 1618-8667, https://doi.org/10.1016/j.ufug.2020.126888.

Windle, J., Rolfe, J., O'Dea, G. (2005). Selecting Market-Based Incentives for Natural Resource Management. Burnett Mary Regional Group Report, no. November.

Winkel, G. and Sotirov, M. (2016). Whose integration is this? European forest policy between the gospel of coordination, institutional competition, and a new spirit of integration. Environment and Planning C: Government and Policy, 34(3), 496-514.

Živojinović I, Weiss G, Lidestav G, Feliciano D, Hujala T, Dobšinská Z, Lawrence A, Nybakk E, Qui-roga S, Schraml U (2015). Forest Land Ownership Change inEurope. COST Action FP1201 FAC-ESMAP Country Reports, Joint Volume. EFICEEC-EFISEE Research Report. University of Natural Resources and Life Sciences, Vienna (BOKU), Vienna (AT)

2. Paper I: Mapping mechanisms for provision of forest ecosystem services in Europe: what's new?

Under submission to Ecosystem Services

Authors: Giorgia Bottaro[1], Paola Gatto[1], and Davide Pettenella[1]

[1] University of Padova, Land Environment Agriculture and Forestry Department (TeSAF), Italy

Abstract

Global changes are increasingly highlighting the need to conserve natural resources maintaining adequate levels of forest ecosystem services (FES) provision. Several policies, financial and market-based instruments have been designed and implemented worldwide in the last decades to align FES demand and supply. This increasing complexity in the field of FES provision calls now for systematisation of the existing experience, focusing on those innovative mechanisms (IMs) able to encourage landowners in FES provision. This paper aims to provide a European overview of innovative mechanisms able to sustain FES provision and enhancement. A survey of 105 IM cases was compiled. A framework to systematise the IM cases was created to gather information about their main features. These features have been analysed through descriptive and multivariate descriptive statistics. The results of the analysis provide a comprehensive characterisation of IM cases implemented at the European level, showing the economic instruments most adopted, the FES most targeted, the main actors involved, and the most applied innovation types. Finally, the Multiple Correspondence Analysis (MCA) casts light on those features that tend to be found in combination within the innovative mechanisms: social organisation to provide bundled FES, and public regulation for the provisioning of public FES by private actors.

Keywords: market-based instrument; economic instrument; Multiple Correspondence Analysis; innovation, payments for ecosystem services, PES

2.1 Introduction

Forests are terrestrial ecosystems with high natural values and capacity to provide a wealth of forest ecosystem services (FES) (Costanza et al., 1997). Today, the evolution of societal needs linked to growth in world population and global change is driving higher and wider needs of FES. In parallel, however, global warming and land use change are increasingly

threatening the capacity of forests to provide FES, amplifying the gap between demand and supply (EEA 2015).

The provision of FES that are external to the market is mainly recognised to be governments' responsibility (Daly and Farley, 2004). However, several public FES are offered by private forests, implying that landowners have to be motivated and supported if public provision of FES from private land has to be encouraged.

To this end, a range of economic instruments, have been designed and implemented. Such instruments, encompassing a range of policy tools, can be distinguished in non-Market Based Instruments (n-MBIs), Market-Based Instruments (MBIs) and Information and Education Instruments (E&Is) (Prokofieva and Wunder, 2014). n-MBIs, also called Command and Control instruments, do not have a direct link to the market; they include, for example, prescribed activities or licences permits, monitoring and penalties. MBIs, the most applied instruments for environment and biodiversity conservation of FES nowadays (Pirard and Lapeyre, 2014), refer to the suite of "instruments or regulations that encourage behaviour through market signals rather than through explicit directives" (Stavins, 2002). Examples of MBIs are Payment for Ecosystem Services, biodiversity offsets, taxes and subsidies, certifications. Information and education instruments include education and training, technical assistance, and consumers' awareness raising.

All three types of instruments show a wide variety of specific mechanisms, each with different features in terms of e.g., targeted ecosystems and FES, geographical and institutional scale, governance structures, types of actors involved. Various authors, e.g., Stavins, 2002; Windle et al., 2005; Schomers and Matzdorf, 2013; Wunder et al., 2018 have contributed to the analysis and systematization of different mechanisms, but this wide complexity is yet to be fully explored. Deeper investigation is needed on the mechanisms mostly used today for stimulating the provision of FES, on their specific features, and on the possible interlinks amongst such features (Froger et al., 2015 Ezzine-de-Blas et al., 2016).

Furthermore, with the evolution and broadening of environmental policy and practice, new models have emerged, incorporating innovation in delivered FES, processes, business models, stakeholders' participation. In general, MBIs are already considered more innovative than n-

MBIs (Boisvert et al., 2013; Ezzine-de-Blas et al., 2016), however there is not yet an agreement on when an instrument can be considered “genuinely” innovative (Boisvert et al., 2013).

In this context, this paper aims to map cases of mechanisms for the provision of FES in place in Europe, to analyse their features, especially the type of policy instrument used and the forms of innovation introduced, and to study if any of the features that characterize the mechanism are likely to be jointly implemented in the same mechanism. Through this, an updated overview of mechanisms adopted in Europe to provide FES is presented, with a focus on innovation. The geographical focus on Europe is connected to the recent EU policy developments, i.e., the European Green Deal, the European Climate Law (EC 2020a), the New EU Forest Strategy (EC2021), and the European Biodiversity Strategy (EC 2020b), all stressing the need for further research on FES in the face of current environmental and climate challenges. Furthermore, the information available on what is in place to stimulate the provision of FES is scarcer in Europe than in other continents (Wunder et al., 2019).

A framework has been purposely conceived for systematizing the features of the mechanisms and the related information gathered on the European cases. This framework addresses, for the first time, issues of innovation in delivered services, processes, models and stakeholders’ involvement. Univariate and multivariate statistics have helped understanding which specific features of cases are likely to be interlinked.

The structure of the paper is the following: section 2.2 discusses the conceptual framework of the research. i.e., the concept of innovation in the context of provision of forest ecosystem services and the framework for systematizing the information on the mechanisms; section 2.3 presents the methods used in the research. Section 2.4 reports the results in terms of cases found, their features, their innovative aspects, the policy tools used, the interplay. Section 2.5 discusses on what is new about mechanisms supporting FES provision and enhancement in Europe and the type of innovation they incorporate. The conclusions are drawn in section 2.6.

2.2 Conceptual framework

2.2.1. Types of innovation in the provision of FES

The concept of innovation includes a variety of meanings and definitions according to the discipline in which is considered, and it also evolves in time depending on the socio-cultural and historical contexts where it has developed (Edwards-Schchter, 2018).

In economic and business theory, the concept of innovation was traditionally intended from a technologically-oriented perspective. This is reflected in the 1934 classification by Schumpeter (1934) who is considered one of the most influential theorists of innovation. Only more recently, attention was given to non-technological elements such as social aspects, software development, branding, improved product or process, innovation in services and other investments than R&D (Martin, 2016).

In the forestry domain, the trends are similar to those of the economic disciplines, but with younger records. The most studied innovation types are those of technological and organizational innovation, with a focus on the firm and the role played by wood-related products and value chains (Kubeczko et al., 2006). An overview on forest innovation research from 1980 to nowadays shows that a more open and modern view on innovation gained higher representation only in the last five years, with the rise of bio-economy related topics (Van Lancker et al.,2016; Lovric et al., 2020). In this view, innovation is no more relegated only within enterprises, but is open to the institutional system (Weiss et al., 2010). Non-technological elements such as organisational (Kubeczko et al., 2006) institutional innovation and market innovation (e.g., O'Driscoll et al., 2017) are introduced. The concepts of "Innovation Systems" and "Open Innovation" (Weiss et al., 2020) enrich the perspective, highlighting the pivotal role of actors and their interactions in developing and implementing innovation (Rametsteiner and Weiss, 2006). Also important is the introduction of the concept of social innovation, which is concerned with the reshaping of social and relational practices (Polman et al., 2017).

An intrinsic feature of innovation, regardless of its type, is its radical or incremental nature. The former indicates a development of innovation that introduces revolutionary modifications (Henderson and Clark, 1990), while the latter refers to a type of innovation that

introduces small marginal changes on existing products or services. However, this has to be seen with relation to the context of implementation (Lazdinis et al., 2005): an innovation that is new for an area can be a long-established practice in another area. The radicalness of innovation hence varies according to the local, regional, national, international contexts in which it is embedded (Kleinknecht, 1999).

Grounding on the findings of relevant studies on innovation types in different disciplinary fields including forestry (Schumpeter, 1942; Kubeczko et al., 2006; Sawhney et al., 2006; Weiss et al.,2010; O'Driscoll et al., 2017; Polman et al.,2017; Edwards-Schachter, 2018; Lovric et al., 2020) summarised in Table S2.1 in the Supplementary Material, a conceptual framework for analysing innovation in the field of FES provision has been developed. Through a process of transposition and linking of the main innovation types from literature, two main categories of innovation types have been identified (Figure 2.1):

1. when a new FES is being provided – either a provisioning, regulating, cultural, FES or a new bundle of different FES. This is the transposition of "product", "service" and "outcome" innovation types;
2. when new ways of providing the FES are implemented. This is the transposition of several innovation types:
    - *Process Innovation*, when a renovation in the process of delivery the FES occurs, like new ways to capture value, e.g. the recognition of the spiritual value of a forest creating a system able to provide an economic revenue from it by establishing a funeral forest, and new practices of forest management focused on FES provision.
    - *Technological Innovation*, when a new technology for providing the FES is adopted, e.g. the development of a online platform that raises funds to support reforestation and afforestation actions in European and extra-European countries.
    - *Business Model Innovation*, when new elements of the FES-provision business model are implemented, such as a new internal organisation of the company, a new communication strategy, a new target of FES consumers or producers, new actors from the demand or the supply side are involved.
    - *Institutional Innovation*, when new policy and governance models of FES provision are implemented: for example, scaling up of an existing PES initiative widened at

a landscape scale, including ecosystems beyond forests, or even transboundary initiatives among different countries; or new networks and formal/informal relationships amongst different stakeholders; or adoption of a new policy mechanism or a new combination of existing policy mechanisms.

- *Social Innovation*, when a "new social practice" is introduced. New social practices include, among the others, the participation of local communities and the establishment of grass-roots initiative to valorise forests and the goods and services they provide.

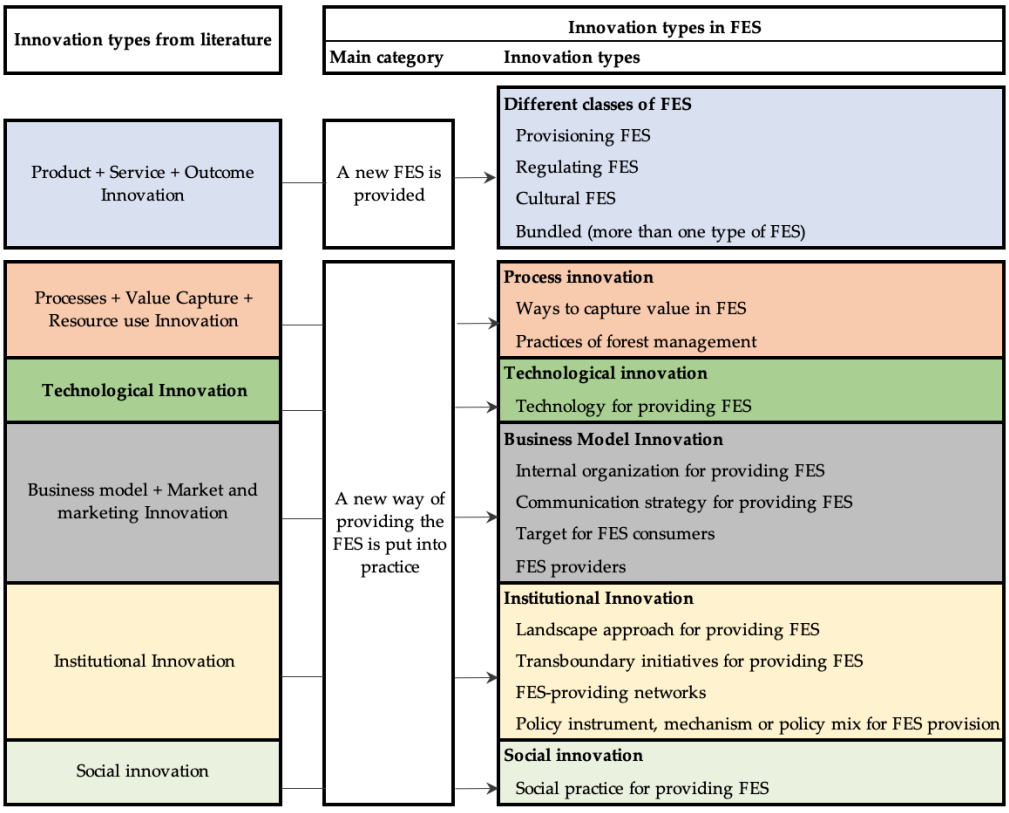


Figure 2.1. Innovation types for FES provision and enhancement

Following this conceptualisation of innovation in FES, a mechanism is considered innovative – and hence defined an 'innovative mechanism (IM)' for the purpose of this paper – when it includes at least one of the innovation types in FES, either radical or incremental, reported in Figure 2.1.

2.2.2. Framework for systematizing the IMs features

The IM cases and the related information were systematized in a framework developed on the basis of work by Sattler et al. (2013) and Leonardi (2015). However, while these authors

focused mainly on PES schemes, this framework is conceived for a larger spectrum of mechanisms and, besides, it includes the information on innovation.

Five groups of descriptive variables representing the features of IMs are recognised: 1) Identification; 2) Spatial and Temporal Scales; 3) Targeted Ecosystem and Ecosystem Services; 4) IM governance; 5) Innovation (Table 2.1):

1. *Identification*: it includes information to identify the IM, such as the country in which it is located and the type of administrators, i.e., the type of actors in charge of the management and supervision.
2. *Spatial and Temporal Scales*: the spatial scale at which the IM is implemented is categorised by a qualitative attribute spanning from local to international. The time scale has been defined according to age of IM (year of establishment) and IM duration: short (< 5 years), medium (5 to 10 years), or long (> 10 years). The status of IM is also considered, i.e., whether the IM is active or abandoned, and whether it is a pilot project, or in a design phase. The spatial and temporal scales are extremely relevant in dealing with ecological phenomena and environmental management (Gibson et al., 2000), hence the provision of FES can vary according to such scales (Geijzendorffer and Roche 2014), and so the mechanism effectiveness and efficiency (Raudsepp-Hearne and Peterson, 2016; Lu et al., 2020; Havinga, 2020).
3. *Targeted Ecosystem and Ecosystem Services*: this group gathers core information of the IMs, describing their ecological context. A variable aims to define whether also other ecosystems besides forests are targeted by the IM. Then, variables describing the forest subsystems and the bioclimatic regions where the IM is implemented are included. The next variable, type of setting, refers to the context where the IM is located i.e., natural park, peri-urban, urban, or rural areas. The targeted FES variable focuses on whether the IM case is addressed to just one FES, or to a principal and a secondary FES, or to a bundle of FES. FES characterisation (FES Section and specific FES) is based on a elaboration implemented for the study purposed, simplifying the CICES V5.1 classification of groups and classes of biotic FES (Haines-Young and Potschin, 2018) (see Supplementary Material Table S2.2).
4. *IM governance*: first, a short narrative description of the mechanism is included, describing the IM rationale and mode of functioning; then other variables classify the

typology of FES providers and users in terms of type of forest ownership, the type of final beneficiaries and the presence of intermediaries; these variables are especially relevant when describing and analysing specific types of mechanisms, like e.g. PES.

5. *Innovation*: the variable describing innovation connected to the IM cases refers to the innovation types of Figure 2.1.

Table 2.1. Framework variables and description

Group	Variable	Variable description
Identification	Country	Name of the country
	Administrator	Private, public, semi-public , NGOs, other
	Economic instrument	Types of instrument as reported in Table 2.2
Spatial and Temporal Scales	Mechanism Scale	Local scale, municipality level, provincial scale, regional scale, interregional scale, national scale, international scale
	Year of establishment	date (year)
	Mechanism duration	Long term (>10 years), medium term (5 to 10 years), short term (< 5 years)
	Mechanism Status	Active, design phase, pilot, unknow
Targeted Ecosystem and Ecosystem Services	Other Ecosystems Involved	Agricultural land, meadow, wetland, other
	Type of forest subsystem	Agro-forest, natural forest, planted forest, other
	Type of bioclimatic region	Alpine, boreal, Mediterranean, temperate continental, temperate oceanic
	Type of setting	Natural-park, peri-urban, rural, urban
	Target FES	Target, Bundled, or Target + Bundle
	FES Section	Provisioning, Regulating, Cultural ES
	Specific FES	See Table S2.2
IM governance	IM description	Narrative description
	FES providers	Collectively owned forests, local forest communities, private forest owners/managers, public forest owners, public private partnership, other
	FES users	Collectively owned forests, local forest communities, private forest owners/managers, public forest owners, public private partnership, other
	Final beneficiaries	Civil society, local communities, households, forest owners, firms, other
	Intermediaries	Presence or absence
Innovation	Innovation types in FES	Types of innovation as reported in Figure 2.1

2.3 Materials and Methods

2.3.1. Data collection process

To fulfil the aims of the paper, a survey of IM cases in Europe was undertaken. Data collection (from March 2018 to June 2020) and systematization was accomplished in four steps:

1. *Survey of publicly-available information*. The cases were initially identified by consulting publicly available information, such as peer-reviewed and grey literature, existing databases, and more widely in the web. The principal keywords used in the literature research were: "forest*" OR "ecosystem services" OR the names of individual ecosystem services such as "non wood forest product*", "natural hazard*", "water*", "biodiversity", "pest*", "education*", "tourism*", "recreation*", "health*", "spiritual", or "cultur*" AND "market-based instrument*" OR "non-market-based instrument*" AND the names of the different European countries, OR the word "innovati*", and a combination of these terms. The review was conducting using only keywords in English. The databases consulted were: Ecosystem Market Place, Ecosystems Services Partnership, The Economics of Ecosystem and Biodiversity, United Nation Economic Commission for Europe, Ecosystems Knowledge Network, Species Banking, Forest Carbon Portal, Domestic Carbon Initiative in Europe, Verified Carbon Standard Project Database, Alpine Convention, Oppla, and ECOSTAR. A further consultation was implemented in the web using different combinations of the keywords described before. In this case Italian, English, and Spanish have been used as languages. The cases have then been selected based on the following criteria: they had to be connected to forests or trees, be implemented in Europe, and be innovative according to our definition.
2. *Expert consultation*. Once a provisional list was compiled, cases were sent to experts, researchers and practitioners from the SINCERE network (Table S2.3) to be validated. Each defined expert was assigned the cases in his/her own country (and cases of other countries which he/she knew well) and was asked to check whether such cases were in line with the research aim, mainly in term of their innovativeness related to the context where the case were developed. The cases that did not pass this second step were discharged. Experts were also asked, if the case, to add new relevant cases they were aware of, that were not captured by step 1.

3. *Structuring of data in the framework*: for each validated case, the information required by the framework of Table 2.1 was compiled by the experts and integrated by the authors of this paper, when the present information was not sufficient to meet the research needs. In this step the additional information fund in the web has incorporated.
4. *Attribution of the policy tool*: finally, based on the description of the IMs emerged from the survey and reported in the framework, the policy tool applied by each IM was recognized and attributed to one of the three types of policy tool as either an n-MBI, a MBI or a E&I as reported in Table 2.2.

2.3.2. Statistical analysis

Descriptive statistics and frequency analysis have been implemented to characterise the set of existing IM cases. The non-linear nominal variables of the framework features have been transformed into dichotomic and categorical variables, except the "year of establishment" that is numerical (Table S2.4).

Table 2.2. Types of economic instrument

Instrument	Type
Prescribed or prohibited activities	**n-MBIs**
Licences/permits	
Public ownership and land acquisition	
FES provision through direct public management	
Mitigation banking	**MBIs**
Offset schemes	
Cap-and-trade schemes	
Subsidies and grants	
Tax exemption and rebates	
Soft loans	
Competitive tenders/auctions	
Land acquisition by private bodies	
Public-private management contracts	
PES and PES-like schemes	
Public Procurement Schemes	
Corporate Social Responsibility	
Definition of standards, certifications, eco-labelling	
Other initiatives like branding, promotion, sponsoring	
Technical assistance	**E&Is**
Education and training	
Consumers' awareness raising	

Modified from Windle et al. 2005, Stavins 2001, Prokofieva and Wunder, 2014

To determine the presence of patterns among the categorical variables, Multiple Correspondence Analysis (MCA) has been computed. MCA allows to analyse high dimension contingence tables where qualitative variables are presented. Each level of the nominal variables is coded as binary (0= absence, 1=presence). MCA can be also applied to quantitative variables after their recoding in different levels (Abdi and Valentin, 2007). The method is based on indicator matrix, where the rows represent the IM cases, and the columns represent dummy levels of the variables. Computing MCA variables are gathered in different dimensions able to explain data variation. Dimensions extraction is based on the eigenvalues, or inertia, and on the related percentage of inertia, i.e. the explained variance, of the relevant combinations of active variables (Husson and Josse, 2014). The statistical model distinguishes between active variables, used to compute the dimensions, and supplementary variables, that are excluded from dimensions identification but support their final interpretation. MCA aimed to explore the correspondence among the economic instrument used in the IM cases, the type of targeted FES, and the innovation types introduced. Hence, the "type of policy tool", the "FES section", and the "innovation type" have been chosen as active variables. In order to implement the analysis, the data of the active variables had to be aggregated to reduce data dispersion. Concerning the type of policy tool, the main category was considered, i.e., n-MBI, MBI and E&Is, and a further category deemed relevant after analysing the cases (cfr § 4.5). For the innovation type variable, its main dimensions were considered as shown in Figure 2.1.

The remaining variables were considered as supplementary variables. To reduce biases in the MCA implementation, the variable levels not enough represented (less than 10%) were excluded. MS Excel has been used to implement descriptive statistics and frequency analysis, while MCA was computed using the statistical software R (4.1.0) and R packages FactoMineR (Le et al. 2008), and factoextra (Kassambara and Mundt, 2020).

2.4 Results: existing IMs for FES provision in Europe and their features

2.4.1 Overview

The survey of IMs in Europe resulted in the identification of 105 cases in several European countries (https://sincereforests.eu/innovation/innovation-inventory-map/).

Geographically, the cases are not evenly distributed across Europe, with Italy, Switzerland,

Germany, and Spain accounting for 57% of the total. Other countries represented by cases are Albania, Austria, Belgium, Bulgaria, Denmark, Estonia, Finland, France, Croatia, Ireland, Moldova, Norway, Portugal, Romania, Sweden, Slovenia, and United Kingdom.

In order to provide some examples of the cases present in the analysed survey, hereafter a brief description of a selection of IMs is presented according to the type of FES take into account. Considering provisioning FES, an example, located in Italy, refers to the selling of mushroom picking, by the local community, through the network of ATMs (Automated Teller Machines) of local banks. Another case targeting a different FES, in Germany, consists in the implementation of awareness campaigns to increase the value of the red-core beech timber. When regulating FES are considered, an example of IM, located in Denmark, sees the establishment of a payment scheme, to convert agricultural lands to broadleaved woodland, to preserve drinking groundwater quality. A further example, from Spain, consist in the establishment of an association of forest owners, volunteers, and local administration to fight forest fire, organising, among the others, prevention programmes and educational activities. Concerning the support of cultural FES, an example is the case of the establishment of forest paths, in an Italian forest, to support people health, mindfulness, and wellbeing. Another example is located in Romania and consists in the creation of a heritage trail connecting different protected areas to improve the touristic value of the region. Finally, some of the IMs aimed to target a bundle of FES. This is, for instance, the case of a initiative in Belgium that bring together a group of experts, supported by the central government, aimed to developed a vision for the forestry sector able to valorise forests multifunctionality. The designed vision has been already translated into concrete policies. The cases just described are not representative for all the cases present in the survey, but were introduced to give to the reader the possibility to understand its nature.

Following the analysis of the survey, the cases reveal a predominance of private (40%) and public administrators (35%), with a lower representation of mixed types (semi-public, 12%) and NGOs (7%), while the remaining 6% is represented by other categories, such as ethical purchasing groups, community forests, forest corporations, forum of experts. From these outcomes is already evident the important role played by the private sector and the public institution in managing and supervising the implementation of these kinds of initiatives.

2.4.2. Features of IMs: scale and Ecosystem Services

The analysis of spatial and temporal scales of cases (Table 2.3), shows that the majority of IMs were implemented at local scale, followed by national and then by regional scales; in addition, the majority of cases has a long-term time horizon of duration, more than 10 years.

Table 2.3. Spatial and temporal scale of the IMs cases

Spatial Scale	
local scale	38%
national scale	25%
regional scale	23%
municipality scale	5%
provincial scale	5%
international scale	4%
interregional scale	1%

Temporal scale	
long term (>10 years)	88%
medium term (5 to 10 years)	7%
short term (< 5 years)	5%
NA	1%

Considering the targeted ecosystems (Table 2.4), in roughly half of the cases, forest is the only ecosystem involved, while, in the other half also other types of ecosystems – such as agricultural land, meadows, and wetlands – are involved. As regards the forest subsystem and setting, natural forests and rural areas prevail. The distribution of the cases by bioclimatic region places 46% of cases in the temperate oceanic region, 31% in the Mediterranean region, and 12% in the temperate continental region. Only 6% of cases are located in alpine areas and 5% in the boreal region.

Table 2.4. Targeted ecosystems

Other Ecosystems Involved	
forest	49%
agricultural land	19%
meadow	17%
wetland	13%
other	3%

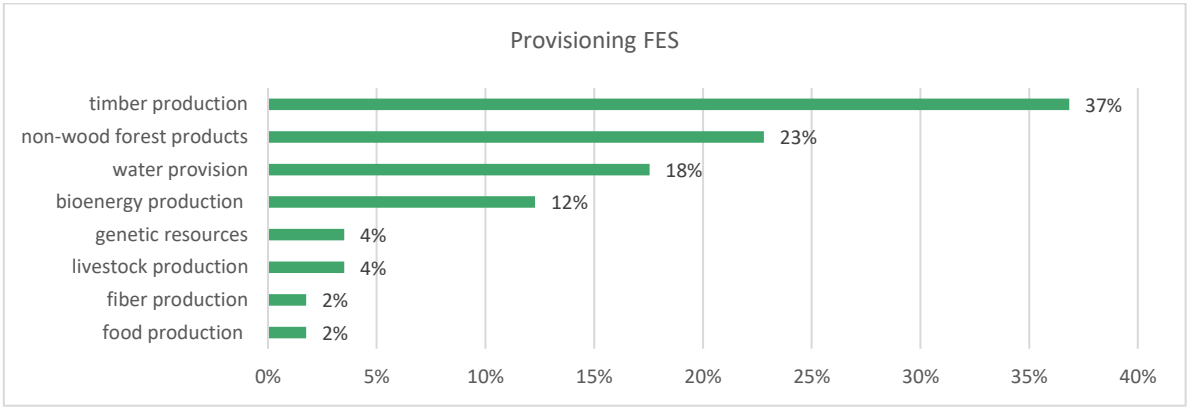
Type of forest subsystem	
natural forest	61%
planted forest	28%
agro-forest	8%
other	2%

Type of setting	
rural	63%
peri-urban	17%
natural-park	14%
urban	6%

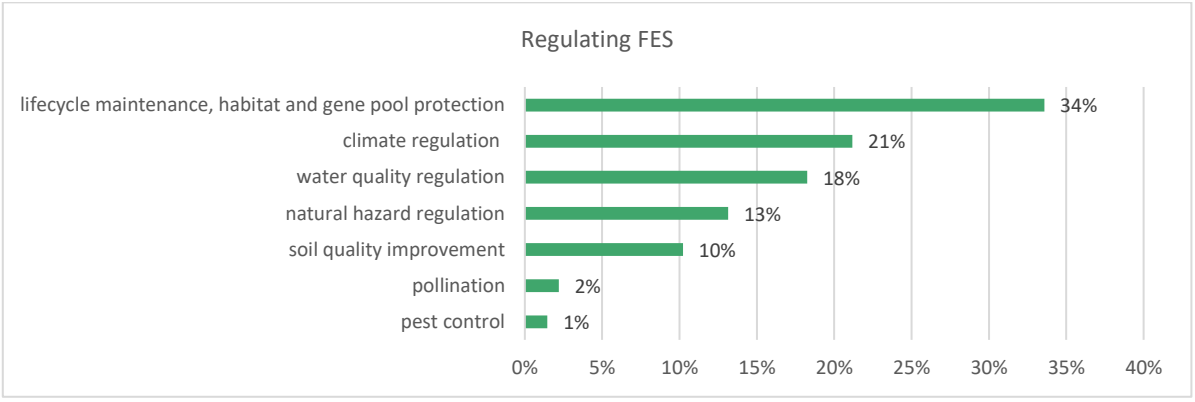
Regarding the target FES, the IM targets a single FES in 40% of cases, a bundle of them in 33% and one main FES and one secondary FES in the remaining 27%. The distribution amongst FES categories reveals that regulating FES are the most represented (42%) followed by cultural FES (35%), and by provisioning FES (23%).

The total provisioning FES targeted by the cases (Figure 2.2a) are equal to 57. Among them, the more targeted FES is timber production (21 times), followed by non-wood forest products (13 times), water provision (10 times), and bioenergy production (7 times). Considering the

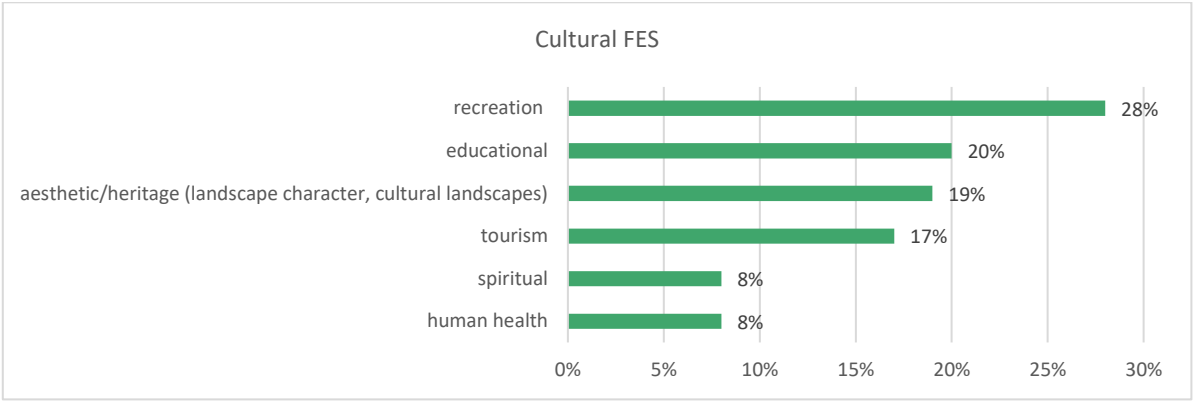
total regulating FES (Figure 2.2b) they are equal to 137. Among them, distribution is more balanced, the most targeted being lifecycle maintenance, habitat, and gene pool protection (46 times), followed by climate, water quality, natural hazard regulation (respectively 29, 25, 18 times), and soil quality improvement (14 times). Finally, considering cultural FES (Figure 2.2c), that have been targeted for 100 times, the majority focuses on recreation (28 times), followed by education (20 times), aesthetics and heritage (19 times), and tourism (17 times). Spiritual, and human health -related FES have been targeted at a smaller rate.



(a)



(b)



(c)

Figure 2.2. Distribution of targeted provisioning FES (a), regulating FES (b), and cultural FES (c) by the IM cases

2.4.3. Governance

Data on FES providers, users, final beneficiaries and intermediaries are reported in Table 2.5. Private forest owners and managers are the stakeholders' categories that mostly participate as FES providers, followed by public forest owners. Concerning users, the predominant category is society at large, and similarly occurs for the final beneficiaries. Finally, only in the 36% of the cases at least one intermediary is present.

Table 2.5. Stakeholders' characterisation within the IMs cases

Providers	
private forest owners/managers	36%
public forest owners	23%
public private partnership	20%
other	12%
collectively owned forests	5%
local forest communities	4%

Final beneficiaries	
civil society	48%
local communities	21%
forest owners	19%
other	7%
householdes	3%
firms	2%

Users	
civil society (end-users, tourists, visitors, ...)	36%
private companies	17%
other	12%
public private parnership	10%
government	9%
regional government	6%
public utility company	6%
funds	3%
NGOs	2%
municipalities	1%

Intermediaries/ facilitators	
presence of an intermediary	36%

2.4.4. Innovation

The types of innovation introduced by the IM cases is reported in Table 2.6. It is evident how the introduction of new ways of providing FES prevails over the provision of new FES. Within the first group of cases introducing new ways of providing FES, the innovation categories are represented as following: Business Model innovation (29%), process innovation (27%), institutional innovation (22%), social innovation (5%), and technological innovation (3%). The innovation types that have been represented by a higher frequency are the introduction of a new way to capture the value of the targeted FES, the adoption of a new or more sustainable forest management, and the establishment of a new network.

Table 2.6. Innovation types introduced by the IMs

Innovation Type	Number of cases	% Frequency
A new FES provided	**52**	**14%**
Different classes of FES	*52*	*14%*
Provisioning FES	1	0%
Regulating FES	1	0%
Cultural FES	12	3%
Bundled (more than one type of FES)	38	10%
A new way of providing the FES is put into practice	**330**	**86%**
Process innovation	*103*	*27%*
Ways to capture value in FES	54	14%
Practices of forest management	49	13%
Technological innovation	*13*	*3%*
Technology for providing FES	13	3%
Business Model innovation	*109*	*29%*
Internal organization for providing FES	26	7%
Communication strategy for providing FES	14	4%
Targeted for FES consumers	39	10%
FES providers	30	8%
Institutional innovation	*85*	*22%*
Landscape approach for providing FES	21	5%
Transboundary initiatives for providing FES	3	1%
FES providing networks	46	12%
Policy instrument, mechanism or policy mix for FES provision	15	4%
Social Innovation	*20*	*5%*
Social practice for providing FES	20	5%
	382	**100%**

2.4.5. Economic instruments used by the IMs

Table 2.7 presents the results of the attribution of policy tools used by the IMs to induce the provision of FES: 74% of the economic instruments are MBIs, 21% are Information and Education, while only 5% are n-MBIs. The MBIs adopted with a higher frequency are PES and PES-like schemes.

We found that only in half of the cases one sole instrument was adopted, while in 36% of cases two instruments were used and in 14% of cases more than two instruments were applied simultaneously. This explains why the total number of policy tools found are 156 (Table 2.7). For example, in a French case, a offset scheme, a biodiversity standard, and educational instruments have been jointly implement. The use of different instruments, from one hand allowed to involve and support private enterprises that will to compensate their impacts on biodiversity On the other hand, it increases local awareness about the importance of biodiversity conservation project. This made the project more sustainable in time and increase its acceptance within the community to which was addressed. The adoption of a mix of instruments is already an innovation, capable to bring successful environmental policy-

making cases (Flanagan et al., 2011). Indeed, the interaction of different policies or instruments allows to expand the target of the more traditional policies, for instance, to others and more indirect actors, to others policy fields, or to different implementation scales and times. This contributes to increase the effectiveness of the policies allowing to achieve specific goals or outcomes, otherwise impossible to address.

Considering the 171 types of instruments adopted by the cases, the identification of the economic instruments, according to Table 2.2, was however possible only for 156 cases. For the remaining 15 instrument types, the type of policy tool could not be pigeonholed to any of those listed in Table 2.2. A deeper exam of these 15 instrument types brought us to conclude that the mechanism through which the IMs in which they are present, promoted the provision of FES was the development of new social organisations through new networks among a wide number of stakeholders, mainly belonging to civil society and local communities. In different cases of the survey under analysis, the establishment of a community cooperative, an association, a coalition, or a partnership among different actors belonging to different categories, has been the most important aspect. Indeed, the establishment of a kind of social organisation led to the possibility of implementing specific actions addressed to sustain the provision or enhancement of FES. This is the case of different local partnerships developed in United Kingdom, able to promote local natural capital, to support sustainable management, to raise local awareness about local natural environment, and to reach other objectives that allowed to include nature in the local decision making processes.

Table 2.7. Type of economic instrument used by the IMs

Instrument type	Number of cases	% Frequency
n-MBIs	**8**	**5**
Prescribed or prohibited activities	5	3
Licences/permits	3	2
MBIs	**116**	**74**
Mitigation banking	1	1
Offset schemes	17	11
Cap-and-trade schemes	3	2
Subsidies and grants	6	4
Tax exemption and rebates	2	1
Competitive tenders/auctions	3	2
Land acquisition by private bodies	2	1
Public-private management contracts	19	12
PES and PES-like schemes	34	22
Public Procurement Schemes	4	3
Corporate Social Responsibility	10	6
Definition of standards, certifications, eco-labelling	10	6
Other, e.g. branding, promotion, sponsoring	5	3
E&Is	**32**	**21**
Technical assistance	9	6
Education and training	14	9
Consumers' awareness raising	9	6
	156	**100%**
Establishment of social organizations	15	9%

2.4.6. Interplay amongst IMs features

The tables below report the description of the dimensions emerged from MCA. The maximum number of dimensions considered was calculated according to the eigenvalues. Only the dimension with a variance higher than 1/J (where J is the number of the active variables, in our case equal to 13), are considered (Husson and Josse, 2014). In our case, this occurs for six calculated dimensions (Figure S2.1). Moreover, higher total variance among the variables of a dimension is indicated by higher eigenvalue. Consequently, low eigenvalues imply a greater heterogeneity of the variable within a dimension. For this reason, only the first two dimensions with higher eigenvalues were considered, representing the 29.8% of the total variance (Table S2.5).

The following tables summarise the outcome of the first two dimensions (Table 2.8-2.9). The two dimensions identify two groups of variables that can describe bundled features of IM cases. Only the significant variables and levels are shown. Variables and levels have been ranked according to their contribution to the dimension: positive coordinates (coord.)

entailed positive contribution, while negative coordinates entailed negative contribution. The value of R2 indicates the correlation between the category of the variable and the dimension. P-value has been calculated for $\alpha<0.05$.

Table 2.8. MCA result: description of the first dimension

	Dim.1	Coord.	R^2	p-value
ACTIVE VARIABLES	Econ.Inst_Social_Y	1,82	0,45	1,30E-19
	Social.Innov_Y	1,52	0,39	4,03E-19
	Econ.Inst._MarketBasedInstr_N	1,55	0,39	6,62E-17
	Econ.Inst._Info.Edu_Y	0,81	0,22	4,69E-06
	Istit.Innov_Y	0,38	0,20	4,04E-07
	FES.Innov_Y	0,34	0,14	8,21E-04
	Econ.Inst._Info.Edu_N	-0,23	-0,22	4,69E-06
	FES.Innov_N	-0,31	-0,14	8,21E-04
	Econ.Inst_Social_N	-0,30	-0,45	1,30E-19
	Econ.Inst._MarketBasedInstr_Y	-0,32	-0,39	6,62E-17
	Social.Innov_N	-0,36	-0,39	4,03E-19
	Istit.Innov_N	-0,58	-0,20	4,04E-07
SUPPLEMENTARY	Bundled.FES	0,69	0,27	1,58E-07
	Belgium	1,40	0,53	8,76E-05
	Targeted.FES	-0,53	-0,24	3,89E-06

Table 2.9. MCA result: description of the second dimension

	Dim.2	Coord.	R^2	p-value
ACTIVE VARIABLES	Cultural.FES_N	0,89	0,27	1,05E-21
	BusinessModel.Innov_N	0,80	0,18	3,93E-06
	RegulatingFES_Y	0,39	0,21	5,50E-10
	Econ.Inst._CommandControl_Y	1,13	0,21	7,67E-04
	ProvisioningFES_Y	0,51	0,14	3,89E-05
	FES.Innov_N	0,37	0,14	4,53E-05
	Econ.Inst._CommandControl_N	-0,09	-0,21	7,67E-04
	BusinessModel.Innov_Y	-0,24	-0,18	3,93E-06
	ProvisioningFES_N	-0,30	-0,14	3,89E-05
	FES.Innov_Y	-0,41	-0,14	4,53E-05
	RegulatingFES_N	-0,81	-0,21	5,50E-10
	Cultural.FES_Y	-0,67	-0,27	1,05E-21
SUPPLEMENTARY	Provider.private_Y	0,38	0,12	2,41E-04
	Buyer.CivilSociety	-0,45	-0,20	5,40E-04
	Provider.private_N	-0,32	-0,12	2,41E-04

The first dimension (Table 2.8) gathers IMs that have established new social organisation to provide bundle of FES, with a focus on introducing new FES, generally, cultural FES. This first dimension is also related to the adoption of information and educational instruments and the occurrence of institutional innovation (represented mainly by new network). A negative correlation is found with MBI and the target of a single FES.

The second dimension (Table 2.9) places emphasis on the use of n-MBI instruments for the provision of regulating and provisioning FES by private owners. A negative correlation is connected to innovating business model of the IM and to cultural FES.

2.5 Discussion: IMs in Europe – what's new?

Our results allow to draw insights on innovation designed and implemented in Europe to support and enhance FES. The survey we compiled consist of 105 IMs supporting the provision and enhancement of different FES through the implementation of a large variety of economic instruments and introducing different innovation types.

The most used economic instruments applied by the IMs are MBIs, while n-MBIs and E&Is are less represented. This is in line with the findings by Pirard and Lapeyre (2014). This suggests how IMs tend to favour FES valorisation through voluntary, market-oriented approaches. Most IM cases have been implemented at local level and with a long-term period (more than 10 years), resulting in a better target of the needs of local communities, ensuring FES provision for a longer time-span. Given the consolidated normative approach towards ecosystem conservations and valorisation at European level, this might confirm Wunder et al. (2019)'s claim that innovation arises outside regulating systems, being better fit to specific local needs.

The 15 IMs that could be classified through the already existing categories broadens the spectrum of the strategies used to support FES provision and highlights the role of a fertile social milieu where new networks involving different stakeholders, mainly the local communities and the civil society, can develop. Considering that the forest sector is chronically affected by property fragmentation (EEA, 2016), the emphasis on the creation of new associative models and networks is even more relevant (Mendes et al., 2011). In general, these findings are in line with the emergent research on social innovation (e.g., Ludvig et al.,

2020; Ludvig et al., 2019; Nijnik et al., 2019; Kluvánková et al., 2018) investigating the emerging of new social practices.

Beyond the specific economic instruments used, we detected also that half of the IMs rely on a mix of instruments to support FES provision and enhancement. This might be functional to the need of better targeting the FES, or rather a bundle of them. The heterogeneity within the IM cases can be also observed considering other elements such as the targeted ecosystems, the type of forest sub-systems, the settings in which IM cases were applied, or the mix of FES targeted by the IM cases.

Through our conceptual framework on innovation, we could gather information about the type innovation adopted by the IMs in Europe. We found that process innovation is the most adopted type, meaning that, the main innovativeness of the IM cases lies on a renovate capacity to valorise FES through new ways to capture value and on a novel management able to support their provision through the implementation of new management practices. The third most introduced innovation type was the establishment of new networks, highlighting the importance of a more comprehensive number of stakeholders.

Through the MCA, we could identify which features tend to be jointly implemented within the IMs; we identifies two main dimensions, grouping some IM features, describing 29.8% of the total variance of our IMs. The first dimension highlights the tight relation between the occurrence of social innovation and the creation of social organisation for the provision and enhancement of bundled FES. Unexpectedly, a negative correlation was found with the presence of MBIs and of a single FES. Differently from what observed in literature (e.g. Nijnik et al. 2019), this indicates that MBIs might not be the most suitable instruments to prompt social innovation and establishment of new societal organisation, as information and education appear to be instead. This very preliminary result, that needs to be supported through deeper analysis and more data, highlights the positive role of social innovation when a bundle of FES is at stake. MBIs, instead, seem to be more frequently associated with the provision individual FES (Kemkes et al. 2010). The second MCA dimension underlines the role of n-MBIs. Despite being the least present in the IMs analysed, when implemented, n-MBIs are related with provisioning and regulating FES. Non-wood forest products and water provision account for 41% of provisioning FES (Figure 2.2a). Together with regulating FES,

these two provisioning FES are, generally those characterised by more difficult excludability (Brown et al. 2007; Musgrave and Musgrave, 1973). To this end, our results seem to indicate the still important role of regulating instruments in the provision of public or common FES.

It is important to underline that, within both dimensions, do not appear the most frequent economic instrument (i.e. market-based instrument), or the innovation types most introduced by the IM cases (i.e. new way to capture value and implementation of a new or more sustainable management). This is not because they are not relevant in describing the IM cases, but because they are associated to a high number of IMs and consequently, they do not result significant in the dimensions' establishment.

2.6 Conclusions

This paper casts light on a variety of concepts related to innovation in the forest sector and, more specifically, in the provision and enhancement of forest ecosystem services.

A first categorisation of innovation and a framework than can support the systematisation of the information of the upcoming experiences dealing with FES have been developed and tested. These two instruments can support further analysis in a context that, by definition, is in a continuous evolution.

Descriptive analysis provide an overview of the IM cases implemented at the European context. Market-based instruments result to be the most applied economic instruments involving an heterogeneity of targeted FES, actors and ecosystems. These underline and strength an important features of these instruments, their flexibility, and their consequent high potential in supporting decision-makers to prompt forest management for FES provision.

Despite this consideration, our research reveals that the more traditional instruments, such as command and control, still support those forest ecosystem services characterised by difficult excludability. This indication is useful to understand which kind of instrument could be used to target a specific FES according to the context and the possibility to regulate societal accessibility to it.

Finally, this paper support the findings present in literature about social innovation. This innovation type is serving as base to develop new social organisation that our research found to be an innovative instrument that complement market-based, command and control, and information and educational instruments. Social innovation and the construction of new

social organisation result to be valuable to provide a bundle of forest ecosystem services, in contrast with MBIs, that are still more associated to the targeting of single FES. This founding can support civil society, but also local administrators to implement actions able to sustain bundled FES and thus to valorise a plethora of different good and services provided by forests, supporting local communities in rural areas.

The limitations of the paper mainly regard data collection. The intrinsic characterisation of the case studies, i.e. to be innovative, lead to the necessity to not rely only on scientific literature, but also on different data sources such as databases and web. Moreover, data collection would require a continuous update to be able to gather the newest cases. Another limitation regards the countries covered by the consulted experts. Indeed, the experts that have been consulted referred to the consortium of the H2020 project SINCERE. Connected to this, also the languages used during data collection does not allow to gather homogeneous information among the different countries.

Supplementary Materials: Table S2.1: Comparison among classifications of innovation types; Table S2.2: Forest Ecosystem Services used in the framework and link with CICES (V5.1) classification; Table S2.3: Country and institution of the experts consulted for IM cases validation; Table S2.4: Coding of framework variables for the statistical analysis purpose; Table S2.5: Eigenvalues and % variance of MCA dimensions; Figure S2.1: Plot representing the percentage of variance in % explained by each dimension.

Author Contributions: Conceptualization, G.B., P.G., and D.P.; analysis, G.B. and P.G.; writing—original draft preparation, G.B.; writing—review and editing, P.G. and D.P. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded under H2020-EU.3.2.1.4. Grant agreement ID: 773702. SINCERE project.

Acknowledgments: The research has been developed within the H2020 project SINCERE (Grant ID 773702), which has explored innovative approaches to support forest owners in meeting societal needs when managing their forests. The authors thank the experts of the consortium of the H2020, SINCERE project to inspired the research and support data validation.

Conflicts of Interest: The authors declare no conflict of interest.

2.7 References

Abdi, H.; Valentin, D. (2007). Multiple correspondence analysis. In Encyclopedia of Measurement and Statistics; SAGE Publications: Thousand Oaks, CA USA; pp. 651–657.

Barton, D. N., Ring, I., & Rusch, G. M. (2017). Policy Mixes: Aligning instruments for biodiversity conservation and ecosystem service provision. Environmental Policy and Governance, 27(5), 397-403. doi:10.1002/eet.1779

Boisvert, V., Méral, P., & Froger, G. (2013) Market-Based Instruments for Ecosystem Services: Institutional Innovation or Renovation?, Society & Natural Resources, 26:10, 1122-1136, DOI: 10.1080/08941920.2013.820815

Bottaro G., Gatto P. and Pettenella D. (2019). DELIVERABLE 1.2 Inventory of Innovative Mechanisms in Europe. H2020 project no.773702 RUR-05-2017 European Commission, 72 pp.

Brown, T. C. et al. (2007): Defining, valuing, and providing ecosystem goods and services. Nat. Resources J. 47: 329. p.359

Costanza, R., D'Arge, R., De Groot, R., Farber, S., Grasso, M., Hannon, B., Limburg, K., et al. (1997). The Value of the World's Ecosystem Services and Natural Capital. Nature 387 (6630): 253–60. https://doi.org/10.1038/387253a0.

Daly, H. E., Farley, J. 2004. Ecological Economics: Principles And Applications. Edited by USA. Island Press: Washington, DC. Ecological Economics. Vol. 55. https://doi.org/10.1016/j.ecolecon.2005.08.005.

EC 2019. European Commission. The European Green Deal (2019/640/EC). Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2019%3A640%3AFIN

EC 2020a. European Commission. Proposal for a regulation of the European Parliament and of the Council establishing the framework for achieving climate neutrality and amending Regulation (EU) 2018/1999 (European Climate Law, 2020/80/EC). Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1588581905912&uri=CELEX:52020PC0080

EC 2020b. European Commission. EU Biodiversity Strategy for 2030. Bringing nature back into our lives (2020/380/EC).Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1590574123338&uri=CELEX:52020DC0380

EC 2021. European Commission. New EU forest strategy for 2030 (2021/572/EC). Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52021DC0572

Edwards-Schachter, M. (2018). The nature and variety of innovation. International Journal of Innovation Studies. 2, 65-79.

EEA 2015. Growing pressures on ecosystems (GMT 8). European Environment Agency. Available from https://www.eea.europa.eu/soer-2015/global/ecosystems.

EEA 2016. European forest ecosystems. State and trends. European Environment Agency Report No 5/2016

EU Horizon 2020: SINCERE (Spurring INnovations for Forest ECosystem SERvices in Europe). Project Proposal, 2018-2022.

Ezzine-de-Blas et al. (2016) Innovative mechanisms for financing biodiversity conservation: an exchange of experiences between Europe and Mexico. Summary of the key insights for CBD COP13 side event (16 December 2016), Cancun, Mexico.

Ezzine-de-Blas, D., Wunder, S., Ruiz-Pérez, M., Moreno-Sanchez, RdP. (2016). Global Patterns in the Implementation of Payments for Environmental Services. PLoS ONE 11(3): e0149847. https://doi.org/10.1371/journal.pone.0149847

Flanagan, K., Uyarra, E., Laranja, M. (2011). Reconceptualising the 'policy mix' for innovation. Research policy, 40(5), 702-713.

Froger, G., . Boisvert, V., Méral, P., Le Coq, J, F., Caron, A., Aznar, O. (2015). Market-Based Instruments for Ecosystem Services between Discourse and Reality: An Economic and Narrative Analysis. Sustainability (Switzerland) 7 (9): 11595–611. https://doi.org/10.3390/su70911595.

Geijzendorffer, I. R., Roche, P. K. (2013) Can biodiversity monitoring schemes provide indicators for ecosystem services?, Ecological Indicators, Volume 33, Pages 148-157, ISSN 1470-160X, https://doi.org/10.1016/j.ecolind.2013.03.010.

Gibson, C. C., Ostrom, E., & Ahn, T. K. (2000). The concept of scale and the human dimensions of global change: a survey. Ecological economics, 32(2), 217-239.

Haines-Young, R. and M.B. Potschin (2018): Common International Classification of Ecosystem Services (CICES) V5.1 and Guidance on the Application of the Revised Structure.

Havinga, I., Hein, L., Vega-Araya, M., Languillaume, A. (2020). Spatial quantification to examine the effectiveness of payments for ecosystem services: A case study of Costa Rica's Pago de Servicios Ambientales, Ecological Indicators, Volume 108, 105766, ISSN 1470-160X, https://doi.org/10.1016/j.ecolind.2019.105766.

Henderson, R., Clark, K. (1990). Architectural innovation: the reconfiguration of existing product technologies and the failure of established firms. Administrative Science Quarterly 35, 9e30.

http://dx.doi.org/10.5751/ES-08605-210316

Husson F, Josse J. (2014). "Multiple Correspondence Analysis." In M Greenacre, J Blasius (eds.), Visualization and Verbalization of Data, pp. 163–181. Chapman & Hall/CRC, London.

Kassambara, A. and Mundt, F. (2020). factoextra: Extract and Visualize the Results of Multivariate Data Analyses. R package version 1.0.7. https://CRAN.R-project.org/package=factoextra

Kemkes, R. J., Farley, J., Koliba, C. J. (2010). Determining When Payments Are an Effective Policy Approach to Ecosystem Service Provision. Ecological Economics 69 (11): 2069–74. https://doi.org/10.1016/j.ecolecon.2009.11.032.

Kleinknecht, A. (1999). Indicators of manufacturing and service innovation: their strengths and weaknesses. In: Metcalfe, J.S., Miles, I. (Eds.), Innovation Systems in the Service Economy, Measurement and Case Study Analysis. Kluwer Academic Publishers, NL, pp. 169e186.

Kluvánková, T., Brnkaľáková, S., Špaček, M., Slee, B., Nijnik, M.,Valero, D., Miller, D., Bryce, R., Kozová, M., Polman, N., Szabo, T., Gežík, V. (2018). Understanding social innovation for the well-being of forest-dependent communities: A preliminary theoretical framework, Forest Policy and Economics, Elsevier, vol. 97(C), pages 163-174.

Kubeczko, K., Rametsteiner, E., Weiss, G. (2006). The role of sectoral and regional innovation systems in supporting innovations in forestry. Forest Policy and Economics. 8, 704–15. https://doi.org/10.1016/j.forpol.2005.06.011.

Lapeyre, R., Froger, G., Hrabanski, M. (2015). Biodiversity Offsets as Market-Based Instruments for Ecosystem Services? From Discourses to Practices. Ecosystem Services 15: 125–33. https://doi.org/10.1016/j.ecoser.2014.10.010.

Lazdinis, M., Carver, A., Tonisson, K., Silamikele, I. (2005). Innovative use of forest policy instruments in countries with economies in transition: experience of the Baltic States. Forest Policy and Economics, 7, 527–537

Le, S., Josse, J., Husson, F. (2008). FactoMineR: An R Package for Multivariate Analysis. Journal of Statistical Software, 25(1), 1-18. 10.18637/jss.v025.i01

Leonardi, A. (2015). Characterizing Governance and Benefits of Payments for Watershed Services in Europe. Ph.D. Dissertation, Università degli Studi di Padova, Padova, Italy, 30 January 2015. Available online: http://paduaresearch.cab.unipd.it/7832/

Lovrić, N., Lovrić, M., Mavsar, R. (2020). Factors behind development of innovations in European forest-based bioeconomy, Forest Policy and Economics, Volume 111, 102079, ISSN 1389-9341, https://doi.org/10.1016/j.forpol.2019.102079.

Lü Y., Li, T., Whitham, C., Feng X., Fu,B., Zeng, Y., Wu, B., Hu, J. (2020). Scale and landscape features matter for understanding the performance of large payments for ecosystem services. Landscape and Urban Planning, Volume 197, 103764, ISSN 0169-2046, https://doi.org/10.1016/j.landurbplan.2020.103764.

Ludvig, A., Zivojinovic, I., Hujala, T. (2019) Social Innovation as a Prospect for the Forest Bioeconomy: Selected Examples from Europe. Forests, 10, 878, doi:10.3390/f10100878

Ludvig, A.; Rogelja, T.; Asamer-Handler, M.; Weiss, G.; Wilding, M.; Zivojinovic, I. (2020) Governance of Social Innovation in Forestry. Sustainability, 12, 1065. https://doi.org/10.3390/su12031065.

Martin, B. R. (2016). Twenty challenges for innovation studies. Science and Public Policy, 43 (3). pp. 432-450. ISSN 0302-3427

Mendes, A., Stefanek, B., Feliciano, D., Mizaraite, D., Nonic, D., Kitchoukov, E., Nybakk, E., Duduman, G., Weiss, G., Nichiforel, L., Stoyanova, M., Mäkinen, P., Alves, R., Milijic, V. & Sarvašová, Z. (2011). Innovation in European Private Forestry: the Emergence of Forest Owners' Organizations. In: Weiss, G., Pettenella, D., Ollonqvist, P. & Slee, B. (eds.) Innovation in Forestry: Territorial and Value Chain Relationships. Oxfordshire: CABI International.

Musgrave, R. A. and Musgrave, P.B. (1973). Public Finance in Theory and Practice. New York: McGraw Hill, first edition

Nijnik, M., Secco, L., Miller, D., and Melnykovych, M. (2019). Can Social Innovation Make a Difference to Forest-Dependent Communities? Forest Policy and Economics 100: 207-213. DOI: 10.1016/j.forpol.2019.01.001

O'Driscoll, C., Leonardi, A. and Masiero, M. (2017). Are Nature-Based Businesses Really Innovative? An Assessment of European Entrepreneurial Initiatives. ECOSTAR project. Final document.

Pirard, R., Lapeyre, R. (2014). Classifying Market-Based Instruments for Ecosystem Services: A Guide to the Literature Jungle. Ecosystem Services 9: 106–14. https://doi.org/10.1016/j.ecoser.2014.06.005.

Polman, N. B. P., Slee, B., Kluvankova, T., Dijkshoorn-Dekker, M. W. C., Nijnik, M., Gežik, V., & Soma, K. (2017). Classification of Social Innovations for Marginalized Rural Areas. SIMRA. Available at: http://www.simra-h2020.eu/wp-content/uploads/2017/09/D2.1-Classification-of-SI-for-MRAs-in-the-target-region.pdf

Prokofieva, I., Wunder S. (2014). Designing Economic Instruments for Ecosystem Service Provision. In: Jellesmark Thorsen B., Mavsar R., Tyrväinen L., Prokofieva I., Wunder S. (eds) The Provision of Forest Ecosystem Services. Vol II Assessing Costs of Provision and Designing Economic Instruments for Ecosystem Services. EFI Series What Science Can Tell Us (5). Joensuu: European Forest Institute.

Rametsteiner, E., Weiss, G. (2006). Innovation and innovation policies in forestry: linking the innovation process with systems models. Forest Policy and Economics, 8, 691- 703.

Raudsepp-Hearne, C., and G. D. Peterson. (2016). Scale and ecosystem services: how do observation, management, and analysis shift with scale—lessons from Québec. Ecology and Society 21(3):16.

Sattler, C., Trampnau, S., Schomers, S., Meyer, C., Matzdorf, B., (2013). Multi-classification of payments for ecosystem services: How do classification characteristics relate to overall PES success? Ecosyst. Serv. 6, 31–45. https://doi.org/10.1016/j.ecoser.2013.09.007.

Sawhney, M., Wolcott, R. C., & Arroniz, I. (2006). The 12 Different Ways for Companies to Innovate. MIT Sloan Management Review, 47 (3), 1-18. http://doi.org/10.1109/EMR.2007.329139

Schomers, S., Matzdorf, B. (2013). Payments for Ecosystem Services: A review and comparison of developing and industrialized countries. Ecosystem Services, 6, 16–30. https://doi.org/10.1016/j.ecoser.2013.01.002.

Schumpeter, J.A. (1942). Capitalism, Socialism and Democracy, 3rd edition, London: George Allen and Unwin, 1976.

Schumpeter, J.A. (1934), The theory of economic development: an inquiry into profits, capital, credit, interest and the business cycle, Harvard Economic Studies, Vol. 46, Har-vard College, Cambridge, MA.

Secco, L. Pisani, E., Gorriz-Mifsud, E., Masiero, M., Gatto, P., Pettenella, D. [in print]. Innovation for the Mediterranean forest-based bio-economy: breakthroughs, knowledge gaps and recommendations.

Stavins, R. N. (2003). Experience with Market-Based Environmental Policy Instruments. Handbook of Environmental Economics. Vol. 1. Elsevier Masson SAS. https://doi.org/10.1016/S1574-0099(03)01014-3.

Van Lancker, J., Wauters, E., Van Huylenbroeck, G. (2016). Managing innovation in the bioeconomy: An open innovation perspective, Biomass and Bioenergy, Volume 90, Pages 60-69, ISSN 0961-9534, https://doi.org/10.1016/j.biombioe.2016.03.017.

Weiss, G., Salka, J., Dobsinska, Z. et al. (2010). Integrating Innovation in Forest and Development Policies: Comparative Analysis of National Policies across Europe. Chapter 4. COST Action E51 Policy Integration and Coordination: the Case of Innovation and the Forestry sector in Europe. Publications Office of the European Union, 2010. ISBN 978-92- 898-0049-5. doi:10.2831/10578

Weiss, G.; Ludvig, A.; Živojinvić, I. (2020). Four decades of innovation research in forestry and the forest-based industries – A systematic literature review. Forest Policy and Economics, 120, 102288

Windle, J., Rolfe, J., O'Dea, G. (2005). Selecting Market-Based Incentives for Natural Resource Management. Burnett Mary Regional Group Report, no. November.

Windle, J., Rolfe, J., O'Dea, G. (2005). Selecting Market-Based Incentives for Natural Resource Management. Burnett Mary Regional Group Report, no. November.

Wunder, S., Feder, S., Pettenella, D., Bottaro G., & Torralba, M. (2019). DELIVERABLE 1.4 What works? State-of-the-art synthesis report about best-practice design and implementation of PES and other IM in the European context. H2020 project no.773702 RUR-05-2017 European Commission, 66 pp.

Wunder, S., R. Brouwer, S. Engel, D. Ezzine-De-Blas, R. Muradian, U. Pascual, and R. Pinto. (2018). From Principles to Practice in Paying for Nature's Services.

Wunder, S. (2015). Revisiting the Concept of Payments for Environmental Services. Ecological Economics 117: 234–43. https://doi.org/10.1016/j.ecolecon.2014.08.016.

Supplementary Material

Table S2.1. Comparison among classifications of innovation types

Schumpeter, 1942	**Kubeczko et al., 2006**	**Sawhney, *et al.*, 2006**	**Weiss, *et al.*, 2010**	**O'Driscoll *et al.*, 2017**	**Polman et al., 2017**	**Edwards-Schachter, 2018**	**Lovric et al., 2020**	**Summary Innovation Classification**
New Product or a qualitative change in an existing product	Product innovation (wood, non-wood, leasing, recreation,...)	Offering (products)	Product (good)	New product…		Product innovation	Goods…	Product Innovation
	Service Innovation		Product (service)			Service Innovation	…and Services	Service Innovation
		Solutions		…and outcome				Outcome Innovation
New Process/methods for sale or production	Process innovation - technological (infrastructure, machinery, ...)					Technological innovation		Technological Innovation
		Process	Process (production & delivery method)	New processes		Process Innovation	Production	Processes Innovation
		Value capture		New approaches to creating value				Value capture Innovation
Industrial organization	Process innovation - organisational (internal reorganizational, outsourcing, co-operation, ...)	Organization	Organization (business practices/model, workplace organization, External relation)	New organizational structure…		Business model innovation	Workplace organization	Business model Innovation
		Platform					Business Practice	
		Networking	Institutional (Organizations, Law & Policies, Procedures)	…and networks			External relations	Institutional Innovation
								Networking Innovation
Opening of a new market		Presence	Marketing (product placement)				Product placement	Market and marketing Innovation
			Marketing (and product promotion)				Product promotion	
		Customers		New markets: demand and needs			Delivery method	
		Customers experience	Marketing (design/ packaging)				Design/ packaging	
		Brand	Marketing (and pricing)				Pricing	
New Inputs		Supply chain		New approaches to resource use				Resource use Innovation
					Social Innovation	Social innovation		Social Innovation

Own elaboration from Schumpeter, 1942; Kubeczko et al., 2006; Sawhney et al., 2006; Weiss et al.,2010; O'Driscoll et al., 2017; Edwards-Schachter, 2018; Lovric et al., 2020; Polman et al., 2017.

Table S2.2. Forest Ecosystem Services used in the framework and link with CICES (V5.1) classification

Section	Specific FES	CICES references
Provisioning	food production	1.1.1 + 1.1.5 + 1.1.6
	livestock production	1.1.3
	fiber production	1.1.1 + 1.1.5
	bioenergy production	1.1.1 + 1.1.5
	genetic resources	1.2
	water provision	4.2
	timber production	1.1.1 + 1.1.5
	non-wood forest products	1.1.5
Regulating	climate regulation	2.2.6
	pest control	2.2.3
	natural hazard regulation	2.2.1
	water quality regulation	2.2.5
	soil quality improvement	2.2.4
	pollination	2.2.2
	lifecycle maintenance, habitat and gene pool protection	2.3
Cultural	educational	3.1.2.1 + 3.1.2.2
	recreation	3.1.1
	tourism	3.1.1
	human health	3.1.1
	spiritual	3.2.1 + 3.2.2
	aesthetic/heritage (landscape character, cultural landscapes)	3.1.2.3 + 3.1.2.4

Table S2.3: Country and institution of the experts consulted for IM cases validation

Institution	**Acronym**	**Country**
Business Council for Sustainable Development	BCSD	Portugal
Center for International Forestry Research	CIFOR	Peru
Centre de Propietat Forestal	CPF	Spain
Centre for Forest Ecology and Productivity of the Russian Academy of Science	CEPF RAS	Russia
Consorzio Comunalie Parmensi	CCP	Italy
Danish Forest Association	DFA	Denmark
Disputacion Foral de Bizkaia. Servicios de Montes	DBF	Spain
Etifor. Valuing Nature	Etifor	Italy
European Forest Institute	EFI	International
Forest Science and Technology Center of Catalonia	CTFC	Spain
International Union for Conservation of Nature	IUCN	International
KU Leuven	-	Belgium
Natural Resources Institute Finland	Luke	Finland
Natuurinvest	OC-ANB	Belgium
Pan Ben AG	-	Switzerland
Public Institution Nature Park Medvednica	PINPM	Croatia
University of Padova	TESAF-UNIPD	Italy
The Finnish Forest Centre	SMK	Finland
Institute of Food and Resource Economy. University of Copenhagen	IFRO	Denmark
University of Kassel	-	Germany

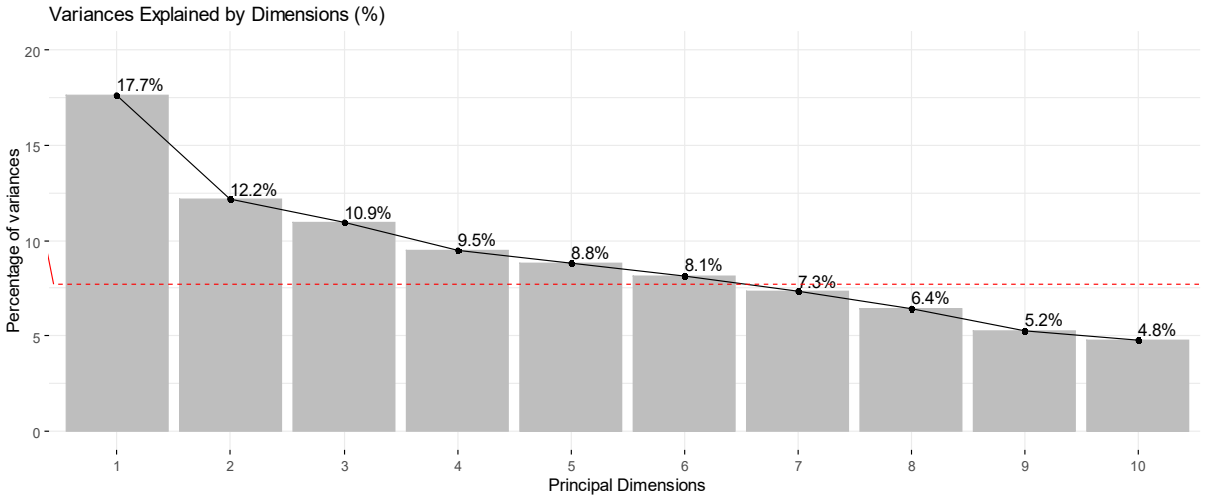
Table S2.4. Coding of framework variables for the statistical analysis purpose

Variable	Variable Description	Code	Type of data
Country	Albania, Austria, Belgium, Bulgaria, Switzerland, Germany, Denmark, Estonia, Spain, Finland, France, Croatia, Ireland, Italy, Moldova, Norway, Portugal, Romania, Sweden, Slovenia, and United Kingdom	*AL, AT, BE, BG, CH, DE, DK, EE, ES, FI , FR, HR, IE , IT, MD, NO, PT, RO, SE, SI, UK*	Categorical
IM Administrator	private, public, semi-public, NGO, other,	*Adm.priv, Adm.pub, Adm.semi, Adm.NGO, Adm.oth*	Categorical
Economic Instrument	non-Market Based Instrument, Market Based Instrument, Information and Education, Development of social organisation	*Econ.Inst_CommandControl, Econ.Inst_MarketBasedInstr, Econ.Inst_Info.Edu, Econ.Inst_Social*	Dichotomic
Mechanism Scale	local scale, municipality level, provincial scale, regional scale, interregional scale, national scale, international scale	*Scale.loc, Scale.mun, Scale.prov, Scale.reg, Scale.inter, Scale.nat, Scale.internat*	Categorical
Year of establishment		*"year"*	Numeric
Mechanism duration	long term (>10 years), medium term (5 to 10 years), short term (< 5 years)	*Dur.long, Dur.med, Dur.short*	Categorical
Mechanism Status	active, design phase, pilot, unknow	*Stat.act, Stat.des, Stat.pil, Stat.un*	Categorical
Other Ecosystems Involved	agricultural land, meadow, wetland, other	*Ecos.agr, Ecos.mead, Ecos.wet, Ecos.oth*	Dichotomic
Type of forest subsystem	agro-forest, natural forest, planted forest, other	*For.agrf, For.nat, For.plan, For.oth*	Dichotomic
Type of bioclimatic region	alpine, boreal , Mediterranean, temperate continental, temperate oceanic	*Bioclim.alp, Bioclim.bor, Bioclim.med, Bioclim.tempco, Bioclim.tempoc*	Categorical
Type of setting	natural-park, peri-urban, rural, urban	*Set.natp, Set.per, Set.rur, Set.urb*	Dichotomic
Target or Bundled FES	Target, Boundle, Targeted + Bundled FES	*Targeted.FES, Bundlesd.FES, TargBund.FES*	Categorical
FES Section	Provisioning FES, Regulating FES, Cultural FES	*Provisioning.FES, Regulating.FES, Cultural.FES*	Dichotomic
Specific FES	See Table S2.3	*FES.Pfo, FES.Pli, FES.Pfi, FES.Pbe, FES.Pge, FES.Pwa, FES.Pti, FES.Pnw, FES.Rcl, FES.Rpe, FES.Rnh, FES.Rwa, FES.Rso, FES.Rpo, FES.Rli, FES.Ced, FES.Cre, FES.Cto, FES.Che, FES.Csp, FES.Cae*	Dichotomic
Provider	collectively owned forests, local forest communities, private forest owners/managers, public forest owners, public private partnership, other	*Provider.coll, Provider.loc, Provider.priv, Provider.pub, Provider.ppp, Provider.oth*	Dichotomic
Demanders	government, municipalities, regional government, public utility company, public private parnership, private companies, funds, NGOs, civil society (end-users, tourists, visitors, ...), other	*Demander.gov, Demander.mun, Demander.reg, Demander.uti, Demander.ppp, Demander.priv, Demander.fun, Demander.ngo, Demander.civ, Demander.oth*	Dichotomic
Final beneficiaries	civil society, local communities, householdes, forest owners, firms, other	*Benefic.civ, Benefic.com, Benefic.hou, Benefic.fow, Benefic.fir, Benefic.oth*	Dichotomic
Intermediaries	*Presence or absence*	*Intermed*	Dichotomic
Innovation types	Different classes of FES, Process innovation, Technological innovation, Business Model innovation, Institutional innovation, Social innovation	*FES.Innov, Process.Innov, Tech.Innov, BusinessModel.Innov, Istit.Innov, Social.Innov*	Dichotomic

Table S2.5. Eigenvalues and % variance of MCA dimensions

	Eigenvalues	% of var	Cumulative % of var.
Dim.1	0,177	17,65	17,65
Dim.2	0,122	12,151	29,801
Dim.3	0,109	10,924	40,725
Dim.4	0,095	9,482	50,207
Dim.5	0,088	8,805	59,012
Dim.6	0,081	8,144	67,156
Dim.7	0,073	7,308	74,464
Dim.8	0,064	6,437	80,901
Dim.9	0,052	5,234	86,135
Dim.10	0,048	4,765	90,899
Dim.11	0,038	3,792	94,691
Dim.12	0,03	3,021	97,713
Dim.13	0,023	2,287	100

Figure S2.1. Plot representing the percentage of variance in % explained by each dimension



3. Paper II: The Italian Forest Management Associations: Innovation and Challenges

Submitted to Small-scale Forestry

Authors: Giorgia Bottaro[1], Nicola Andrighetto[2], Paola Gatto[1], Davide Pettenella[1]

[1] Department of Land, Environment, Agriculture and Forestry of the University of Padova, Viale dell'Università, 16, 35020 Legnaro, Padova, Italy

[2] Etifor S.R.L.

Abstract

Forest land fragmentation connected to inheritance rules induces land abandonment and a not planned use of forest resources. From the experiences in many countries, one of the tools to reduce this problem is forest owners' associations. This study aims to examine the different associative models experienced in Italy in order to provide an updated state of the art of forest associations at the national level never attempted before and to assess their challenges and innovative solutions to overcome the issues of forest fragmentation. It does so through the analysis of national and regional legislation and of specific case studies. The results reveal that several State regulations for addressing this topic were approved in the last century in Italy. Furthermore, with the decentralization process started in the 1970s, the Regions began to operate on the issue without any form of coordination and this led to the emergence of a wide range of different associative models. The different associative models have been described and divided into different categories according to their features. Our analysis concludes that Regional regulations need to be coordinated sharing the lessons learned from the various Regional policies implemented to support forest associations, as clearly defined in the new National Forest Strategy. The importance of associative models based on the multifunctional use of forests, with a large involvement of actors in local communities, is also highlighted for its innovative character.

Keywords: National Forest Strategy, Forest Policy, Land Fragmentation, Cooperative, Land Association, associative models

3.1 Introduction

In Italy, around 37% of the territory is covered by forests and other wooded lands (INFC 2021), the outcome of a process of expansion that has doubled forest cover since the 1950s (ISTAT 2015). This situation is the result of a process of inaction in forest management: harvesting levels in Italy are the lowest among large European countries (Forest Europe 2020). As a consequence, the ecosystem's capacity to provide multiple goods and services decreases and leads to the occurrence of negative environmental, economic, and social externalities (Romano 2017), increasing forests vulnerability to natural hazards, such as wildfires (Corona et al., 2015, Ferrara et al., 2019), and extreme climate events (Chirici et al., 2019). Currently, in Italy, it is difficult to guarantee the societal demand for forest ecosystem services due to a lack of active forest management. Indeed, the last Italian forest inventory (INFC 2021), referring to data from 2015, reveals that only 15.3% of the national forest surface is covered by a valid forest management plan. This percentage has decreased compared with the situation of ten years before (equal to 16.3% in 2005). This trend differs from the situation that can be observed considering Europe. In fact, in the last five years, the use of the forests by European forest owners increased and three-quarters of European forest areas is currently under forest management plans (Forest Europe 2020). The national situation is even more severe in case we exclude from the calculation Trentino and Alto Adige, which traditionally are the two Italian provinces more prone to implement forest activities and planning. Indeed, without these two provinces, the Italian forest covered by a valid forest management plan is equal to 9.4%. Considered jointly, the two provinces management plans cover 85% of their forests (INFC 2021). This data is in line with the situation of the north European countries (Forest Europe 2020). The main actions regulated by the detailed forest plans at the national level concern mainly forest falling, with only 0.3% of the total plans addressing other forest ecosystem services such as recreational and cultural functions and landscape protection. In order to provide a complete overview regarding the status of the Italian forest management, it is important to add that in 37,4% of the national forests no sylvicultural practices are implemented. This data is an important proxy of the status of the management abandonment of the forest properties at the national level.

The reasons for such a low level of active forest management include problems of land fragmentation as a consequence of the inheritance process and landowners migration from

mountain areas to urban centres, both drivers of land abandonment and characteristic weaknesses of the Italian forestry sector (Falcone et al., 2020). The average forest property size is in Italy is equal to 8 hectares (Secco et al., 2017). The division of forest properties in small plots, often far from one another, is an issue that Italy shares with the majority of the other European countries (Forest Europe 2020), and that does not allow for cost-effective forest management (Hatcher et al., 2013, Omizzolo et al., 2015). Observing the trend of the total Italian population, it is evident that in the mountain areas it is ageing. These areas constitute the main geographical location of most Italian forests. Whether in the last 60 years the total population has grown by about 12 million units, in the same period in mountain areas (including the Alpine and pre-Alpine ones), has registered a decrease of about 0.9 million units (Cerea & Marcantoni 2016). From these two data, it is evident how the possibility to introduce innovative approaches capable to support forest management is limited. Traditional forest owners tend to implement traditional practices, while innovative actions could be introduced by new types of forest owners.

To respond to the negative effects of land fragmentation and abandonment, and to stimulate the scarce forest management, different tools can be used. These include the setting up of forest associations and cooperatives, with the aim of supporting links and coordination among forest owners, forest managers, harvesting companies, forest consultants, local authorities and other key stakeholders (Jylhä 2007). This has been also highlighted in Živojinović et al. (2015) that detected how the establishment of cooperation among forest owners, such as cooperatives and associations, is among the most innovative approaches to boost active forest management.

To fully understand the importance of forest associations it is necessary to further know the main reasons that drive forest owners (public or private) or managers, to become part of them. These reasons can be grouped into six main categories according to Brun et al. (1997) and Kittdredge (2005):

a. political-administrative functions, such as assistance for business accounting, administrative attendance, authorizations, incentives. Indeed, among the most important existing measures and policies where associations can have a relevant role in

facilitating the access, there are the funds from the Rural Development Programme (RDP);

b. event organization, such as meetings, field trips, contests;
c. joint economic activity, such as organizing joint sales and other cooperation events related to forest management and product marketing;
d. shared professional services, such as mapping, management planning, boundary surveys;
e. lobbying actions, such as the increase of power in contractual agreements;
f. development of standards, brands, or labels in order to differentiate regional or local forest products.

Kittdredge (2005) analysed these categories highlighting that small and medium private forest owners mainly have to cooperate in order to "scale broader than their individual properties''. In this process, an overall important driver to induce the creation of associations is income generation. Its relevance has to be underlined, even if in Italy, as in other advanced economies, economic motivations are not always among the most important for keeping and managing forests by small private forest owners (Canton & Pettenella 2010). This is well documented by the experience of the local associations managing systems of information, control, and payment for picking wild mushrooms or truffles (Secco et al., 2009); to manage this substantial source of income for land owners, consortia or associations have been established, even without any support from the public sector.

Forest associations represent one of the key elements for stimulating and maintaining active and effective forest management, and for supporting the adoption of innovative management strategies (Živojinović et al., 2015). With this awareness, in former times, some European countries, also close to the Italian context, promoted the creation of associations of private and public forest owners. For instance, ForêtSuisse (formerly Swiss Forest Economy), founded in 1921, represents all private and public forest owners, of Switzerland (Schulz et al., 2018) that are more than 250,000. Another example comes from France, where the Centre National de la Propriété Forestière (CNPF), a public institution made up of 11 regional delegations, represents approximately 3.5 million private forest owners. Other examples of national forest associations very active in a national context can be found also in Bulgaria and Macedonia (Živojinović et al., 2015).

By contrast, in Italy, there are no national wide associations of private forest owners, there is an association of public forest owners, (with representatives of only 6 Regions), and no Italian representatives are present within the two most important associations of European private forest owners, CEPF and EUSTAFOR (Secco et al., 2017), limiting the development of the sector (Falcone et al., 2020) and its representativeness. Due to the lack of reference associations at the national level, information on existing local forestry associations, as well as on the updated regional and national legislative context, is scarce.

Considering the context just described, the following paper aims to take stock of Italian local forest associations, as possible instruments to boost an active forest management, providing an overview of the current national and regional frameworks, as well as analysing some examples of recent associative models developed in the country. To detect and analyse the existing gaps will allow to provide a state of art of the Italian forest associations and to suggest possible future directions.

The paper is organised as follow: in section 3.2 the methodology implemented to achieve the aim of the paper is described, while section 3.3 gathers the outcomes and their discussion, describing the national and regional legislation explored, and the most innovative associative models found. Finally, section 3.4 reports the conclusions, where we have addressed the future challenges of the sector.

3.2 Material and Methods

The associations considered for the paper aim, are not only formal associations but also informal ones, in line with Kittdredge (2005), according to whom informal experiences may be worthwhile considered as a form of cooperation. With informal associations, we mean all existing experiences dealing with the creation of networks and other kinds of cooperation. For instance, the experiences stemming from civil society addressing the needs of the community, involving different stakeholders that have in common interest or objective, and that include activities dealing with the forest sector, have been considered. The methodology used has two main steps. The first step entails the analysis of national and regional regulations boosting the establishment of forest associations. The main national norms regulating associations, within and outside the forest sectors, have been identified and analysed consulting the official journal of the Italian government (i.e., “Gazzetta Ufficiale”) where acts

and decrees are published before taking legal effect. Their consultation provided an overview of the national framework in which regional regulations are embedded. Then, Regional regulations have been identified to provide a deeper insight on the context at a lower scale level. To do this, in the first phase, each regional forest law was examined to see whether actions to support regional associations were mentioned in specific articles of the laws. Twenty-one sets of legislations have been consulted (19 for the Regions and 2 for the autonomous Provinces of Trentino and Alto-Adige). In the second phase, the existence of regional regulations supporting specific associative models was searched by using, in a public search engine, the name of specific associative models jointly with the name of the Italian Regions and autonomous Provinces.

In the second step, the presence of active forest associations within each Regions has been investigated. The research was carried out consulting databases of regulations, scientific papers and grey literature, and other online public available information. The keywords used included the names of the different Italian Regions, the names of the two autonomous Provinces, and different words belonging to the semantic world of associations and cooperation. Concerning the Regional associative models, those financial opportunities that led to the establishment of forest associations have been also taken into consideration. Then, the different associative models found have been analysed. The analysis has been implemented according to the following models' features: regulatory framework (national or regional norms regulating or enabling the establishment of the associative model), associated members (description of the members of the associative model), territory (characteristics and property of the areas belonging or managed by the associative model), innovativeness (description of the degree of innovativeness of the model) and aims (objectives of the associative models). These elements have been used as the basis for grouping the found associative models into categories and characterising them.

The conceptual and methodological approach used in the paper is summarised in the following figure (Figure 3.1).

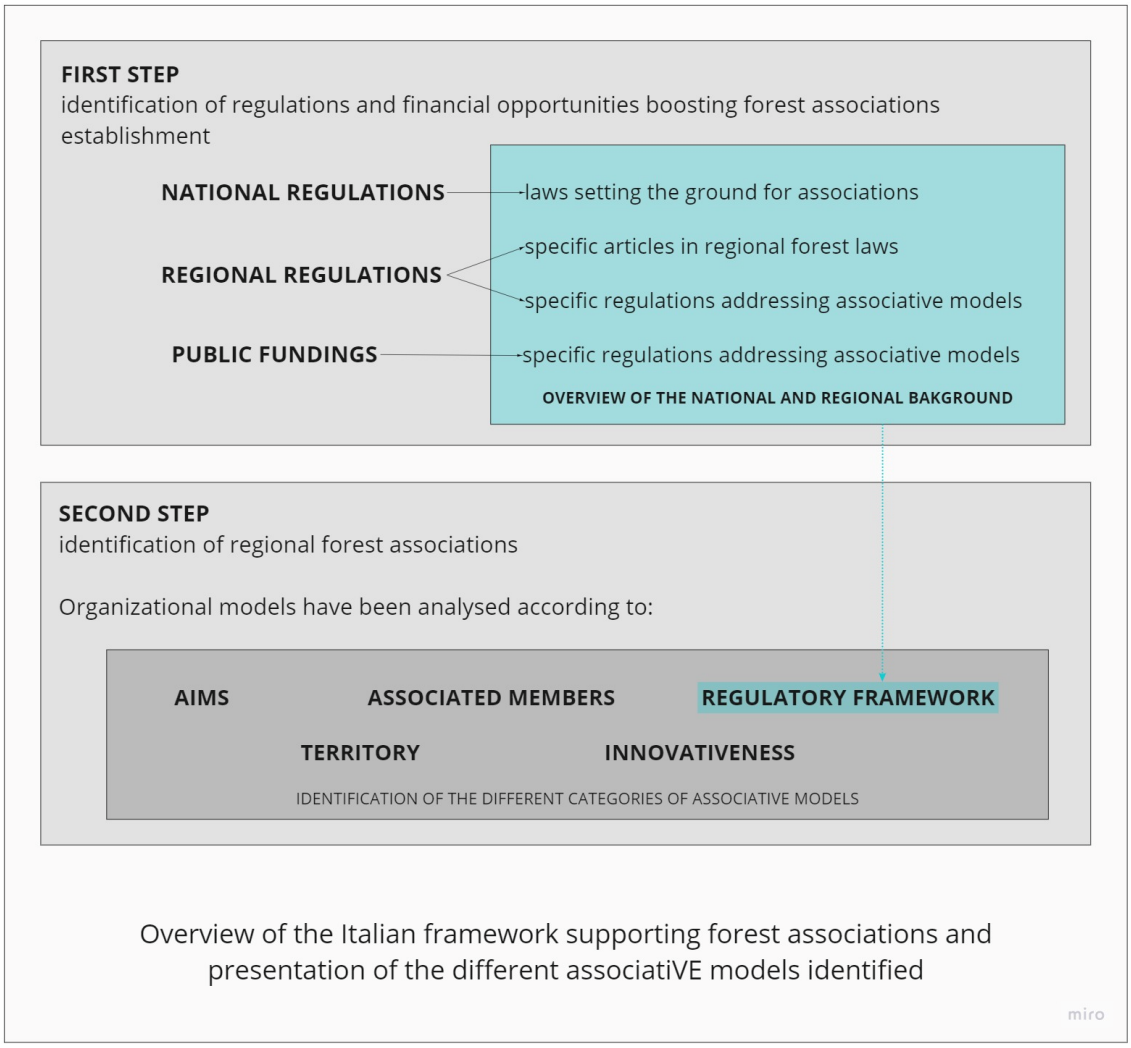


Figure 3.1. Conceptualisation of the methodology used in the paper

3.3 Result and Discussion

3.3.1. Legal framework

Before describing the legal framework, it should be highlighted that, since the 1970s, Italy has moved towards institutional and political decentralisation in the forestry sector (Baldini & Baldi, 2014). This is important in light of the principle that, given the challenges of managing environmental resources, "institutional diversity may be as important as biological diversity for our long-term survival" (Ostrom et al., 1999). Unfortunately, this gradual decentralization process was conditioned by conflicts on competencies and contrasts between the central and regional authorities, and later partially between regional and local authorities (Secco et al., 2011). The outcome of this process was a lack of cooperative attitude among policymakers in sharing the lessons learnt by the implementation of numerous policy initiatives and in

upscaling the positive results. This should be kept in mind when examining the plethora of regulations implemented at different institutional levels.

National legislation.

To analyse the legislation regulating associations is a complex exercise because of the extent of the field of interest. Indeed, there are several scales and sectors in which associations are regulated. At the national level, we found generic frameworks that can be applied in many different sectors, like regulations regarding the establishment of cooperatives (Legislative Decree no. 6/2003) or those supporting young entrepreneurs (National Law no. 95/95). Other more specific regulations deal with the recovery of abandoned land, through land banking, the creation of networks contracts (Decree Law, no. 5/2009) and the replacement or assignment of the management of those properties where private owners are unknown or not available (Legislative Decree no. 34/2018, article 12). A further set of regulations deals with the traditional rights of using some products and services from forest and pastureland, i.e., "Usi civici" - Civic Uses, and collective properties (National Law no. 168/2017). This right may be a driver leading forest owners to cooperate for forest management (Kittdredge 2005). Indeed 'place' and shared 'interest' on common resources, are among the reasons for communities' establishment (Lawrence et al., 2021).

All these national norms also apply to the forestry sector enabling the establishment of associations, cooperatives, consortia, and other networks dealing with sustainable forest management. By contrast, this diversification makes the harmonisation of these experiences more challenging.

At the regional level, associations are regulated within the so-called "Mountain Acts". Mountain Acts have been issued at the national level and then gathered in the national framework Mountain Act no. 97/1994. Later, some Regions have transposed the national law into regional ones. The main aim of the Mountain Act is the enhancement and promotion of the socio-economic development of mountain areas, considering all the different sectors involved.

Looking at the main regulations dealing specifically with the forestry sector, forest management associations and the establishment of consortia to support small forest owners in the management and maintenance of their properties in mountain areas have been

considered by the still fundamental Forest Act, the Royal Decree no. 3267/1923 (article 105). From the promulgation of the Royal Degree until nowadays, interest in associations has not declined. In 2018, the Italian Forest Act (Legislative Decree no. 34/2018), with article 2, establishes associations to spur forest management as one of the sector priorities. This priority is confirmed by the still under discussion Italian Forest Strategy (Mipaaf 2020) and has already been operationalised at the beginning of 2020, through a national call for associations aimed to support the creation of new forms of associations and consortia (Ministerial Decree no. 13329/2020). Unfortunately, the one-century-long political attention towards associations and consortia stated by the formal approval of numerous laws has not been coupled with any significant financial support. Consequently, in the last 3-4 decades the country saw a gradual reduction of associations and consortia, especially among public forest owners.

Regional legislation and financing

When regional legislations are explored, a mosaic of very different situations comes to light. The absence of a nationally coordinated strategy and the institutional decentralisation led Regions to legislate in order to promote different associative models, trying to respond to the needs of the territories they administrate.

In analysing the regional forest regulations, it was found that only in seven regional laws a specific article regarding the promotion of associations is present. However, only in Piedmont a specific regional law aimed to facilitate the creation of models of forest associations has been detected. In table 3.1 the results of the analysis are summarised, showing that not all 21 Italian Regions have specific regulations or articles within their forest law dealing with associations.

Table 3.1. Regional legislation supporting associative models

Region	**Associative model supported**	**Reference to the law**
Piedmont	Land Associations	Regional Law no. 21/2016
Lombardy	Land Associations	Art. 16, Regional Law no. 9/2019
Friuli Venezia Giulia	Land Associations	Art. 49, Regional Law no. 28/ 2017
Tuscany	Forest Communities	Art. 5, Regional Law no. 11/ 2018
Marche	Other associative models	Art. 6, Regional Law, no. 6/2005
Trento Province	Other associative models	Art. 59, Provincial Law no.11/2007

Sardinia	Other associative models	Art. 27, Regional Law no. 8/2016
Abruzzo	Other associative models	Art. 23, Regional Law no. 3/2014

The most innovative and structured models introduced by regional legislations are Land Associations (Beltramo et al., 2018) and Forest Communities. Land Association is a model deriving from a similar experience in France (Charbonnier & Romagny, 2012) that indicates the voluntary union amongst public and private landowners aiming to join abandoned properties to renovate their sustainable and economic use. Local public authorities (e.g., Municipalities) normally participate in land associations guaranteeing and safeguarding the participants' property rights. Piedmont has introduced this model in Italy following the French experience. Since 2012, 36 Land Associations have been established. Although most of them are managing pastureland, other land uses are present, such as forests, chestnut orchards, and vineyards.

Forest Community is defined by article 5 of the Tuscany Regional Law as the cluster of public and private subjects that agree in promoting active management of their forests. More specifically, the Forest Community active in the Region, i.e., the Forest Community of Monte Pisano, aims to regenerate and manage the forest ecosystem of the Monte Pisano and its cultural and artistic values after a severe wildfire that affected the area.
With 'Other associative models' (Table 3.1), different forms of associated management (such as associations, cooperatives, etc.) not further specified by the Regional Laws are meant.

In our research, we have analysed also associative models born through financial supports, in particular, those stimulated by the public regional funds derived from the Rural Development Programmes (RDP). These funds are programmed every 6/7 years and distributed, according to their availability, every 2 or 3 years. Funds from RDP have been used in Piedmont (RDP 2014-2020, measure 4.3.2) where Land Associations resulted the beneficiaries for implementing land reparcelling actions.

The main measures of the RDP that financially support the creation of associations under different programming periods are presented in Table 3.2.

Table 3.2. RDP funds supporting new associative models. Source: ReteRurale (2016)

Region	RDP programming period	Incentive measure
Veneto	RDP 2000-2006	Measure 9.6
Piedmont	RDP 2007-2013	Measure 125
Sardinia	RDP 2007-2013	Measure 122
Lazio	RDP 2014-2020	Measure 9.1.1
Friuli Venezia Giulia	RDP 2014-2020	Measure 9.1
Sardinia	RDP 2014-2020	Measure 9.1.1
Liguria	RDP 2014-2020	Measure 9.1
Marche	RDP 2014-2020	Measure 9.1.A
Piedmont	RDP 2014-2020	Measure 4.3.2

Taking the case of Veneto Region as an example, during the programming period 2000-2006, 8 associations were created and financed through Measure 9.6. Nowadays, only two of these associations are still active: the Plain Forest Association (AFP) and the Vicenza Forest Association. Both were founded in 2003 and are formed by 20 and 13 members, respectively. The common aims of the two associations are to share the cost of forest management planning and implement lobbying actions. If for the AFP the lobbying action is addressed to the search for private investments to support the provision of forest ecosystem services, for Vicenza Forest Association the lobbying action aims mainly to organise joint wood sales, especially wood chips to medium/large biomass plants.

Relying on funds from RDP could be seen as a strategic option to be capable to provide continuous financial support to those initiatives that willing to start and emerge. By contrast, fragmentations and land abandonment are among the factors influencing the scarce affinity of European private forest owners to subsidies (Quiroga et al., 2019). This is the case of Italy, that presents difficulties in managing RDP funds, being among the last European countries in terms of commitment and payment capacity (Sotte, 2018).

3.3.2. Associative models

The implementation of national and regional regulations and the presence of financial supports lead to the creation of different associative models, that differ by structure and aims.

Four different categories of associative models have been identified observing the Italian landscape and gathering those associations that share a similar origin, structure, and aims, as described in section 3.2. The first two categories refer to more traditional and well-

established associative models, related to national legislations, while the third category refers to a group of non-homogeneous and more recent associations and communities, based mainly on regional legislation or public funds. Lastly, the fourth category gathers those innovative experiences born thanks to grassroots initiatives. These categories are:

a. *Historical models*. These are historical institutions (Civic Uses Associations and Collective Properties) collectively managing the commons, including forest land. In Veneto Region, where this model has a longstanding tradition, a recent regional law (Regional Law no. 26/1996) spurs the reconstitution of the traditional Collective Properties (called "Regole") after their suppression during the Napoleon dominance (1805-1813).
b. *Conventional models*. Public and private forest consortia are included in this category. They are regulated by the Italian Civil Code and represent the classic legal form under the Italian legal system, for cooperation among enterprises. Consortia can have different structures according to their main objectives and activities. They are usually mainly concerned with technical management and the response to technical issues of the properties they represent. In Italy, forest consortia have been highly developed in Lombardy Region (24 forest consortia are active in 2021). Consortia differ from the other forms of associations because they are strictly addressed to coordinate and regulate common initiatives among private and public entities (e.g., companies, public bodies) with an economic purpose.
c. *Recent models*. The majority of the associative models included in this category have been developed more recently to respond to regional regulations or specific financial supports. These models are aimed at managing public and/or private properties and improving the forest-wood supply chain, in the latter case, those born mainly through financial support are gathered. Among the models considered in this category, born thanks to regional legislations, there are the already mentioned Land Associations ("Associazioni fondiarie") and Forest Communities ("Comunità forestali").
d. *Innovative models*. The associative models belonging to this category do not respond either to regional or national legislations, nor to specific financial supports. They emerged in response to the societal needs of the community in which they were established. A more detailed description of these models is presented in the next subsection.

Table S3.1 in Supplementary Material presents the division of the different associative models in the previously mentioned categories. For each associative model, the main features (i.e., regulatory framework, actors involved, the territory where it is implemented, and principal aims) have been listed allowing a more comprehensive understanding and comparison among them.

Innovation in forest associations

The last category described above gathers associative models, not always based on a specific regulation framework, describing an important evolutionary trend in the state of forest associations in Italy. These models have been conceived to respond to the special needs of the local communities with an attempt to widen participation to other types of stakeholders and not just to forest owners, managers, and enterprises. The Community Cooperatives ("Cooperative di comunità") are working precisely in this direction. They represent a novel associative model applied also to natural and forest areas. The principal aim of Community Cooperatives is to maximise the benefits of its members and, at the same time, those of the whole community (Atmiş et al., 2009). At the national level, this type of cooperative is not yet regulated. For this reason, the Regions started to act individually to give legal recognition to these Cooperatives. In five Regions (Abruzzo, Campania, Liguria, Puglia, and Tuscany) specific regional laws have been approved, while in the other three Regions (Basilicata, Emilia Romagna, Lombardy) an article in the regional law regulating cooperation has been included. To describe the innovativeness of this associative model, two Community Cooperatives, settled on the Apennines of the Emilia-Romagna Region are hereafter described. The two cooperatives, "Valle dei Cavalieri" and "Briganti del Cerreto" were conceived as a reaction to the abandonment of the mountain villages where they are located. The two communities are composed of 56 and 16 citizens respectively ; the cooperative and their members collaborate with local municipalities, national parks, and mountain communities to valorise the territory where they were established. The shared objectives of the two communities, in addition to the willingness to reduce depopulation, are the revitalization, monitoring, and fruition of the mountain territory where they operate, the promotion of sustainable tourism and forest management, and the implementation of environmental education activities. In addition, in the community "Briganti del Cerreto", an important activity implemented is the sale of forest products from sustainable forest management. Community cooperatives see a higher

participation of the community and are aimed to respond to the needs of the whole community and not only of their members.

The relevance of forest communities in boosting forest management and supporting rural areas start to be recognised in Europe. Indeed, the aims and the reasons that stimulate the establishment of communities are strictly linked to the concept of social innovation. Social innovation is an emerging concept that identifies a transformation of social practices to respond to the community needs in order to provide goods and services otherwise not adequately addressed (Kluvánková et al., 2018, Ravazzoli et al., 2021). In their article, Ravazzoli et al. (2021) presented the case of Scotland where a community was born to manage woodland sustainably.

The Italian situation depicted in this paper allows us to state that, due to the continuous evolution of associative experiences, the creation of a strong national forest owners association or the establishment of an efficient coordination system among the already existing experiences seems to be scarcely conceivable. Furthermore, the dynamism that characterizes the national and regional regulatory frameworks relating to the issue makes their coordination difficult in a sector, the forestry one, where the harmonisation of existing policies already is deemed a utopia (Secco et al., 2018). However, the presence of this richness of diversified experiences, emerging and operating in local and regional contexts, are fundamental for mountain areas in order to face abandonment challenges, respond to local needs, stimulate the creation of new job opportunities, and valorise the most marginalised rural areas (Kluvánková et al., 2018). These associative models could be references for implementing decrees of the Italian Forest Act of 2018 and for favouring a higher adoption of forest management plans. Indeed, the Italian Forest Act of 2018 envisages simplifying bureaucracy and administrative practices to promote the unification of the fragmented forest properties, to enable abandoned land management, to boost a more widespread active sustainable management, and to recover abandoned land with a high agro-silvicultural value.

3.4 Conclusions

The study aimed to provide an insight about possible solutions capable to stimulate the implementation of active forest management. Indeed, one of the main issues driving inaction is property and land fragmentation, that leads to a low national implementation of forest management plans.

An overview of the state of the art of the Italian forest associations and of its regulatory framework is provided. Many different legal and organisational solutions to forestland abandonment have been locally developed, without sharing the positive and negative lessons learnt from these experiences. Knowledge sharing, coordination of public and private forest services, and harmonisation among the different regional and national regulations are essential in order to stimulate private forest owners in managing their properties providing multiple functions as requested by the new EU forest strategy. Indeed, the strategy stresses the point of boosting, through incentives, private owners in providing multiple forest ecosystem services in order to respond to societal requests connected to bio-economy development, biodiversity protection, and climate change adaptation. The element that seems to be missing in the strategy is the delineation of a common approach based on a set of coordinated tools: new legal and entrepreneurial models, provision of technical services and financial assistance, simplification of regulations.

Through the analysis of the cases provided in our research, the importance of the different local experiences was evident. This diversity is important to provide different solutions in facing similar issues. Correspondingly, the presence of different experiences is not to be considered as generating competition among them. Indeed, the challenge that we are facing now is the scaling-up of such initiatives by transforming the pilot experiences into a “system”. This does not mean a unique reference model, but a network of managerial models capable to give positive answers to the diversified questions posed at the local level in terms of forest land availability, presence of private entrepreneurs, the role of local public authorities, and demand for forest ecosystem services. It is not a matter of having the same associative models all around the mountain forests of the country, but of being aware and capable to select the best mix of tools in relation to the local contexts. The coordination among the different models and policies supporting them should be a priority. The coordination and possibility to share lessons learnt and good practices among regions need a supportive environment that,

in turn, should be stimulated by specific policies, otherwise the positive insights achieved by the experiences will remain at the regional or local level. The analysis of the Italian policy framework can be an initial step for this process of knowledge and coordination that can also lead to facilitation on the use of financial resources and the implementation of sustainable forest management as requested by the new EU forest strategy. The coordination among policies regulating associative models, and the creation of a system to share best practices, should be necessary for all EU countries willing to seriously face the issue of fragmentation and land abandonment within the forest sector.

Among the different associative categories outlined, the most innovative models appear to be the ones capable to better target the societal needs and to involve a more variegate category of stakeholders ensuring a higher impact on their members and the whole community. That is why the establishment a national regulation recognising and supporting grassroots initiatives is even more relevant. Some regions are already acting in this direction, providing a legal background, but a more coordinated vision has to be built and implemented to make these experiences relevant in contrasting the lack of the adoption of forest management by private forest owners.

Only by building a strong network among Regions, and among the State and the Regions, the administrative and institutional decentralisation in Italy will be functional, and not an obstacle, to the experimentation and consolidation of the best organisational choices. This study sets the basis for a comprehensive understanding of the existing legislation regulating the recognition and creation of forest associative models, supported by the case studies found. Nonetheless, a more detailed analysis of the existing experiences is needed in order to achieve an exhaustive systematisation, jointly with a deeper exploration of the role of the different funding opportunities for their establishment. Further analysis is needed also for understanding the roles and the efficiency of the different associative models in stimulating forest management.

"Think globally, act locally, and collaborate faithfully", is the principle present both in the Italian Constitution (art. 120) and in the Treaty of the European Union (art. 4): let's make the last part of the sentence feasible.

Acknowledgments

The contribution of the authors is the following: G.B. had the overall responsibility of the paper; D.P., G.B., and N.A. conceive the study and its design; by G.B. and N.A. carried out data collection and analysis; G.B., N.A., and D.P. interpreted the results; G.B. and N.A. wrote the manuscript; and D.P. and P.G. revised it.

This study was implemented within the H2020 project SINCERE (Spurring Innovations for forest eCosystem sERvices in Europe), grant agreement number 773702 and thanks the CAREGA project, financed through RDP of Veneto Region (Measure 16 – Cooperation / Focus Area 5C – D.G.R. 736 del 28/05/2018).

3.5 References

Atmiş E, Günşen B, & Özden S (2009). Forest cooperative and its importance in rural poverty reduction in Turkey. In XIII World Forestry Congress, Buenos Aires, Argentina.

Baldini G, Baldi B (2013). Decentralization in Italy and the troubles of federalization. Regional and Federal Studies, 24, 87 – 108.

Beltramo R, Rostagno A, Bonadonna A (2018). Land Consolidation Associations and the Management of Territories in Harsh Italian Environments: A Review. Resources, 7, 19.

Brun F, Corona P, Pettenella D (1997). Il bosco privato in Italia: caratteristiche organizzative, problemi e prospettive", Atti del Convegno dell'Associazione Nazionale dei Dottori in Scienze Forestali "Boschi privati: tutela e valorizzazione". Firenze, 2.10.1997. Economia Montana - Linea Ecologica, 30(1).

Canton A, Pettenella D (2010). Motivazioni gestionali dei proprietari forestali privati: un caso di studio nel comune di Recoaro Terme (VI). Forest@ 7 (1), 44-57.

Cerea G, Marcantoni M (2016). La montagna perduta. Come la pianura ha condizionato lo sviluppo italiano. Franco Angeli-Tsm, Milano

Charbonnier Q, Romagny T (2012). Pastoralismes d'Europe, Rendez-vous avec la modernité! Cardère Editeur: Avignon, France, 176. ISBN 978-2-914053-64-8.

Chirici G, Giannetti F, Travaglini D, Nocentini S, Francini S, D'Amico G, Calvo E, Fasolini D, Broll M, Maistrelli F et al. (2019). Forest damage inventory after the "Vaia" storm in Italy. For. Riv. Selvic. Ed. Ecol. For. 16, 3–9.

Corona P, Ascoli D, Barbati A, Bovio G, Colangelo G, Elia M, Garfì V, Iovino F, Lafortezza R, Leone V, Lovreglio R, Marchetti M, Marchi M, Menguzzato G, Nocentini S, Picchio R, Portoghesi L, Puletti N, Sanesi G, Chianucci F (2015). Integrated forest management to prevent wildfires under mediterranean environments. Annals of Silvicultural Research. 39, 1-22. doi: 10.12899/ASR-946

Falcone PM, Tani A, Tartiu VE, Imbriani C (2020). Towards a sustainable forest-based bioeconomy in Italy: Findings from a SWOT analysis. Forest Policy Econ., 110:101910.

Ferrara C, Salvati L, Corona P, Romano R, Marchi M (2019). The background context matters: Local-scale socioeconomic conditions and the spatial distribution of wildfires in Italy, Science of The Total Environment. 654, 43-52. ISSN 0048-9697, https://doi.org/10.1016/j.scitotenv.2018.11.049.

Forest Europe (2020). State of Europe's Forests 2020. Ministerial Conference on the Protection of Forests in Europe - Liaison Unit Bratislava

Hatcher J, Straka T, Greene J (2013). The Size of Forest Holding/Parcelization Problem in Forestry: A Literature Review. Resources, 2, 39–57.

INFC (2021). Italian Forests. Selected results of the third National Forest Inventory INFC2015. Published by Carabinieri Command of Forestry, Environmental and Agri-food units & CREA. ISBN: 978-88-338-5140-2. Available at: https://www.inventarioforestale.org/sites/default/files/datiinventario/pubb/Sintesi_INFC2015.pdf

ISTAT (2015). Superficie agricola e forestale per utilizzazione - Anni 1861-2015, Istat, Roma.

Jylhä L (2007). Forest Management Associations - value from cooperation for forest owners Unasylva, 58, 44-47

Kittdredge DB (2005). The cooperation of private forest owners on scales larger than one individual property: international examples and potential application in the United States. Forest Policy and Economics, 7(4), 671-688

Kluvánková T, Brnkaláaková S, Špaek M, Slee B, Nijnik M, Valero DE, Miller D, Bryce R, Kosová M, Polman N, Szabo T, Gežík V (2018). Understanding social innovation for the well-being of forestdependent communities: A preliminary theoretical framework. Forest Policy and Economics, 97, 163-174. https://doi.org/10.1016/j.forpol.2018.09.016

Lawrence A, Gatto P, Bogataj N, Lidestav G (2021). Forests in common: learning from diversity of community forest arrangements in Europe. Ambio, 50, 448-464. 10.1007/s13280-020-01377-x

Mipaaf (2020). Bozza preliminare della Strategia Forestale Nazionale redatta a cura del Gruppo di lavoro incaricato dal Mipaaf, in attuazione dell'art. 6, comma 1, del Decreto legislativo 3 aprile 2018, n.34.

Omizzolo A, Streifeneder T, Santolini R (2015). Impatti della frammentazione fondiaria nelle aree montane italiane e indirizzi di riqualificazione. Ph.D. thesis. Università degli Studi di Urbino Carlo BO.

Quiroga S, Suarez C, Ficko A, Feliciano D, Bouriaud L, Brahic E, Deuffic P, Dobsinska Z, Jarsky V, Law-rence A, Nybakk E (2019). What influences European private forest owners' affinity for subsidies? For. Policy Econ., 99, 136–144, doi:10.1016/j.forpol.2018.08.008.

Ravazzoli E, Dalla Torre C, Da Re R, Marini Govigli V, Secco L, Górriz-Mifsud E, Pisani E, Barlagne C, Baselice A, Bengoumi M, Dijskhoorn-Dekker M, Labidi A, Lopolito A, Melnykovych M, Perlik M, Polman, N, Sarkki S, Vassilopoulos A, Koundouri P, Miller D, Streifeneder T, Nijnik M (2021). Can Social Innovation Make a Change in European and Mediterranean Marginalized Areas? Social Innovation Impact Assessment in Agriculture, Fisheries, Forestry, and Rural Development. Sustainability, 13(4), 1823. https://doi.org/10.3390/su13041823

Rete Rurale (2016). l sostegno per la competitività nei PSR 2014-20: analisi delle focus area 2A e 3A. Available at: https://www.reterurale.it/flex/cm/pages/ServeAttachment.php/L/IT/D/4%252F7%252F5%252FD.e9c1b833a009d98a9931/P/BLOB%3AID%3D16494/E/pdf"

Romano R (2017). L"evoluzione della materia forestale nelle politiche dello sviluppo rurale. Agriregionieuropa. n°48

Schulz T, Lieberherr E, Zabel A (2018). Network governance in national Swiss forest policy: Balancing effectiveness and legitimacy. Forest Policy and Economics, 89, 42-53

Secco L, Pettenella D, Maso D (2009). 'Net-system' models versus traditional models in NWFP marketing: the case of mushrooms. Small-Scale Forestry, 8, 349-365

Secco L, Pettenella D, Gatto P (2011). Forestry governance and collective learning process in Italy: Likelihood or utopia? For. Policy Econ.,13, 104–112.

Secco L, Favero M, Masiero M, Pettenella D (2017). Failures of political decentralization in promoting network governance in the forestry sector: Observations from Italy. Land Use Policy, 62, 79-100. https://doi.org/10.1016/j.landusepol.2016.11.013

Secco L, Paletto A, Romano R, Masiero M, Pettenella D, Carbone F, De Meo I (2018). Orchestrating forest policy in Italy: Mission impossible? Forests, 9, 468

Sotte F (2018). I tempi (lenti) della politica di sviluppo rurale in Italia. Agriregionieuropa anno 14, n°52 Available on:

https://agriregionieuropa.univpm.it/it/content/article/31/52/i-tempi-lenti-della-politica-di-sviluppo-rurale-italia

Živojinović I, Weiss G, Lidestav G, Feliciano D, Hujala T, Dobšinská Z, Lawrence A, Nybakk E, Qui-roga S, Schraml U (2015). Forest Land Ownership Change inEurope. COST Action FP1201 FAC-ESMAP Country Reports, Joint Volume. EFICEEC-EFISEE Research Report. University of Natural Resources and Life Sciences, Vienna (BOKU), Vienna (AT) Online publication

Normative references

National legislation

Decree Law, no. 5/2009. “Misure urgenti a sostegno dei settori industriali in crisi, 10 febbraio 2009”. Available at: https://www.tuttocamere.it/files/dirsoc/2009_5_Artt_3_4.pdf

Legislative Decree no. 6/2003. “Riforma organica della disciplina delle società di capitali e società cooperative, in attuazione della legge 3 ottobre 2001, n. 366” (in Gazzetta Ufficiale, 22 gennaio 2003, n. 17). Available at: https://www.camera.it/parlam/leggi/deleghe/03006dl.htm

Legislative Decree no. 34/2018. “Testo Unico in materia di Foreste e Filiere forestali, 3 aprile 2018” (in Gazzetta Ufficiale., 20 aprile 2018, n. 92). Available at: https://www.gazzettaufficiale.it/eli/id/2018/04/20/18G00060/sg

Ministerial Decree no. 13329/2020. “Approvazione del Bando di selezione delle proposte progettuali per la costituzione di forme associative o consortili di gestione delle aree silvo-pastorali, 22 aprile 2020”. Available at: https://www.politicheagricole.it/flex/cm/pages/ServeBLOB.php/L/IT/IDPagina/15522

National Law no. 97/1994. “Nuove disposizioni per le zone montane, 31 gennaio 1994” (in Gazzetta Ufficiale, 9 febbraio 1994, n. 32). Available at: https://www.gazzettaufficiale.it/eli/id/1994/02/09/094G0108/sg

National Law no. 95/95. “Sviluppo dell’imprenditorialità giovanile, 29 marzo 1995”. Available at: http://www.biocert.it/sfera/db/Imprgiov.html#a3

National Law no. 168/2017. “Norme in materia di domini collettivi, 20 November 2017” (in Gazzetta Ufficiale, 28 novembre 2017, n. 278). Available at: https://www.gazzettaufficiale.it/eli/id/2017/11/28/17G00181/sg

Royal Decree no. 3267/1923. “Boschi e Foreste Regio decreto-legge, 30 dicembre 1923” (in Gazzetta Ufficiale., 17 maggio 1924, n. 117). Available at: https://www.minambiente.it/sites/default/files/R.D._30-12-1923_n._3267.pdf

Regional legislation

Provincial Law no. 11/2007. “Legge provinciale sulle foreste e sulla protezione della natura, 23 maggio 2007”. Available at: https://www.consiglio.provincia.tn.it/leggi-e-archivi/codice-provinciale/Pages/legge.aspx?uid=16530

Regional Law no. 26/1996. “Riordino delle Regole”. Available at: https://www.gazzettaufficiale.it/atto/regioni/caricaDettaglioAtto/originario?atto.dataPubblicazioneGazzetta=1997-01-25&atto.codiceRedazionale=096R0733

Regional Law no. 6/2005. “Legge forestale Regionale Marche, 23 febbraio 2005”. Available at: https://www.consiglio.marche.it/banche_dati_e_documentazione/leggi/dettaglio.php?arc=vig&idl=1455

Regional Law no. 3/2014. “Legge organica in materia di tutela e valorizzazione delle foreste, dei pascoli e del patrimonio arboreo della regione Abruzzo, 4 gennaio 2014”. Available at: http://www2.consiglio.regione.abruzzo.it/leggi_tv/abruzzo_lr/2014/lr14003/Intero.asp

Regional Law no. 8/2016. “Legge forestale della Sardegna, 27 aprile 2016”. Available at: https://www.legislazionetecnica.it/2725672/normativa-edilizia-appalti-professioni-tecniche-sicurezza-ambiente/l-r-sardegna-27-04-2016-n-8/legge-forestale

Regional Law no.21/2016. “Disposizioni per favorire la costituzione delle associazioni fondiarie e la valorizzazione dei terreni agricoli e forestali, 2 novembre 2016”. Available at: http://www.regione.piemonte.it/governo/bollettino/abbonati/2016/44/attach/l201621_agri.pdf

Regional Law no. 28/2017. “Disposizioni in materia di risorse agricole, forestali e ittiche e di attività venatoria, 21 luglio 2017”. Available at: https://lexview-int.regione.fvg.it/fontinormative/xml/xmllex.aspx?anno=2017&legge=28

Regional Law no. 11/2018. “Disposizioni in materia di gestione attiva del bosco e di prevenzione degli incendi boschivi. Modifiche alla l.r. 39/2000, 20 marzo 2018”. Available at: http://raccoltanormativa.consiglio.regione.toscana.it/articolo?urndoc=urn:nir:regione.toscana:legge:2018-03-20;11

Regional Law no.9/2019. “Legge di revisione normativa e di semplificazione 2019, 6 giugno 2019”. Available at: http://normelombardia.consiglio.regione.lombardia.it/NormeLombardia/Accessibile/main.aspx?view=showpart&selnode=lr002019060600009&idparte=lr002019060600009

Supplementary Material

Table S3.1. Characterisation of the associative categories and models

Category	Associative model	Regulatory framework	Associated members	Territory	Innovativeness of the model	Aims
Historical models	Civic Uses associations "Associazioni Usi Civici"	National Law[2,3]	Citizens belonging to a local community (e.g., municipality)	Land under a regime of special rights by the members of the community	Historical and well-established	Collective management of the commons
Conventional models	Consortia	Italian Civil Code[4]	Public and/or private landowners and other operators (e.g., enterprises, cooperatives)	Forests owned by consortium's members	Traditional and well-established	Management of the forest in response to economic-technical needs of the associated members
Recent models	Association created through specific funds	[Incentives from Rural Development Programme (RDP)]	Public and private forest owners and managers jointly with the other actors belonging to the value chain (e.g., sawmills, carpentry, furniture stores, etc.)	Forests owned by the members of the associations	More recent associations based on specific financial support	Sharing the cost of forest management planning, implement lobbying actions, and develop forest-wood supply chain
Recent models	Land Associations	Regional Law	Private and public landowners (with the	Fragmented plots of various owners given	More recent associations based	Promoting associated use of abandoned forest and farmland

[2] National Law no.1766/1927. "Conversione in legge del R.D. 22 maggio 1924, n. 751, riguardante il riordinamento degli usi civici nel Regno"
[3] National Law no.168/2017. "Norme in materia di domini collettivi"
[4] Civil Code no.2602 approved by Royal Decree no.262/1942. "Testo della carta del lavoro"

	"Associazioni fondiarie"	(Piedmont[5]*, Lombardy[6]*, Friuli Venezia Giulia[7]*)	municipality often playing a role of animator)	to and managed by an association	on regional regulations	delegating the management responsibilities to third parties
Recent models	Forest Communities "Comunità forestali"	Regional Law (Tuscany[8])	Public and private subjects that agree in promoting active management of their forests (citizens, enterprises, associations, municipalities)	Fragmented forests of private and public owners managed by enterprises and other interested subjects	More recent associations based on regional regulations	Regeneration and management of forest ecosystems and cultural and artistic values
Innovative models	Community cooperatives ""Cooperative di comunità"	Regional Law (Abruzzo[9]*, Campania[10]*, Liguria[11]*, Puglia[12]*, Tuscany[13]*, Basilicata[14], Emilia Romagna[15], Lombardy[16])	Operators promoting multifunctional management of their forests and other rural areas under concession owned by individual citizens, local municipality, mountain community, National Park, and others	Territory of the mountain villages in which the Community is located	Innovative communities based on regional regulations or even created without a special regime but as normal cooperatives	Maximisation of the benefits of associated members and of the whole local community through sustainable forest management, selling of local forest products, slow tourism, environmental educational activities, and other activities connected to the specific local resources

[5] Regional Law no.21/2016. "Disposizioni per favorire la costituzione delle associazioni fondiarie e la valorizzazione dei terreni agricoli e forestali, 2 novembre 2016"
[6] Regional Law no.9/2019. "Legge di revisione normativa e di semplificazione 2019, 6 giugno 2019"
[7] Regional Law no. 28/2017. "Disposizioni in materia di risorse agricole, forestali e ittiche e di attività venatoria, 21 luglio 2017"
[8] Regional Law no. 11/2018. "Disposizioni in materia di gestione attiva del bosco e di prevenzione degli incendi boschivi. Modifiche alla l.r. 39/2000, 20 marzo 2018"
[9] Regional Law no. 25/2015. "Disciplina delle Cooperative di Comunità"
[10] Regional Law no. 1/2020. "Disposizioni in materia di cooperative di comunità"
[11] Regional Law no. 14/2015. "Azioni regionali a sostegno delle cooperative di comunità"
[12] Regional Law no. 23/2014. "Disciplina delle Cooperative di comunità"
[13] Regional Law no.67/2019. "Cooperazione di comunità"
[14] Regional Law no. 12/2015. "Promozione e sviluppo della cooperazione"
[15] Regional Law no. 12/2014. "Norme per la promozione e lo sviluppo della cooperazione sociale"
[16] Regional Law no. 36/2015. "Nuove norme per la cooperazione in Lombardia"

4. Paper III: The role of the forestry sector in the National Recovery and Resilience Plans: a comparative analysis

Being submitted to a peer-reviewed journal

Authors: Giorgia Bottaro[1], Ludwig Liagre[1], and Davide Pettenella[1]

[1] Department of Land, Environment, Agriculture and Forestry of the University of Padova, Viale dell'Università, 16, 35020 Legnaro, Padova, Italy

Abstract

The European Union (EU) is making significant efforts to support the recovery process after the Covid-19 pandemic, allocating more than €672.5 billion to the EU Member States (MS). On the one hand, forests are the most relevant «green infrastructure» in Europe, as they play a fundamental role in the future of the local bioeconomy, while on the other hand, wood biomass is still the first renewable energy source in the region. Owing to this it is interesting to analyse how the forestry sector has been taken into account in the recovery programme. The present survey aims at comparing the contents of all the 26 National Recovery and Resilience Plans (NRRPs) describing the key forest-related themes they consider, as well as the planned financial contribution to the sector. Cluster analysis has been implemented to distinguish the presence of common elements in the implementation of the forest-related components of the NRRPs, thus identifying which themes have been given a priority.

As a result, forest investments are considered of central importance for eleven EU MS, while four countries do not mention forests in their NRRPs. The approaches that countries followed b to include the forestry sector are very heterogeneous. Moreover, it seems that we are very far from having a common conceptual framework to implement a forest policy among the EU MS. However, climate change considerations play a key role in the financing of new forest investments, in particular concerning the need of forest adaptation. Similarly, the relevance of forests for supporting the bioeconomy emerges as a common priority, with various member states recognizing innovation in the sector as critical. In most cases, funding allocated specifically to the sector through the NRRPs is very limited, except for Sweden and Romania which have allocated significant funding for ambitious forest actions.

The cluster analysis identified three clusters describing MS funding policies related to forest themes. The first one is characterised by countries with a more conservative and inward-

looking orientation.In contrast, the other clusters are represented by countries with a more innovative attitude. A further distinction has been done between MS oriented to innovation to boost wood-related provisioning ecosystem services (ES), and those innovating towards a multifunctional use of forests (considering mainly regulating and cultural ES) and a more outward-looking orientation.

Keywords: recovery plans, forestry sector, ecosystem services, policy innovation

4.1 Introduction

The covid-19 pandemic has constrained the global economy in the last two years forcing all countries to innovate and develop urgent approaches to cope with the situation (Kapoor et al., 2021; Patrucco et al., 2021; Azoulay and Jones, 2020). The European Union (EU) has made significant efforts to support national EU economies to face pandemic-related challenges. With the Next Generation EU programme, the European Union aimed to support Member States (MS) to recover from the negative economic and social impacts caused by the sanitary emergence. It did so with the provision of a clear direction in which this recovery has to tend, thus transforming the EU into a greener, healthier, and more digital economy and society.

The relevance of these measures is considerable. Indeed, it is the first time after the "European Recovery Program" of 1948, known also as the Marshall Plan, that some European countries, receive economic and financial support to recover from a disruptive event.

The Next Generation EU pillar has been the promotion of the development of national recovery and resilience plans (NRRPs). The Recovery and Resilience Facility (RRF) financed the implementation of these plans through "*€672.5 billion (in 2018 prices) in loans and grants available to support reforms and investments undertaken by Member States*"[17]. The aim of this facility is "*to mitigate the economic and social impact of the coronavirus pandemic and make European economies and societies more sustainable, resilient and better prepared for the challenges and opportunities of the green and digital transitions*". The NRRPs thus come with significant funding allocations for all EU countries.

While the RRF aims at supporting both the digital and green transitions, one can question how far the NRRPs take into ccount the forestry sector. Indeed, the recently approved EU Forest

[17] https://ec.europa.eu/info/business-economy-euro/recovery-coronavirus/recovery-and-resilience-facility_en

Strategy emphasizes the role of the sector for a sustainable bioeconomy, green jobs and the provision of ecosystem services (EC 2021). It can thus be expected that the forestry sector would have a significant place in these plans.

The research questions addressed in the paper include: i) how are NRRPs currently integrating the forestry sector? ii) are there trends and key forest-related themes emerging from the NRRPs? iii) can the forestry sector be considered as a priority topic in NRRPs, in particular, based on financing made available for forests through these plans? iv) are national domestic financing schemes, such as national forest funds (NFFs) and other economic instruments,supporting the provision of forest ecosystem services (FES) used as means to channel RRF resources effectively? v) what recommendations and orientations could be proposed to policy makers in view of NRRPs revisions and/or future submissions?

In order to try to reply to these questions, this paper analysed the NRRPs of the European Member States. The methodology used is described in section 4.2, while section 4.3 presents the main findings. The discussion of the results is introduced in section 4.4 and a brief conclusion is finally highlighted in section 4.5.

4.2 Material and methods

This section presens the method used to reply to the research questions previously stated.

In the first phase, the NRRPs that each member state to the European Commission (EC) presented, have been collected from the EC dedicated website[18]. Not all the countries submitted their NRRP at the same moment. Different consultations have been done to collect all the available programs, and a total of 26 national plans (out of 27 member states) have been analysed. The NRRPs were collected from May 2021 to September 2021. During the mentioned period full reports have been continuously uploaded to the EC website making them available for public consultation. The full NRRPs have been presented to the EC only in the national languages by each MS. A further synthesis in English is available for each country. Furthermore, only the available full texts have been taken into considerationto have a comprehensive overview of how the forestry sector has been addressed within the NRRPs..

[18] https://ec.europa.eu/info/business-economy-euro/recovery-coronavirus/recovery-and-resilience-facility_en

After the NRRPs collection, their analysis has been implemented through the use of keywords. Because of the use of the national languages in the plans, each keyword has been translated into the national language of the analysed country. The keywords used, in English, were: "*forest**", "*silviculture**", "*wood**", "*biomass*", "*tree**", "*ecosystem service**", "*innovation**", and "*forest fund**". Research on the full text was conducted once the keywords were translated. . The portions of the text found as relevant were then translated. These included whole paragraphs, subchapters, or chapters. The text portions to be translated depended on: (1) the extent to which the forestry sector was included in the portion where the keywords were found, (2) the relevance of the forest-related topics included. The relevant texts were translated from the national language to English using the multilingual translation services provided by Google: Google Translate. The portions of the NRRPs translated correspond to the data that have been further analysed.

After NRRPs translation it was thus possible to proceed to data analysis. Two different analyses have been implemented to respond to the different research questions. In the first phase the paper investigated how the forestry sector was integrated into the NRRPs. This was achieved through the analysis of data data, to understand if the forestry sector was directly or indirectly mentioned within the NRRP, or if no mention was present. *A direct* mention includes some aspects related to the forestry sector in dedicated chapters, sub-chapters, or investment sections within the NRRPs. Differently, the forestry sector is *indirectly* mentioned in the NRRPs when it is embedded as part of sections and chapters/sub-chapters focusing on other sectors. Later, the texts have been deeper analysed to identify which forestry sector-relevant themes appear in NRRPs. The establishment of the final themes used in the analysis followed an inductive and deductive process. In the first phase, a list of themes was drafted considering the main topics belonging to the forest sectors and addressed by national and EU policies. The second phase was implemented during the analysis of the text. The pre-established themes were confirmed and incorporated and new forest-related themes were added, if not yet present.

To analyse the selected portions of the NRRPs, the texts were labelled using the insofar found themes, which allowed to identify more precisely trends of how the forestry sector is included in NRRPs.

In a second phase, data on the amounts of investments and budgets allocated to the forestry sector were collected and analysed. Thus investigating the relevance of the forestry sector in the NRRPs from a financial point of view. For most MS, where a direct mention of the sector was present, these data were available. Moreover, the information about the total amount of investments planned was found for each country. European disbursement is divided into grants and loans. The two different funding instruments have been considered jointly. When the specific funds allocated to the forestry sector were expressed in local currency, it was necessary to convert them into € millions to homogenise the data.

4.2.1. Cluster analysis

After the descriptive analysis of the MS's reports, a cluster analysis has been implemented to group MS based on the presence of the different themes related to the forestry sector within their NRRPs. Similarly, the Hierarchical Clustering on Principal Components (HCPC) statistics has been implemented. Dealing with qualitative dichotomous data, the Multiple Correspondence Analysis (MCA) has been computed as the principal component method. The presence of a forest-related theme within the NRRPs has been coded as 1, while the absence of the theme within the NRRP has been coded as 0. MCA implementation allowed to transform these categorical variables into continuous ones. Continuous variables have been later used to compute the Hierarchical Clustering on Principal Components. 11 dimensions from the MCA have been considered for the implementation of HCPC,. The number of selected dimensions have been set considering all those dimensions with a variance higher than 1/J, with J representing the total number of variables considered.

The outcomes of the HCPC describe the clusters according to the significance of the variables under analysis. For each variable the analysis provides the following data:

- *Cla/Mod*: percentage of the cases (MS) belonging to the cluster that presents the variable under analysis.
- *Mod/Cla*: percentage of the cases (MS) within the cluster that is represented by the variable under consideration.
- *Global*: percentage of the cases (MS) present within the cluster out of the total cases that present the variable under analysis.
- *p.value*: significance of the categorical variables within the cluster ($\alpha < 0.05$)

the R statistical software has been used to compute the cluster analysis (R 4.1.0). The R packages FactoMineR (Le et al., 2008), and factoextra (Kassambara and Mundt, 2020) have been then implemented.

The HCPC analysis allowed to cluster MS according to the different forest-related themes they introduced in their NRRPs.

4.3 Results

Out of 27 Member States, 26 NRRPs were analysed. Only the Netherlands did not present their NRRP in the period considered in this research.

The following table (Table 4.1) answers the first key question of the paper. How are NRRPs currently integrating the forestry sector?

Table 4.1. Presence of direct or indirect mention of the forestry sector within the EU NRRPs.

Country	**Direct mention**	**Indirect mentioned**	**No mentioned**
Austria			x
Belgium	x		
Bulgaria		x	
Croatia		x	
Cyprus	x		
Czechia	x		
Denmark		x	
Estonia		x	
Finland	x		
France	x		
Germany	x		
Greece	x		
Hungary		x	
Ireland			x
Italy		x	
Latvia		x	
Lithuania		x	
Luxembourg			x
Malta			x
Poland		x	
Portugal	x		
Romania	x		
Slovakia		x	
Slovenia	x		
Spain		x	
Sweden	x		

The twelve forest-related themes identifies and used to label and analyse the portions of the NRRPs are the following:

-*circular bioeconomy*: introduction of wood products in other sectors, e.g. for construction and industrial use, considering the whole product lifecycle, from its harvesting to its application (and recycling);

-*green revolution/ecological transition*: recognition of the importance of forest ecosystem services, wood and non-wood forest products to build a sustainable and resilient economy;

-*green jobs*: forestry is seen as a favourable sector to sustain the increase of green jobs;

-*rural development*: actions impacting positively rural areas through forest-based solutions;

-*climate action (adaptation)*: make forest ecosystems more resilient to climate change (which includes forest fire and natural hazard prevention) and increase resilience of territories and people through forest-based solutions (ecosystem-based adaptation);

-*climate action (mitigation)*: forests and wood products as carbon sinks;

-*biodiversity*: actions addressed to support and improve forest biodiversity and biodiversity in forests;

-*sustainable forestry*: improvement and higher adoption of sustainable forest management practices;

-*forest ecosystem services (FES) provision/enhancement*: willingness to improve or address forest management towards FES provision and enhancement;

-*urban nature-based solution*: forest-related solutions implemented in urban areas;

-*gender balance and women inclusion*: commitment to make forestry a fairer sector;

-*innovation*: willingness to introduce innovative practices and technologies within different forest-related activities.

The analysis of the themes characterising the forestry sector within the NRRPs is depicted in Table 4.2. This table presents the key themes where forest-related topics have been mentioned in the NRRPs both directly and indirectly. Data on the table support the answering to the second research question. Are there trends and key forest-related themes emerging from the NRRPs?

Table 4.2. Themes related to the forestry sector emerging from the NRRPs

Country	**Circular bioeconomy**	**Green revolution/ ecological transition**	**Green jobs**	**Rural Development**	**Climate Adaptation/ natural hazard prevention**	**Climate Mitigation**	**Biodiversity**	**Sustainable Forestry**	**FES provision/ enhancement**	**Urban Nature-Based solution**	**Gender Balance and women inclusion**	**Innovation**
Austria												
Belgium			x		x		x		x	x		
Bulgaria			x	x	x	x	x		x			
Croatia				x			x					
Cyprus					x	x	x					
Czechia		x		x	x	x	x	x	x			
Denmark						x	x			x		
Estonia	x	x				x						x
Finland	x				x	x	x	x	x			x
France	x			x	x	x	x	x	x			x
Germany	x		x			x		x				x
Greece			x	x	x		x		x			
Hungary				x	x		x					
Ireland												
Italy				x			x		x	x		x
Latvia		x			x							x
Lithuania	x											x
Luxembourg												
Malta												
Poland				x					x			
Portugal	x		x	x	x	x	x	x	x			x
Romania					x		x	x		x		
Slovakia	x	x	x		x	x	x	x	x	x		x
Slovenia	x	x	x		x	x	x	x				x
Spain				x	x		x	x	x		x	
Sweden		x					x		x		x	

The final implemented analysis allowed us to understand the relevance of the forestry sector within the NRRPs from a financial point of view, assessing, in particular, the share of the forestry sector in the overall MS financing allocation (Table 4.3).

Table 4.3. Proportion of NRRP funds allocated for the forestry sector

Country	**Financed actions**	**million €**	**total NRRP fund (million €)***	**% of NRRP funds**
Sweden	Compensation for restrictions on land use of valuable forests	245	3200	**7.66%**
Romania	Afforestation	1,5	29300	**5.12%**
Portugal	Landscape Transformation of Vulnerable Forest Territories	270	16600	**2.35%**
	Fuel management lanes - primary network	120		
Slovenia	construction of the Centre for Seed, Nursery and Forest Protection	6.18	2505	**2.16%**
	Greater wood processing for a faster transition to a climate-neutral society	48		
Finland	Climate action in the land use sector	30	2100	**1.43%**
Greece	National Reforestation Plan	224	30500	**0.73%**
France	Adaptation of forests to climate change, forest restoration	150	39400	**0.38%**
Germany	Investment for the development of wood sustainable building	70	25600	**0.27%**
Czechia	Investment on built forests resistant to climate change	0.34	7100	**0.17%**
	Water retention in forests	11.8		

* from: https://ec.europa.eu/info/business-economy-euro/recovery-coronavirus/recovery-and-resilience-facility_en

4.3.1. Clustering of the member states

The cluster analysis has been implemented to assess if the analysed countries present some clusters, which are capable to highlight the different behaviour of the MS in including the forestry sector in their NRRPs. The implementation of the Hierarchical Clustering on Principal Components revealed the presence of three different clusters, illustrated in Figure 4.1. The forest-related themes (variables) that resulted significant in describing the clusters (with $\alpha < 0.05$) were, in order of significance, biodiversity, circular bioeconomy, innovation, sustainable forestry, climate mitigation, FES provision/enhancement, climate adaptation/natural hazard prevention.

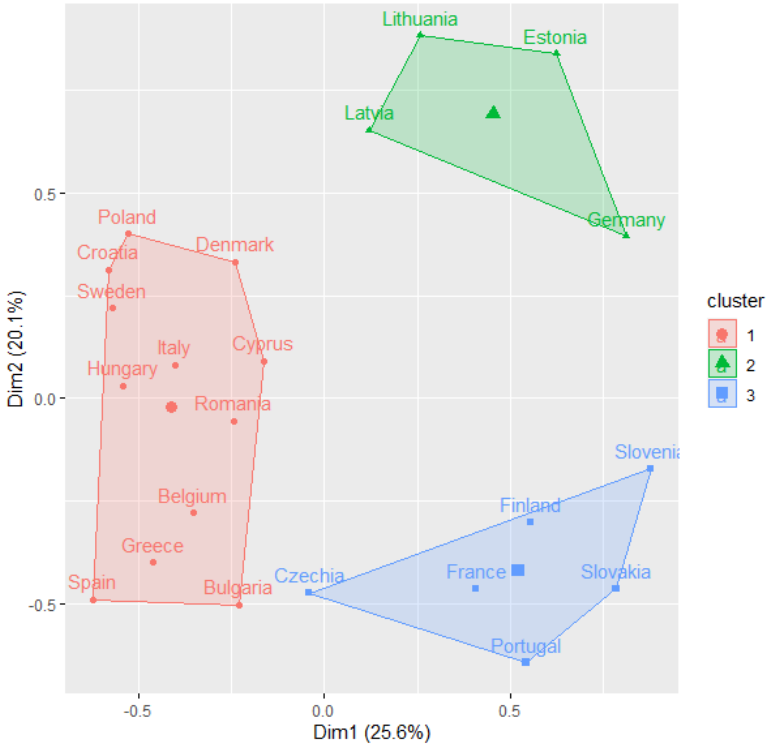


Figure 4.1. Clustering of the Member States according to the forest-related themes included in the NRRPs

The first cluster comprises Belgium, Bulgaria, Croatia, Cyprus, Denmark, Greece, Hungary, Italy, Poland, Romania, Spain, and Sweden. The cluster is determined more by the absence of some of the significant variables, than that by their presence. Indeed, the majority of these countries are characterised by the absence of themes such as circular bioeconomy, innovation, climate mitigation, and sustainable forestry (Table 4.4).

Table 4.4. Clusters description

Cluster	Forestry Theme	Cla/Mod	Mod/Cla	Global	p.value	v.test
1	Circular Bioeconomy=0	85.71	100	85.71	0.000140726	3.806889
	Innovation=0	91.67	91.67	91.67	0.000188666	3.733729
	Climate Mitigation=0	81.82	75	81.82	0.015939169	2.410305
	Sustainable Forestry=0	76.92	83.33	76.92	0.018133569	2.362879
2	Biodiversity=0	80	100	80	0.000683527	3.396103
	Innovation=1	40	100	40	0.028708134	2.187471
	FES provision=0	40	100	40	0.028708134	2.187471
3	Sustainable Forestry=1	66.67	100	66.67	0.001125809	3.257039
	Climate Mitigation=1	54.55	100	54.55	0.00619195	2.73744
	Circular Bioeconomy=1	62.50	83.33	62.50	0.011258092	2.534584
	Climate Adaptation=1	42.86	100	42.86	0.040247678	2.051198
	Innovation=1	50	83.33	50	0.046158176	1.993944

Differently, clusters 2 and 3 are determined by the presence of significant themes in the NRRPs.

Indeed, the second cluster is characterised by countries where the mention of innovation and the absence of topics such as biodiversity and FES provision/enhancement, resulted significant in differentiating their Plans from the ones of the others MS. The countries embedded in this cluster are Estonia, Germany, Latvia, and Lithuania. It is important here to underline that they are not the only MS where innovation has been mentioned, but where it resulted significant according to the other mentioned variables.

Within this cluster, forest innovation has been addressed mainly to process, production and small and medium enterprises (SME) improvement. Lithuania stressed the topic of start-up and SME support, while Latvia introduced innovation as necessary for the amelioration of wood-related products, technologies, and processes. The concept of social innovation was also presented in Latvian NRRP and was addressed to the increase of sector productivity and resource efficiency. Finally, Estonia in its NRRP underlined the necessity to introduce technological innovation to be capable to valorise bio-resources, being efficient and improving products value-added. Also in Estonia was underlindes the importance of incentivising SME in innovation.

Within this cluster, it is possible to characterise forest innovation as necessary to improve forest products and related technologies.

Innovation, jointly with the absence of biodiversity and FES related themes, are the significant variable for the cluster establishment. Thus, it could be possible to characterise this cluster as represented by those countries that will allocate NRRP funds towards provisioning FES without direct and explicit attention to more environmental components, represented by biodiversity and FES (regulating and cultural FES).

Finally, the third cluster comprises Czechia, Finland, France, Portugal, Slovakia, and Slovenia. As shown in table 4.4, the significant variables depicting the cluster are the presence within the NRRPs of actions related to sustainable forestry, climate mitigation, circular bioeconomy, climate adaptation/natural hazards prevention, and innovation. Differently from the previous cluster, in this one the innovation involves a large spectrum of actions. For instance, in Finland innovation is addressed to forest management towards precision forestry, an approach capable to support the improvement of carbon sequestration. Portugal has higher attention in apport innovation to improve local conditions, to fight forest fires, and to ameliorate bio-based products. Slovakia stated the willingness to introduce novel strategies to decarbonise

its economy, similarly to Slovenia, which in addition will innovate to reduce the negative environmental impacts of the supply chain and support SME.

A deeper analysis and explanation of the clusters is depicted within the discussion section (section 4.4).

4.4 Discussion

It is evident from table 4.1 that there is a certain heterogeneity in the way the forestry sector has been integrated by the EU Member States. In only four cases there is no explicit mention of the forestry sector (Austria, Ireland, Luxembourg, Malta). The other MS are homogeneously distributed in mentioning it both directly and indirectly, with 11 MS integrating the forestry sector directly and the other 11 mentioning it indirectly.

Among the countries that do not mention forests at all, Austria, Luxembourg and Ireland are forested countries, with respectively a forest cover of 47%, 37%, and 11% (FAO, 2020). Austria disposes of a dynamic forest industry, forest-related jobs in Luxembourg reach up to 24% of the total employment in the northern province, while Ireland has designed innovative finance solutions for the forestry sector such as the Irish Sustainable Forestry Fund[19]. The fact that these three countries have not included the forestry sector in their NRRP is surprising at first glance. A hypothesis is that current resources available at a national level for the sector suffice, and NRRPs resources would be better used in less supported sectors. For example, while Luxembourg is engaged in wood-based innovations through its Wood Cluster[20] with the development of a digital interface to connect the local wood demand and offer, it does not use the NRRP resources for economic digitalisation for this, also probably because internal domestic resources are sufficient to cover the costs of such an initiative.

Among the countries that mentioned forests directly in their NRRPs with a dedicated chapter, section, or investment programme, one can observe very different rationales from one country to another.These mainly depending on the challenges that the forest sector in the country is facing. For instance, Sweden, investment in the protection of valuable nature and forest ecosystems is being characterised by a very active and industrial-oriented forest

[19] http://www.siff.ie/

[20] https://www.luxinnovation.lu/cluster/luxembourg-wood-cluster/

management. France, Finland, the Czech Republic, and Romania insist on the importance of adapting forest ecosystems to climate change increasing ecosystems resilience, while Germany promotes wood-based construction as part of a bioeconomy development. Slovenia also underlines the importance of improving the national wood value chain to facilitate the transition to a circular bioeconomy. Cyprus, Portugal, and Greece clearly identify forest fires prevention and fighting as a priority.Indeed, this seems logical for countries exposed to the climate risks of the Mediterranean region and affected by land abandonment and fragmentation issues.

The forestry sector in NRRPs is addressed in a diversity of ways, and the analysis with key themes (table 4.2) shows different trends. For example, the links between forests, biodiversity, and ecosystem services are quite present, as well as with rural development and climate change adaptation. Even though climate mitigation is mentioned in several NRRPs it seems the biggest priority is put on the need to adapt forests to climate change, and to promote forests as a way to build more resilient territories, including in the context of natural hazards. The importance of forests for green jobs is mentioned in less than 50% of the NRRPs while the role of the sector for job creation is well known (UNECE & FAO, 2020).

Forest innovation and bioeconomy are emerging topics of interest in NRRPs that resonates with the efforts to promote such fields of work at EU levels (e.g. through the Circular Bioeconomy Alliance[21] , Knowledge Centre for Bioeconomy[22] and research programmes from the Joint Research Centre[23]). Innovation is an important forest-related theme in some NRRPs. Several MS clearly mention the willingness to introduce innovative approaches to their forestry sector. It addresses a variety of topics, from the technological innovation to support precision forestry (Finland) and improve energy efficiency (Slovenia), to social innovation mentioned in Latvia to sustain the productivity increase of the sector.

A further novel element that was expected to be found, due to the increase of social and policy attention on this topic, was the introduction of Payment for Ecosystem Services schemes. Indeed, the funds deriving from the NRRP could be a good opportunity to sustain

[21] https://efi.int/cba

[22] https://knowledge4policy.ec.europa.eu/bioeconomy_en

[23] https://publications.jrc.ec.europa.eu/repository/handle/JRC120324

this innovative and well-studied instrument and to spread its implementation. By contrast, support to payments for ecosystem services is rarely mentioned in the NRRPs. Further investigations can help the understanding of this finding. Indeed, it could be that PES have been not introduced because there are still present difficulties in designing and implementing them. Or MS are not aware of PES's potentiality in facing the main challenges that the forest sector is facing. Another explanation can be linked to the main objectives of the NRRP in the short term: increase the MS' GDP and have a positive impact on the employment rate. Further research is needed to understand the role of PES in these two aspects.

Furthermore, the mention of National Forest Funds was present just in a case (Romania). Such mechanisms, despite being quite rare in EU countries, represent good opportunities to channel incentives and financial resources directly to local beneficiaries, thus increasing local ownership of forest projects and activities. In the new EU forest strategy, it is mentioned that the EU commission "*is exploring how to facilitate the use of national funds for forestry measures and target them better for ecosystem services*" (EC, 2021). This is a positive signal that could be supported further by NRRPs.

Finally, table 4.3 highlights that when forest-related interventions are integrated into NRRPs, they benefit from a limited portion of the NRRPs budgets. Sweden and Romania result to be the countries that allocated the highest portion of their budget in forestry, respectively more than 7% and 5% of the budgets. Meanwhile most other countries show a proportion between 2.35% and 0.17%. In the case of Sweden, the state is planning to establish new protected areas through the purchase of forest properties and the compensation to local forest owners who will lose the possibility to manage their forest for economic purposes (Sweden RRP, 2021). Such a policy has significant costs given the opportunity costs of forest exploitation. In Romania, the forest cover accounts for 29% of the country land, with an optimal percentage of 40% (Romanian RRP, 2021). Plans are in place to restore forests being degraded (mainly because of illegal logging and climate change). Restoration and afforestation projects, combined with efforts to improve forest health and adapt to climate will turn quite costly (Romanian RRP, 2021).

4.4.1 Description of the member states' attitude

The outcomes of the cluster analysis reveal an interesting picture of the different behaviours present at the European level concerning forest-related themes and forest innovation.

Observing the description of the cluster according to the themes present in the plans (Table 4.5) it is possible to clearly identify the high presence, or absence, of other themes in addition to the ones significant for cluster delineation.

A first distinction can be done observing the innovation column in table 4.5, which represents the attitude to innovate of the MS. Two groups can be distinguished, countries that are more conservative and are not prone to innovate (cluster 1) and, countries where the attitude to innovate (cluster 2 and cluster 3) is evident. Within these last clusters it is possible to observe a further distinction. The second cluster was determined by the absence of themes such as biodiversity and FES (Table 4.4) Moreover,we illustrated that innovation within this cluster is mainly addressed to improvement of products, processes, and related technologies, depicting clear attention towards the productive aspect of the forestry sector-oriented mainly towards provisioning FES. Differently, the third clusters reveal higher attention for the environmental and multifunctional aspects of the sector. Indeed, the countries characterising this cluster reserve high attention to biodiversity, FES, but also climate mitigation and adaptation, and sustainable forestry (table 4.5). In addition, the theme of the circular bioeconomy is well represented. In the NRRP of the countries of this last cluster are also present the principal topics that received attention from the latest European Strategies (e.g. Biodiversity Strategy, Forest strategy, Farm to Fork Strategy).

Coming back to cluster 1 it is possible to notice how it has a more inward-looking orientation. For instance, cluster 3 resulted to be sensible to the current and urgent challenges we have to face globally,stating in their NRRP that they will act in that direction. Conversely, countries in cluster 1 seem to address their actions in the opposite way. They will face the current challenges with a more national perspective. To make this statement we observed the behaviour of these MS. The themes more related to the last European strategies mentioned above are only slightly present (i.e. circular bioeconomy, ecological transition, climate mitigation, and sustainable forestry). Themes related to biodiversity are widely present jointly with the ones concerned with rural development. In addition, it is also interesting to observe

the differences among the presence within the NRRPs of actions related to climate adaptation and climate mitigation. These last are just slightly represented while climate adaptation is highly represented. Indeed, climate adaptation is intended to improve forest resilience that has an impact on local communities, and consequently on rural development. In addition to the improvement of the national forestry sector, these MS have a further outward attention.

The last element that is interesting to highlight is the characterisation by direct and indirect mention within the clusters (table 4.5). Indeed, when considering cluster 1 no relevant information appears. Thus the characterisation of cluster 2 and 3 results evident. In cluster 2 the majority of the countries indirectly mentioned the forest sectors (3 out of 4). Oppositely, cluster 3 is characterised by countries that directly mentioned the sector (5 out of 6) underlying their proactive attitude in considering the forest sector and investing in it.

Summarising, the three clusters can be identified as follow:

Cluster 1 – Traditional and more conservative countries.
This cluster is characterised by MS addressing more conventional themes, allocating funds from NRRP to local development strategies more than dealing with challenges impacting a larger scale.

Cluster 2 – Innovative countries supporting more traditional forestry (provisioning FES).
This cluster is characterised by MS that are willing to innovate through NRRP funds. This innovation is addressed to the support of the more traditional FES: provisioning wood-related FES, improving their production innovating processes and technologies.

Cluster 3 - Innovative and active countries supporting forests multifunctionality (regulating and cultural FES).
This cluster is characterised by MS that are willing to innovate through NRRP funds. This innovation is addressed to support forest multifunctionality: regulating and cultural FES. Moreover, the environmental component of the sector is more present in this cluster, underlying its multisectoral attention.

Because in this paper we are considering the allocation of EU funds we can make a parallelism with the Rural Development Program (RDP). Whether RDP is considered as the Business as Usual (BaU) through which the MS can support their national agro-sylvo-pastoral systems, the

actions introduces within the NRRPs underline the additional attentions and exigence of the MS in addition to the BaU. The themes related to the forestry sector that are presented in the NRRPs highlight the deficiency of the BaU in addressing the exigence of the MS. Despite this interpretation, it is necessary to further explore its rationale. The two financing programmes have different rules and timespan. Nevertheless, the forest-related themes highlighted within the NRRPs could represent the areas, within the forest sectors, that require higher attention and investments. Indeed, the attitude of the member states that appears from the NRRPs analysis can be considered as a proxy to identify those sectors that each MS will enforce and improve, and that are not already covered by national funds or measures.

Building on the present analysis, a few recommendations for policy-makers can be derived, for example in view of a possible resubmission or improvement of NRRPs in the future:

- Take stock of the diversity of approaches for integrating forests in NRRPs considering lessons learned and good practices from other EU countries.
- Consider existing national forest strategies and policies, as well as the new EU forest strategy, to align key orientations with the content of NRRPs.
- Promote multiple forest ecosystem services, introducing innovative practices to support both public and private forest owners in their provision.
- Recognise the role of the forestry sector for a wood-based bioeconomy as a catalyst for green jobs creation and ensuring a resilient development of rural areas.
- Support the use of payment of ecosystem services schemes and of relevant domestic funds as ways to channel NRRPs resources to local beneficiaries and forest stakeholders.
- Promote EU-level dialogues on the importance of forests in NRRPs, and help mainstream the forestry sector in the plans and strategies of key ministries, in particular the Finance Ministries.

Key organisations at the EU level may have a critical role to facilitate such policy processes and dialogues, such as (among others) ForestEurope[24], the European Forest Institute (EFI)[25], the Confederation of European Forest Owners (CEPF)[26], and the European State Forest

[24] https://foresteurope.org/
[25] https://efi.int/
[26] https://www.cepf-eu.org/

Association (EUSTAFOR)[27]. It can be expected that they would be driving forces to ensure NRRPs include forests adequately in NRRPs.

4.5 Concluding remarks

Our study focused only on the strategies coming from NRRPs. The outcomes of the research, and specifically, of the clusters analysis NRRPs, do not pretend to characterise the whole policies of the EU MS but want to describe the trend appearing once extra funds are allocated. Further research could include i) additional national-level analysis, to assess more in detail the linkages between national contexts and the forest-related content of the NRRPs, ii) further assessment of the trends in geo-climatic regions with similar forest-related issues. Such advanced research work could help identify tailor-made recommendations at the country level on how to better integrate forests in NRRPs, while promoting regional or sub-regional cooperation between EU MS with similar geoclimatic conditions. This effort may also turn positive in view of the EU forest strategy implementation and to address some of the challenges ahead at the EU level. Indeed, it is proven that more than half of EU countries are prone to desertification (EU, 2018) and forests have surely a role to play to counterbalance this aggravating trend. While the UN Decade on Ecosystem Restoration has started, the EU has an opportunity to bring a significant restoration contribution to the world. To maximize positive impacts all financing solutions should be seized, and NRRPs represent one of the best opportunities going forward.

[27] https://eustafor.eu/

Table 4.5. Clusters description according to the forest-related themes present on the member states' NRRPs

Country	**Mention**	**Circular bioeconomy**	**Green revolution/ ecological transition**	**Green jobs**	**Rural Development**	**Climate Adaptation/ natural hazard prevention**	**Climate Mitigation**	**Biodiversity**	**Sustainable Forestry**	**FES provision/ enhancement**	**Urban Nature-Based solution**	**Gender Balance and women inclusion**	**Innovation**
Belgium	Direct	0	0	1	0	1	0	1	0	1	1	0	0
Bulgaria	Indirect	0	0	1	1	1	1	1	0	1	0	0	0
Croatia	Indirect	0	0	0	1	0	0	1	0	0	0	0	0
Cyprus	Direct	0	0	0	0	1	1	1	0	0	0	0	0
Denmark	Indirect	0	0	0	0	0	1	1	0	0	1	0	0
Greece	Direct	0	0	1	1	1	0	1	0	1	0	0	0
Hungary	Indirect	0	0	0	1	1	0	1	0	0	0	0	0
Italy	Indirect	0	0	0	1	0	0	1	0	1	1	0	1
Poland	Indirect	0	0	0	1	0	0	0	0	1	0	0	0
Romania	Direct	0	0	0	0	1	0	1	1	0	1	0	0
Spain	Indirect	0	0	0	1	1	0	1	1	1	0	1	0
Sweden	Direct	0	1	0	0	0	0	1	0	1	0	1	0
Estonia	Indirect	1	1	0	0	0	1	0	0	0	0	0	1
Germany	Direct	1	0	1	0	0	1	0	1	0	0	0	1
Latvia	Indirect	0	1	0	0	1	0	0	0	0	0	0	1
Lithuania	Indirect	1	0	0	0	0	0	0	0	0	0	0	1
Czechia	Direct	0	1	0	1	1	1	1	1	1	0	0	0
Finland	Direct	1	0	0	0	1	1	1	1	1	0	0	1
France	Direct	1	0	0	1	1	1	1	1	1	0	0	1
Portugal	Direct	1	0	1	1	1	1	1	1	1	0	0	1
Slovakia	Indirect	1	1	1	0	1	1	1	1	1	1	0	1
Slovenia	Direct	1	1	1	0	1	1	1	1	0	0	0	1

4.6 Reference

Azoulay, P., Jones, B. (2020). Beat COVID-19 through innovation. Science. 368: 553. https://doi.org/ 10.1126/SCIENCE.ABC5792

EC (2021). New EU Forest Strategy for 2030 (2021/572/EC). Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. Available on: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52021DC0572

EU, (2018). Combating desertification in the EU: a growing threat in need of more action. European court of auditors. Special report n°33/2018.

FAO, 2020. Global Forest Resources Assessment 2020: FRA 2020 database. Rome. Available at: https://fra-data.fao.org/

Kapoor, H., Ticku, A., Tagat, A., Karandikar, S. (2021). Innovation in Isolation? COVID-19 Lockdown Stringency and Culture-Innovation Relationships. Frontiers in Psychology. 0: 83. https://doi.org/ 10.3389/FPSYG.2021.593359

Kassambara, A. and Mundt, F. (2020). factoextra: Extract and Visualize the Results of Multivariate Data Analyses. R package version 1.0.7. https://CRAN.R-project.org/package=factoextra

Le, S., Josse, J., Husson, F. (2008). FactoMineR: An R Package for Multivariate Analysis. Journal of Statistical Software, 25(1), 1-18. 10.18637/jss.v025.i01

Patrucco, A.S., Trabucchi, D., Frattini, F., Lynch, J. (2021). The impact of Covid-19 on innovation policies promoting Open Innovation. R&D Management. https://doi.org/ 10.1111/RADM.12495

Romanian RRP, 2021. National Recovery and Resilience Plan (Planul Național de Redresare și Reziliență). Ministry of European Investments and Projects, Romania. Available at: https://mfe.gov.ro/pnrr/

Sweden RRP, 2021. Sweden's recovery plan (Sveriges återhämtningsplan). Ministry of Finance, Sweden. Available at: https://www.regeringen.se/rapporter/2021/05/sveriges-aterhamtningsplan/

UNECE & FAO (2020). Forestry sector workforce in the UNECE region. Overview of the social and economic trends with impact on the forestry sector. GENEVA TIMBER AND FOREST DISCUSSION PAPER 76. Forestry and Timber Section, Geneva, Switzerland. Available on: https://unece.org/DAM/timber/publications/2020/DP-76.pdf

5. Concluding remarks and recommendations

The present chapter presents the final overview of the dissertation integrating the main findings of the papers. It is structured in 3 sections. The initial section (subchapter 5.1) describes the main theoretical contributions of the research implemented within the three papers, describing their main contributions. Section 5.2 discusses the limitations encountered in the three papers and the possible directions for future research. Finally, section 5.3 provides policy recommendations merging the outcomes of the three papers.

5.1 Theoretical contribution

This dissertation focuses on innovation in forestry. It explored different approaches (economic, social, and policy) to provide a broader overview. During the research design, different frameworks and classifications have been developed to meet the research's specific objectives.

Two frameworks have been developed and tested for the purpose of paper **I**. More specifically, a first framework was built to systematise information about the main features of those innovative experiences able to support FES provision and enhancement. It merged two already existing frameworks developed to analyse Payment for Ecosystem Services (PES) schemes (Sattler et al., 2013 and Leonardi, 2015). Furthermore it has been adapted to include a more diversified typology of innovative mechanisms. It includes the possibility to gather ecosystem-related and organisational information, but also data referring to the forest ecosystem services targeted, and the innovativeness introduced by the cases analysed. These features are essential for a comprehensive understanding of the innovative mechanisms. Indeed, the framework can be a useful tool to continuously systematise and collect these experiences implemented in the European context That is because it can describe how innovation evolves in the continent and in which direction it proceeds. Furthermore, a visual map was built from the inventory allowing an easier consultation of the found cases (sincereforests.eu[28]). With the representation of the innovative experiences within the forest sector, our inventory has the potential to catalyse the best practices to support private and public forest owners to manage their forests. It can also be a practical and helpful support for

[28] https://sincereforests.eu/innovation/innovation-inventory-map/

policy-makers and private actors, to stimulate strategies and to involve further stakeholders in supporting FES provision and enhancement.

The second framework developed under paper **I** aims to support the detection and analysis of the innovation types introduced by the innovative mechanism cases. Different classifications of innovation exist in literature, whichrefer mainly to other sectors (e.g. Schumpeter, 1942; Sawhney et al., 2006; Edwards-Schachter, 2018). Regarding the forest sector, despite a literature review describing the innovations for FES securing (Maier et al., 2021) having been recently published, a detailed classification oriented specifically to the forest sector, especially to those mechanisms designed to support FES, is not present.. The framework developed can be considered as a first attempt to organise the available information about the depiction of innovation within the forest sector, with a strong orientation toward FES. The framework will support the comprehension of the novelties introduced by experiences aimed to reduce the gap between the provision and the demand of FES. Both frameworks have been developed and tested within the European context but they have the potential to be used in analysing worldwide experiences without any geographical restriction.

Considering the study implemented in a national context (paper **II**), the analysis of the Italian forest management associations has resulted in a classification that attempted to categorise the associative models present in the national territory. Each category has been identified and described according to different criteria such as the associations' aim, members, innovativeness, territory, and regulatory framework. These categorisations could allow to prioritize the more suitable associative models according to the regulatory system, the needs, and the settled objectives. For instance, if the association establishment wills to benefit the whole community toward forest management addressed to the provision of a range of different ecosystem services, then the community cooperatives could be the most appropriated associative model. Differently, if the aim is to support a wood-related value-chain, involving the direct stakeholders, then the most appropriate associative model could be the consortium.

In paper **III** a specific methodology has not been developed. Nevertheless, its relevance relies on the outcomes obtained. The analysis of the member states' NRRP reveals their different attitude, allowing the distinction of three different groups: more traditional countries

managing the forest sector more conventionally, and more innovative oriented countries. Within these most innovative countries, a further distinction can be made. If on the one hand some member states support more traditional forest management addressed mainly to traditional FES (provisioning FES). On the other hand, differentmember states address innovation towards more multifunctional forest management integrating also regulating and cultural FES.

5.2 Limitation and recommendations for future research

This subchapter describes the limitations of the research and provides indications for future research. These are presented for the three papers separately.

In paper **I,** the first limitation is related to the intrinsic characterisation of the IM cases. Indeed, because of their innovative character, it was not possible to consult exclusively scientific literature for their collection, since they have not yet been fully analysed and studied. Another limitation related to data collection regards the process of experts consultation. Indeed, the experts consulted within the H2020 project SINCERE did not cover all the European countries. This limited the integration of the inventory for some countries.
Connected to this, also the languages and the keywords used have influenced the ability to gather the needed data.
Dealing with innovation was challenging from the beginning. Its conceptualisation can be highly interpretable, limiting the possibility of including cases that might have been suitable to the research objectives. The development of the framework to identify and classify the different types of innovation was done to respond to this need.
If on the one hand the heterogeneity of the data found allowed us to describe a high diversity of cases, on the other hand, it limited the implementation of more robust statistical methods (e.g. regressions). Indeed, the number of features considered within the framework to analyse IM cases is high and the consequent dispersion of the data resulted in a small representation of the cases within the different categories. The aggregation of the data was considered, but it would have required major simplifications. For this reason, in order to implement different statistical analyses, the dataset should be enriched with a higher number of cases. This improvement can lead to understand, for instance, the statistical relationship

between the different policy tools implemented and the FES targeted, hence providing more robust indications.

One of the outcomes of the MCA has been the link between new social organisations and the provision of bundled FES. This positive relation has not been further analysed in more detail. Its exploration could cast light on the best associative models capable to target specific bundles of FES.

Paper **II** investigated forest management associations in Italy and the regulatory framework that supports their establishment. After the paper was written, a new regulation was promulged: the Forest Agreements (D.L.N. 77/2021), which provides for the promotion and development of business networks for forests and FES valorisation.

The analysis of the effects of this new regulation on forest associations' establishment in the different Italian Regions can be a valuable direction for future research. The role of forest associations in supporting the achievement of the Italian Forest Act's priorities concerning FES provision, can be further investigated. Future studies can also explore the occurrence of forest associations in different countries by implementing the same methodology. Consequently, the classification of associative models can be extended and adapted to different contexts, thus providing a wider panorama of the existing associative models at the international level. Further research could also address the analysis of the link between the different associative models and the targeted FES. Which associative models better target the provision of specific FES and or a bundle of them?

Similarly, the investigation of the role that the community cooperatives could have within the forest sector could be deepened. Lastly, an interesting development of this research could further analyse the factors that enable or hinder the establishment of different associative models.

The principal limitation of paper **III** lies in the local languages used within the NRRPs. Indeed, each member state presented its plan in its original language, hence the use of translated keywords was necessary. This methodology could have negatively affected the full comprehension of the texts. The selected keywords were identified to cover the completeness of words capable to detect the portion of the text connected with forest-related themes. Despite this, we cannot exclude the possibility that in some cases they were not able to identify all the mentions of forest-related concepts, especially for the cases where

forestry was indirectly mentioned. Unfortunately, to deeply investigate the NRRPs the knowledge of the original languages would be necessary, or alternatively, the translation of the original plans in English.

Directions for future research have been already highlighted within the paper: future analysis comparing member states' policy choices according to the bioclimatic regions in which they are located, or to the forest types and conditions, can improve the understanding of current strategies but also set a basis for future exchanges of best practices.

5.3 Recommendation for policymakers

Based on the results of the three papers, this section highlights the main recommendations addressed to those policy-makers that will undertake actions to stimulate the adoption of innovative approaches that provide and enhance forest ecosystem services towards forest management:

- To encourage the provision of bundles of forest ecosystem services stimulating private and public forest owners and managers to adopt novel practices also by promoting the establishment of social organisations.
- To recognise the role of the different social organisations as innovative actors able to play an important role in supporting forest ecosystem services provision and to support their establishment both legally and financially.
- To stimulate and promote the establishment of Public-Private Partnerships. They are not largely implemented but have a high potential in introducing innovative practices in forest ecosystem services provision.
- To consider the fundamental role of the local initiatives within forest-related policies. These experiences are capable of better targeting societal needs and challenges and should be inserted in a network that allows them to exchange positive and negative outcomes of their implementation processes.
- To provide support for coordination among different:
    - *experiences,* to share lessons learnt and best practices improving their possibility to be scalable in different regional contexts;
    - *policies,* to effectively spur and sustain the provision and enhancement of forest ecosystem services;

- *stakeholders,* to increase the social benefits of the initiatives implemented.

A separate recommendation that I would like to add refers to the availability of the EC official documents presented by the member states, although knowing that probably its feasibility is limited. The presence of these official documents, such as the National Recovery and Resilience Plans, in the most recognised international languages – i.e., English –, could highly support the study and analysis of the latter allowing their cross-comparison and stimulating further investigations at a more international scale.

5.4 References

Edwards-Schachter, M. (2018). The nature and variety of innovation. International Journal of Innovation Studies. 2, 65-79.

Knickel, K. and Maréchal, A. (2018). Stimulating the social and environmental benefits of agriculture and forestry: An EU-based comparative analysis, Land Use Policy, Vol. 73, Pages 320-330, ISSN 0264-8377, https://doi.org/10.1016/j.landusepol.2017.12.064.

Leonardi, A. (2015). Characterizing Governance and Benefits of Payments for Watershed Services in Europe. Ph.D. Dissertation, Università degli Studi di Padova, Padova, Italy, 30 January 2015. Available online: http://paduaresearch.cab.unipd.it/7832/

Maier, C., Hebermehl, W., Grossmann, C.M., Loft, L., Mann, C., Hernández-Morcillo, M. (2021). Innovations for securing forest ecosystem service provision in Europe – A systematic literature review, Ecosystem Services, Vol. 52, 101374, ISSN 2212-0416, https://doi.org/10.1016/j.ecoser.2021.101374.

Sattler, C., Trampnau, S., Schomers, S., Meyer, C., Matzdorf, B., (2013). Multi-classification of payments for ecosystem services: How do classification characteristics relate to overall PES success? Ecosyst. Serv. 6, 31–45. https://doi.org/10.1016/j.ecoser.2013.09.007.

Sawhney, M., Wolcott, R. C., & Arroniz, I. (2006). The 12 Different Ways for Companies to Innovate. MIT Sloan Management Review, 47 (3), 1-18. http://doi.org/10.1109/EMR.2007.329139

Schumpeter, J.A. (1942). Capitalism, Socialism and Democracy, 3rd edition, London: George Allen and Unwin, 1976

Part II: Collaborative Manuscripts

Paper **IV** has been written in collaboration with other experts form two funded EU Horizon 2020 projects: SINCERE and InnoForESt. My contribution, described in Table 1.1, was to participate to the scanning exercise, mainly in the economic area, and being active on the discussions regarding the others analysed areas. I contributed also on data analysis and on the review of the manuscript. The paper aims to explore the main challenges that hinder a sustainable provision of forest ecosystem services and the possible solutions to overcame them.

Paper A: Scanning the solutions for the sustainable supply of forest ecosystem services in Europe

Accepted by Sustainability Science

Authors: Hernández-Morcillo, M.[1], Torralba, M.[2], Baiges, T.[3], Bernasconi, A.[4], Bottaro, G.[5], Brogaard, S.[6], Bussola, F.[7], Díaz-Varela, E.[8], Geneletti, D.[9], Grossman, C.M.[10], Kister, J.[11], Klingler, M.[12], Loft, L.[13], Lovric, M.[14], Mann, C.[1], Pipart, N.[15], Roces-Díaz, J.V.[16], Sorge, S.[1], Tiebel, M.[2], Tyrväinen, L.[17], Varela, E.[18], Winkel, G.[19], Plieninger, T[2].

[1] Eberswalde University for Sustainable Development, Sustainable Forest Resource Economics, Schicklerstrasse 9 5, 16225 Eberswalde, Germany
[2] Faculty of Organic Agricultural Sciences, Universityof Kassel, and Department of Agricultural Economics and Rural Development, University of Göttingen, Platz der Göttinger Sieben 5, 37073 Göttingen, Germany
[3] Centre de Propietat Forestal (CPF), Santa Perpètua de Mogoda, 08130, Barcelona, España
[4] Pan Bern AG, Postfach, 3001 Bern, Switzerland
[5] University of Padova, Land Environment Agriculture and Forestry Department (TeSAF),Viale dell'Università 19 16, 35020 Legnaro, Padova, Italy
[6] Lund University Centre for Sustainability Studies Lund University Box 170 SE-221 00 Lund, Sweden
[7] Forest Service of the Autonomous Province of Trento, via Trener 3, 38121 Trento, Italy
[8] Research Group COMPASSES-Planning and Management in Social-Ecological Complex Adaptive Systems University of Santiago de Compostela. Campus Universitario, s/n 27002 - Lugo, Spain
[9] Department of Civil, Environmental and Mechanical Engineering, University of Trento, via Mesiano 77, 25 Trento, Italy
[10] Forest Research Institute Baden-Wuerttemberg (FVA), Wonnhaldestrasse 4, 79100 Freiburg, Germany
[11] University of Innsbruck, Department of Geography, Innrain 52f, 6020 Innsbruck, Austria
[12] University of Natural Resources and Life Sciences Vienna, Institute for Sustainable Economic Development, 29 Feistmantelstraße 4, 1180 Vienna, Austria
[13] Working Group Governance of Ecosystem Services, Leibniz Centre for Agricultural Landscape Research 31 (ZALF), Eberswalder Str. 84, 15374 Müncheberg, Germany
[14] European Forest Institute Yliopistokatu 6B, 80100 Joensuu, Finland 33 15 KU Leuven, Department of Earth and Environmental Sciences Celestijnenlaan 200E, 3001 Leuven, Belgium
[15] Centre for Ecological Research and Forestry Applications (CREAF), Cerdanyola del Valles 08193, Spain
[17] Natural Resources Institute Finland, Latokartanonkaari 9, 00790 Helsinki, Finland

[18] Forest Science and Technology Centre of Catalonia, Ctra. St. Llorenç de Morunys, E-25280 Solsona, Spain
[19] European Forest Institute (EFI), Platz der Vereinten Nationen; 753113 Bonn, Germany

Abstract

Forests are key components of European multifunctional landscapes and supply numerous forest ecosystem services (FES) fundamental to human well-being. The sustainable provision of FES has the potential to provide responses to major societal challenges, such as climate change, biodiversity loss, or rural development. To identify suitable strategies for the future sustenance of FES, we performed a solution scanning exercise with a group of transdisciplinary forest and FES experts from different European regions. We identified and prioritized fifteen major challenges hindering the balanced provision of FES and identified a series of potential solutions to tackle each of them. The most prominent challenges referred to the increase of extreme weather events and the normative mindset of forest management. The respective solutions pointed to the promotion of forest resilience via climate-smart forestry and mainstreaming FES-oriented management in a threefold strategy: education, awareness raising, and networking. Most solutions were assessed as highly effective, transferable, and susceptible to being monitored over time, while none of them were evaluated as being economically inefficient. The implementation of the solutions could have potential synergistic effects when applying the notion of leverage points. Seven emerging pathways towards the sustainable supply of FES have been identified. These pathways build on each other and are organized from the one with the greatest to the least transformational potential: (1) shifting forest management paradigms towards pluralistic ecosystem valuation; (2) using integrated landscape approaches; (3) increasing forest resilience; (4) coordinating actions between forest-related actors; (5) increasing participation in forest planning and management; (6) continuous, open, and transparent knowledge integration; and (7) using incentive-based instruments to support regulating and cultural FES. These pathways can contribute information to the implementation of the new EU Forestry Strategy to support the balanced delivery of multiple FES.

Keywords: European forests; ecosystem services; sustainability; solution scanning; leverage points; EU Forestry Strategy

Introduction

European forests are ecosystems that deliver manifold benefits to society via so-called Forest Ecosystem Services (FES) (Orsi et al. 2020). They sequester carbon, protect soils and water basins, provide income opportunities, and contribute to the general wellbeing of rural and urban inhabitants. Furthermore, forests provide renewable resources that offer alternatives to fossil-fuel based products, thus contributing to climate change mitigation (Forest Europe 2020). However, at the same time the resilience of forests and the provision of FES are increasingly challenged by numerous external and internal drivers such as climate change, which threatens almost 60% of European forests by increasing their vulnerability to windstorms, fires, and pest infestations (Forzieri et al. 2021), or diverging societal demands ranging from an increased production of wood or biofuel to the promotion of wilderness for recreational purposes (EEA, 2016).

To navigate these challenges, it is imperative that forests are sustainably managed so they can continue being part of the solution to mitigate climate change, biodiversity loss, or to control epidemic outbreaks (Swaddle and Calos 2008; Khalil et al. 2016), while maintaining a crucial role in the efforts towards a more sustainable society and economy in Europe (Wolfslehner et al. 2020). Sustainable management is at the core of the European Union's (EU) forest policy (EC 2013). The last EU Forest Strategy already highlighted the importance of "balancing various forest functions, meeting demands, and delivering vital ecosystem services". It called for supporting protection and management efforts aimed at maintaining, enhancing, and restoring the resilience and multi-functionality of forest ecosystems for both urban and rural areas (EC 2013). Various studies have highlighted the importance of multifunctional management for safeguarding different forest functions (Wolf and Primmer 2006; Gustafsson et al. 2012; Benz et al. 2020); meanwhile, the paradigm of multifunctionality has been strongly embedded in forest policies at global and EU levels (EC 2013). In addition, forest products and services are increasingly an inherent and integrated element of many other policy sectors, ranging from energy to food production to conservation and public health (Aznar-Sánchez et al. 2018).

Yet, there is a mismatch between the biophysical supply and the political demands of different FES across Europe, inducing a bias towards timber provision (Primmer et al. 2021).

Strategies for a broad supply of FES often entail competing objectives (Lazdinis et al. 2019). Besides, the disproportionated focus on biomass production especially in large parts of central and north Europe, baulk the potential development of other FES initiatives. These conflicting demands can be due to the fact that most actions impacting forest landscapes are primarily associated with policy areas and interests outside the forestry sector. As a result, some forest objectives are torn between different sectoral interests whenever new targets evolve outside the forestry sector (Sotirov et al. 2016).

The current sustainability challenges for European forests demand innovative solutions for which the renewal of EU policy frameworks, such as the new EU Green Deal and Forestry Strategy, offers emerging opportunities. To support the development and implementation of the new European Forest Strategy, it is fundamental to have clarity on the challenges hindering the sustainable provision of multiple FES and scan the most effective solutions. While a plethora of information exists about the measures needed to ensure the provision of specific services such as wood or biomass, no comprehensive effort has been made to identify the best solutions with a potential to overcome the impediments in the supply of cultural or regulating FES in Europe.

To shed light on this issue, we conducted a solution scanning exercise with experts working in different fields of science, policy, and practice in the European forestry sector. Three specific research questions were addressed in this study:

What are the most pressing challenges hindering the sustainable provision of multiple FES in Europe?

Which are the most effective solutions to overcome those challenges?

How can the solutions be logically implemented so their transformational potential is maximized?

Materials and methods

In this study, we applied an extended version of the solution scanning method. Solution scanning has been increasingly used in the past years to identify specific solutions for a particular problem (Sutherland et al. 2014). Solution scanning follows a stepwise methodology to identify a set of actions, interventions, or approaches that respond to a specific challenge. This can be useful to point out potential policy interventions in decision-making processes but also for setting research agendas (Dicks et al. 2017). In this method an objective is firstly defined, which in most cases emerges from specific societal demands (Pullin et al. 2013). Then, a group of experts are asked to identify courses of action they know from their own experience can leverage the system towards the stated goal. Finally, the proposed solutions are listed and distributed to the same experts to be assessed and prioritized according to given criteria (Hernández-Morcillo et al. 2018).

Our solution scanning exercise was structured in three phases (Figure 1). The first phase of the process consisted of the identification of the challenges hampering the sustainable provision of FES in Europe. To that end, an exploratory survey was distributed in November 2020 among all expert participants in the study (S 1). The survey was structured along a series of open questions which inquired about the most pressing challenges affecting the sustainable provision of FES in Europe across five thematic areas: economy, environment, socio-culture, management, and governance. Additionally, the survey assessed key knowledge gaps required to address these challenges. The answers of the survey were analyzed and synthesized by the coordination team. As a result, three challenges were merged and another three eliminated as they were considered out of the scope of this exercise. The remaining 36 challenges were structured and bundled according to the thematic areas. Prior to the next phase, the list of challenges was shared among all participants to identify potentially uncovered relevant challenges.

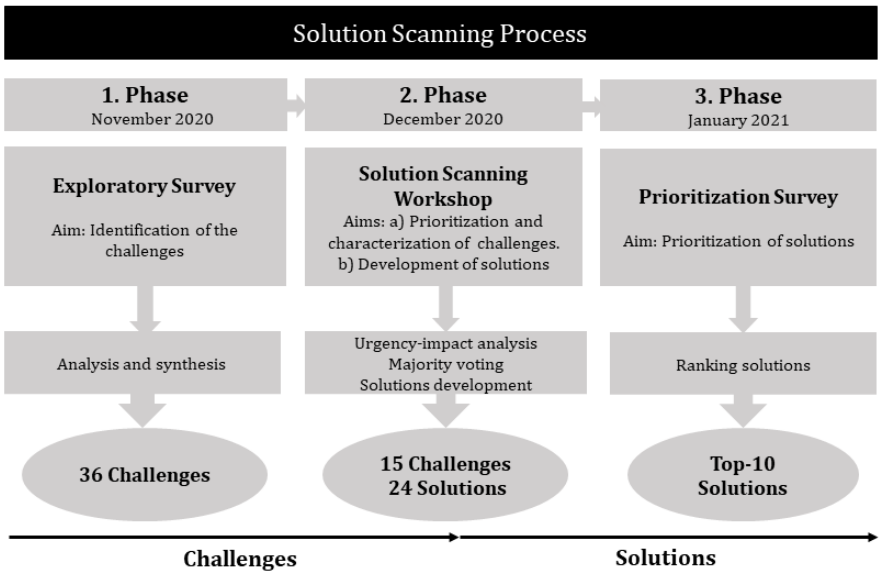


Figure 1. Workflow of the solution scanning exercise.

In the second phase, a two-day participatory solution scanning workshop was organized in December 2020. The aim of the workshop was to prioritize the challenges identified in the first phase and develop strategic solutions for the most relevant ones. The participants were divided into smaller groups of three to five individuals, and distributed across the five thematic areas (economy, environment, socio-culture, management, and governance) based on their expertise. On the first day, each thematic group prioritized and characterized the respective subsets of thematic challenges resulting from the exploratory survey. The prioritization included, for each challenge, a general assessment of the urgency (how immediately this challenge needs to be tackled), their impact (degree to which solving this challenge would contribute to the sustainable supply of multiple FES in Europe), the types of FES affected, scale, and the inter-relations between each of these challenges and all the thematic areas. Accordingly, each thematic group reduced the list of challenges to the five most relevant. At the end of the first day, the number of challenges was reduced through a series of anonymous majority voting rounds in plenary to the three most pressing challenges for each thematic area. During the second day, the thematic groups reconvened to formulate and characterize strategic solutions for each of the three selected challenges. The characterization consisted of a description of the solution, detailing its level of implementation, a time frame, and the resources needed for implementation.

During the third phase, the identified solutions were evaluated in an online survey distributed again to all participants in January 2021 (S 2). The respondents rated each solution according to five different criteria of optimal solutions, adapted from the concept report on climate policy mix optimality (Gorlach 2013) (see Box 1) using a five point Likert scale (from 1=very little to 5=very much).

BOX 1. Criteria for solution assessment

Social-ecological effectiveness: the degree to which the solution respects the natural and social environment and/or improves it.

Economic efficiency: the degree to which the resources needed for implementing the solution are allocated to their most valuable uses and waste is avoided.

Readiness: the degree to which the solution can be implemented in the shortest period of time.

Feasibility: the degree to which the solution can be successfully implemented.

Transferability potential: the degree to which the solution can be transferred to other European contexts.

The participants in the solution scanning process were 24 experts from academia, policy, and practice working directly on FES in Europe. Several participants were related to the EU Horizon 2020 funded projects, SINCERE and InnoForESt, both dealing with the promotion of FES-related innovations. One representative of each project composed the coordination team in charge of selecting the experts, designing the method, analyzing the data, and coordinating the synthesis process. The implementation of the solution scanning exercise was supported by a team of three facilitators selected among partners from both projects. In relation to the composition of the expert participants, particular attention was paid to balance backgrounds between academia and practice, disciplines, geographic foci, seniority level, and gender (S 3).

Most of the selected experts worked at scientific organizations at the interface between science, policy, and practice (41%). The covered areas of knowledge of the forestry sector

were broad, including experts on forest ecosystem services governance and innovation, urban forestry, European forest policy, and forest owner representatives. Partly because the coordination of both Horizon 2020 projects is based in Germany, most of the participants worked at German organizations (41%). However, seven other European countries were also represented in the exercise by Spain, Italy, Austria, Belgium, Switzerland, Finland, and Sweden. Gender balance was achieved and consciously maintained along the process. Finally, the notion of leverage points understood as areas of a system where actions can be implemented to induce deep changes (Abson et al. 2017; Dorninger et al. 2020) was used to organize the strategic solutions into powerful pathways of intervention according to their potential to transform the forestry sector.

Results

The most pressing challenges for the sustainable provision of FES

After the prioritization process, 15 challenges were selected, three per thematic area, based on their urgency and impact (Table 1).

Table 1. Definition of the final selected challenges for each sustainability area.

Area	Challenge	Definition
Environment	**Challenge 1.** Increasing frequency and intensity of extreme weather events	Climatic change results in an increase of extreme weather events regarding the frequency/intensity impacting the response of forest to climatic variability (e.g., storms, droughts, and rainfall). It affects the susceptibility to wildfires as well as forest health, functionality, and FES provision all around Europe. Despite the inherent resilience of European forests, the induced changes in forest structure, composition, and thus ecological functioning could be irreversible.
	Challenge 2. Increasing extension, frequency, and impacts of pests and diseases in forest habitats	Due to climate change, forests are increasingly vulnerable to pests and diseases, as seen in the extent of recent bark beetle infestations. Especially less adapted are forest dominated by mono-culture structured stands with a higher density of trees, resulting in a lower provision of all FES at a European scale.
	Challenge 3. Fragmentation of forest habitats	Land use change, growing infrastructure, and built-up areas result in fragmented forest structures, habitat quality decline, and negative impacts on biodiversity. The lack of connectivity especially affects forest

		dependent and endemic species, while the lack of spatial continuity hinders FES provision.
Management	**Challenge 4.** Narrow focus and normative mindset on forest management	Traditional and often normative mindsets on forest management are focused on timber and biomass production especially in central and north European regions. Biodiversity and other FES such as cultural or regulating services could be affected by this challenge. Integrating all forest functions and socio-cultural dimensions is key for preserving healthy ecosystems, local cultures, knowledge, and values.
	Challenge 5. Lack of adaptive forest management practices	Forests are undergoing continuous changes in environmental, social, or political conditions that demand an adaptive approach. The lack of adapted management decreases forest resilience to rapid changes affecting people and forests in specific contexts. Continuous monitoring and flexible adapted forest management practices are challenging to implement, due to strict administrative conditions, lack of resources, and the absence of suitable knowledge among other factors.
	Challenge 6. Unknown demand and supply of FES	There is a lack of information on specific FES, especially regulating or cultural services on the biophysical supply and societal demand across European countries. Information about the FES flows, synergies, trade-offs, and bundles is precarious. Some services are often absent in policy discussions and decisions (e.g., cultural FES). Additionally, the accessibility of specific FES can be affected by barriers inducing social inequality.
Economy	**Challenge 7.** Insufficient financial support to changing conditions	Support to cover losses from, and adaptation towards natural hazards are deficient to non-existent. This challenge particularly affects forest owners' capacities to take the risk of investing in innovations, specially when there is no guarantee of receiving sufficient revenue or at least mitigating losses. Facing periodic natural hazards without financial support exposes forest owners to unbearable risky conditions.
	Challenge 8. Economic power asymmetries among actors in the European forestry sector	These power asymmetries are generally influenced by a reduced number of actors, who take decisions, control, and direct the markets through something legitimate and not pernicious itself, but on many occasions operate regardless of the negative externalities of intensive wood/timber production.
	Challenge 9. Lack of efficient economic instruments and business models for regulating and cultural FES	Efficient economic instruments and business models capable of recognizing and promoting regulating and cultural FES are scarce to non-existent in Europe. This also affects non-wood forest products, particularly those of public good character provided by forests in Europe.

		Many forest owners are motivated to provide those services, but the lack of economic based incentives impede actions to this aim.
Governance	**Challenge 10.** Lack of coordination and competition among different policy sectors	This challenge occurs across all administrative levels and policy sectors especially those with contradicting goals affecting forest owners. Taking simple decisions on planning and management activities often becomes an ordeal. This could lead to irreversible changes in FES provision, depending on the importance and urgency of policies and decisions to be made.
	Challenge 11. Lack of representation of key stakeholders in forest management decision	Forest planning and management decisions are often made despite the effects that could impact several actors far beyond forest owners, managers, or policy makers. There is almost no space (vertically or horizontally) for participation of other members of the wider community of potential beneficiaries (e.g., local communities) in the decision-making process on the provision and use of FES.
	Challenge 12. Tensions and mismatching expectations about the role of public forests	Planning and management decisions in public forests are particularly complex. Mismatching expectations about the role of public forests might emerge, either as a strategic profitable resource on the one hand and/or as public goods with the public mandate to provide FES on the other.
Socio-culture	**Challenge 13.** Diminished diverging perceptions of forest values by society	This challenge focuses on the multiplicity of social-cultural values associated with FES as well as the difficulties of identification, prioritization, and integration in forest planning and management. This is particularly true for the recognition of marginalized indigenous peoples and traditional communities and the associated risk of vanishing forest-related forms of knowledge and livelihoods.
	Challenge 14. Conflicts between FES providers and beneficiaries	The conflicts between FES providers and beneficiaries may arise due to diverging interests, demands and rights. On most occasions, private owners are expected to supply a series of public goods without any incentive. This incentive is not only or necessarily an economic issue about rewarding the provision of FES. It is to the same extent a communication and conceptual issue about understanding public-private relationships, power structures, and interests that regulate the use, provision, and access to forests and forest resources.
	Challenge 15. Rural migration and impacts on rural areas	European rural areas are increasingly experiencing migratory flows to cities leading to a lack of generational turnover in the forestry sector and/or abandonment of forested lands. The challenge is to build and support forest owners and local networks, to launch initiatives, and revitalize rural populations. Additionally, a trend of urban dwellers

		moving to the countryside exists, which might have other priorities that might not be related to engaging with forest-related economic activities.

Figure 2 displays the prioritization of these 15 most important challenges based on the expert group perception of their urgency and impact. Most of the prioritized challenges were classified as being urgent and having a high impact. The increasing extension, frequency, and impacts of pests and diseases (Ch. 2), the tensions and mismatching expectations about the role of public forests (Ch. 12), and the diminished diverging perceptions of forest values by society (Ch. 13) were the challenges perceived by the experts as those that should be most immediately tackled and whose resolution would hold the maximum potential to contribute to the sustainable supply of multiple FES in Europe. Challenges referring to the fragmentation of forest habitats (Ch. 3), lack of efficient economic instruments (Ch. 9), and lack of coordination among policy sectors (Ch. 10) were considered as having a medium impact due to the fact that solving these challenges would contribute to the sustainable supply of multiple FES although over a longer period of time. The increasing frequency and intensity of extreme weather events (Ch.1) was considered as the least urgent challenge, meaning that it would be occurring during a longer time frame, although having the biggest impact.

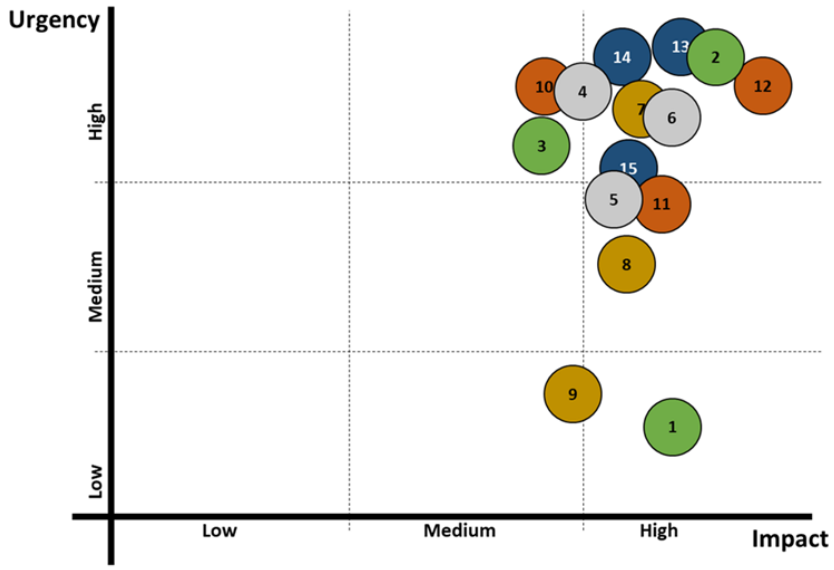


Figure 2. Prioritization of challenges based on urgency and impact. The colours correspond to five different areas of sustainability (green=environment, brown=socio-culture, grey=economy, blue=management, orange=governance); the numbers correspond to the challenges identified (Table 1).

The most suitable solutions to improve the sustainable provision of FES

To address the 15 challenges, a total of 24 solutions were identified by the team of experts (see S4 for a detailed description of all the solutions). The suitability of each solution was subsequently assessed and ranked based on the following six criteria: social-ecological effectiveness, economic efficiency, readiness, feasibility, and transferability potential (Box 1). Table 2 shows the prioritized challenges per thematic area with the respective solutions and the final ranking. The social-ecological effectiveness, respecting the human-environmental contexts, and the transferability potential to other contexts were the strongest traits shared by the proposed solutions. In contrast, the readiness, or the short-term implementation potential and the feasibility, understood as the potential for its successful implementation, were generally the weakest traits. After summing up the rankings of all the different criteria for all solutions, the top ten solutions were obtained and are presented in the next section.

Table 2. Solutions to foster sustainable FES provision in European forests. The colours indicate the degree to which each solution fulfils the implementation criteria (white=very low; light grey=low; grey=normal; dark grey=high; black=very high). Bold font indicates the ten highest ranked solutions.

Area	Challenge	Solution	Socio-Ecological Effectiveness	Economic efficiency	Readiness	Ascertain. Monitoring	Feasibility	Transfer. potential	Rank
Environment	Challenge 1. Increasing frequency and intensity of extreme weather events	**Solution 1 - Promotion of climate-smart forestry and forest resilience**							**1**
		Solution 2 - Improved integration of regulating forest ecosystem services in local and regional planning							**8**
	Challenge 2. Increasing extension, frequency, and impacts of events in forest habitats	**Solution 3 - Strategic regional coordination between forestry stakeholders to join forces against biological and environmental threats**							**9**
	Challenge 3: Fragmentation of forest habitats	Solution 4 - Systematic and comprehensive implementation of environmental assessments considering multiple scales and cumulative effects of forest fragmentation on FES at landscape level							16
Management	Challenge 4. Narrow focus and normative mindset on forest management	**Solution 5 - Mainstreaming FES-oriented management in a threefold strategy: education, awareness raising, and networking**							**2**
		Solution 6 - Develop adaptive strategies to sustain multiple FES based on regional scenarios							13

	Challenge 5. Lack of adaptive forest management practices	Solution 7 - Ensuring diversity at the different levels (genetic, species, and forest)							18
	Challenge 6. Unknown demand and supply of FES	Solution 8 - Establishment of regional observatories for capturing societal FES demand and supply							23
Economy	Challenge 7. Insufficient financial support to changing conditions	**Solution 9 - Foster investments into FES oriented forest management to increase resilience (prevention and adaptation) towards natural hazards**							**3**
		Solution 10 - Increase availability, volume, and accessibility of supporting financial instruments to cover losses from natural hazards							**10**
	Challenge 8. Economic power asymmetries in the forestry sector	**Solution 11 - Support economic instruments and business models promoting regulating and cultural FES with consistent policies**							**4**
		Solution 12 - Alignment of finances and administration of different sectors							22
	Challenge 9. Lack of efficient economic instruments and business models for regulating and cultural FES	Solution 13 – Improvement of the adaptation of business models to particular contexts of implementation							11
		Solution 14 - Systematic monitoring and social-ecological impact assessment of economic instruments							15
Governance	Challenge 10. Lack of coordination and competition among different policy sectors	Solution.15 - Vertical and horizontal orchestration of the administration							19
		Solution 16 - Clear and stable delineation of power and responsibilities							21
	Challenge 11. Lack of representation of key	Solution 17 - Generation of spaces for stakeholders' engagement and representation in							14

	stakeholders in forest decisions	decision making processes in cooperative and participative approaches							
	Challenge 12. Tensions and mismatching expectations about the role of public forests	**Solution 18 - Community engagement for participatory decision-making in management approaches in public forests to respond to societal demands, while embracing innovations towards improved management and efficiency in the use of forest resources**							**5**
		Solution 19 - Integration of all actors in participatory decision making about management goals of public forest lands							20
		Solution 20 - Streamline public forest management organization and administration following the principles of the private forestry sector							24
Socio-culture	Challenge 13. Diminished divergence in perceptions of forest values by society	**Solution 21 - Implementation of practices for (re)connecting people with forests**							**6**
		Solution 22 - Strengthening of the recognition, identification, and integration of social-cultural values in forest management, governance, and research							12
	Challenge 14. Conflicts between FES providers and beneficiaries	**Solution 23 - New forms of communication and interaction between society and FES providers with a focus on public forests**							**7**
	Challenge 15. Rural migration and impacts on rural areas	Solution 24 - Capacity building as a tool to prevent abandonment and promote generational turnover in the forestry sector							17

The top ten solutions for the sustainable provision of FES in Europe

Top 1. Promotion of climate-smart forestry and forest resilience

Sustainability Area: Environment; Challenge 1 - Increasing frequency and intensity of extreme weather events

Climate-smart forestry is a targeted approach to manage forests in response to climate change (Bowditch et al. 2020). It aims to increase the climate regulation benefits from forests and the forestry sector, in a way that creates synergies with other societal needs related to forests. It is a large-s cale strategy which unfolds in three main lines of action: the enhancement of natural regeneration and avoidance of deforestation; active forest management; and adaptive forest management to build resilient forests (Nabuurs et al. 2018; Verkerk et al. 2020). For example, a recent analysis along a climate gradient across Europe showed that the higher resilience and resistance to drought events happened in mixed stands compared to monospecific with higher benefits in conifer-broadleaved stands (Pardos et al. 2021). Here, forest resilience considers the maintenance of regimes and the adaptive capacity of forests as a coupled human-natural system in the face of drivers of change (Nikinmaa et al. 2020). As such, climate-smart forestry strives beyond storing carbon to mitigate climate change and generate synergies with other FES and biodiversity. The implementation of this solution needs to carefully consider the different regional contexts in Europe to identify the most cost-effective management options. It would also require sustained commitment as the benefits from this solution would only emerge in a mid-long term.

Top 2. Mainstreaming FES-oriented management in a threefold strategy: education, awareness raising, and networking

Sustainability Area: Management; Challenge 4 - Narrow focus and normative mindset on forest management

This solution invites broadening the often narrow perspective of forest management focused on the timber and biomass production of highly productive stands (Jönsson and Snäll 2020) with the help of education and information strategies. In particular, this could be done by diversifying education at the administration and university level (Nair 2004), fostering

knowledge transfer to forest operators (Perera et al. 2006), starting and reinforcing social campaigns to make visible the multiple services of forest, and developing and enabling long lasting cross-sectorial networks (Guerrero and Hansen 2021). Although this solution requires long-term commitment and significant attitudinal change within and beyond the forestry sector (shifting management goals, seeking long term instead of short-term benefits, or changing contractual arrangements) before its effects become apparent, this solution has the potential to largely generate synergistic and long-lasting effects over forest management in Europe. To tackle complex challenges and developing opportunities for innovation at EU level, collaboration can be enhanced through existing European Innovations Partnership (EIP) operational groups on forest and EU projects through multi-actor approaches such as InnoForESt and SINCERE. Moreover, in the light of the new EU CAP, Agricultural Knowledge, and Innovation Systems (AKIS) are key to support the share of knowledge and innovative applications more intensively.

Top 3. Fostering investments into FES oriented forest management to increase resilience (prevention and adaptation) towards natural hazards

Sustainability Area: Economy; Challenge 7 - Insufficient financial support to changing conditions

Investing in increasing forest resilience (Nikinmaa et al. 2020) is key for ensuring the prevention and adaptation towards natural hazards and ensuring the sustainable provision of FES (Keenan 2015; Lecina-Diaz et al. 2021). After assessing the redundancies and ambiguities of forest-related investments, local to regional forestry together with nature conservation administrations levels should oversee articulating and administering these investments. This should be implemented and monitored in a short-medium term to ensure that they foster sustainable solutions with regard to multiple forest functions. This support needs to be continuous and outcome-oriented by designing policies that consider spatial targeting to FES density, threats and cost levels, payment differentiation, and improved conditionality (Wunder et al. 2020). This solution requires an integrated forest policy that addresses various system dimensions in terms of policy sectors and administrative levels, including both local and landscape-level land uses with indicators oriented towards minimizing socio-ecological damages and losses (Moreira et al. 2020).

Top 4. Support economic instruments and business models promoting regulating and cultural FES with consistent policies

Sustainability Area: Economy; Challenge 8 - Economic power asymmetries in the forestry sector

Effective economic instruments as well as business models that contribute to the sustainable provision of FES (particularly for regulating and cultural FES) should be consistently supported by cross-scale European and national policies similar to those in place for timber and biomass production (Wunder et al. 2019). This could be achieved through, on the one hand, nested multi-scale policies (Ostrom 1990) and, on the other hand, a strategy of making available and advertising successful business models along with the key features leading to their success to allow their replication elsewhere. In relation to incentive-based and result-based payments for ecosystem services (PES) schemes, it is important to target forest owners of those forest areas that show a) high levels of FES supply (e. g., high carbon stocks/ha or endemic biodiversity hotspots), and b) areas with high potential risks (e.g., high threat of deforestation and degradation). This strategy would focus PES in areas where they can realistically make a difference (Börner et al. 2020; Wunder et al. 2020).

Top 5. Community engagement for participatory decision-making in management approaches in public forests to respond to societal demands, while embracing innovations towards improved management and efficiency in the use of forest resources

Sustainability Area: Governance; Challenge 12 - Tensions and mismatching expectations about the role of public forests

This solution strategy promotes participatory forest management overcoming outdated management approaches that do not respond to current societal demands and larger social-ecological challenges (such as biodiversity loss or climate change). These strategies are often coupled with a philosophy of embracing innovations towards improved forest management for the provision of FES bundles, especially for regulating and cultural FES, for the promotion of ecological and societal transformation, and for the sustainable use of public goods. Public forests would be used as niches of innovation (Geels 2005) of, for example, public-private

partnerships or novel actor alliances to improve the provision of regulating and cultural FES or enhance non-wood forest product (NWFP) value chains. Public forests would act as 'incubation rooms' for radical novelties, providing locations for learning processes, and spaces to build the social networks which support innovation. Initiatives and innovations would be carefully addressed so that public resources do not end up creating exclusively private benefits, but rather improving local economies with a share of benefits re-invested in improved forest management.

Top 6. Implementation of practices for (re)connecting people with forests

Sustainability Area: Socio-culture; Challenge 13 – Diminished diverging perceptions of forest values by society

Understanding forests as a mean to solve economic problems is a reductionist standpoint. In the pursuit of sustainable forest management, increased identification and inclusion of cultural bonds is crucial. To achieve a deeper understanding of the mutual constitution of the society-forest relation, it is also necessary to recognize the multi-layered spectrum of forests' contributions (Ritter and Dauksta 2013). Mainstreaming forest models that (re)connect people and forests (like forest kindergartens and forest schools) is crucial. Increasing studies show the perceived linkages of people to spiritual and cultural values in forests that are not necessarily related to livelihoods (Rodríguez-Morales et al. 2020; Torralba et al. 2020). In parallel, there is a need to strengthen the social and cultural sciences in FES assessments with a clearer representation of non-material values (Jacobs et al. 2016) and more-than-human thinking (Whatmore 2006).

Top 7. New forms of communication and interaction between society and FES providers with a focus on public goods

Sustainability Area: Socio-culture; Challenge 14 - Conflicts between FES providers and beneficiaries

When forests provide more regulating or cultural services than provisioning services, governance mechanisms are key to maintaining the supply of FES, especially in private owned forests. To overcome the lack of markets to deal with public goods and services, social support

is needed to finance the expenses which keep the sustainable forest management ongoing; this is especially important in situations where management is key to guarantee the provision flow of these goods and services, but where these are under high threat (e.g., wildfire risk in the Mediterranean region that increases with the lack of active forest management). European studies of public perception (Rametsteiner et al. 2009) have revealed that forestry issues are not well understood outside the forestry community and have suggested that improving communication to the general public is essential. Management goals and objectives must be identified and communicated on the short as well as long term, a wide variety of channels should be used, messages should be simple and clear, and collaboration with other organizations (agriculture, wood construction, etc.) should be enhanced. The joint effort with media professionals would lead to more successful results. In parallel, further research into the public perception of forests and forestry is needed to define targeted communication strategies (Fabra-Crespo and Rojas-Briales 2015).

Top 8. Improved integration of regulating forest ecosystem services in local and regional planning

Sustainability Area: Environment; Challenge 1 - Increasing frequency and intensity of extreme weather events

This solution proposes that forest planning authorities consider to a larger extend those specific strategies that have been proven to enhance regulating services such as watershed protection, erosion prevention, or flood control, for example by promoting mixed forest stands of uneven ages (Bravo-Oviedo 2018; Felipe-Lucia et al. 2018). These should be economically supported to cover the opportunity costs needed to restructure forests. Such measures, like PES, already exist in some settings worldwide with different degrees of success (Wunder et al. 2020). The implementation of PES has been polarized between pro-market and anti-neoliberal arguments. A political–cultural reconceptualization should be achieved to attain their potential while ensuring an improved environmental governance, (Van Hecken et al. 2015). Moreover, PES implementation may encounter obstacles hampering the promotion of regulating FES and impeding the improvement of the socioeconomic situation of forest-dependant communities and stakeholders. Some of these obstacles are on the social side, the lack of know how, insecure property rights, and problematic benefits distribution, on the

market side, the adverse PES s elf-selection, inadequate administrative targeting, and enforced conditionality (Pagiola et al. 2005; Wunder et al. 2020). There is a large potential for the adaptation of these experiences to the European context.

Top 9. Strategic regional coordination between forestry stakeholders to join forces against biological and environmental threats

Sustainability Area: Environment; Challenge 2 - Increasing extension, frequency and impacts of events in forest habitats

This solution proposes the regional-level implementation of coordinated actions and monitoring strategies. Risk can be assessed using analytical techniques that account for threats both spatially and temporally. Subsequently, risk-management strategies need to account more fully for multi level responses that act to balance conflicting interests between stakeholder organizations concerned within the managed and natural environments (Mills et al. 2011). These strategies would integrate private and public forest owners together with the regional-national administration and other sectors depending on the context (e.g., nature conservation, local communities), and backed with national support. The objective would be to share knowledge about affected areas and to join forces for specific forest interventions, increasing the readiness, monitoring capacity, and hence increasing the resilience of the system to these perturbations. An example comes from some regions in the Mediterranean, where civil society engage in wildfires extinction through volunteer groupings (Górriz-Mifsud et al. 2019). Coordination strategies would need to be specifically adapted to each individual context, as its transferability can be hampered by the heterogeneous systems of management and governance in Europe.

Top 10. **Increase availability, volume, and accessibility of supporting financial instruments to cover losses from natural hazards**

Sustainability Area: Economy; Challenge 7 - Insufficient financial support to changing conditions

The current natural hazards require planning and management strategies that increase forest capacity for adaptive transformation. It could provide an opportunity to steer the objectives

of forest management towards a more sustainable and less production-oriented model. To be efficient, financial instruments need to be conditional upon sustainable practices that ensure a diverse FES provision, while being adapted to the different realities existing in the European forestry sector. This could be achieved by dedicating part of existing economic support (e.g., EU rural development fund, common agricultural policy, other regional/local funds) for business model implementation to its adaptation to each specific context, refocusing for example on forest protection measures (Alliance Environnement EEIG 2017) and encouraging the use of result-based schemes to potentially increase the impact of the funding, while linking the business model with a positive and measurable impact on the FES provision (ECA 2020). Within this scheme, a requirement for eligibility to receive funds would be the direct link between the business model and a positive impact FES provision (Wunder et al. 2018; Ovando et al. 2019).

Discussion

European forests are exposed to fundamental and interconnected threats that put many forest ecosystem services that are vital for human wellbeing at risk. At the same time, various national and EU-wide policies are rapidly emerging in Europe, which try to solve pressing societal challenges with a forward-looking view on FES potential (Primmer et al., 2021). A diagnosis focused on FES provision, integrating different perspectives from science, policy, and practice is crucial to understand where the flaws of forest socio-economic systems are so that solutions can be strategically designed and implemented.

Deep and shallow leverage solutions

Most of the proposed solutions were considered as highly effective, transferable, and susceptible of being monitored over time, while none of them were evaluated as economically inefficient by the team of experts. However, more than half of the proposed solutions were considered not to be yet ready for implementation or currently feasible. This is particularly relevant for those solutions that imply a multilevel governance component and/or coordination among vertical and horizontal levels of actors (e.g., solutions 5 and 21). These types of solutions would normally require long-term commitment, institutional changes, and socio- political will (e.g., solutions 18, 24). Furthermore, they directly or

indirectly interfere with long-established cultural elements or strong economic interests (e.g., solution 12). These solutions can be considered as aiming for or being dependent on larger, perhaps even fundamental system changes which require the alteration of existing paradigms, institutions (such as policies but also mindsets), and actors' behaviours.

A closer look at the solutions' definitions and prioritization suggests a possible sequence of implementation. Inspired on the notion of leverage points, where solutions can induce shallow or deep changes (Abson et al. 2017; Dorninger et al. 2020), we could arrange the prioritized solutions according to their potential to solve the challenges for the sustainable provision of FES. While there are some low-hanging fruits, which could be easily implemented, some of the proposed solutions require a longer and more sustained effort due to their profound transformative potential and respective resistance. Advances towards the implementation of the former, which could be seen as encompassing fundamentally paradigm change solutions, would smooth the way for the later, which could be seen as managerial solutions. This is best illustrated with the highest ranked solutions. The strategic solution of "mainstreaming FES oriented management in a threefold strategy: education, awareness, and networking" is focused on changing mindsets towards an integrated multiple FES thinking and has the potential to shift the classic market-oriented economic rationale that reinforces a timber production-oriented paradigm. Similarly, the solution of the "promotion of climate-smart and resilient forest" is fundamental to ensure the adaptation of existing forests to the conditions and disturbance regimes associated to climate change so that they can continue to provide FES services. This solution is the precondition for targeting several economic, socio-cultural, and environmental challenges.

Due to the complexity inherent of the forestry sector and the entangled character of the challenges, the proposed solutions are highly interconnected, which pledges for a need of system change across all sectors, levels, and actors. A paradigm shift affecting institutions, academia, and forestry administrations is needed to go beyond forest biomass production and leverage the costs induced by investing into regulating and cultural FES.

The seven pathways towards sustainable FES supply

Many of the solutions have synergistic effects if they are combined and implemented in an orchestrated manner according to their capacity to enable transformation. For example, the integration of social-ecological values proposed in solution 21, could benefit to and from the regional observatories proposed in solution 8. By looking into the elements that are at the core of each individual solution, we propose seven emerging pathways on which European forest policies should focus in the middle and far future to ensure the sustainable supply of multiple FES. These strategic pathways could collectively build the backbone of European forest policy implementation. Although all of them are relevant, they can be distinguished by their capacity to leverage change in European forest and to secure the supply of multiple FES in relation to future disturbances and social-ecological changes (Fig. 3). Collectively, the seven identified strategic pathways can be seen as being in a hierarchical order, where the paradigm shift forms the basis for a deep forestry system transformation, which then allows for system-based management strategies up to concrete measures.

Changing production focused forest management paradigm towards pluralistic ecosystem valuation (Core element of solutions 6, 11, 22, 23, and 24)

Decision-making processes affecting FES provision need to embrace broader views, preferences, and values from a multi-actor perspective. Expanding the focus towards regulating, cultural, and supporting FES and understanding their valuation from a pluralistic and integrative point of view would advance the (re)connection between people and nature. Forestry education at all levels, forest management, and policies need to pursue a shift from the single consideration of instrumental values, to increasingly consider intrinsic and specially relational value dimensions (Chan et al. 2016; Jacobs et al. 2016).

Using integrated landscape approaches to adapt the solutions to local-regional contexts (Core element of solutions 1, 2, 5, 7, and 10)

Due to the inherent heterogeneity of European forests, future policies need to embrace the context-specificity of forest social-ecological dynamics, and use the landscape scale as the most appropriate one to address the multi-scalar pressures on forests (Opdam et al. 2018). A landscape scale provides the framework to orchestrate problems related to improving

coordination and transparency in decision making processes (Termorshuizen and Opdam 2009; Sayer et al. 2013).

Increasing forest resilience to boost forest multifunctionality (Core element of solutions 3, 8, 13, 14, and 23)

Forest policies and interventions should focus on ensuring the balanced provision of multiple ecosystem services. Integrated landscape solutions promoting forest resilience and multifunctionality should therefore be at the forefront of these policies. It is fundamental to increase European forest resilience by balancing intensive management to ensure adaptation to fluctuating climatic conditions. As recently observed by Pohjanmis et al. (2021) in boreal forests, multifunctionality is substantially diminished under intensive forestry and recovers slower, the longer the intensive forestry has been operating.

Coordinating actions between forest-related actors (Core element of solutions 4, 5, 12, 15, and 16)

The lack of coordination across forestry stakeholders and among different administrative levels can currently be considered an entrenched problem in the European forestry context (Winkel and Sotirov 2016). However, its disentanglement is a requirement for the successful implementation of any forest policy. Once a multifunctional view on forests is emerging and impregnated through educational programmes and policies, the forest institutional and social fabric would be better disposed to implement coordinated actions.

Increasing participation from a larger diversity of stakeholders during forest planning and management, with a focus on public forests (Core element of solutions 5, 7, 17, 18, 20, and 22)

Greater levels of participation from the public into forest management decision making is at the essence of several solutions. To do so, forest policies should increasingly promote participation in multi-level governance models (Muradian and Rival 2013) by using for example collaborative digital tools, and capitalize from ongoing and former initiatives engaged in the provision of FES and nature models that have proved successful in ecosystem management and conservation (Armitage et al. 2020).

Continuing, open and transparent knowledge integration from different stakeholders, disciplines, and policy sectors (Core element of solutions 5, 6, 9, and 21)

Translating sustainable management policy objectives into action on the ground has been described as a "wicked problem" (Duckett et al. 2016). This leverage area is fundamental to establish a fluid dialog to value and to integrate perspectives from "outsiders" disciplines and sectors affecting forests. To do so, several solutions point towards the use of inter- and transdisciplinary approaches as a way to integrate available knowledge and to create ownership for problems and solution options (Lang et al. 2012).

Using incentive-based instruments to support regulating and cultural FES (Core element of solutions 2, 8, 11, 13, and 14)

PES and PES-like schemes are currently scarce in Europe. An increased role for PES could manifest itself through government-financed PES (e.g., through flexible reforms of the Common Agricultural Policy), or through user-financed PES in those areas where there is sufficient willingness to pay for a specific FES (Wunder et al. 2020).

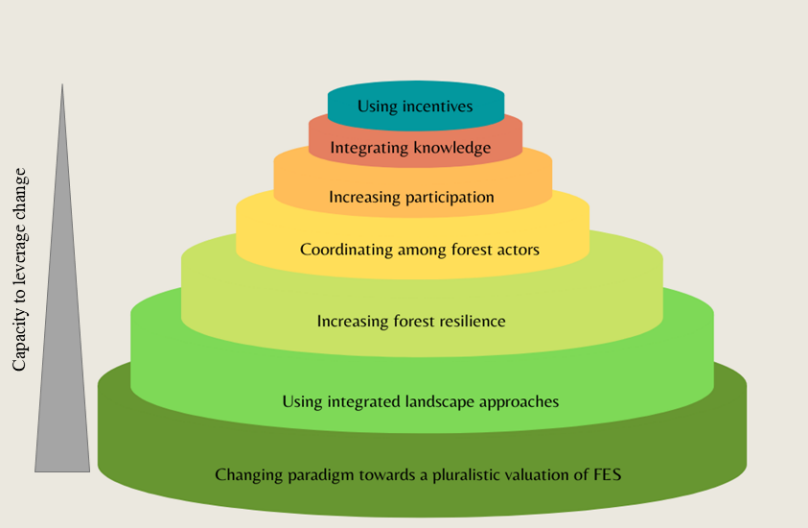


Figure 3. Seven strategic pathways for the sustainable supply of FES in Europe.

Methodological reflections

This solution scanning exercise synthesizes the currently fragmented views on forests challenges and targets suitable solutions to foster the sustainable provision of FES. The beforehand organization of the exercise into three well-defined phases allows a clear and

transparent communication among the coordinators and experts, facilitating a smooth iterative process. Due to COVID-19 restrictions, the participatory process was conducted entirely online. Adapting the workshops to a digital format has been an opportunity to explore creative ways to advance teamwork, like improving outcomes from group work processes via designated reporters, enhanced interaction among participants through regular group and individual exchange spaces, and keeping the motivation up by integrating periodic interactive games. Two important aspects of this sequential participatory method have been the regular communication with the group, the use of preparatory materials before each workshop through two surveys, and the presentation of the state of the work at the beginning of each session.

Conclusions

Emerging EU policy frameworks such as the New Green Deal and the Forestry Strategy offer a unique opportunity to serve as catalysts for solving the challenges hindering the sustainable supply of FES. To support this endeavour, the scanning exercise presented here not only disentangles the most pressing challenges in all sustainability areas but also offers a set of prioritized solutions to each of those challenges. Just as the assessed hindrances affect each other, similarly the strategic solutions can be used synergistically. This way, like concentric levels of mutually supportive implementation (Figure 3), a paradigm shift to better integrate pluralistic values of forests in a more balanced way would sustain the rest of the strategic solutions. Next, increasing forest resilience through integrated landscape approaches should be prioritized followed by strategies promoting coordinated, inclusive, and transparent decision processes. While the multifunctional forest paradigm gains momentum, the forest's biophysical conditions enable the balanced supply of FES and the social fabric of forest governance is more cohesive, it is possible to sustain a prosperous environment for incentive-based mechanisms to flourish.

References

Abson DJ, Fischer J, Leventon J, et al (2017) Leverage points for sustainability transformation. Ambio 46:30–39. doi: 10.1007/s13280-016-0800-y

Alliance Environnement EEIG (2017) Evaluation study of the forestry measures under Rural Development. European Commission

Armitage D, Mbatha P, Muhl E, et al (2020) Governance principles for community-centered conservation in the post-2020 global biodiversity framework. Conserv Sci Pract 2:e160. doi: 10.1111/csp2.160

Aznar-Sánchez JA, Belmonte-Ureña LJ, López-Serrano MJ, Velasco-Muñoz JF (2018) Forest ecosystem services: An analysis of worldwide research. Forests 9:453. doi: 10.3390/f9080453

Benz JP, Chen S, Dang S, et al (2020) Multifunctionality of forests: A white paper on challenges and opportunities in China and Germany. Forests 11:266. doi: 10.3390/f11030266

Börner J, Schulz D, Wunder S, Pfaff A (2020) The Effectiveness of Forest Conservation Policies and Programs. Annu Rev Resour Econ 12:45–64. doi: 10.1146/annurev-resource-110119-025703

Bowditch E, Santopuoli G, Binder F, et al (2020) What is Climate-Smart Forestry? A definition from a multinational collaborative process focused on mountain regions of Europe. Ecosyst Serv 43:101113. doi: 10.1016/j.ecoser.2020.101113

Bravo-Oviedo A (2018) The Role of Mixed Forests in a Changing Social-Ecological World. In: Dynamics, Silviculture and Management of Mixed Forests. Managing Forest Ecosystems. Springer, Cham, pp 1–25

Chan KMA, Balvanera P, Benessaiah K, et al (2016) Why protect nature? Rethinking values and the environment. 113:1462–1465. doi: 10.1073/pnas.1525002113

Dicks L, Haddaway N, Hernández-Morcillo M, et al (2017) Knowledge synthesis for environmental decisions: An evaluation of existing methods, and guidance for their selection, use and development. A report from the EKLIPSE project

Dorninger C, Abson DJ, Apetrei CI, et al (2020) Leverage points for sustainability transformation: a review on interventions in food and energy systems. Ecol. Econ. 171:106570

Duckett D, Feliciano D, Martin-Ortega J, Munoz-Rojas J (2016) Tackling wicked environmental problems: The discourse and its influence on praxis in Scotland. Landsc Urban Plan 154:44–56. doi: 10.1016/j.landurbplan.2016.03.015

EC (2013) A new EU Forest Strategy: for forests and the forest-based sector

ECA (2020) Special Report Biodiversity on farmland: CAP contribution has not halted the decline

EEA (2016) European forest ecosystems - State and trends

Fabra-Crespo M, Rojas-Briales E (2015) Comparative analysis on the communication strategies of the forest owners' associations in Europe. For Policy Econ 50:20–30. doi: 10.1016/j.forpol.2014.06.004

Felipe-Lucia MR, Soliveres S, Penone C, et al (2018) Multiple forest attributes underpin the supply of multiple ecosystem services. Nat Commun 9:1–11. doi: 10.1038/s41467-018-07082-4

Forest Europe (2020) State of Europe's Forests 2020

Forzieri G, Girardello M, Ceccherini G, et al (2021) Emergent vulnerability to climate-driven disturbances in European forests. Nat Commun 12:1–12. doi: 10.1038/s41467-021-21399-7

Geels FW (2005) Processes and patterns in transitions and system innovations: Refining the co-evolutionary multi-level perspective. Technol Forecast Soc Change 72:681–696. doi: 10.1016/j.techfore.2004.08.014

Gorlach B (2013) What Constitutes an Optimal Climate Policy Mix? Defining the Concept of Optimality, Including Political and Legal Framework Conditions. CECILIA2050. Deliverable 1

Górriz-Mifsud E, Burns M, Marini Govigli V (2019) Civil society engaged in wildfires: Mediterranean forest fire volunteer groupings. For Policy Econ 102:119–129. doi: 10.1016/j.forpol.2019.03.007

Guerrero JE, Hansen E (2021) Company-level cross-sector collaborations in transition to the bioeconomy: A multi-case study. For Policy Econ 123:102355. doi: 10.1016/j.forpol.2020.102355

Gustafsson L, Baker SC, Bauhus J, et al (2012) Retention Forestry to Maintain Multifunctional Forests: A World Perspective. Bioscience 62:633–645. doi: 10.1525/bio.2012.62.7.6

Hernández-Morcillo M, Burgess P, Mirck J, et al (2018) Scanning agroforestry-based solutions for climate change mitigation and adaptation in Europe. Environ. Sci. Policy 80:44–52

Jacobs S, Dendoncker N, Martín-López B, et al (2016) A new valuation school: Integrating diverse values of nature in resource and land use decisions. Ecosyst Serv 22:213–220. doi: 10.1016/J.ECOSER.2016.11.007

Jönsson M, Snäll T (2020) Ecosystem service multifunctionality of low-productivity forests and implications for conservation and management. J Appl Ecol 57:695–706. doi: 10.1111/1365-2664.13569

Keenan RJ (2015) Climate change impacts and adaptation in forest management: a review. Ann For Sci 72:145–167. doi: 10.1007/s13595-014-0446-5
Khalil H, Ecke F, Evander M, et al (2016) Declining ecosystem health and the dilution effect. Sci Rep 6:1–11. doi: 10.1038/srep31314
Lang DJ, Wiek A, Bergmann M, et al (2012) Transdisciplinary research in sustainability science: Practice, principles, and challenges. Sustain Sci 7:25–43. doi: 10.1007/s11625-011-0149-x
Lazdinis M, Angelstam P, Pülzl H (2019) Towards sustainable forest management in the European Union through polycentric forest governance and an integrated landscape approach. Landsc Ecol 34:1737–1749. doi: 10.1007/s10980-019-00864-1
Lecina-Diaz J, Martínez-Vilalta J, Alvarez A, et al (2021) Characterizing forest vulnerability and risk to climate-change hazards. Front Ecol Environ 19:126–133. doi: 10.1002/fee.2278
Mills P, Dehnen-Schmutz K, Ilbery B, et al (2011) Integrating natural and social science perspectives on plant disease risk, management and policy formulation. Philos Trans R Soc B 366:2035–2044. doi: 10.1098/rstb.2010.0411
Moreira F, Ascoli D, Safford H, et al (2020) Wildfire management in Mediterranean-type regions: Paradigm change needed. Environ. Res. Lett. 15:011001
Muradian R, Rival L (2013) Ecosystem Services and Environmental Governance: Some Concluding Remarks. In: Muradian R, Rival L (eds) Governing the Provision of Ecosystem Services. Studies in Ecological Economics. Springer, Dordrecht, pp 465–471
Nabuurs G-J, Verkerk PJ, Schelhaas M-J, et al (2018) Climate-Smart Forestry: mitigation impacts in three European regions. European Forest Institute
Nair CTS (2004) What does the future hold for forestry education? Unasylva 55: 216:
Nikinmaa L, Lindner M, Cantarello E, et al (2020) Reviewing the Use of Resilience Concepts in Forest Sciences. Curr For Reports 6:61–80. doi: 10.1007/s40725-020-00110-x
Opdam P, Luque S, Nassauer J, et al (2018) How can landscape ecology contribute to sustainability science? Landsc Ecol 33:1–7. doi: 10.1007/s10980-018-0610-7
Orsi F, Ciolli M, Primmer E, et al (2020) Mapping hotspots and bundles of forest ecosystem services across the European Union. Land use policy 99:104840. doi: 10.1016/j.landusepol.2020.104840
Ostrom E (1990) Governing the Commons. Cambridge University Press, Cambridge
Ovando P, Beguería S, Campos P (2019) Carbon sequestration or water yield? The effect of payments for ecosystem services on forest management decisions in Mediterranean forests. Water Resour Econ 28:100119. doi: 10.1016/j.wre.2018.04.002
Pagiola S, Arcenas A, Platais G (2005) Can Payments for Environmental Services help reduce poverty? An exploration of the issues and the evidence to date from Latin America. World Dev 33:237–253. doi: 10.1016/j.worlddev.2004.07.011
Pardos M, del Río M, Pretzsch H, et al (2021) The greater resilience of mixed forests to drought mainly depends on their composition: Analysis along a climate gradient across Europe. For Ecol Manage 481:118687. doi: 10.1016/j.foreco.2020.118687
Perera AH, Buse LJ, Crow TR (2006) Knowledge Transfer in Forest Landscape Ecology: A Primer. Springer New York
Pohjanmies T, Eyvindson K, Triviño M, et al (2021) Forest multifunctionality is not resilient to intensive forestry. Eur J For Res 140:537–549. doi: 10.1007/s10342-020-01348-7
Primmer E, Varumo L, Krause T, et al (2021) Mapping Europe's institutional landscape for forest ecosystem service provision, innovations and governance. Ecosyst Serv 47:101225. doi: 10.1016/j.ecoser.2020.101225
Pullin AS, Sutherland W, Gardner T, et al (2013) Conservation priorities: Identifying need, taking action and evaluating success. In: Macdonald DW, Willis KJ (eds) Key Topics in Conservation Biology. John Wiley and Sons, pp 1–22
Rametsteiner E, Eichler L, Berg J (2009) Shaping Forest Communication in the European Union: Public Perceptions of Forests and Forestry. ECORYS. Final Report
Ritter E, Dauksta D (2013) Human-forest relationships: Ancient values in modern perspectives. Environ Dev Sustain 15:645–662. doi: 10.1007/s10668-012-9398-9
Rodríguez-Morales B, Roces-Díaz J V., Kelemen E, et al (2020) Perception of ecosystem services and disservices on a peri-urban communal forest: Are landowners' and visitors' perspectives dissimilar? Ecosyst Serv 43:101089. doi: 10.1016/j.ecoser.2020.101089
Sayer J, Sunderland T, Ghazoul J, et al (2013) Ten principles for a landscape approach to reconciling agriculture, conservation, and other competing land uses. Proc Natl Acad Sci U S A 110:8349–8356. doi: 10.1073/pnas.1210595110
Sotirov M, Storch S, Aggestam F, et al (2016) Forest Policy Integration in Europe: Lessons Learnt, Challenges Ahead, and Strategies to Support Sustainable Forest Management and Multifunctional Forestry in the Future. Project INTEGRAL

Sutherland WJ, Gardner T, Bogich TL, et al (2014) Solution scanning as a key policy tool: Identifying management interventions to help maintain and enhance regulating ecosystem services. Ecol Soc 19:. doi: 10.5751/ES-06082-190203
Swaddle JP, Calos SE (2008) Increased avian diversity is associated with lower incidence of human West Nile infection: Observation of the dilution effect. PLoS One 3:e2488. doi: 10.1371/journal.pone.0002488
Termorshuizen JW, Opdam P (2009) Landscape services as a bridge between landscape ecology and sustainable development. Landsc Ecol 24:1037–1052. doi: 10.1007/s10980-008-9314-8
Torralba M, Lovrić M, Roux JL, et al (2020) Examining the relevance of cultural ecosystem services in forest management in Europe. Ecol Soc 25:2. doi: 10.5751/ES-11587-250302
Van Hecken G, Bastiaensen J, Windey C (2015) Towards a power-sensitive and socially-informed analysis of payments for ecosystem services (PES): Addressing the gaps in the current debate. Ecol Econ 120:117–125. doi: 10.1016/j.ecolecon.2015.10.012
Verkerk PJ, Costanza R, Hetemäki L, et al (2020) Climate-Smart Forestry: the missing link. For. Policy Econ. 115:102164
Whatmore S (2006) Materialist returns: Practising cultural geography in and for a more-than-human world. Cult Geogr 13:600–609. doi: 10.1191/1474474006cgj377oa
Winkel G, Sotirov M (2016) Whose integration is this? European forest policy between the gospel of coordination, institutional competition, and a new spirit of integration. Environ Plan C Gov Policy 34:496–514. doi: 10.1068/c1356j
Wolf SA, Primmer E (2006) Between incentives and action: A pilot study of biodiversity conservation competencies for multifunctional forest management in Finland. Soc Nat Resour 19:845–861. doi: 10.1080/08941920600835601
Wolfslehner B, Pülzl H, Kleinschmit D, et al (2020) European forest governance post-2020. From Science to Policy 10
Wunder S, Börner J, Ezzine-de-Blas D, et al (2020) Payments for Environmental Services: Past Performance and Pending Potentials. Annu Rev Resour Econ 12:209–234. doi: 10.1146/annurev-resource-100518-094206
Wunder S, Brouwer R, Engel S, et al (2018) From principles to practice in paying for nature's services. Nat Sustain 1:145–150. doi: 10.1038/s41893-018-0036-x
Wunder S, Feder S, Pettenella D, et al (2019) "What works?" State-of-the-art synthesis report about best-practice design and implementation of PES and other IM in the European context. SINCERE project. Deliverable 1.4

Paper **V** has been written in collaboration with the two EU Horizon 2020 projects: SINCERE and InnoForESt. My role in this paper (Table 1.1) was to implement the statistical analysis related to forest ownership and size and to interpret the results. Additionally, I have participated to the writing and the review of the final manuscript. The aim of the paper was to analyse the governance innovation occurring in Europe to sustain the sustainable FES provision.

Paper B: Governance Innovations for forest ecosystem service provision – Insights from an EU-wide survey

Accepted by Environmental Science and Policy

Authors: Mann, C.[1], Loft, L.[2], Hernández-Morcillo, M.[1], Primmer, E.[3], Bussola, F.[4], Falco, E.[5], Geneletti, D.[5], Dobrowolska, E.[1], Grossmann, C.M.[6], Bottaro, G.[7], Schleyer, C.[8], Stegmaier, P.[9], Kluvankova, T.[10], Garcia, G.[1], Lovrić, M.[11], Torralba, M.[12], Plieninger, T.[12], Winkel, G.[13]

[1] Eberswalde University for Sustainable Development, Chair for Sustainable Forest Resource Economics, Schicklerstrasse 5, 16225 Eberswalde, Germany

[2] Leibniz Centre for Agricultural Landscape Research (ZALF), Research Area 2 "Land Use and Governance", Eberswalder Straße 84, 15374 Müncheberg, Germany

[3] Finnish Environment Institute, Research Director, Professor, Latokartanonkaari 11, 00790 Helsinki, Finland

[4] Forest Service of the Autonomous Province of Trento, via Trener 3, 38121 Trento, Italy

[5] Department of Civil, Environmental, and Mechanical Engineering, University of Trento, Via Mesiano 77, 38123, Trento

[6] Forest Research Institute Baden-Wuerttemberg (FVA), Department of Societal Change, Wonnhaldestr. 4, 79100 Freiburg. Brsg., Germany

[7] University of Padova, Land Environment Agriculture and Forestry Department (TeSAF), Italy. Viale dell'Università 16, 35020 Legnaro, Padova, Italy

[8] Institute of Geography, University of Innsbruck, Innrain 52f, 6020 Innsbruck, Austria, and Faculty of Organic Agricultural Sciences, University of Kassel, Steinstraße 19, 37213 Witzenhausen, Germany

[9] University of Twente, Faculty of Behavioural, Management and Social Sciences, Ravelijn, The Netherlands

[10] Slovak University of Technology and Slovak Academy of Sciences, Vazovova5, 81243 Bratislava

[11] European Forest Institute, Yliopistokatu 6B, 80100 Joensuu, Finland

[12] Faculty of Organic Agricultural Sciences, Universityof Kassel, and Department of Agricultural Economics and Rural Development, University of Göttingen, Platz der Göttinger Sieben 5, 37073 Göttingen, Germany

[13] European Forest Institute (EFI), Platz der Vereinten Nationen; 753113 Bonn, Germany

Abstract

This paper analyses the occurrence of governance innovations for forest ecosystem service (FES) provision in the forestry sector in Europe and the factors that influence innovation development. Based on a European-wide online survey, public and private forest owners and managers representing different property sizes indicate what type of governance innovation activities they engage in, and why. To investigate forestry innovations as systems, the analysis focuses on biophysical, social and technical factors influencing innovation development. Our results show that most innovation activities are largely oriented towards biomass production. Accordingly, most forest owners implement efficiency-driven optimisation strategies for forest management and technological improvement for provisioning service supply, to generate income. In contrast, the provision of regulating and cultural services is not yet a prominent part of forestry innovation activities. Reasons are rooted in a market-oriented economic rationale focusing on timber production, which is related to a lack of financial resources to compensate for other FES provision or institutions to provide backup and security to forest owners and managers for engaging in innovation development outside wood production. If other FES beyond timber provision shall be provided, new forms of communication, cooperation and financing are needed. Given that the provision of a wide range of FES is a politically well-established objective for forest management in Europe, a strategy is needed that helps to align actors and sectors for supporting related forest management approaches and business models. The current revision of the forest related policy framework on EU level under the EU Green deal poses a window of opportunity for better fostering novel governance approaches for more sustainable FES provision.

Keywords Forest ecosystem services; forest governance; governance innovation; enabling factors; European forests; forest ownership

Introduction

European forests have multiple functions and provide a range of forest ecosystem services (FES) to society (García-Nieto et al., 2013; Saarikoski et al., 2018; Orsi et al., 2020). Yet, how this broad range of FES is being produced and how governance and innovation could effectively support the sustainable provision of FES has received less attention in forest science and policy. One reason is the traditional focus of professional forest management systems on increasing the efficiency of timber and biomass production (Winkel and Sotirov, 2016; Nichiforel et al., 2020). Indeed, standardized forestry practices and uniform forest management structures prevail, even when policy goals are directed towards multi-functionality (Puettmann et al., 2012; Sotirov and Storch, 2018; Sutherland and Huttunen, 2018; Aggestam et al., 2020).

Coinciding with intensified primary production processes, socio-political demand for the broad range of non-timber FES has grown, in particular for habitat provision, carbon sequestration and scenic beauty (Ranacher et al., 2017; Primmer et al., 2021). This has resulted in shifting focus in forest management approaches and policy objectives towards sustained flows of goods and services, beneficiaries' values and ecological functions (e.g., Bauhus et al., 2017a; Borrass et al., 2017; Grassi et al., 2017; Kleemann et al., 2020). These expanding expectations build on notions of sustainable forest management and multifunctional forest management. These have been institutionalised as a core forest policy paradigm and practice in many European countries (e.g., Messier et al., 2019; Sotirov et al., 2014), seeking to integrate timber production with a range of regulating and cultural ecosystem services (e.g., Winkel et al., 2011). However, to date, forest management decisions in most regions of Europe are heavily based on financial returns from timber production (as marketable products) and wood prices rather than the delivery of additional non-timber ecosystem services (Coll et al., 2018; Quine et al., 2013). Against this background it remains unanswered as to how novel and innovative ways of ecosystem service provision can be promoted and what context factors constrain or enable such innovations and vice versa.

Various aspects of forest governance in Europe pose challenges for institutional adjustments. One challenge to providing regulating and cultural forest ecosystem services lies in their character of being public goods and common-pool resources (e.g., Farley and Costanza, 2010).

FES such as water regulation, air filtration, or recreation are largely non-rival (Nichiforel et al., 2018), and users cannot be (easily) excluded from their consumption. Markets thus fail to determine their value and forest management approaches and reference systems can easily overlook such services. Examples of this are biodiversity conservation (Gamfeldt et al., 2013), climate change mitigation (Grassi et al., 2017), and cultural and recreational benefits (Plieninger et al., 2015). This often leads to their under-provision and/or under-valuation in many private and public forest management regimes (e.g., Dwyer et al., 2015). Another challenge is that the forestry sector is shaped by a range of policies besides forest policy, such as agriculture, energy, nature conservation, climate protection, and rural development (e.g., Winkel and Sotirov, 2016; Primmer et al., 2021). These sectors and their formal systems of rules are only partially aligned, leading to conflicts in objectives and management decisions for FES provision (Sotirov and Arts, 2018; Sotirov and Storch, 2018). For instance, it is hardly possible to achieve high carbon storage in a forest stand as part of a climate mitigation strategy, increase forest biodiversity as part of a Biodiversity Strategy, and simultaneously increase timber harvest as part of a National Policy Strategy on Bioeconomy (Bartkowski et al., 2015; Borys et al., 2016; Temperli et al., 2017).

As diverse as forest administrative levels and policy sectors are forest ownership structures. Approximately 40% of European forests are public or state-owned, while nearly 60% is private. One result of the heterogeneous ownership structure is differences in management priorities, ranging from a primary focus on timber production to the management of forest for urban population recreation or nature conservation purposes. Forest owner goals and types of forest owners vary across Europe and also within each institutional context, yet with some forest owner types across contexts associating with multifunctionality (Ficko et al., 2019). This diversity results in variation in the expectations that forest owners have for governance (Lawrence et al., 2020).

Due to the public good character of many FES, the institutional complexity, and variation in forest ownership and forest owner goals, governing the range of FES requires new and innovative approaches for coordination. In the past decades, various governance approaches emerged throughout Europe that support the provision of non-marketable FES or bundles thereof. These include for example changing silvicultural practices to more close-to-nature management or improving species mix in the stands (e.g., Puettmann et al., 2012; Bauhus et

al., 2017a; Krumm et al., 2020), but also the establishment of collaborative forest owner associations or forest policy processes (Primmer, 2011; Bowditch et al., 2020), the setup of certification systems, and the design of payment schemes for ecosystem services (Živojinović et al., 2015). Often these governance approaches emerge as pilot studies at local level. Some of them proved to secure conservation and social functions of forests, and were capable to provide alternative income streams for forest owners (e.g., Živojinović et al., 2015), while for many other governance approaches a systematic evaluation of their design, implementation, and outcomes are missing (e.g., Börner et al., 2020; Baylis et al., 2016).

To date, a systematic empirical analysis of the need for such novel governance approaches for the sustainable provision of FES has not yet been carried out. As a large number of factors influences the effectiveness and outcomes of forest governance, we develop here an integrated multi-disciplinary perspective that combines concepts and methods of social-ecological, socio-technical systems analysis (e.g., McGinnis and Ostrom, 2014; Ostrom, 2011) and innovation systems analysis (e.g., Asheim, 2011; Geels, 2011) and apply it in our empirical analysis of forest owner's views on their FES provision and governance innovations as well as the factors conditioning these. We structure our analysis along four research questions:

What type of governance innovations exist in European forests?
What is the relation between governance innovation types and FES they address?
What factors are enabling or hindering the development of governance innovations?
What is the influence of forest ownership type and forest size on the development of governance innovations?

This paper is structured as follows: Next, the theoretical foundation conceptualizing forestry systems as complex social-ecological-technical systems that foster or hinder governance innovation development and outcomes through context conditions is detailed in section 2. Section 3 describes the empirical analysis and the applied methodology building on a European-wide online survey that addressed forest owners and managers. Section 4 reports the findings regarding innovations and the factors influencing FES provision. In section 5 we discuss the potential and implications for the upgrading and upscaling of FES governance innovations in Europe. We conclude with implications for forest management, detailing policy and business recommendations as well as some guidance on future research in section 6.

Theoretical orientation

Forest ecosystem services (FES)

Since the 1990s, the concept of ecosystem services has been mainstreamed into science and policy, highlighting the essential role that ecosystems play in supporting both life and economic systems (e.g., Costanza et al., 1997; Daily, 2000; IPBES, 2018; Rasmussen et al., 2018). Since then ecosystem services frameworks and classification systems have been developed (MEA, 2005; Diaz et al., 2019). The Common International Classification of Ecosystem Services (CICES) (Haines-Young and Potschin, 2013) is widely acknowledged in science and policy, and employed in the EU initiative on Mapping and Assessment of Ecosystems and their Services (MAES) (EC 2014). For this analysis, we base our forest ecosystem services (FES) categorization on the CICES system (Annex B).

Governance innovation types

In this paper, we make use of pertinent innovation frameworks to elaborate on governance innovation types and influences for innovation establishment and development, especially related to transitions towards more sustainable resource uses and economic models (Geels and Schot, 2007; Smith and Stirling, 2010; Van Lancker et al., 2016; Lovrić et al., 2019). This framing is then tested in our empirical application in the forest owner survey.

Innovation is understood as the process of making changes to something established by introducing something new, organised as a holistic and collaborative approach (Van Lancker et al., 2016). These changes can be gradual and incremental or radical and disruptive. The innovation term can be applied to products, processes, or services, and in any organization (O'Sullivan and Dooley, 2009). Innovation is a social process within given cultural, scientific, technological, and/or political configurations that is often experienced or observed as open-ended, while also the context remains fluid (Rip, 2012). Innovation is thus not a straight-forward, linear process that can be programmed or would lead to precisely defined results (Smits et al., 2010).

Sustainable provision of the range of FES going beyond timber and biomass production requires novel approaches of actor constellations and coordination that we frame as

governance innovations. At its core, governance is about processes of interaction between societal and political actors and their interdependencies in a defined system (Kooiman, 2003). Governance structures concretize in institutions that organise processes, determine objectives, set standards, influence motivations, initiate or reduce conflicts, and resolve disputes among actors (Eden and Hampson, 1997). They execute these functions by ways of hierarchies, markets, networks, and/or hybrid arrangements (Williamson, 2004; Mayntz, 2004). Institutions and actors are linked through systems of knowledge production and information sharing and the political negotiation processes that lead to institutional design and their use and adaptation (e.g., Brockhaus and Angelsen, 2012). As governance innovations we consider new policies and governance arrangements resulting in novel forms of management that allow for a sustainable provision of FES to improve income sources or to provide alternative benefit streams. These governance innovations include the establishment of new markets and payment schemes for carbon sequestration and biodiversity preservation as well as novel actor alliances and collaborative networks, including their adapted or innovative means of communication, that foster improved value chains or bundles of provisioning, regulating, and cultural FES.

Governance innovations often have the character of process innovations, being closely related to social innovations by similarities in reconfigurations of existing institutions to novel social practices (Nijnik et al., 2019; Kluvankova et al., 2018). In addition, governance innovation may also refer to process, product and service innovations, when it comes to the establishment of a novel mode of actor collaboration or coordination approach. The latter can be a new policy (hierarchy), a new market or business model (markets), a new network of actors, such as public-private partnership (networks), or mixes thereof (hybrids). In particular hybrid governance approaches that combine market and self-governance components prove to be capable to address the complexity of the sustainable provisioning of FES and to overcome social dilemmas (Ostrom et al., 2011; Kluvankova et al., 2021). We elaborate these different types of governance innovations occurrence in European forestry contexts for FES provision.

Forestry system interactions and conditioning factors

On a conceptual level, links between the provision of ecosystem services and governance have often been defined as social-ecological systems (e.g., de Groot et al., 2010; Loft et al., 2016). The provision of FES is largely determined by biophysical conditions, such as climate, geography, ecosystem/forest conditions, and the past and present management decisions of the land owner or manager. The demand for FES, on the other hand, is determined by a set of socio-economic and political factors such as societal interests and institutions, actor constellations, and power relations amongst different groups and their capabilities to express and lobby for their FES demand. In addition, research into social-ecological systems has further recognised technology as a key factor for securing system resilience (Young et al., 2008). To assess the role of infrastructure, technical artefacts, and knowledge for change processes, conceptual inspiration comes from Socio-Technical-Systems (STS) research (e.g., Borrás and Edler, 2014; Smith and Stirling, 2010). Guiding this strand of research is a (quasi-)evolutionary understanding of technological change which regards technological innovation as an open-ended process, shaped in interactions between various actors and stabilizing gradually over time (Geels and Shot, 2007).

In summary, a forest management system in which innovations for FES provision develop can be understood as a social-ecological-technical system (Sorge and Mann, 2019). It provides particular conditions that are shaped by ecological, social (institutions/rules and actors), and technical conditions (infrastructures, knowledge) that can enable or hinder innovation development. These forestry systems are nested in larger systems, and influenced by external factors that are difficult to influence by the forestry systems, for example EU legislation or climate change. Taking on a system-based innovation understanding helps us to gain a more comprehensive picture on innovation establishment, in particular regarding the type of innovation, their relation to FES provision as well as regarding how innovation develops and what factors condition its emergence. In our survey, we test how the above-mentioned conditioning factors from different ecological, social, and technical system dimensions influence, i.e. enable or hinder innovation development for the provision of FES in Europe.

Material and methods

Survey design

To empirically analyse the factors influencing FES supply among forest owners and the factors influencing their FES provision and pertinent governance innovations, we conducted a European-wide online survey administered to private and public forest owners and managers using Maptionnaire software[29]. The survey was promoted by two H2020 Innovation Actions on novel policies and business models for the sustainable supply of forest ecosystem services (SINCERE and InnoForESt) as well as by the FOREXT network (see Annex A for the full survey). This paper reports the responses regarding FES governance innovations. A filter question selected respondents who stated to have implemented a FES-related governance innovation within the last two decades. It was followed by a total of six closed-ended questions (Table 1).

Table 1: Survey questions and their variables

	Question	**Variable**	**Type / measurement**
Q1	What type of forest ownership are you representing?	Land Tenure	Nominal / Multiple choice
Q2	Please state the size of the forest you own or are responsible for.	Forest size	Continuous / Whole number [ha]
Q3	Please describe what ecosystem services in view of: a) your forest area currently provides, and b) what societal demand for these services do you perceive.	FES supply	Continuous scale / independent
Q4	In relation to your forests, has there been such an innovation for at least one ecosystem service in the last two decades?	Presence of Innovation	Binary
Q5	Which innovations have you developed? [choice of 10] Please also separately mark the most economically important one, and the most innovative one.	Economic and innovative relevance	Binary / dependent
Q6	To what extent do the following 15 factors support or constrain the innovations you have been developing?	Influencing factors enabling and hindering innovation	Continuous scale / Independent

Variables, data selection, and statistical analyses

[29] https://maptionnaire.com/

Governance innovation types in European forests

To analyse general trends in the types of governance innovations that are developed by forest owners and managers across Europe, we only used datasets from respondents who answered 'yes' to question 4 (Q4) 'In relation to your forests, has there been such an innovation for at least one ecosystem service in the last two decades?'. For an overview, we applied descriptive statistics including frequencies to derive information about the statistical distribution of innovation types, objectives, and influences.

For the investigation of implemented governance innovations, ten specific innovations were offered for selection to forest owners and managers (Q5: 'Which innovations have you developed?'). These were supplemented with descriptive examples, for example, Q5_1 'New ecosystem service (e.g., a pollination strip or burial forest was newly established)'. Table 2 shows how specific innovations are linked to the conceptual orientation of the survey design referring to the FES categories they address, the governance innovation type, as well as type of innovation. In sum, the listed items represent all three governance innovation types defined (see section 2.2).

Table 2: FES specific innovations and their relation to FES categories, governance innovation type, and focus

Q5	Specific innovations offered for selection	Short name	Example provided in the Survey	FES categories addressed	Governance innovation type	Focus of innovation
Q5_1	New ecosystem service	New ES	e.g., a pollination strip or burial forest was newly established	Regulating, Cultural	Hierarchy, Market , Hybrid	Product / Service
Q5_2	New technology for biomass production	Technology biomass	e.g., usage of harvester instead of chainsaws or using satellite imagery for identifying logging sites	Provisioning	Market	Process
Q5_3	New technology for other ecosystem services	Technology other ES	e.g., a new technology for extracting resin	Provisioning	Market	Process
Q5_4	New way to generate value from ecosystem services	Value from ES	e.g., organizing auctions for high-quality timber or water protection	Provisioning, Regulating	Market	Communication

Q5_5	Change of forest management to improve / sustain biomass production	FM for biomass	e.g., new thinning measures for increased wood increment or for increased resilience	Provisioning, Regulating	Market	Process
Q5_6	Change of forest management to provide other ecosystem services	FM other ES	e.g., new thinning measures for growth of mushrooms or support nature tourism	Provisioning, Cultural	Market	Process, Product / Service
Q5_7	New communication or marketing strategy implemented	New communication	e.g., a website or a hired branding professional	Any	Market	Communication
Q5_8	New users of ecosystem service(s)	New users	e.g., children or urban citizens	Any	Network, Hybrid	Communication
Q5_9	New trans-sectoral contract created	New contract	e.g., a new agreement with conservation groups or eco-tourism enterprises	Regulating, Cultural	Hierarchy	Communication
Q5_10	New transboundary cooperation created	New cooperation	e.g., a sustainable tourism project across country borders	Cultural	Network, Market, Hybrid	Communication, Product / Service

Relation between FES and governance innovation types

The relationship between perceived supply of FES and innovations was analysed using answers to question 3 relating to ecosystem service provision and demand (see Table 1) with a scale ranging from 'not supplied/ demanded by society' to 'very much supplied/ demanded by society' (see Annex C "Conversion of continuous scale (1-100) to a 7-point Likert scale"). Based on the classes generated, values in the range 44-57 (value 4 on the Likert scale) were excluded from subsequent correlation analyses, to concentrate on the more meaningful values.

The addressed FES were analysed by calculating means for each FES supplied or societally demanded, and tested for normal distribution of individual variables (Kolmogorov-Smirnov test) with the use of histograms (see Supplementary Material Table S2 and S3). The distribution of variables relating to the 11 surveyed groups of FES was non-normal. Usually, more observations were found above the mean. Because a transformation of the continuous

scale from the survey was made, a reliability analysis was performed to check whether the 7-point Likert scale is equivalently suitable to measure specific FES. This scale reliability was tested using Cronbach Alpha measurement, which in case of FES sub-categories indicated a scale consistency $\alpha = 0.812$ (n=11). It is assumed that a Cronbach Alpha value ≥ 0.7 indicates a reliable and acceptable scale (Taber, 2018). By means of a correlation analysis, we then explored the relationship between perceived supply and societal demand of FES. Based on very high correlations for most FES, we decided to consider only the perceived supply for testing their relationship to governance innovation types.

In order to reduce the dimensionality and complexity of supplied FES variables and to check whether new factors would emerge from inter-correlated items, we carried out an exploratory factor analysis (Principal Axis Factoring Method) with Varimax rotation. We thereby identified FES categories, i.e., provisioning, regulating, and cultural FES (see Table 6) as perceived by forest owners and managers and later compared them with the CICES categories. The procedure of exploratory factor analysis includes also prior inspection of the power of the relationships and factorability of the variables involved in the analysis (Beavers et al., 2013). The suitability of the questionnaire data for factor analysis was tested. A first test, the Bartlett's Test of Sphericity checks whether there is or isn't a certain redundancy between items analysed that could be interpreted as a factor later on. It compares the observed correlation matrix of variables to the identity matrix, and checks if they are both the same. The sample adequacy was then checked with the KMO (Kaiser-Meyer-Olkin) Test which measures the degree of common variance among items selected for the factor analysis. Both tests revealed that the sample is adequate for the factor analysis (KMO=0.799) and the Bartlett's test was significant (Bartlett's test of sphericity $p=0.000$) $p<0.05$ which confirmed that the correlation matrix differs from the identity matrix so the factor analysis is proper to use.

In factor analysis it is crucial to determine the number of factors which will represent best the whole data set. The goal is to select only those factors which are representative and theoretically adequate (Fabrigar et al., 1999; Beavers et al., 2013). We based our selection on Eigenvalue criteria (Eigenvalue > 1), scree plot, and the percent of variance explained by each factor. The final decision should take into account the interpretability and accuracy of the selected factors (Beavers et al., 2013). Therefore, initially the three, four, and five-factors

solutions were investigated. Due to the highest total variance explained, clear factor loading values, and better comprehensibility the four-factor solution was chosen. The point-biserial correlation was then run, to determine the relationship between the resulting factors, respectively FES categories, and the governance innovation types being developed.

6.3.2.3. Conditioning factors enabling or hindering governance innovations

In order to understand the reason why some governance innovations emerge more often than others, we were interested in the conditioning factors that could influence, i.e. enable or hinder the emergence and development of innovations in the forestry sector. For analysis, responses to question 6 (Q6) 'To what extent do the following factors support or constrain the innovations you have been developing?' form the basis. Respondents could select the degree to which 15 predefined factors (Table 3) are supporting the respective innovation ranging from 'very strongly not supporting to very strongly supporting'. Similar as for question 3 the 1-100 scale was converted into a 7-point Likert scale to allow for a better interpretation of the results (see Table C in the Appendix).

These variables were tested against the normal distribution with the use of the Kolmogorov Smirnov test. Histograms were produced, for the 1-7 (without neutral values) and for standardized values 0-1 (see Supplementary Material Table S5 and Table S6). None of the variables confirmed a normal distribution of the data. The peak of the observations distribution was always on the extreme side of the scale (close to 1 or close to 7). The reliability of answers re-coded to the 7-point Likert scale was cross-checked by conducting the Cronbach Alpha test. The test indicated that the new Likert scale assumed for 30 variables reached acceptable reliability (Cronbach's Alpha = 0.819).

Table 3: Overview of potential influencing factors for governance innovation development offered in the survey, their system dimensions, and their codes used for the visualization of results

Q6 Factor codes	Factors conditioning the emergence of governance innovation	System dimension
Q6_1	Regulatory framework (laws and rules)	Institutional (Social)
Q6_2	Policy makers and stakeholders	Actors (Social)
Q6_3	Private sector and business	Actors (Social)
Q6_4	Societal demand for the ecosystem service	Actors (Social)
Q6_5	High profitability/viability before the innovation happened	Markets (Social)
Q6_6	Low profitability/viability before the innovation happened	Markets (Social)
Q6_7	Profitability of the innovation	Markets (Social)
Q6_8	Abundance of ecosystem services	Biophysical (Ecological)
Q6_9	Scarcity of ecosystem services	Biophysical (Ecological)
Q6_10	Knowledge available	Technical
Q6_11	Public financial support (e.g., subsidies)	Markets (Social)
Q6_12	(Access to) private investment capital	Markets (Social)
Q6_13	Culture of your organization	Institutional (Social)
Q6_14	Individual leadership	Actors (Social)
Q6_15	Climate change	External

To identify those factors that mostly influence the development of governance innovations by forest owners, the distribution of answers over all respondents and the mean values of perceived influence of these factors were analysed. Internal correlation between factors influencing the self-perceived "most economically important" and the "most innovative innovations" was tested. A correlation matrix was then developed to test the governance innovation types against the given influencing factors. Therefore, we calculated confidence intervals based on random sampling with a replacement (bootstrapping) of the survey responses (for all variables of Q3 and Q6). They represent confidence intervals that are data-specific and thus more realistic that the ones usually obtained – i.e. pre-sampling confidence intervals where the distribution of responses is unknown and thus assumed to be normally distributed.

Influence of forest ownership types and size

We explored how forest size and ownership type influenced the development of innovations in general (Q4), and the implementation of specific governance innovation types (Q5) in particular. Respondents could select one out of six predefined options for different types of private and public forest ownership (see Supplementary Material Tables S8 and Figure S3 and S4). An indication of the size of the forests under their responsibility was requested in hectares (ha) offering continuous values. Respective frequencies were examined together with the data distribution and the results of a correlation analysis, considering all types of governance innovations implemented or not.

All analyses were run with SPSS 26 and R (RStudio); graphs and tables were prepared with MS Excel. All graphs and tables produced are stored in the Supplementary Material

Participants description

In total, 1,234 forest owners and managers participated in the survey. Among them, 467 participants (37.85%) stated that they had developed a FES related innovation (Q4). Of these 467 respondents, 101 respondents did not further detail the innovations developed (Q5). The final dataset of respondents who implemented a specific innovation comprised 366 cases which in sum developed a total of 1,114 innovations and were the target of our analysis.

Respondents from 17 European countries participated in varying numbers (see Torralba et al., 2020a for details). Germany was the most represented country, followed by The Netherlands and Finland. In the dataset, the forest ownership types were distributed unevenly. The majority of respondents identified with 'Private ownership by individuals or families', while 'Public ownership by state at national level' was chosen by fewer respondents. Regarding forest size, small forest properties were more represented than large forest properties, with half of the respondents owning or managing properties less than 60 ha.

Results

Governance innovation types in European forests

Governance innovations were mostly developed for the improved provision of biomass (wood). Most prominently, 'Change of forest management to improve/sustain biomass production' and 'New technology for biomass production' together represent 34.8% of total governance innovation types, while 'Changes of forest management to provide other FES presented' and 'New technology for other ecosystem services' represented only 15.1 percent of total governance innovation types (Table 4). The innovations directly related to biomass provision are considered the most economically important and innovative ones.

Table 4: Governance innovation types developed by forest owners

Governance innovation type	The most economically important*	The most innovative	Total Innovations developed	% of Innovations developed
Change of forest management to improve/sustain biomass production	58	25	236	21.2
New technology for biomass production	67	37	151	13.6
Change of forest management to provide other ecosystem services	34	27	134	12.0
New way to generate value from ecosystem services	33	11	108	9.7
New users of ecosystem service(s)	20	15	108	9.7
New ecosystem service	28	32	107	9.6
New trans-sectoral contract created	22	21	99	8.9
New communication or marketing strategy implemented	19	18	86	7.7
New transboundary cooperation created	15	15	50	4.5
New technology for other ecosystem services (then biomass production)	14	13	35	3.1
TOTAL	310	214	1114	100.0

*Number of governance innovations stated

Relation between FES provision and governance innovation types

The majority of respondents indicated that their forests mainly supplied wood-based provisioning services, which were also the FES perceived as being most demanded by society (Table 5). The inter-item correlation analysis confirmed that the perceived demand and supply for each FES variable were highly correlated (see Table D in Annex). Comparing the mean value given to each FES by respondents, the supply of seven FES was perceived greater than the demand, in particular for the three regulating FES 'Habitat for plants and animals',

'Air quality regulation', and 'Climate change mitigation'. In contrast, FES that were considered more societally demanded than supplied by their forests included cultural FES such as 'Healthcare, sports and outdoor recreation', 'Education', and 'Wild forest products'. All correlations are significant at the 0.01 level (2-tailed), p-value < 0.01.

Table 5: Perceived FES supply and demand

	Mean		
FES sub-categories	**supplied**	**relation**	**demanded**
Wild forest products	43.56	<	51.41
Biomass (wood) for material	66.92	>	64.29
Biomass (wood) for energy	59.50	~	60.61
Cultural, emotional and spiritual values	64.55	>	57.93
Education	48.82	<	54.09
Game (hunting)	61.39	>	57.22
Healthcare, sports and outdoor recreation	62.04	<	66.72
Watershed protection	63.07	>	60.96
Air quality regulation	71.37	>	65.29
Climate change mitigation	77.99	>	70.73
Habitat for plants and animals	80.53	>	69.35
Valid N (listwise)	366		

Table 5 shows how FES such as 'Climate change mitigation' and 'Habitat for plants and animals' were perceived as the most supplied and demanded services with a higher perceived supply than demand. 'Biomass for material and energy' was perceived as having a balanced supply and demand while the culture related FES, 'Education' and 'Healthcare, sports and outdoor recreation' were perceived as in higher demand than currently supplied.

The conceptual allocation of the FES sub-categories using factor analysis is presented in Table 6. The resulting factors largely reflected the CICES FES categories from our conceptual framework, and could be interpreted as: regulating services (18% of the total variance), provisioning services (12%), cultural services (12%), and 'Wild forest products' as an extra provisioning service category (6%). Altogether they explained 48% of the variance. Table 6 displays all factor loadings, where significant factor loadings which contributed the most to specific FES categories are bolded.

Table 6: Four-factors of forest ecosystem services, based on 'perceived supply' data

FES sub-category	Regulating FES	Provisioning FES I (biomass and game)	Cultural FES	Provisioning FES II (other wild forest products)
Climate change mitigation	**0.779**	0.220	0.093	0.033
Air quality regulation	**0.740**	0.041	0.144	0.142
Habitat for plants and animals	**0.541**	0.152	0.318	0.003
Watershed protection	**0.490**	0.299	0.270	0.282
Biomass (wood) for material use	0.194	**0.764**	0.072	-0.041
Game (hunting)	0.062	**0.576**	0.131	0.230
Biomass (wood) for energy use	0.117	**0.511**	0.124	0.161
Education	0.121	0.146	**0.761**	0.096
Healthcare, sports and outdoor recreation	0.290	0.153	**0.627**	0.103
Wild forest products	0.101	0.199	0.114	**0.634**
Cultural, emotional and spiritual values	0.382	0.069	0.381	0.304
Eigenvalue	3.965	1.414	1.105	0.927
Explained variance (%)	18.160	12.981	12.471	6.312
Significant factor loadings are in bold (n=366, p = 0.000)				

The relationship between the governance innovation types and FES categories was then tested with a correlation matrix, using the FES factor scores derived from the Factor Analysis (Table 7). Significant correlations were found between the governance innovation type 'New ecosystem services' (Q5_1) and all four FES categories in a range from rpb = .137 to .208, p = 0.000. The correlations confirmed that the developments of a 'New technology for biomass production' were linked to 'Provisioning FES I (biomass and game)' (rpb = .224, p = 0.000).

A significant negative correlation was found only between the 'Change of forest management to provide other ecosystem services' and 'Provisioning FES I (biomass and game)' (rpb= -.119, p=0.023). The governance innovations 'New users of ecosystem service(s)', 'New trans-sectoral contract created', and 'New transboundary cooperation created' correlated significantly only with 'Cultural FES' (rpb = .168 to .188). No significant correlation was found for 'New way to generate value from ecosystem services' or 'Change of forest management to improve/sustain biomass production' with any of the FES categories, therefore omitted in Table 7. The category 'Cultural FES' is the one most significantly correlated with governance innovations especially with 'New ES' and 'New ways of communication and cooperation'. The complete correlation matrix with all variables and exact significance values can be found in the Supplementary Material, Table S9.

Table 7: Significant correlations between governance innovation types and FES categories

FES group / Governance Innovation type	Regulating FES	Provisioning FES I (biomass and game)	Cultural FES	Provisioning FES II (other wild forest products)
New ES	0.160**	0.137**	0.208**	0.142**
Technology biomass		0.224**		
Technology other ES				0.136**
FM other ES		-0.119*		
New communication		0.111*	0.188**	0.111*
New users			0.179**	
New contract			0.168**	
New cooperation			0.188**	

*Correlation is significant at the 0.05 level (2-tailed); ** Correlation is significant at the 0.01 level (2-tailed)

Correlation based on the results from Pearson's correlation matrix (n=366): measured as a point-biserial correlation matrix between the factors obtained in Factor Analysis (Table 6) and the governance innovation types (Table 4).

Factors conditioning the development of governance innovations

Several analysed conditioning factors appeared to influence innovation development. Table 8 presents the significant correlations between enabling/hindering factors for the self-perceived most economically important governance innovation types. To analyse whether factors were perceived as enabling or hindering innovation development, the mean value for each factor was calculated (see Supplementary Material Table S4). They range from 3.13 for 'Low profitability/viability before the innovation happened' up to 5.67 for 'Individual leadership'.

'Climate change' and 'Knowledge available' arise as strong enabling factors that contribute to 'New trans-sectoral contracts created' (Table 8). 'Climate change' together with 'Culture of your organisation' were seen as factors attracting 'New users of ecosystem service(s)'. Further, 'High profitability/viability before the innovation happened' and 'Private sector and business' are particularly enabling the development of 'New technology for biomass production' whereas 'Low profitability/viability before the innovation happened' is hindering these innovations. Negative correlations were found between 'Change of forest management to improve/sustain biomass production' and 'Individual leadership' as well as between 'High profitability/viability before the innovation happened' and 'Change of forest management to provide other ecosystem services'.

Table 8: Summary of significant correlations between factors enabling or hindering the most economically important governance innovation types

Governance innovation type (Q5)	Conditioning factor (Q6)	Correlation	P-value	Valid N (listwise)
New technology for biomass production	Private sector and business	0.239**	**0.001**	177
	High profitability/viability before the innovation happened	0.241**	**0.005**	135
	Low profitability/viability before the innovation happened	-0.204*	**0.022**	126
	Climate change	0.169*	**0.033**	159
Change of forest management to improve/sustain biomass production	Individual leadership	-0.169*	**0.048**	137
Change of forest management to provide other ecosystem services	High profitability/viability before the innovation happened	-0.185*	**0.031**	135
New users of ecosystem service(s)	Culture of your organization	0.213*	**0.013**	135
	Climate change	0.242**	**0.002**	159
New trans-sectoral contract created	Knowledge available	0.167*	**0.030**	170
	Climate change	0.193*	**0.015**	159

*Correlation is significant at the 0.05 level (2-tailed); ** Correlation is significant at the 0.01 level (2-tailed)

Correlation based on the results from Pearson's correlation matrix: measured as a point-biserial correlation matrix between the factors enabling or hindering the most economically important innovations and governance innovation types. Blue colour symbolizes a positive correlation between the factors and innovation types (enabling), red colour indicates a negative correlation (hindering factors). Only significant correlations between variables are presented in this table.

Influence of forest ownership and size on innovation development

An exploratory analysis of the influence of forest size and ownership types on governance innovation revealed that 'Public ownership by state at national level' is the least represented ownership type, but represents the larger forest properties (>470 ha). 'Private ownership by individual or family' is the most represented ownership type in the survey, but represents the smallest forest properties (0-8 ha) (Supplementary Material Figure S4).

Relating innovation development to ownership types, we found that 'Public ownership by state at sub-national, regional level' and 'Private ownership by private institution as church, foundation, etc.' develop governance innovations more often (>60%) than 'Public ownership by local government, municipality or equivalent' and 'Private ownership by individuals or families' (<35% each) (Figure 2).

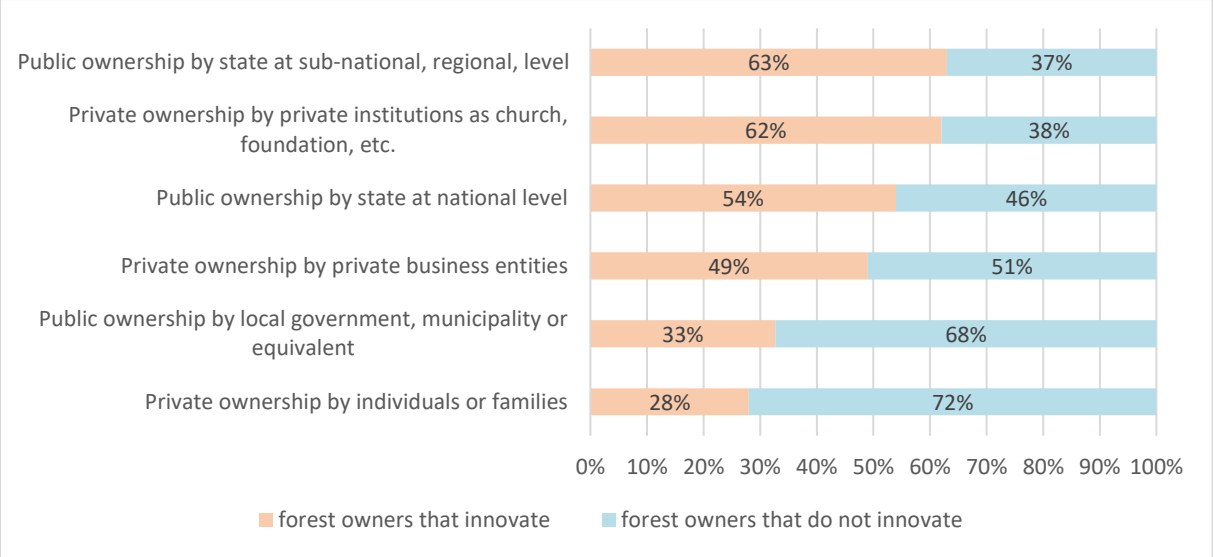


Figure 2: Development of innovations by forest ownership types

Analysing patterns of the relationships between forest ownership types and governance innovations, it appears that 'New technologies for biomass production' were developed by all forest ownership types. Inversely, 'New technologies for other ecosystem services' are commonly less developed by all types of forest owners and managers. The focus on biomass production was also reflected in innovations that target forest management practices, i.e. 'Change of forest management to improve/sustain biomass' is commonly more applied compared to 'Change of forest management to provide other ecosystem services'. Observing the general shapes of the curves, public national and regional forest owners seem to have rather comparable innovation strategies that differ from innovation strategies of other ownership types. Moreover, innovation strategies of public forest owners at the local/municipality level seem to be closer to those of private forest owners, with few exceptions (Figure 3).

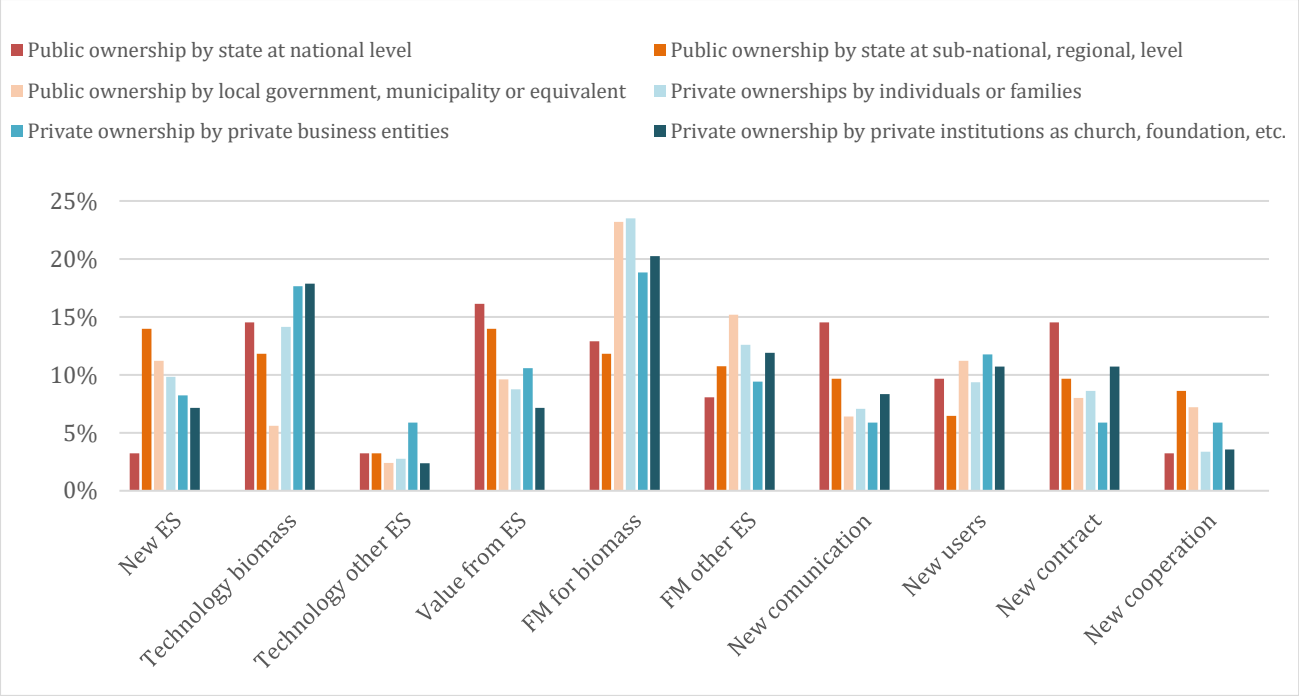


Figure 3: Types of innovation (in percentage) implemented by the different ownership types

Forest size also correlated with governance innovation development. In general, forest owners appeared to engage in innovation activities to improve/sustain biomass production rather than to provide other ecosystem services, independently of the size of the forest (Figure 4). Owners of small forest properties showed comparatively lower engagement for new technologies that support biomass production compared to owners with larger properties. However, we also found forest owners with smaller properties who innovated more in terms of changing forest management to provide other ecosystem services than owners with larger forest properties.

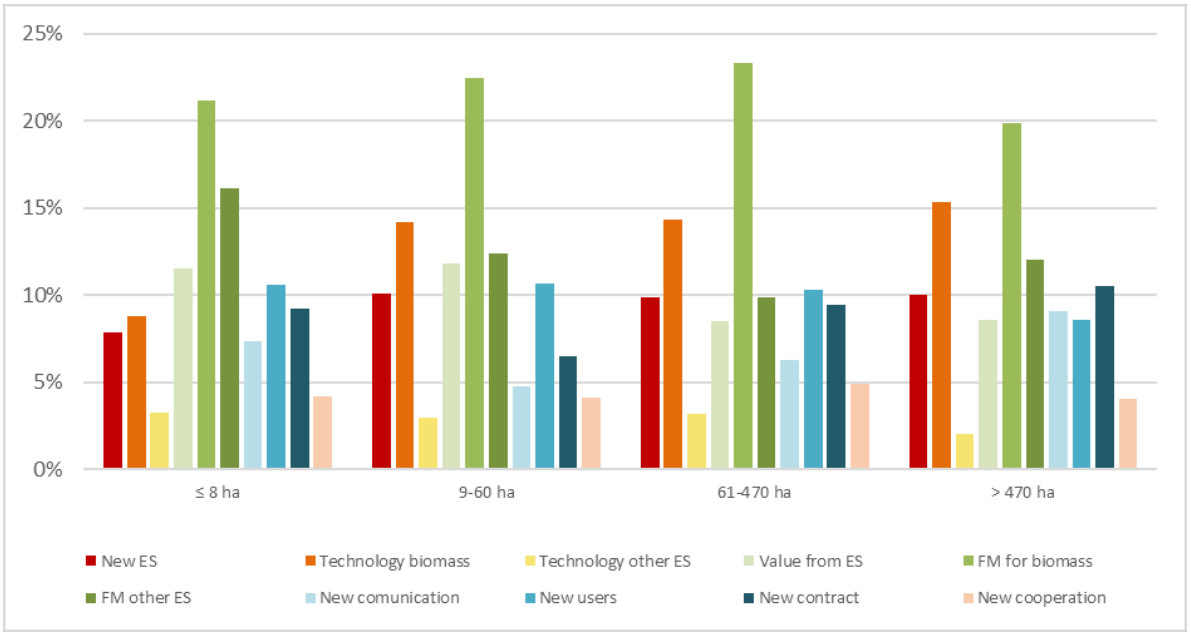


Figure 4: Types of innovation (in percentage) implemented in different sizes of forest properties

Discussion

In this paper, we analysed FES innovations potentials of private land owners and forest managers from all types of ownership in Europe to provide FES. We studied what governance innovations exist in the European context, the relations between governance innovations and the FES they address, as well as the factors that enable or hinder the development of innovations, including forest ownership and size of the forest property. As a result, we gained insights into forest owners' mindsets and perceptions about innovation processes related to FES that are currently provided and socio-economically demanded.

A snapshot of governance innovation types and FES provision in Europe

Our analysis of forest owners and managers developing governance innovations for FES provision offers insights on the social, economic, and ecological challenges the European forestry sector is currently facing. A central finding is that innovation activities are largely linked to biomass production. Most forest owners and managers - private like public – implement efficiency-driven optimisation strategies, i.e. new technologies for/or change of forest management to improve or sustain biomass production as provisioning services to generate income. They either change their forest management practices and/or invest in new technologies for biomass production, in particular for wood-chip production. This underlines that forestry related innovations largely continue the long history of focusing on material aspects of forestry through developing effective silvicultural practices (Puettmann et al., 2012) to satisfy respective local needs (Elbakidze and Angelstam, 2007) or provide industrial material (Eurostat, 2008) and create an effective wood-based value chain (Melnykovych et al., 2018; Prokofieva and Wunder, 2014).

The focus on biomass related innovations is understandable given the underlying economic rationale of provisioning services (Lindahl et al., 2017) and the public or common good character of many regulating and provisioning FES resulting in positive external effects. The latter makes it difficult to trade them at markets (Muradian and Rival, 2012) and with that to be incorporated in the "innovation system" of forestry companies oriented towards profits or financial stability. Yet, trade-offs in the provision of different FES exist (Hauck et al., 2013), as increasing provisioning services can reduce the provision of regulating and cultural FES. This

increases conflicts over forest uses, in particular between production and conservation functions, goods and services (e.g., Jellesmark et al., 2014; Kleinschmit et al., 2017). Land-use conflicts between timber production and provision of other FES can take different shapes, but can be severe and difficult to resolve, also relating to fundamentally different perceptions or worldviews of forests and forest management (Sotirov and Winkel, 2016). Forest management and external factors such as climate change influence the type, amount, and quality of ecosystem services provided by forests (Gutsch et al., 2018), and market or policy trends, for example related to advancing the bioeconomy to incentivize increased harvesting can increase trade-offs specifically with biodiversity conservation and cultural ecosystem services such as recreation (Bauhus et al., 2017b; Tyrväinen et al., 2017). Even though such regulating and cultural FES are promoted in various national and international policy agendas such as the EU Green Deal, the Biodiversity Strategy, and the EU Forest Strategy (Wolfslehner et al., 2020), the challenge to align the innovation perspectives of forest owners and managers with such policy demands remains.

Moreover, the development of policy instruments at local-regional level, strategic and tactical planning, and operational management that promote ecological, social, and cultural forest objectives still lag behind (Angelstam et al., 2018; Lindahl et al., 2017). Research on policy implementation shows that ambitious policies and concepts to integrate, for instance, biodiversity conservation with wood production face challenges in implementation, despite a substantial interest of forest owners and managers in regulatory (Winkel et al., 2015; Maier and Winkel, 2017) or cultural FES (Torralba et al., 2020b).

These findings underpin the necessity to establish stronger demand and reward systems for the broad spectrum of FES if ambitious policy objectives are meant to be implemented in forest management on the ground (cf. Kluvankova et al., 2021; Prokofieva and Gorriz, 2013). Social-political awareness is given but as innovation development may be associated with establishment and development costs, for example for new technologies or change of management to provide other FES or the identification of new user groups, these developments are (financially) burdensome and hence not undertaken by forest owners and managers (yet). Recognizing that about half of the responding forest owners and managers have indicated that they do innovate to provide other FES, to generate value or to identify new users, more advanced forms of policy instruments, operational management, and

financing schemes rooted in close communication and cooperation among stakeholders seem to be needed in order to foster this trend.

Factors enabling or hindering the development of innovations for FES

Using a system-based approach to understand the forestry contexts for innovation allowed us to gain insights into required context conditions for action. In particular, private forest owners and businesses whose innovation practices increase provisioning services with targeted management and market strategies and infrastructures are open to innovations. Also climate change and related adaptation needs are seen as an enabling factor for – or enforcing – innovations referring to forests carbon sequestration and mitigation potentials (Bowditch et al., 2020; Jordan and Hiutema, 2014). However, the low profitability of other FES, or bundles thereof, largely hinders innovation development in the private and public sector. For their provision, changes are needed on individual and institutional levels with help of governmental and state interventions.

On an individual level, individual leadership seems a crucial factor for "out of the box" innovations (i.e. innovations with other FES), while changes in forest management practices for improved biomass provision are negatively correlated with individual leadership. One might interpret this in a way that the path dependencies of the 'classical' forestry regime with its focus on optimizing biomass production are too strong and preventive to changes (Lindahl et al., 2017). Thus, requiring even more leadership and respective knowledge to explore new business or activities relating to new FES, niche innovation development, testing, and momentum for successful change (Geels, 2011). Forest owners responses indicate that in particular cultural FES are addressed with new communication and marketing strategies, and the identification of new users is a precondition for such service provision. This kind of innovations require changes not only on individual level but also in "the culture of organisation", to be open towards societal demands. Coordinated action and mechanisms to "open-up" and "broaden out" problem perceptions and solution development as well as to make necessary trade-offs explicit seems key (Karpouzolou et al, 2016; Meier et al., 2016; Lindahl et al., 2017).

On an institutional level, changes in demand structure for FES need to be accompanied by benefit transfers to FES providers before investments into innovation activities are considered. For governance, two pathways for action are supported by our analysis findings: one option is the design of new trans-sectoral contracts between public and private forest owners for better aligning FES demand and supply. These might directly link up to climate change pressures as a "hook" to support forest owners in changing their management focus as well as to respond to growing socio-political demands for regulating services that require the integration of new knowledge to overcome knowledge gaps. Examples are public-private partnerships for linking forest management with tourism demands and recreation activities or with nature conservation initiatives (Abruscato et al., 2020; Thellbro, 2018). The other option is to advance with payments for ecosystem services (PES). Research in other contexts showed that PES and other incentive-based instruments can foster the provision of regulating and cultural FES. But their design and implementation are challenging. Issues such as trust, fairness, and others' perceptions may play a crucial role in the process of establishing payment schemes (Prokofieva and Wunder, 2014; Primmer et al., 2014). Many PES programs reinforced conflicts over access and control over forest resources (Corbera et al., 2007; Sconfienza, 2017). To encounter this, a growing body of literature related to PES (Alpizar et al., 2015; Ferraro, 2014) and other incentive programs (e.g., Ashraf et al., 2014; Fryer et al., 2012) points out that building non-monetary decision-making preferences into policy instruments can increase conservation efforts and people's satisfaction with the transaction. Conversely, failing to do so can have unintended negative effects.

Finally, our results indicate the influence of forest ownership types and size on innovation activities. Land tenure appears to be more relevant than forest size for innovations. There is a tendency that private forest owners focus on innovations related to biomass production while the public sector seems more active in innovations for FES diversification. Given the high share of private forests in Europe this finding is important for formulating policy recommendations (Nichiforel et al., 2018). Knowing that a lack of formal rules for financing, collaboration and contracts are perceived burdens for FES provision in practice, these conditions require improvement for the private forestry sector to stronger convert towards multiple FES provision. In contrast, public forest owners show a higher attitude towards innovation development for new ecosystem services. This is not surprising due to the

common welfare orientation of public forests in general (Ruppert-Winkel and Winkel, 2011; Sotirov et al., 2017), and the chance for experimenting and diversifying forest products and services on large scale.

Discussion of methods

One limitation of our analysis is the uneven distribution of respondents in terms of geographical origin, ownership patterns, and distribution of forest size. This impacted statistical analysis to understand correlations between these factors and the implementation of innovations and, more specifically, of the different types of governance innovation. Another limitation was the large number of missing values. Some governance innovation types appear to be of very low interest and applicability by forest owners (like 'New technology for other ecosystem services', or 'New transboundary contract created') with consequently little data provided for them. For questions about factors influencing the governance innovation development about two third of the answers were empty. This issue led us to implement some modifications such as re-coding empty answers to „neutral" options, hence giving them a specific value. Because of the lack of big-size samples, we could not develop a regression model (binary logistic regression). The non-normal distribution of data restricted our analysis to exploratory statistics to see general trends in data distribution, factor analysis and correlation matrices. Other methods applied which might have allowed developing a binary logistic regression model to gain more information about relationships between variables and their influence was not successful. All this limits the representativeness of our findings. However, our findings do provide a snapshot of forest owner perceptions and attitudes towards governance innovations for FES provision in times of societal challenges with forests being a central part of the solution not yet sufficiently recognised.

Conclusions

Innovations in the European forestry sector to sustain FES are scarce and scattered, in particular for regulating and cultural services. The main obstacle for the latter is the reliance of forestry on a classic market-oriented economic rationale for biomass production that reinforces a timber production-oriented forest management paradigm. Due to the lack of competitive options for generating income, innovators are directed towards biomass production where the market exists. In addition this leads to a lack of financial resources to compensate for other FES provision as well as a lack of institutions that provide backup and security to forest owners and managers to engage in related governance innovation development for other FES. This poses a dilemma. However, foresters in Europe largely recognise the socio-political need to manage forests according to their various functions and roles to encounter today's challenges and to work towards future-resilient forests.

We see in our analysis that societal demand and motivation from forest owners and managers for improved ecosystem service delivery exists, but their supply requires institutional support that allows for needed transformations. On EU policy level, currently the Green Deal as well as revisions of the Forestry Strategy offer windows of opportunity to better foster FES provision on a European scale. More than before are forests at the heart of solution strategies for biodiversity conservation and climate change adaptation. These political quests need to become materialized for private and public forest owners to acknowledge and compensate their additional efforts for FES provision. What becomes visible is that currently mainly public forests undertake innovation activities for better service provisioning, while large parts of the private forest owners innovate largely only in relation to biomass production, following established market incentives. Considering the large share of forest area in Europe in private hands, leaving these actors out of the solution process is a lost opportunity. Prospectively the provision of biodiversity habitat, carbon sequestration, and recreation services should be an explicit part of the forestry portfolio and a management alternative where the EU provides a framework with a forestry strategy that helps to align actors and sectors for sustainable forests. It is promising that we find many good examples of innovations all over Europe that successfully provide the range of FES with functioning compensation mechanisms and collaboration efforts in place. These should serve as good practice examples for scientific as

well as practice exchange and for learning how to showcase functioning innovation development across sectors and scales (cf. Huber, 2008).

Acknowledgements

The research leading to these results has received funding from the European Union Horizon 2020 under Grant Agreement number 763899, InnoForESt project, and Grant Agreement number 773702, SINCERE project, within the two Innovation Actions.

References

Abruscato, S., Joa, B., Winkel, G. (Eds.), 2020. Governing and managing forests for multiple ecosystem services across the globe. Book of abstracts. International conference 26-28 February 2020, Bonn, Germany. European Forest Institute.

Agrawal, A., Chhatre, A., Hardin, R., 2008. Changing Governance of the World's Forests. Science Vol 320: 1460-1462.

Aggestam, F., Konczal, A., Sotirov, M., Wallin, I., Paillet, Y., Spinelli, R., … Winkel, G., 2020. Can nature conservation and wood production be reconciled in managed forests? A review of driving factors for integrated forest management in Europe. Journal of Environmental Management, 268, 110670.

Angelstam P., Elbakidze M., Lawrence A., Manton M., Melecis V., Pereira A., 2018. Barriers and bridges for landscape stewardship and knowledge production to sustain functional green infrastructures. In: Pereira A, Peterson U, Pastur G, Iverson L (eds) Ecosystem services from forest landscapes. Springer, Berlin, pp 127–167

Asheim, B. T., Smith, H. L., Oughton, C., 2011. Regional Innovation Systems: Theory, Empirics and Policy. Regional Studies, 45(7), 875–891. https://doi.org/10.1080/00343404.2011.596701.

Bartkowski B., Lienhoop N., Hansjürgens B., 2015. Capturing the complexity of biodiversity: A critical review of economic valuation studies of biological diversity, Ecological Economics, 113, 1-14.

Bauhus, J., van der Meer, P., Kanninen, M., 2010. Ecosystem Goods and Services from Plantation Forests. New York, USA: Earthscan.

Bauhus, J., Forrester, D.I., Pretzsch, H., 2017a: Mixed-species forests: the development of a forest management paradigm. In: Pretzsch H, Forrester DI, Bauhus J (eds) Mixed-species forests - ecology and management. Springer Verlag Germany, Heidelberg, pp 1–25.

Bauhus, J., Kouki, J., Paillet, Y., Asbeck, T., Marchetti, M., 2017b. How does the forest-based bioeconomy impact forest biodiversity? In: G. Winkel (Ed) Towards a sustainable European forest-based bioeconomy – assessment and the way forward. EFI What Science can tell us, 8, pp. 67 - 77.

Baylis, K., Honey-Rosés, J., Börner, J., Corbera, E., Ezzine-de-Blas, D., Ferraro, P. J., ... , Wunder, S., 2016. Mainstreaming Impact Evaluation in Nature Conservation. Conservation Letters, 9(1), 58–64. doi: 10.1111/conl.12180

Beavers, A.S., Lounsbury, J.W., Richards, J.K., Huck, S.W., Skolits, Gary, Esquivel, S.L., 2013. Practical considerations for using exploratory factor analysis in educational research. Practical Assessment, Research and Evaluation. 18. 1-13.

Bijker, W. E., Hughes, T. P., & Pinch, T. J. (Eds.), 1987. The social construction of technological systems: New directions in the sociology and history of technology. UK: MIT press.

Börner, J., Schulz, D., Wunder, S., Pfaff, A., 2020. The Effectiveness of Forest Conservation Policies and Programs. Annual Review of Resource Economics 2:19.1–19.20. doi/10.1146/annurev-resource-110119-025703

Borrás, S., Edler, J., 2014. The Governance of Socio-Technical Systems. Cheltenham, UK: Edward Elgar Publishing Limited.

Borrass, L.; Kleinschmitt, D.; Winkel, G., 2017. The „German model" of integrative multifunctional forest management – Analysing the emergence and political evolution of a forest management concept. Forest Policy and Economics, 77:16-23.

Borys, A., Suckow, F., Reyer, C., Gutsch, M., & Lasch-Born, P., 2016. The impact of climate change under different thinning regimes on carbon sequestration in a German forest district. Mitigation and Adaptation Strategies for Global Change, 21(6), 861-881.

Bowditch, E., Santopuoli, G., Binder, F., del Río, M., La Porta, N., Kluvankova, T., …,. Tognetti, R., 2020. What is Climate-Smart Forestry? A definition from a multinational collaborative process focused on mountain regions of Europe Ecosystem Serviceschttps://doi.org/10.1016/j.ecoser.2020.101113

Brockerhoff, E. G., Barbaro, L., Castagneyrol, B., Forrester, D. I., Gardiner, B., González-Olabarria, J. R., ... & Jactel, H., 2017. Forest biodiversity, ecosystem functioning and the provision of ecosystem services. Biodivers Conserv 26, 3005–3035. https://doi.org/10.1007/s10531-017-1453-2

Brockhaus, M., Angelsen, A., 2012. Seeing REDD+ through 4Is: a political economy framework. Analysing REDD+: challenges and choices. Center for International Forestry Research, Bogor, Indonesia, 15-30.

Byrnes, J. E., Gamfeldt, L., Isbell, F., Lefcheck, J. S., Griffin, J. N., Hector, A., Cardinale, B. J., Hooper, D. U., Dee, L. E., Emmett, D. J., Freckleton, R., 2014. Investigating the relationship between biodiversity and ecosystem multifunctionality: challenges and solutions. Methods Ecol Evol, 5: 111-124. doi:10.1111/2041-210X.12143.

Chaudhary, S., McGregor, A., Houston, D., Chettri, N., 2015. The evolution of ecosystem services: A time series and discourse-centered analysis. Environmental Science & Policy, 54, 25-34.

Coll, L., Amezteguib, A., Colletd, C., Löfe, M., Masonf, B., Pachg, M., Verheyenh, K., Abrudani, I., Barbatij, A., Barreirok, S., Bielakl, K., Bravo-Oviedom, A., Ferrarij, B., Govedaro, Z., Kulhavyp, J., Lazdinaq, D., Metslaidr, M., …, Ponettea, Q., 2018. Knowledge gaps about mixed forests: What do European forest managers want to know and what answers can science provide? Forest Ecology and Management 407: 106-115.

Costanza, R., d'Arge, R., De Groot, R., Farber, S., Grasso, M., Hannon, B., …, Raskin, R. G., 1997. The value of the world's ecosystem services and natural capital. Nature, 387(6630), 253-260.

Daily, G. C., 2000. Management objectives for the protection of ecosystem services. Environmental Science & Policy, 3(6), 333-339.

De Groot R. S., Alkemade, R., Braat, L., Hein, L., Willemen, L., 2010. Challenges in integrating the concept of ecosystem services and values in landscape planning, management and decision making. Ecological Complexity, 7, 260-272.

De Groot, R., Brander, L., Van Der Ploeg, S., Costanza, R., Bernard, F., Braat, L., ... Hussain, S., 2012. Global estimates of the value of ecosystems and their services in monetary units. Ecosystem Services, 1(1), 50-61.

Dwyer, J. C., Short, C. J., Berriet-Solliec, M., Gael-Lataste, F., Pham, H. V., Affleck, M., ... & Déprès, C., 2015. Public Goods and Ecosystem Services from Agriculture and Forestry – a conceptual approach. Pegasus Project Deliverable WP1.1. Brussels: IEEP. GrantAgreement 633814 http://pegasus.ieep.eu.

EASAC, 2020. Emissions Trading System: Stop Perverse Climate Impact of Biomass by Radically Reforming CO2 Accounting Rules. https://easac.eu/media-room/press-releases/details/emissions-trading-system-stop-perverse-climate-impact-of-biomass-by-radically-reforming-co2-accounting-rules/

Eden, L., Hampson, F. O., 1997. Clubs Are Trump: The Formation of International Regimes in the Absence of a Hegemon." Pp. 361–94, in J. Rogers Hollingsworth and Robert Boyer (Eds.), Contemporary capitalism: The embeddedness of institutions. Cambridge, England: Cambridge Univ. Press.

Elbakidze M., Angelstam P., 2007. Implementing sustainable forest management in Ukraine's Carpathian Mountains: the role of traditional village systems. For Ecol Manage 249:28–38

European Commission (EC), 2014. Mapping and Assessment of Ecosystems and Their Services: Indicators for Ecosystem Assessments Under Action 5 of the EU Biodiversity Strategy to 2020. 2nd Report – Final. February 2014.

EUROSTAT, 2008. Forest-based industries in the EU-27. Eurostat, Statistics in focus 74/2008

EUROSTAT, 2011. Forestry in the EU and the World.

Fabrigar, L. R., Wegener, D. T., MacCallum, R. C., Strahan, E. J., 1999. Evaluating the use of exploratory factor analysis in psychological research. Psychological Methods, 4, 272-299.

Farley J., Costanza R., 2010. Payments for ecosystem services: from global to local. Ecological Economics 69: 2060-2068.

Felipe-Lucia, M. R., Soliveres, S., Penone, C., Manning, P., van der Plas, F., Boch, S., …, Allan, E., 2020. Multiple forest attributes underpin the supply of multiple ecosystem services. Nature Communications 9, 4839 (2018)

Ficko, A., Lidestav, G., Dhubháin, Á.N., Karppinen, H., Zivojinovic, I. and Westin, K., 2019. European private forest owner typologies: A review of methods and use. Forest Policy and Economics, 99, pp.21-31.

Food and Agriculture Organization (FAO), 2010. Forest Resource Assessment. Main Report 2010.

FOREST EUROPE, 2015. State of Europe's Forests 2015.

Gamfeldt, L., Snäll, T., Bagchi, R., Jonsson, M., Gustafsson, L., Kjellander, P., …, Mikusiński, G., 2013. Higher levels of multiple ecosystem services are found in forests with more tree species. Nature Communications, 4, 1340.

García-Nieto, A. P., García-Llorente, M., Iniesta-Arandia, I., & Martín-López, B., 2013. Mapping forest ecosystem services: from providing units to beneficiaries. Ecosystem Services, 4, 126-138.

Geels, F. W., Schot, J., 2007. Typology of sociotechnical transition pathways. Research Policy, 36(3), 399–417. https://doi.org/10.1016/j.respol.2007.01.003.

Geels, F. W., 2011. The multi-level perspective on sustainability transitions: Responses to seven criticisms. Environmental Innovation and Societal Transitions, 1(1), 24–40. https://doi.org/10.1016/j.eist.2011.02.002

Gómez-Baggethun, E., Muradian, R., 2015. In markets we trust? Setting the boundaries of market-based instruments in ecosystem services governance. Ecological Economics, 117: 217-224.

Grassi G., House J., Dentener F., Federici S., den Elzen M., Penman J., 2017. The key role of forests in meeting climate targets requires science for credible mitigation. Nat Clim Change 7:220–226. https://doi.org/10.1038/nclimate3227

Gutsch, M., Lasch-Born, P., Kollas, C., Suckow, F., Reyer, C., 2018. Balancing trade-offs between ecosystem services in Germany's forests under climate change. Environ. Res. Lett. 13 045012.

Haines-Young, R., Potschin, M., 2013. Common International Classification of Ecosystem Services (CICES): Consultation on Version 4, August-December 2012. EEA Framework Contract No EEA. Contract No EEA/IEA/09/003.

Hauck, J., Görg, C., Varjopuro, R., Ratamäki, O., & Jax, K., 2013. Benefits and limitations of the ecosystem services concept in environmental policy and decision making: some stakeholder perspectives. Environmental Science & Policy, 25, 13-21.

Huber, J., 2008. Pioneer countries and the global diffusion of environmental innovations: Theses from the viewpoint of ecological modernisation theory. Global Environmental Change, 18(3), 360-367.

IPBES, 2018. Summary for policymakers of the thematic assessment report on land degradation and restoration of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. In: Scholes, R.; Montanarella, L.; Brainich, A.; Barger, N. et al. (eds) IPBES secretariat. Bonn, Germany

Jordan, A., Huitema, D., 2014. Policy innovation in a changing climate: Sources, patterns and effects. Global Environmental Change, 29, 387-394.

Karpouzoglou, T., Dewulf, A., & Clark, J., 2016. Advancing adaptive governance of social-ecological systems through theoretical multiplicity. Environmental Science & Policy, 57, 1-9.

Kleemann, J., Schröter, M., Bagstad, K. J., Kuhlicke, C., Kastner, T., Fridman, D., ... & Bonn, A., 2020. Quantifying interregional flows of multiple ecosystem services–a case study for Germany. Global Environmental Change, 61, 102051. https://doi.org/10.1016/j.gloenvcha.2020.102051

Kleinschmit, D., Arts, B., Giurca, A., Mustalahti, I, Sergent, A., Pülzl, H., 2017. Environmental concerns in political bioeconomy discourses. International Forestry Review Vol.19(1): 41-55.

Kluvánková, T., Brnkaľáková, S., Špaček, M., Slee, B., Nijnik, M., Valero, D., ... & Gežík, V., 2018. Understanding social innovation for the well-being of forest-dependent communities: A preliminary theoretical framework. Forest Policy and Economics, 97, 163–174.

Kluvankova, T., Nijnik, M., Spacek, M., Sarkki, S., Lukesch, R., Perlik, M., Melnykovych, M., Valero, D., Brnkalakova, S., 2021. Social innovation for sustainability transformation and its diverging development paths in marginalised rural areas. Sociologia Ruralis https://doi.org/10.1111/soru.12337

Kooiman, J., 2003. Governing as Governance. Thousand Oaks, California: Sage.

Krumm, F., Schuck, A., Rigling, A., 2020. How to balance forestry and biodiversity conservation - A view across Europe European Forest Institute and Swiss Federal Research Institute WSL. www document: https://www.wsl.ch/de/publikationen/how-to-balance-forestry-and-biodiversity-conservation-a-view-across-europe.html

Lawrence, A., Deuffic, P., Hujala, T., Nichiforel, L., Feliciano, D., Jodlowski, K., Lind, T., Marchal, D., Talkkari, A., Teder, M. and Vilkriste, L., 2020. Extension, advice and knowledge systems for private forestry: Understanding diversity and change across Europe. Land Use Policy, 94, p.104522.

Lindahl, K.B., Sandström, C., Stens, A., 2017. Alternative pathways to sustainability? Comparing forest governance models. Forest Policy and Economics 77: 69-78.

Loft, L., Mann, C., Hansjürgens, B., 2015. Challenges in Ecosystem Services Governance: Multi-levels, multi-actors, multi-rationalities. In: L. Loft; C. Mann & B. Hansjürgens "Governance of Ecosystem Services – Challenges for sustainable development", Journal of Ecosystem Services, Special Issue 16, pp. 150 – 157, DOI: 10.1016/j.ecoser.2015.11.002.

Loft, L., Lux, A., Jahn, T., 2016. A social-ecological perspective on ecosystem services. In: Potschin, M., Haines-Young, R., Fish, R. and Turner, R.K. (eds.) Routledge Handbook of Ecosystem Services. Routledge, London and New York, pp. 88-98.

Lovrić, N., Lovrić, M., Mavsar, R., 2019. Factors behind development of innovations in European forest-based bioeconomy. Forest Policy and Economics 111:102079.

Loorbach, D., 2007. Transition Management. New mode of governance for sustainable development. Utrecht: International Books.

Loorbach, D., 2010. Transition management for sustainable development: A prescriptive, complexity-based governance framework. Governance 23(1): 161-183.

Maes, J., Egoh, B., Willemen, L., Liquete, C., Vihervaara, P., Schägner, J. P., Grizzetti, B, Drakou, E.G., La Notte, A., Zulia, G., Bouraoui, F. Paracchini, M.L., Braat, L., & Bidoglio, G., 2012. Mapping ecosystem services for policy support and decision making in the European Union. Ecosystem Services, 1(1), 31-39.

Maier, C., Winkel, G., 2017. Implementing nature conservation through integrated forest management: A street-level bureaucracy perspective on the German public forestry sector. Forest Policy and Economics, 82, 14-29.

Masiero, M., Pettenella, D., Boscolo, M., Barua, S.K, Animon, I. & Matta, J.R., 2019. Valuing forest ecosystem services: a training manual for planners and project developers. Forestry Working Paper, No. 11. Rome, FAO. 216 pp. Licence: CC BY-NC-SA 3.0 IGO.

McGinnis, M. D., Ostrom, E., 2014. Social-ecological system framework: Initial changes and continuing challenges. Ecology and Society, 19(2). https://doi.org/10.5751/ES-06387-190230.

Meier, C., Lindner, T., Winklel, G., 2016. Stakeholders' perceptions of participation in forest policy: A case study from Baden-Württemberg. Land Use Policy 39: 166-176.

Maier, C., Winkel, G., 2017. Implementing nature conservation through integrated forest management: A street-level bureaucracy perspective on the German public forestry sector. Forest Policy and Economics, 82, 14-29.

Melnykovych, M., Nijnik, M., Soloviy, I., Nijnik, A., Sarkki, S., Bihun, Y., 2018. Social-ecological innovation in remote mountain areas: adaptive responses of forest-dependent communities to the challenges of a changing world. Science of the Total Environment, 613–614: 894–906. https://doi.org/10.1016/j.scitotenv.2017.07.065.

Messier, C., Bauhus, J., Doyon, F., Maure, F., Sousa-Silva, R., Nolet, P., Mina, M., Aquilué, N., Fortin, M.-J., Puettmann, K., 2019. The functional complex network approach to foster forest resilience to global changes. Forest Ecosystems, 6:21 https://doi.org/10.1186/s40663-019-0166-2

Miteva D. A., Pattanayak, S.K.; Ferraro, P.J., 2012. Evaluation of biodiversity policy instruments: what works and what doesn't? Oxford Review of Economic Policy 28(1): 69–92.

Miura, S., Amacher, M., Hofer, T., San-Miguel-Ayanz, J., & Thackway, R., 2015. Protective functions and ecosystem services of global forests in the past quarter-century. For. Ecol. Manag. 352, 35–46.

Mori, A. S., 2017. Biodiversity and ecosystem services in forests: management and restoration founded on ecological theory. J. Appl. Ecol. 54, 7–11.

Muradian, R., Rival, L., 2012. Between Markets and Hierarchies: The Challenge of Governing Ecosystem Services. Ecosystem Services, 1(1).

Nichiforel, L., Keary, K., Deuffic, P., Weiss, G., Thorsen, B. J., Winkel, G., ... & Mifsud, E. G., 2018. How private are Europe's private forests? A comparative property rights analysis. Land Use Policy, 76, 535-552. https://doi.org/10.1016/j.landusepol.2018.02.034

Nichiforel, L., Deuffic, P., Thorsen, B.J., Weiss, G., Hujala, T., Keary, K., Lawrence, A., Avdibegović, M., Dobšinská, Z., Feliciano, D. and Górriz-Mifsud, E., 2020. Two decades of forest-related legislation changes in European countries analysed from a property rights perspective. Forest Policy and Economics, 115, p.102146.

Nijnik, M., Secco, L., Miller, D., Melnykovych, M., 2019. Can social innovation make a difference to forest-dependent communities? Forest Policy and Economics 100, 207-213. https://doi.org/10.1016/j.forpol.2019.01.001 https://www.sciencedirect.com/journal/forest-policy-and-economics/special-issue/10H9J184QXV

Niemela, J., Palomo, I., Martinez Pastur, G., Peri, P., Preda, E., Priess, J., Santos, R., Schleyer, C., Turkelboom, F., Vadineanu, A., Verheyden, W., Vikström, S., & Young, J., 2018. Institutional challenges in putting ecosystem service knowledge in practice. Ecosystem Services, 29, Part C, 579-598.

O'Sullivan, D., & Dooley, L., 2009. Applying Innovation (I. SAGE Publications, Ed.). London, United Kingdom.

Orsi, F., Ciolli, M., Primmer, E., Varumo, L., Geneletti, D., 2020. Mapping hotspots and bundles of forest ecosystem services across the European Union. Land Use Policy 99, 104840 (2020).

Ostrom, E., 2011. Background on the Institutional Analysis and development framework. Policy Studies Journal, 39(1), 7–27. https://doi.org/10.1111/j.1541-0072.2010.00394.x.

Parrotta J, Trosper R (eds), 2012. Traditional forest-related knowledge: sustaining communities, ecosystems and biocultural diversity, vol 12. Series world forests. Springer, Dordrecht, pp 251–279

Plieninger, T., Bieling, C., Fagerholm, N., Byg, A., Hartel, T., Hurley, P., …, Van Der Horst, D., 2015. The role of cultural ecosystem services in landscape management and planning. Current Opinion in Environmental Sustainability, 14, 28-33.

Pohjanmies, T., Triviño, M., Le Tortorec, E., Salminen, H., Mönkkönen, M., 2017. Conflicting objectives in production forests pose a challenge for forest management. Ecosystem Services, 28, 298-310.

Potschin, M. B., Haines-Young, R. H., 2011. Ecosystem services: Exploring a geographical perspective. Progress in Physical Geography, 35, 575-594.

Primmer, E., 2011. Policy, project and operational networks: channels and conduits for learning in forest biodiversity conservation. Forest Policy and Economics, 13(2), pp.132-142.

Primmer, E., Paloniemi, R., Siilä, J. Tainio, A., 2014. Forest owners perceptions of institutions and voluntary contracting for biodiversity conservation: Not crowding but staying out. Ecological Economics, 103, 1-10

Primmer, E., Jokinen, P., Blicharska, M., Barton, D. N., Bugter, R., Potschin, M., 2015. Governance of Ecosystem Services: A framework for empirical analysis. Ecosystem Services, 16, 158–166. https://doi.org/10.1016/j.ecoser.2015.05.002.

Primmer, E., Varumo, L., Krause, T., Orsi, F., Geneletti, D., Brogaard, S., Aukes, E., Ciolli, M., Grossmann, C., Hernández-Morcillo, M., Kister, J., Kluvánková, T., Loft, L., Maier, C., Meyer, C., Schleyer, C., Spacek, M., Mann, C., 2020. Mapping Europe's institutional landscape for forest ecosystem service provision, innovations and governance. Journal of Ecosystem Services 27, 101225. https://doi.org/10.1016/j.ecoser.2020.101225

Prokofieva, I., Gorriz, E., 2013. Institutional analysis of incentives for the provision of forest goods and services: An assessment of incentive schemes in Catalonia (north-east Spain). Forest Policy and Economics, 37, 104–114. https://doi.org/10.1016/j.forpol.2013.09.005

Prokofieva, I., Wunder, S., 2014. Designing economic instruments for ecosystem services. From traditional regulation to economic instruments. In: T. Jellesmark, B.; R. Mavsar; L. Tyrvainen; I. Prokofieva, and A Stenger (ed) The provision of forest ecosystem services. Volume II: Assessing cost of provision and designing economic instruments for ecosystem services. What Science can tell us No 5. EFI, pp. 59-63.

Puettmann, K. J., Coates, K. D., Messier, C. C., 2012. A critique of silviculture: managing for complexity. Island press, Washington DC

Quine, C. P., Bailey, S. A., Watts, K., 2013. Sustainable forest management in a time of ecosystem services framework: common ground and consequences. J. Appl. Ecol. 50, 863-867.

Ranacher, L., Lähtinen, K., Järvinen, E., & Toppinen, A., 2017. Perceptions of the general public on forestry sector responsibility: A survey related to ecosystem services and forestry sector business impacts in four European countries. Forest Policy and Economics, 78, 180-189.

Rasmussen, L., Coolsaet, B., Martin, A., Mertz, O., Pascual, U., Corbera, E., Dawson, N., Fisher, J., Franks, P., Ryan, C., 2018. Social–ecological outcomes of agricultural intensification. Nat Sustain 1:275–282

Rip, A., 2012. The Context of Innovation Journeys. Creativity and Innovation Management, 21(2), 158-170. doi:10.1111/j.1467-8691.2012.00640.x

Ruppert-Winkel, C., Winkel, G., 2011. Hidden in the woods? Meaning, determining, and practicing of 'common welfare' in the case of the German public forests. European Journal of Forest Research, 130(3), 421-434.

Saarikoski, H., Primmer, E., Saarela, S-R., Antunes, P., Aszalós, R., Baró, F., Berry P., Garcia Blanco, G., Goméz-Baggethun, E., Carvalho, L., Dick, J., Dunford, R., Hanzu, M., Harrison, P., Izakovicova, Z., Kertész, M., Kopperoinen, L., Köhler, B., Langemeyer, J., Lapola, D., Liquete, C., Luque, S., Mederly, P., Smits, R. E., Kuhlmann, S., & Shapira, P. (Eds.), 2010. The theory and practice of innovation policy. An international handbook. Cheltenham: Elgar.

Saarikoski, H., Jax, K., Harrison, P. A., Primmer, E., Barton, D. N., Mononen, L., ... Furman, E., 2015. Exploring operational ecosystem service definitions: The case of boreal forests. Ecosystem Services, 14, 144-157.

Schwachula, A., Vila Seoane, M., Hornidge, A.-K., 2014. Science, technology and innovation in the context of development An overview of concepts and corresponding policies recommended by international organisations. ZEF Working Paper Series, ISSN 1864-6638.

Sconfienza, U.M., 2017. What can environmental narratives tell us about forestry conflicts? The case of REDD+. International Forestry Review Vol. 19(S1): 98-112.

Smith, A., Stirling, A., 2010. The politics of social-ecological resilience and sustainable socio- technical transitions. Ecology and Society, 15.1.

Sotirov, M., Schüll, E., Sällnas, O., Borges, J., Jonsson, R., Riemer, A., Eriksson, E., 2014. Future scenarios of forest management in Europe. Integral second policy brief. http://www.integral-project.eu/images/Documents/Publications/PolicyBriefs/INTEGRAL_policy_brief_2_v2015.pdf.

Sotirov, M., Winkel, G., 2016. Toward a cognitive theory of shifting coalitions and policy change: Linking the advocacy coalition framework and cultural theory. Policy Sciences, 49(2), 125-154.

Sotirov, M., Arts, B., 2018. Integrated Forest Governance in Europe: An Introduction to the Special Issue on Forest Policy Integration and Integrated Forest Management. Land Use Policy 79 (2018): 960-967.

Sotirov, M., Storch, S., 2018. Resilience through policy integration in Europe? Domestic forest policy changes as response to absorb pressure to integrate biodiversity conservation, bioenergy use and climate protection in France, Germany, the Netherlands and Sweden. Land Use Policy 79 (2018): 977-989.

Sutherland, L. A., Huttunen, S., 2018. Linking practices of multifunctional forestry to policy objectives: Case studies in Finland and the UK. Forest Policy and Economics, 86, 35-44.

Taber, K.S., 2018. The Use of Cronbach's Alpha When Developing and Reporting Research Instruments in Science Education. Res Sci Educ 48, 1273–1296, https://doi.org/10.1007/s11165-016-9602-2

Thellbro, C., Bjärstig, T., Eckerberg, K., 2018. Drivers for Public–Private Partnerships in Sustainable Natural Resource Management—Lessons from the Swedish Mountain Region. Sustainability, 10, 3914.

Temperli, C., Stadelmann, G., Thürig, E., Brang, P., 2017. Silvicultural strategies for increased timber harvesting in a Central European mountain landscape Eur. J. Forest Res., 136, 493–509.

Torralba, M., Lovrić, M., Bottaro G., Gatto, P., Pettenella, D., Winkel, G., Plieninger, T., 2020a. DELIVERABLE 1.3 Analysis and relationships between Forest ecosystem Services supply and demand, and Innovative mechanisms across Europe. H2020 project no.773702 RUR-05-2017 European Commission, 76pp.

Torralba, M., Lovrić, M., Roux, J. L., Budniok, M. A., Mulier, A. S., Winkel, G., Plieninger, T., 2020b. Examining the relevance of cultural ecosystem services in forest management in Europe. Ecology and Society

Tyrväinen, L., Plieninger, T., Sanesi, G., 2017. How does the forest-based bioeconomy relate to amenity values?. Towards a sustainable European forest-based bioeconomy, 92.

Van der Plas, F., Manning, P., Allan, E., Scherer-Lorenzen, M., Verheyen, K., Wirth, C., ... Fischer, M., 2016. Jack-of-all-trades effects drive biodiversity-ecosystem multifunctionality relationships in European forests. Nat. Comm. 7 (11109).

Van Lancker, J., Wauters, E., Van Huylenbroeck, G., 2016. Managing innovation in the bioeconomy: An open innovation perspective. Biomass and Bioenergy 90:60–69.

van Oudenhoven, A. P. E., Petz, K., Alkemade, R., Hein, L., de Groot R. S., 2012. Framework for systematic indicator selection to assess effects of land management on ecosystem services. Ecological Indicators, 21, 110-122.

Vatn, A. 2009. Cooperative Behavior and Institutions. The Journal of Socio-Economics 38(1): 188–96.

Viszlai, I., Barredo, J. I., San-Miguel-Ayanz, J., 2016. Payments for FES. SWOT Analysis and Possibilities for Implementation. Report, Publications Office of the European Union, EUR 28128, doi:10.2788/957929.

Wood, S. L., Jones, S. K., Johnson, J. A., Brauman, K. A., Chaplin-Kramer, R., Fremier, A., …, Mulligan, M., 2018. Distilling the role of ecosystem services in the Sustainable Development Goals. Ecosystem Services, 29, 70-82.

Williamson, O. E., 2004. Transaction Cost Economics and Agriculture: An Excursion. Pp. 19–39, in Guido Van Huylenbroeck, Wim Verbeke, and Ludwig Lauwers (Eds.), The Role of Institutions in Rural Policies and Agricultural Markets. Amsterdam: Elsevier.

Winkel, G., Gleißner, J., Pistorius, T., Sotirov, M., Storch, S., 2011. The sustainably managed forest heats up: discursive struggles over forest management and climate change in Germany. Critical Policy Studies, 5:4, 361-390. http://dx.doi.org/10.1080/19460171.2011.628002

Winkel, G., Blondet, M., Borrass, L., Frei, T., Geitzenauer, M., Gruppe, A., …, Turnhout, E., 2015. The implementation of Natura 2000 in forests: A trans-and interdisciplinary assessment of challenges and choices. Environmental Science & Policy, 52, 23-32.

Winkel, G., Sotirov, M., 2016. Whose integration is this? European forest policy between the gospel of coordination, institutional competition, and a new spirit of integration. Environment and Planning C: Government and Policy, 34(3), 496-514.

Wolfslehner, B., Pülzl, H., Kleinschmit, D., Aggestam, F., Winkel, G., Candel, J., Eckerberg, K., Feindt, P., McDermott, C., Secco, L., Sotirov, M., Lackner, M., Roux, J.-L., 2020. European forest governance post-2020. From Science to Policy 10; European Forest Institute, https:doi.org/10.36333/fs10.

Živojinović, I., Weiss, G., Lidestav, G., Feliciano, D., Hujala, T., Dobšinská, Z., Lawrence, A., Nybakk, E., Quiroga, S., Schraml, U., 2015. Forest Land Ownership Change in Europe. COST Action FP1201 FACESMAP Country Reports, Joint Volume. EFICEEC-EFISEE Research Report. University of Natural Resources and Life Sciences, Vienna (BOKU), Vienna, Austria. 693 pages. [Online publication]

Annex

A) Full survey

https://app.maptionnaire.com/en/5199/

B) Classification of Forest ecosystem services addressed in the survey

Category	Sub-Category	Examples
Provisioning	Biomass (wood)	Fibres, wood, timber for material use
		Wood for energy use
	Game	Hunting
	Wild forest products	Berries, mushrooms, nuts, medicinal plants
Regulating	Watershed protection	Water and erosion control
	Air quality regulation	Filtration, pollutant sequestration
	Climate change mitigation	Carbon sequestration and storage
	Habitat for plants and animals	Habitat provision and biodiversity, incl. pollinators or seed dispersal forest species
Cultural	Cultural, emotional and spiritual values	
	Education	Forest kindergarten, schools
	Healthcare, sports and outdoor recreation	Nature-based tourism

C) Conversion of continuous scale (1-100) to a 7-point Likert scale

Likert scale code	Range	Conceptual interpretation
1	1-14	very strongly not supplied/demanded
2	15-29	strongly not supplied/demanded
3	30-43	not supplied/demanded
4	44-57	neutral (discarded in analyses)
5	58-71	Supplied/demanded
6	72-86	strongly supplied/demanded
7	87-100	very strongly supplied/demanded

D) Perceived FES supply and demand

	Mean			Correlation
FES sub-categories	supplied	relation	demanded	supplied vs demanded
Wild forest products	43.56	<	51.41	0.642
Biomass (wood) for material	66.92	>	64.29	0.641
Biomass (wood) for energy	59.50	~	60.61	0.606
Cultural, emotional and spiritual values	64.55	>	57.93	0.605
Education	48.82	<	54.09	0.590
Game (hunting)	61.39	>	57.22	0.562
Healthcare, sports and outdoor recreation	62.04	<	66.72	0.551
Watershed protection	63.07	>	60.96	0.487
Air quality regulation	71.37	>	65.29	0.418
Climate change mitigation	77.99	>	70.73	0.320
Habitat for plants and animals	80.53	>	69.35	0.298
Valid N (listwise)	366			

E) Question of the survey regarding forest ownership (Chapter 3)

Question 1): What type of forest ownership are you representing? (Please mark the most relevant option. Answer is obligatory to proceed)
• Public ownership by the state at national level
• Public ownership by the state at sub-national (regional) level
• Public ownership by local government (municipality or equivalent)
• Private ownership by individual or family
• Private ownership by private business entity
• Private ownership by private institutions (e.g. church, foundation, etc.)
• Unknown Ownership / Other (please specify)

Supplementary material

All Tables S1-S9 and Figures S1-S4 can be found in the Supplementary material under the link:

https://nextcloud.hnee.de/s/eQTJ24kN5YxXopi

Appendix : Supporting publications

During the PhD research a precedent and parallel investigation has been finalised. Within this research, the effects of climate changes in the provision of forest ecosystem services by mountain forests have been determined. The research has been capitalised in a chapter of a book written in collaboration with CLIMO COST Action CA15226, Climate-Smart Forestry in Mountain Regions (CLIMO). Funded by the EU's Horizon 2020 COST Action programme. The book is titled "Climate-Smart Forestry in Mountain Regions". The full text is inserted in this dissertation in case the reader likes to deepen the topic.

Reference: ***Bottaro, G.***, *Gatto, P., Pettenella, D. (2021) Assessing the Economic Impacts of Climate Change on Mountain Forests: A Literature Review. In: Managing Forest Ecosystems, Vol. 40, Tognetti, R., Smith, M., Panzacchi, P. (Eds): Climate-Smart Forestry in Mountain Regions. Springer Nature, Switzerland, AG*