Forest Policy and Economics 145 (2022) 102849

Contents lists available at ScienceDirect

Forest Policy and Economics

journal homepage: www.elsevier.com/locate/forpol

Governing Europe’s forests for multiple ecosystem services: Opportunities, challenges, and policy options

Georg Winkel [a,*], Marko Lovrić [b], Bart Muys [c], Pia Katila [d], Thomas Lundhede [e], Mireia Pecurul [h], Davide Pettenella [i], Nathalie Pipart [c], Tobias Plieninger [j,k], Irina Prokofieva [h], Constanza Parra [c], Helga Pülzl [b,f], Dennis Roitsch [a,g], Jeanne-Lazya Roux [a,g], Bo Jellesmark Thorsen [e], Liisa Tyrväinen [d], Mario Torralba [j,k], Harald Vacik [m], Gerhard Weiss [f], Sven Wunder [l]

[a] Forest and Nature Conservation Policy Group, Wageningen University, P.O. box 47, 6700, AA, Wageningen, the Netherlands
[b] European Forest Institute, Yliopistokatu 6B, 80100 Joensuu, Finland
[c] Department of Earth & Environmental Sciences, KU Leuven, Celestijnenlaan 200 E, box 2411, 3001 Leuven, Belgium
[d] Natural Resources Institute Finland, Latokartanonkaari 9, 00790 Helsinki, Finland
[e] Department of Food and Resource Economics, University of Copenhagen, Rolighedsvej 23, DK-1958 Frederiksberg C, Denmark
[f] University of Natural Resources and Life Sciences Vienna, Department of Economics and Social Sciences, Institute of Forest, Environmental and Natural Resource Policy, European Forest Institute Forest Policy Research Network, Feistmantelstrasse 4, 1180 Vienna, Austria
[g] European Forest Institute, Platz der Vereinten Nationen 7, 53113 Bonn, Germany
[h] Forest Science and Technology Centre of Catalonia, Carretera de Sant Llorenç, km 2, 25280 Solsona, Spain
[i] University of Padua, Department of Land, Environment, Agriculture and Forestry TESAF, Viale dell'Università, 16, 35020 Legnaro, Italy
[j] Faculty of Organic Agricultural Sciences, University of Kassel, Steinstraße 19, 37213 Witzenhausen, Germany
[k] Department of Agricultural Economics and Rural Development, University of Göttingen, Platz der Göttinger Sieben 5, 37073 Göttingen, Germany
[l] European Forest Institute- Mediterranean Facility, St. Antoni Maria Claret 167, 08025 Barcelona, Spain
[m] University of Natural Resources and Life Sciences Vienna, Department of Forest and Soil Sciences, Institute of Silviculture, Peter Jordanstr. 82 1190, Vienna, Austria

ARTICLE INFO

Keywords:
Forest ecosystem services
EU forest policy
PES
Policy integration

ABSTRACT

Europe’s forest provide multiple ecosystem services for societies, ranging from provisioning (e.g. wood) and regulating (e.g. climate mitigation and biodiversity) to cultural (e.g. recreation) services. In this paper, we assess the state and prospects of forest ecosystem services provision in Europe, introducing new data from the European collaborative research projects SINCERE, NOBEL and CLEARING HOUSE, and combining it with findings from the literature. We identify six challenges (1 an insufficient alignment of FES supply and demand, 2 lacking policy integration, 3 ambiguous and conflicting regulatory frameworks, 4 a lack of precise information on FES demand and provision, and innovations to align both, 5 an increasing pressure to adapt to climate change, and 6 a striking diversity constraining European level policy solutions) and three opportunities (1 increasingly heterogenous forest owner objectives potentially matching pluralistic societal demands, 2 diversifying forest enterprises levering innovations in regulating and cultural ecosystem services provision, and 3 the potential of forests to mitigate climate change). Subsequently, we introduce four distinct but complimentary policy pathways for European forest policy to better align forest ecosystem services provision and demand: 1 Better monitoring of FES supply and demand, 2 Enhanced policy integration, 3 Payments for ecosystem services, and 4 Bottom-up participation and learning among ecosystem services innovators. We conclude by emphasizing the momentum that the EU Green Deal unfolds for a future European forest policy to incentivise the provision of multiple forest ecosystem services.

* Corresponding author.
E-mail addresses: georg.winkel@wur.nl (G. Winkel), marko.lovric@efi.int (M. Lovrić), bart.muys@kuleuven.be (B. Muys), pia.katila@luke.fi (P. Katila), thlu@ifro.ku.dk (T. Lundhede), mireia.pecurul@ctfc.cat (M. Pecurul), davide.pettenella@unipd.it (D. Pettenella), plieninger@uni-goettingen.de (T. Plieninger), irina.prokofieva@ctfc.cat (I. Prokofieva), constanza.parra@kuleuven.be (C. Parra), helga.puelzl@efi.int (H. Pülzl), dennis.roitsch@efi.int (D. Roitsch), jeanne-lazya.roux@efi.int (J.-L. Roux), bjt@ifro.ku.dk (B.J. Thorsen), liisa.tyrvainen@luke.fi (L. Tyrväinen), mario.torralba@uni-kassel.de (M. Torralba), harald.vacik@boku.ac.at (H. Vacik), gerhard.weiss@boku.ac.at (G. Weiss), Sven.wunder@efi.int (S. Wunder).

https://doi.org/10.1016/j.forpol.2022.102849
Received 2 May 2022; Received in revised form 16 September 2022; Accepted 18 September 2022
Available online 6 October 2022

1. Introduction

Forests and other wooded lands currently cover 43.5% of the EU's territory (European Commission, 2021). They provide European society with multiple forest ecosystem services (FES), which include provisioning services (e.g., wood for construction and energy, non-wood forest products), regulating services (e.g., local and global climate mitigation, hydrological regulation and soil protection) and cultural services (e.g., recreational and health benefits). Most forests in the EU are privately owned (58%), and a large share of the EU's forests is actively managed, in many cases primarily for wood production, but with substantial regional variation (Levers et al., 2014).

Forests offer employment and income along various value chains relating to wood and non-wood forest products, and multiple other FES (Winkel, 2017), including recreation and nature-based tourism (Tyrväinen et al., 2017a). Forest-based products and services play a critical role in the envisaged transition towards a European circular bioeconomy (Hetemäki et al., 2017). Furthermore, Europe's inhabitants appreciate forests as natural and recreational spaces (Ranacher et al., 2017; Ranacher et al., 2020). While nature-based tourism is mainly located in rural areas, most recreational forest use takes place in urban and peri-urban areas; both are examples of forests providing substantial health benefits (Tyrväinen et al., 2017a). Recent EU forest-related policies particularly emphasise the importance for biodiversity conservation and climate change mitigation (European Commission, 2021).

Aligning the variety of societal and political demands for FES with FES supply, given the management objectives that private and public forest owners define for their forests, is one of the main tasks for forest policy making in Europe (Wolfslehner et al., 2020). Matching supply and demand must be placed in the context of three interconnected mega-challenges faced by European forests: 1) the need to adapt forests to a rapidly changing climate (Seidl et al., 2017); 2) the progressing "biodiversity crisis" (Watson et al., 2018); and 3) the need to transition the economy towards greater reliance on renewable energy and materials (Hurmekoski et al., 2019; Navare et al., 2021). This paper provides ideas to guide future European forest governance towards such an alignment. To do this, we first identify challenges and opportunities related to the supply of FES in Europe. Subsequently, we outline four pathways for future European forest policy to address these challenges and seize the opportunities. Our paper complements recent work published by Mann et al. (2021) and Hernández-Morcillo et al. (2022) on challenges and solutions regarding FES in Europe, and Loft et al. (2015) on ecosystem services governance in general, thus together providing a robust basis for EU policymakers to (re-)consider policy approaches.

Methodologically, this paper is based on insights from the European research and innovation projects SINCERE (H2020), NOBEL (Forest Value ERA Network) and CLEARING HOUSE (H2020). A series of meetings between scientists in the first two projects identified key challenges and possible solution pathways for future EU forest policy. While challenges are basic tasks for policy to deal with, the discussions also identified specific opportunities that we add to the assessment of challenges. Challenges, opportunities, and solution pathways included in this paper were enriched by discussions with policy actors in two virtual events in September and December 2021, and through consultation of relevant scholarly literature. During the iterative process of internal and stakeholder discussions that accompanied writing this paper, the interconnectedness (and also partially ambiguity – as challenges may hold elements of opportunities and vice versa) of challenges, opportunities, and solutions became apparent (see also Hernández-Morcillo et al., 2022). While acknowledging interdependences and ambiguity, and the inevitable limits of the issues emphasised, we believe this paper has identified key challenges and opportunities, and points to main elements of an EU policy addressing these. As such, we are confident that it offers a valuable contribution for guiding EU policy-making in fostering multiple FES provision in Europe's forests.

2. Challenges for the supply of multiple forest ecosystem services in Europe

2.1. Insufficient alignment of FES supply and demand

FES can be conceptually approached by distinguishing supply and demand (Luck et al., 2009). Supply refers to forests' ability to supply ecosystem services (ES); it relates to forest attributes and is often significantly impacted not only by the size and location of the forest, but also its management. Demand refers to expectations and needs arising from forest beneficiaries, ultimately from the whole society.

Table 1 presents findings from a European-wide survey conducted within the H2020 project CLEARING HOUSE. Compiling 10,391 responses from 33 European countries, the survey provides data on the importance European citizens assign to different types of FES as an indication of societal demand. The key finding is that regulating and cultural FES were viewed as most important, while provisioning services were evaluated as considerably less important (Table 1). This finding is well in line with other studies on social perceptions towards forests (e.g., Pülzl et al., 2021), and on ecosystem services demand, as reviewed by Ranacher et al. (2020), as well as with studies assessing the welfare economic values of biodiversity as assigned by the public (Jacobsen and Hanley, 2009; Bakhtiari et al., 2018).

The findings displayed in Table 1 also correspond to the perceptions of forest owners and managers of the trends in societal demand for FES. Figs. 1 and 2 present findings from another European-wide survey on the importance of FES, conducted within the H2020 project SINCERE in collaboration with the H2020 project InnoForESt (see Mann et al., 2022). This survey focuses on forest owners' and managers' perceptions of various aspects relating to FES supply and demand.

Most forest owners and managers in the sample perceive that the societal demand for FES has increased or even strongly increased. Complementary to the societal perception survey data presented in Table 1, this increase is most significant for regulating FES, followed by cultural services, while it is less pronounced for provisioning services (Fig. 1).

Yet, the survey also shows that the relative importance of each FES does not correspond to their respective contribution to forest owners'/managers' income. Provisioning services – meaning mostly wood – are by far the most important source of income, while regulating and

Table 1
Importance of different FES for European citizens (Roitsch et al., 2022). Data is from a representative sample of 10,391 responses from 33 countries. The question posed was: "How important are the following benefits of this forest to you?" Citizens were asked to respond in reference to a specific forest they visit most often and that they could locate on a map. Scale: 0 = Not important, 100 = Most important.

FES (Provisioning, Regulating, Cultural)	Median	IQR	FES (Provisioning, Regulating, Cultural)	Median	IQR
Habitat for plants and animals (R)	95	21	Water quality and erosion (R)	80	40
Aesthetics (C)	95	22	Spiritual and cultural value (C)	80	39
Air quality (R)	95	21	Education	70	43
Human health (R)	93	23	Food from wild plants (P)	66	47
Carbon storage (R)	89	29	Employment (C)	50	50
Noise reduction (R)	85	32	Fuelwood (P)	31	56
Recreation (C)	82	38	Timber (P)	26	54
Natural hazard protection (R)	81	38	Hunting (P)	13	47
Temperature reduction (R)	81	38			

FES categories are "provisioning" (P), "regulating" (R), and "cultural" (C). The median value is the frequency distribution midpoint. The interquartile range (IQR) measures the range from the 75th percentile to the 25th percentile of the overall measured values.

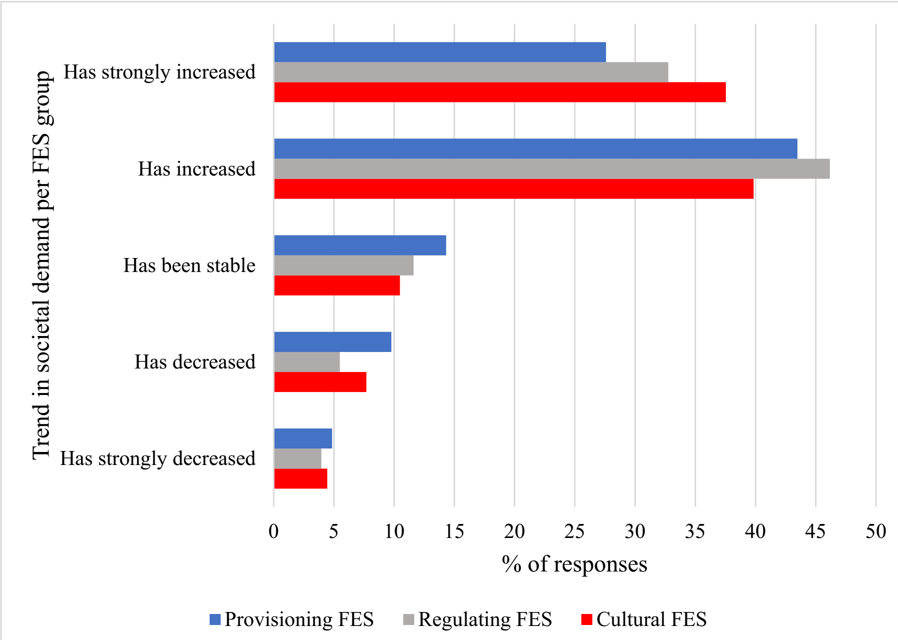

Fig. 1. Societal demand towards FES as perceived by European forest owners and managers (Source: Torralba et al., 2020). Data is from a sample of 1186 responses from forest owners and managers across Europe. The question posed was: “If you consider the last two decades, have societal demands for forest ecosystem services in your forest changed?” Respondents were asked to answer this question in reference to a specific forest in mind, that they own or manage. Answers were made on a scale from 0 (Has strongly decreased) to 100 (Has strongly increased). Values ranging between 0 and 20 were categorised as “Has strongly decreased”, between 20 and 40 as “Has decreased”, between 40 and 60 as “Has been stable”, between 60 and 80 as “Has increased”, and between 80 and 100 as “Has strongly increased”.

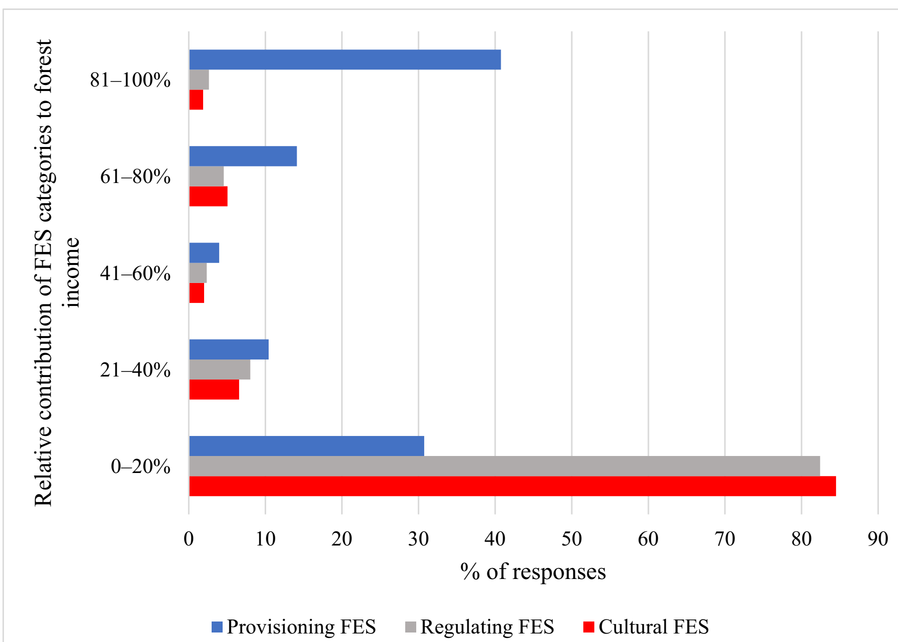

Fig. 2. Relative importance of forest income from provisioning, regulating and cultural FES as reported by European forest owners and managers (Source: Torralba et al., 2020). Same data source as for Fig. 1. The respondents were asked to assess the relative contribution of income linked to supplying provisioning, regulating, and cultural FES (including income from subsidies and other public funds) in the total forest income (expressed as percentages of total forest income).

cultural FES each provide less than 20% of forest owners' income according to a majority (over 80%) of the owners/managers surveyed (Fig. 2). The importance of provisioning FES for income was, according to the survey, even more pronounced in Northern and Eastern Europe, while income sources were more balanced across different ecosystem services in Southern and Western Europe.

Taken together, these findings point to a major challenge for European forestry: On average across Europe, while the stated societal demand for cultural and regulating FES is high (as measured by societal perceptions, Table 1) and is perceived by forest owners and managers to be increasing (Fig. 1), there is relatively less societal appreciation for provisioning FES such as wood and hunting (Table 1). By contrast, the reported economic importance of provisioning services for forestry enterprises and owners is high, with wood supply being by far the most important source of income (Fig. 2). Given potentially major trade-offs in forest management relating to the provision of regulating and cultural FES vis-à-vis provisioning FES (Torralba et al., 2020), the considerable mismatch between societal demands for, and potential income from, regulating and cultural FES is likely to result in a supply which is insufficient to satisfy societal demand. This calls for the development of an economic incentive system to tackle the mismatch (Section 4.3).

2.2. Lack of policy integration and missing political support for FES incentives

Many EU policies relate to forests and forest products, ranging from energy and rural development to biodiversity and climate protection, even though forest policy is only weakly institutionalised at the EU level (Pülzl and Hogl, 2013; Pülzl et al., 2018; Wolfslehner et al., 2020). Some of these policies approach forests from a single key perspective with ambitious targets (e.g., EU biodiversity policy targeting 30% protected, and 10% strictly protected areas, European Commission, 2020); others are broad yet generically lacking clear objectives and priorities (e.g., forest policy focusing on the SFM concept, see Winkel and Sotirov, 2016). There are ongoing disputes about the level and extent of EU competencies concerning forest issues (Winkel et al., 2013; Lazdinis et al., 2019; Wydra, 2013; Onida, 2020). Furthermore, EU forest policy is characterised by an ideological polarisation between environmental/conservation and forest use interests that adds to the competence issue (Winkel and Sotirov, 2016). Both ideological and competence related frictions play out in debates about the variety of forest-related policies (Sotirov et al., 2021). Many of these forest-related policies include their own objectives and goals, often targeting specific FES, resulting in a multiplicity of partly conflicting goals for forests (Wolfslehner et al., 2020; Aggestam and Pülzl, 2018; Edwards and Kleinschmit, 2013; Lazdinis et al., 2019; Pülzl et al., 2018; Pülzl and Hogl, 2013; Winkel and Sotirov, 2016). As a result, the challenges of prioritising among different policy goals are passed on to policy implementation at lower levels, from (sub-) national policy to practical forest management levels (Aggestam and Pülzl, 2020; Maier and Winkel, 2017; Roux et al., 2020).

Traditionally in most European countries, forest policies have focused mainly on wood production over other FES, such as non-wood forest products, or regulating and cultural FES (Wolfslehner et al., 2019; Weiss et al., 2011). This is also visible in the lack of support for innovation relating to FES other than wood and wood products (Rametsteiner and Weiss, 2006; Weiss, 2019), even though recent research indicates an increasing additional emphasis on biodiversity conservation (Primmer et al., 2021). For instance, while research has shown that non-wood forest products play a significant role for society, and to some degree also for the local economy, this significance is not visible in market statistics or other information systems, which tend to focus predominantly on wood production (Amici et al., 2020; Lovrić et al., 2020; Vacik et al., 2020). Consequently, the potential of non-wood forest products is often neglected by forest policymakers, who conceive them as "by-products" of sustainable wood production (Weiss et al., 2019a). In addition, established interests may hinder the development of new business models around forest products when they are seen as competing with existing production systems focusing on wood production (Buttoud et al., 2011). The same challenges apply for cultural ecosystem services: while they are sometimes acknowledged as policy goals in forest or bioeconomy strategies, incentives to manage forests for recreation and tourism are usually missing (e.g., Tyrväinen et al., 2017b).

In science and policy debates, market-based instruments (MBIs) (Anderson et al., 2010; Pagiola et al., 2002) have been proposed as a remedy or solution to incentivise the supply of ecosystem services other than biomass production (Engel et al., 2008). While the underlying theory for MBIs is well developed, the practice and literature on MBIs have expanded to include a multitude of actions and instruments, where many have found to have little influence on prices, costs or returns of economic agents, and hence little effect on their economic decisions (Gómez-Baggethun and Muradian, 2015). Furthermore, for key ecosystem services like biodiversity or watershed protection, the range of beneficiaries is so broad that state governments need to represent them. In these cases, market-based instruments can become state subsidies, which run the risk of becoming insufficiently performance-based or insufficiently targeted, and thus potentially inefficient (Weiss, 2000). Furthermore, market-based instruments may run against conventional bureaucratic logics of public administrations (Primmer et al., 2013). In the case of Natura 2000 in forests, research indicates that market-based instruments have been frequently proposed to resolve conflicts between biodiversity conservation and wood production but, paradoxically, have not been pursued seriously by governments or forestry interest groups because they are seen to run counter to wood production interests, and due to doubts about the permanence of such financial support (Weiss et al., 2017; Geitzenauer et al., 2017).

In sum, a lack of policy integration at least partially caused by underlying conflicting worldviews and political interests inhibits consistent MBI policy approaches for multiple FES. This emphasises the importance of policy integration and political agreement on systemic objectives if new policy instruments are to be advanced in Europe (Sections 4.2 and 4.3).

2.3. Ambiguous and conflicting regulatory frameworks

Conflicting policy objectives across policy sectors relating to ideological differences and divergent interests occur on all policy levels, and translate into diverging and often ambiguous regulatory frameworks for FES across EU countries. In the SINCERE-InnoForESt survey with European landowners and forest managers, the regulatory framework and policymakers/stakeholders are evaluated, respectively, as the second and third most inhibiting factor for FES-related innovations (Fig. 3).

The significance of these factors in the perceptions of land managers is not surprising, as the regulatory framework defines property rights for FES, which are a strong determinant for landowners' possibilities to innovate with FES supply. Across Europe, the institutional frameworks for FES vary greatly (see Fig. 4). While in northern Italy, for instance, the right to pick mushrooms can be sold privately, in Scandinavia mushrooms are predominantly a common-pool resource allocation, i.e., they can be collected by everybody free of charge. In some European countries, forest users can be excluded from specific types of recreational access (e.g., horse-riding), while in others not. Where these FES are supplied to society or specific groups of users for free (e.g., "everyone's right" regarding the collection of non-wood forest products and free recreational access to undeveloped land in some Nordic countries), or at a price that is far below the production costs of equivalent goods and services, forest owners have little or no monetary incentive to provide them. Hence, limited access rights can allow on-site markets for FES club or private good types to develop, whereas this will not happen for FES of a common-pool type when access is free. How far this enhances supply of such FES remains, however, subject to debate.

For public good FES with a spatial divide between ES provision and use – from watershed protection to climate change mitigation – beneficiaries cannot be excluded from enjoying any enhanced supply, even when they are far away from the supplying forests. In some cases, local PES schemes (e.g., within a watershed) can be developed to pay landowners to provide for these services. In other cases, especially at larger scales, regulation may need to ensure forest management practices for safeguarding such FES. Yet, regulation also risks shortcomings, such as lack of compliance, if not monitored and sanctioned effectively. Regulation may face opposition from landowners if it pushes ambitious targets that conflict with owners' (economic) interests. Furthermore, in contrast to market-based instruments, regulation may not be easily adaptable (e.g., to temporarily variable values and prices of FES, nor to a significant spatial heterogeneity of forest owner objectives (Boon et al., 2004; Vedel et al., 2015)). Consequently, regulation alone normally cannot ensure a societally optimal supply, leading to suggestions for organising FES governance through a mix of policy instruments (Winkel, 2007). However, adjusting different policy instruments in such a mix is also demanding: it will include contextually defining what is enhanced FES supply above the levels required by law. Yet, when payments to forest owners transform into legal compliance subsidies, FES additionality will be limited. In the worst case, already compliant providers may be disincentivised, causing some owners to reduce supply they would

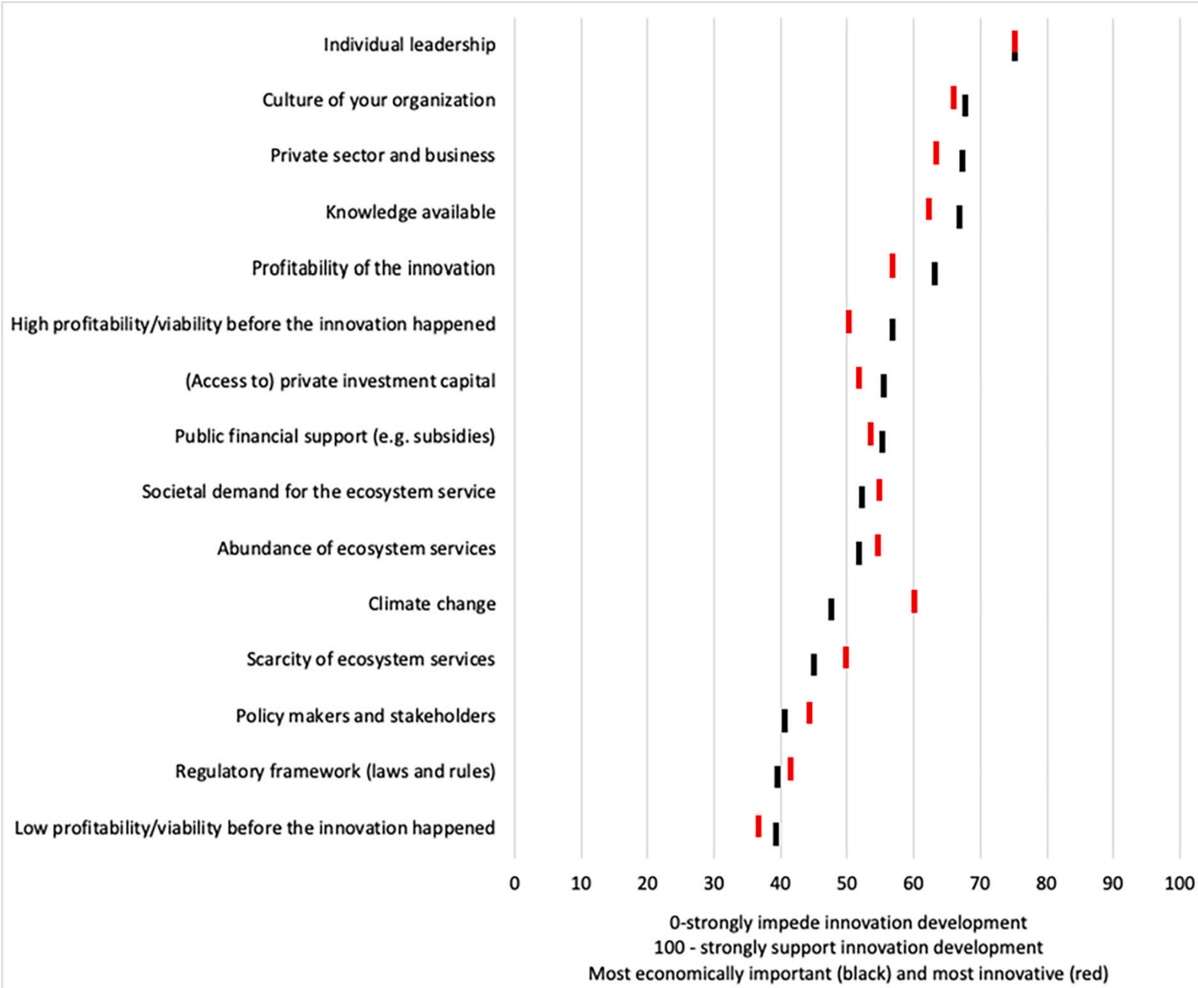

Fig. 3. Enabling and impeding factors for FES-related innovations, as reported by European forest owners and managers (Torralba et al., 2020, Mann et al., 2022). Forest owners and managers across Europe were asked, in case that they have developed some FES-focused innovation in the last twenty years, which factors have affected innovation development (scaled from 0 – strongly impeded to 100 – strongly supported). Please see Figs. 1 and 2 for specification of the surveyed sample.

have otherwise offered for free (motivational crowding-out) (Ezzine-de-Blas et al., 2019).

In sum, the interplay of regulation and FES innovations is critical for adjusting FES supply and demand. EU policy needs to acknowledge the strong variations in national regulatory frameworks, and any FES policy instrument must be contextualised vis-à-vis pre-existing regulations. Moreover, issues of fair competition may arise due to varying regulation on the EU common market and will need to be considered specifically when designing new market-based instruments at an EU scale (Section 4.3).

2.4. Lack of precise information on FES demand and provision, and innovations to align both

The practice of mapping and assessing existing ecosystems and their services is increasing among EU Member States. Several Spatial Information Platforms (SIPs) provide information on the spatial distribution of ecosystem services. Examples include the Ecosystem Services Partnership Visualization Tool (ESP-VT) developed by the Joint Research Centre, the Mapping and Assessment of Ecosystems and their Services (MAES) digital atlas, and CGIAR's Mapping Ecosystem Services to Human Well-Being (MESH). These initiatives, however, are not specifically designed to support the development and implementation of business models and policies for FES. A crucial gap is that they do not connect ecosystem services to related policy objectives and targets (for the latter see Primmer et al., 2021). Current SIPs are populated with information on the (potential) supply of ecosystems services, but they tend to lack spatial information about ecosystem services providers, beneficiaries, and demands for these services now and in the future. Moreover, the SIPs tend to utilise global, EU and national datasets, whereas business model development requires regional and local data as well.

Despite progressive advances in generating robust information on FES across Europe, there are still considerable knowledge gaps obstructing the practical operationalisation of FES data at a European scale and its integration into the design of forest governance instruments – ranging from information to financial instruments – and forest management practices, including operational forest management planning. The major obstacle is the lack of comprehensive datasets on (potential) supply, (potential) demand, and access to the full range of FES at different scales, as well as for the linkages between FES and specific forest areas, characteristics, and management approaches.

Forest inventories and forest management plans are decisive for how forests are managed. In many cases they focus largely on data relating to standing timber stock and forest growth, and partially to vitality (relating to biomass production) and related information (e.g., about soil fertility). Other services are usually not accounted for, despite their significant socio-economic importance, such as recreation or non-wood forest products (Sheppard et al., 2020). Biodiversity-related information remains scattered and scarce in forest inventories (Knoke et al., 2021;

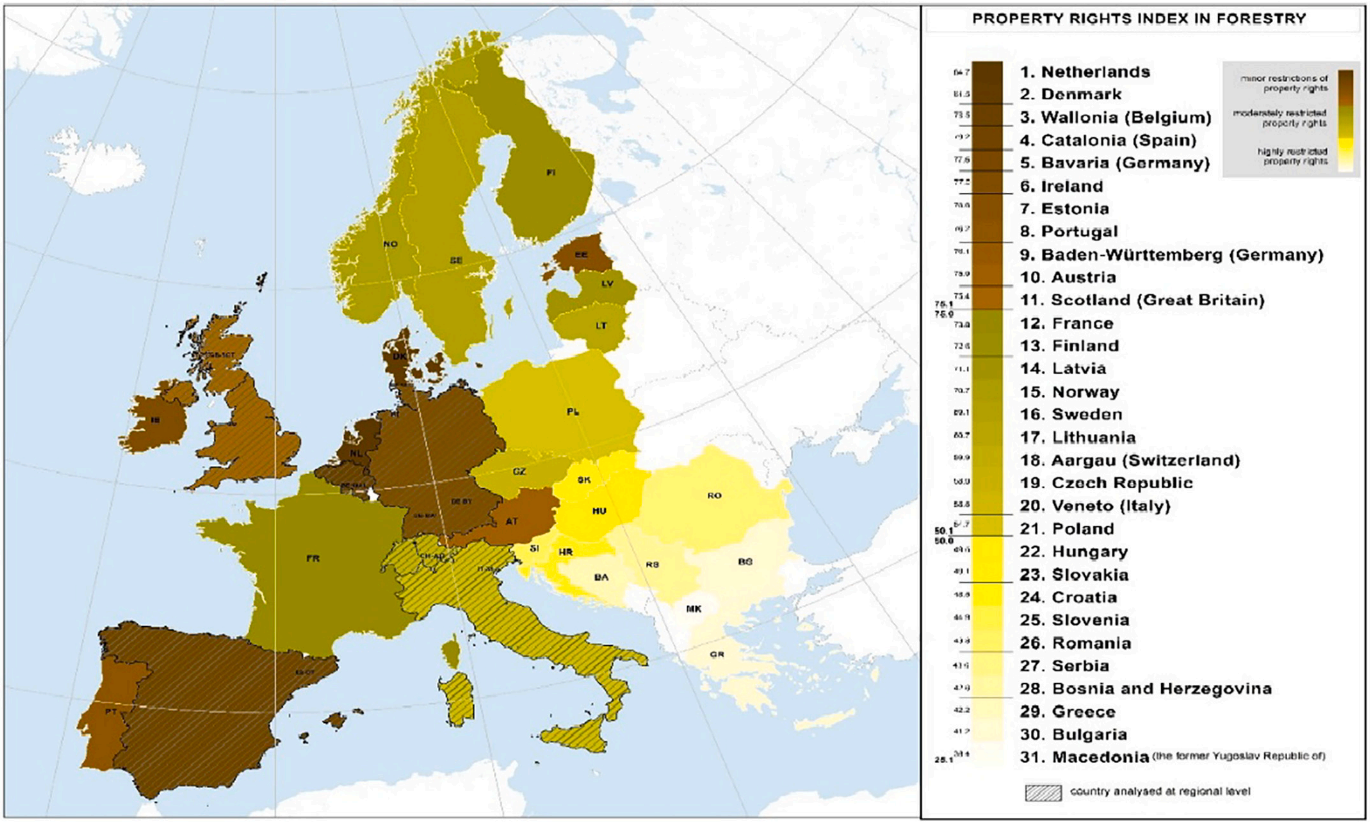

Fig. 4. Level of restrictions in private forest management identified across Europe (calculated based on 37 indicators assessing owner's rights (Nichiforel et al., 2018)).

Muys et al., 2022). Demand and access to FES other than wood production, and related changes, have received limited attention in the past, and are thus rarely reflected in management planning. Consideration of other demands is, however, necessary to successfully manage forests for a broad range of FES, and to integrate these demands into landscape or forest planning and management (Meyer and Schulz, 2017). In many contexts this results in a disconnect: whereas large-scale FES mapping activities focus on FES potential, regional and local operational forest management planning rarely consider this potential, and thereby inhibit innovation. Additionally, there is little information exchange regarding (business) models and innovations relating to FES other than wood, and extension services providing advice to forest owners largely focus on sustainable wood production and related silvicultural measures.

In sum, policymakers and forest managers will in many cases need more robust information on FES other than wood production if related policies and innovations are to be advanced. This calls for an effective monitoring system that gathers relevant information on both supply and demand for all key FES at relevant levels for decision making (Section 4.1).

2.5. Increasing pressure to adapt to climate change

Forests are increasingly affected by climate change and a related higher intensity and frequency of disturbances such as drought, fire, storms, pests and disease (Seidl et al., 2017). This situation challenges forest resilience and threatens the supply of FES (Nikinmaa et al., 2020). Innovative mechanisms to support a more balanced FES supply need to include climate change adaptation. Successful climate change adaptation strategies will increase the overall resilience of forests and the ecosystem services they supply.

How to pursue adaptation and ecosystem resilience depends significantly on the targeted ecosystem service(s). Mechanisms focusing on wood production and other provisioning ecosystem services emphasise "healthy" forests, the adoption of adapted tree species and genetic provenances, adapted management practices (e.g., shorter rotations, increasing thinning intensity), and enhancing climate change mitigation through an increased use of forest products. In contrast, mechanisms targeting regulating and cultural services, such as biodiversity conservation, may rather strive for low management intensity or protection, longer forest rotations, and increasing species mixture and unevenagedness. Arguably, there is substantial tension between these two perspectives, which are embedded in the general polarisation of conservation versus forest use interests described under the second challenge (Winkel et al., 2011; Winkel, 2013; De Koning et al., 2014). However, their integration may be possible at the landscape level.

Climate change adaptation adds substantial complexity and uncertainty for the development of innovations to support FES supply. Surveys among European forest managers showed a strong need for knowledge and information to address climate-related challenges (Sousa-Silva et al., 2018). Innovations related to FES supply can be greatly hampered by uncertainty regarding the future climate, and specifically with regard to increasing (perceived and manifested) risks to forest resilience (Messier et al., 2021). Here, climate change poses questions of hitherto "natural" interdependences and functions within forest ecosystems and how they are correlated with forest management, thus questioning also the basis for policy interventions that aim to incentivise a specific forest management strategy with the expectation of a certain FES outcome. For instance, PES schemes for carbon storage in forests may be hampered by increasing risks of disturbances (e.g., wildfires, or prospects of decreasing forest growths) that may greatly reduce the willingness of both FES suppliers and demanders to engage in such schemes. Similarly, other provisioning, regulatory or cultural FES may be compromised regarding options to manage their supply under progressing climate change.

In sum, adapting to climate change will be a key challenge to deal with when advancing policies for multiple FES (see also Hernández-Morcillo et al., 2022); depending on the situation and public/policy response, this challenge may prevent or enable FES (policy) innovations.

2.6. Striking diversity constraining one-size-fits-all solutions

Forests and the ecosystem services they provide across the EU are notably diverse. In the SINCERE-InnoForESt survey of forest managers and owners, the reported profitability of supplying provisioning FES increased along a gradient from South-Western to North-Eastern Europe, while no such clear geographical trends can be observed for the profitability of supplying regulating and cultural FES (Section 2.1).

Below, we illustrate the diversity of FES supply and demand with further examples. Fig. 5 provides an overview on the forest harvesting intensities across Europe in the 2000–2010 period (Kraxner et al., 2017, based on Levers et al., 2014), while Fig. 6 presents the percentage of households who engaged in the collection of non-wood forest products in 2015.

The significant regional variations in both figures exemplify the large variability of provisioning FES supply in Europe, shaped by the context-specific interplay related to demand and supply. In short, forest (wood) harvesting intensity is – as a rule – high in Central and Southern Scandinavia, Central Eastern Europe, and selected regions of the Atlantic coast in France and Spain, while it is low in large parts of the Mediterranean region (Fig. 5). In contrast, the percentage of households engaged in harvesting non-wood-forest products generally increases along a gradient from Western to Eastern Europe, partially correlated to the availability of forest land per capita (Fig. 6).

Differences in the demand for FES by society are also indicated in the findings of a representative European survey conducted in the CLEARING HOUSE project (Roitsch et al., 2022). Figs. 7, 8 and 9 illustrate societal perceptions regarding the importance of a specific forest for the provision of: 1) habitats for plants and animals (Fig. 7); 2) recreation (Fig. 8); and 3) timber production (Fig. 9). In short, the findings indicate significant regional variations in the importance attributed to these FES by citizens. For instance, wood production is generally considered more important in Northern and Eastern Europe. At the same time, as described earlier (Table 1), in all regions of Europe the reported societal demand towards FES mostly focuses on regulatory and cultural FES, and less on provisioning FES.

In sum, the notable diversity of FES supply and demand patterns across the EU emphasises the necessity for EU forest policy to consider a diversity of national and local settings in governing FES supply, and to possibly emphasise "bottom up" priority setting with regard to the ecosystem services local societies demand, and forests can provide (Section 4.4).

3. Opportunities related to forests supplying multiple ecosystem services

3.1. United diversity? Heterogenous forest owner objectives can match pluralistic societal demands

New opportunities for the supply of a broader set of FES arise from various social changes both on the side of forest owners and the potential beneficiaries. The changes can be categorised as: 1) increasing societal demand for FES; 2) new types of forest owners; and 3) changing ownership structures and new rural-urban interrelations impacting innovations.

On the first point, new market opportunities related to FES are mostly connected to the tertiary sector and an "experience economy" (Tyrväinen et al., 2017a, 2017b; Weiss et al., 2020; Haukeland et al., 2021; Zivojinovic et al., 2020). There is a growing demand for experiential services such as recreation and nature-based tourism, educational, health and wellbeing-related or spiritual activities in forests or in nature (Tyrväinen et al., 2017a, 2017b; Haukeland et al., 2021; Roux et al., 2022). Market trends for natural, retro- or sustainable products create

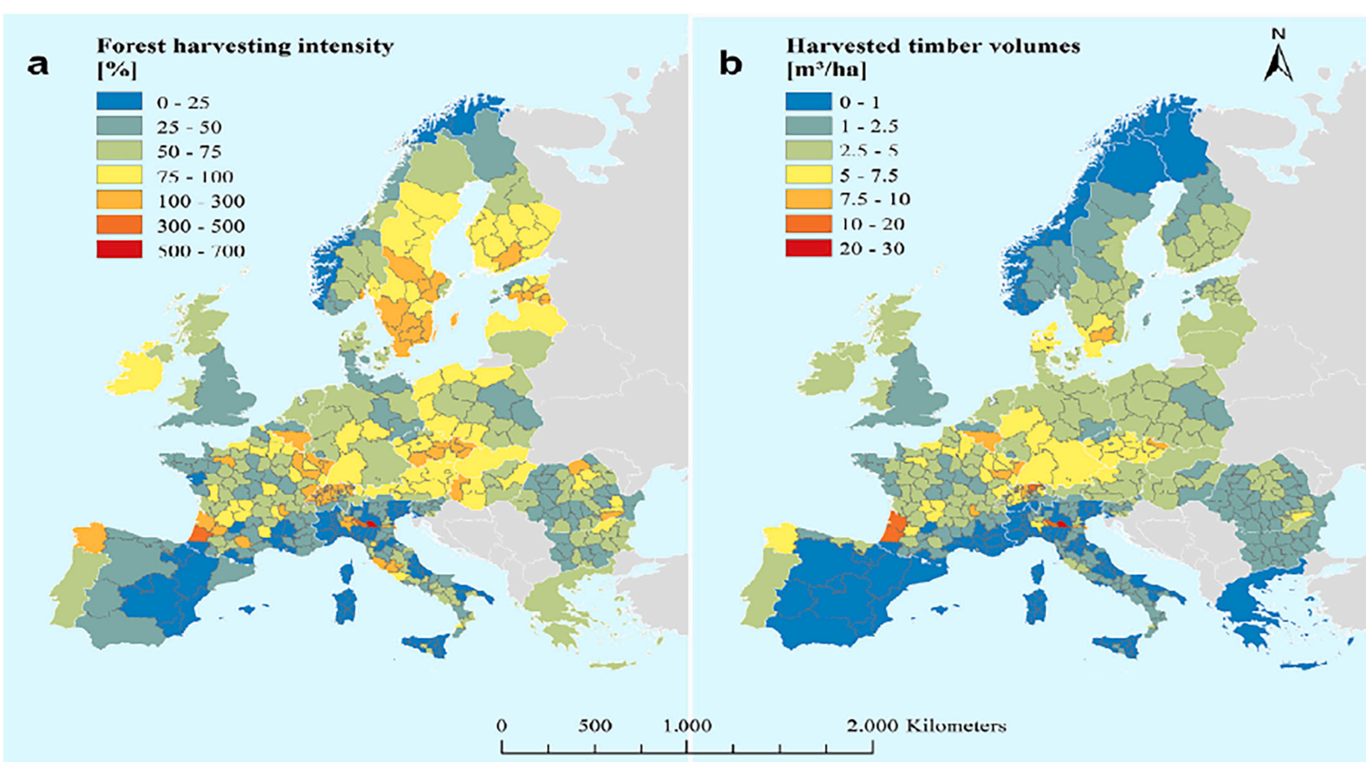

Fig. 5. Average harvesting intensity (a; %) and harvested timber volumes (b; m3/ha) for the period 2000–2010 (Source: Levers et al., 2014, here based on Kraxner et al., 2017).

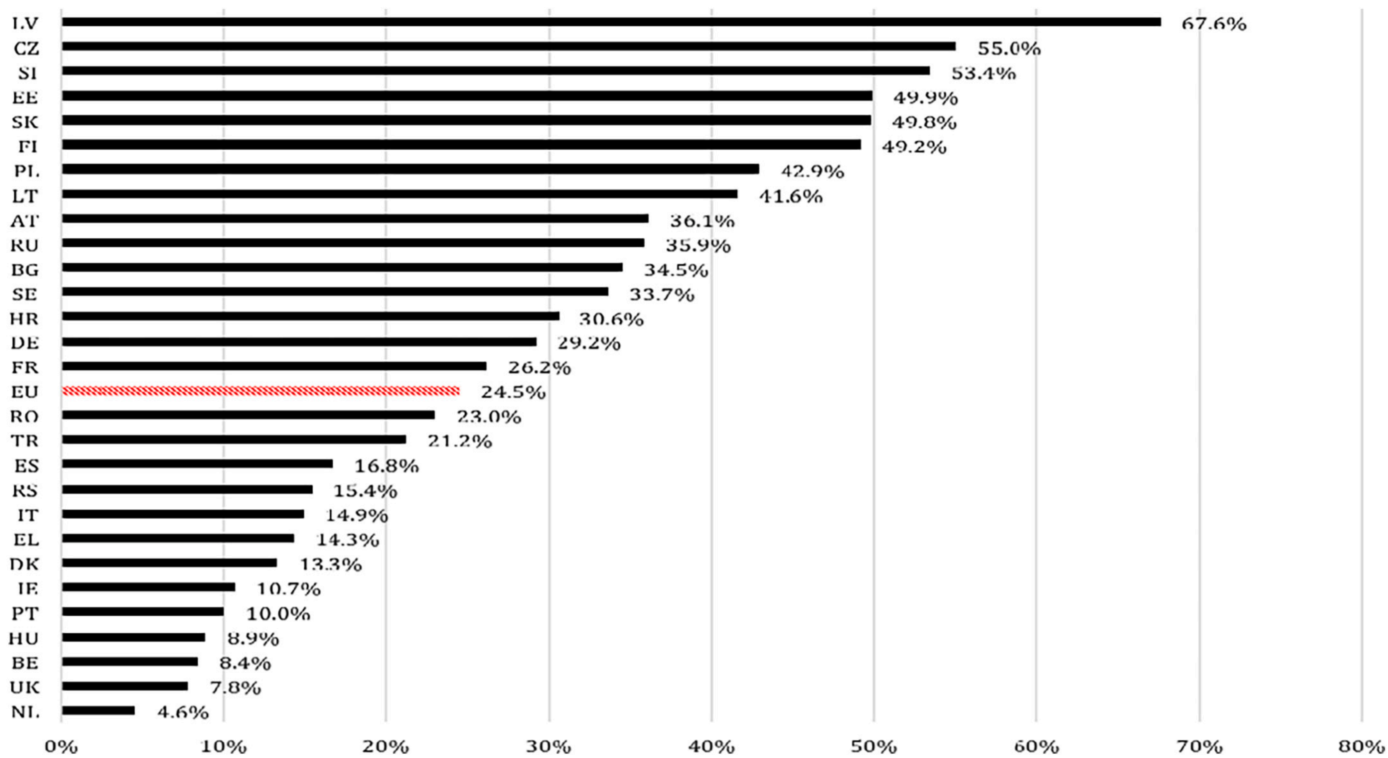

Fig. 6. Percentage of European households engaged in non-wood forest product harvesting in 2015 (Lovrić et al., 2020).

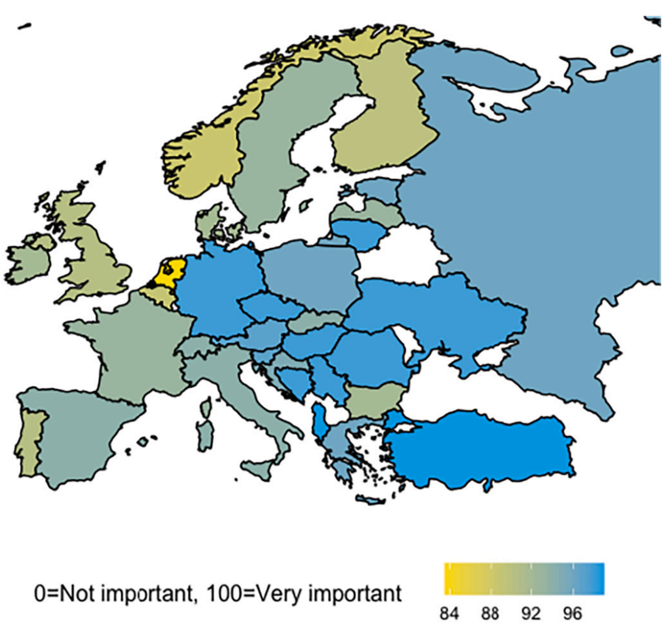

Fig. 7. Societal perception of the importance of a most frequently visited forest as habitat for plants and animals on a scale from: 0 = Not important to 100 = Very important (Roitsch et al., 2022). Data is from a representative sample of 10,391 responses from 33 countries (here *N* = 5658 as only those respondents who responded for a specific forest were considered). The question posed was: "How important are the following benefits of this forest to you?"

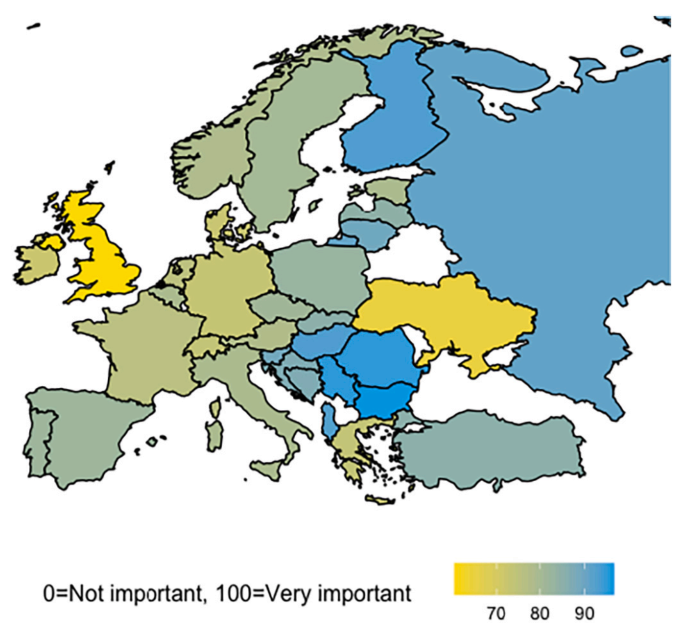

Fig. 8. Societal perception of the importance of a most frequently visited forest for recreation on a scale from: 0 = Not important to 100 = Very important (Roitsch et al., 2022). Data is from a representative sample of 10,391 responses from 33 countries (here N = 5658 as only those respondents who responded for a specific forest were considered). The question posed was: "How important are the following benefits of this forest to you?"

new demand for wild foods, traditional modes of production, as well as artisanal and handcrafted products (Huber et al., 2019; Weiss et al., 2019a; Wiersum et al., 2018).

Secondly, changing societal demands towards forests are also often mirrored in forest owners' values and expectations. Among private forest owners, there is an increasing share of "urban" or "non-traditional" forest owners who are not productively and economically dependent on farming or forestry, and/or hold "urban" values and attitudes towards forests (Boon et al., 2004; Vedel et al., 2015; Lidestav et al., 2019; Weiss et al., 2019b). Although they may only own small

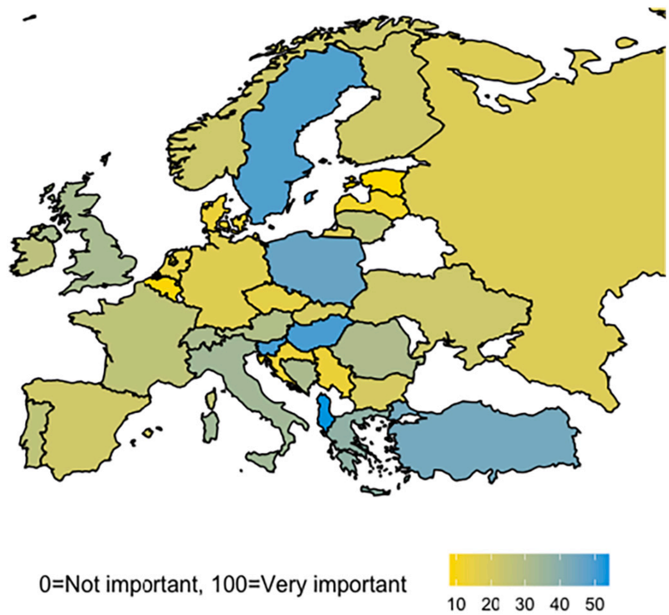

Fig. 9. Societal perception of the importance of a most frequently visited forest for timber production on a scale from: 0 = Not important to 100 = Very important (Roitsch et al., 2022). Data is from a representative sample of 10,391 responses from 33 countries (here N = 5658 as only those respondents who responded for a specific forest were considered). The question posed was: "How important are the following benefits of this forest to you?"

parcels far away from their home, shifting societal demands match those landowners' own ideas about their forests. This creates new opportunities for innovative business models for regulatory or cultural FES (e.g., environmental education, food forests, and nature art museums (Torralba et al., 2020; Weiss, 2013)) – or may simply result in an intrinsically motivated alignment of forest owners management practices with diversifying societal FES demand.

Finally, a broader spectrum of FES may also be provided through new forms of ownership, or relationships between forest management and users. Examples are new forms of common local forest ownership and social enterprises that support management for multiple or specific local forest values or services (Lawrence et al., 2020; Barlagne et al., 2021; Lidestav et al., 2017; Ludvig et al., 2018). Another example of social and institutional innovation is participatory forest management on state or municipal forest land or local partnership formats, such as the Model Forest approach and movement (Angelstam et al., 2019). Rapidly evolving IT and virtual networks and marketplaces may offer additional possibilities to connect FES suppliers with the demand side (Bingham et al., 2021). Web-based auctioning platforms support both the analysis of trade-offs among multiple FES and the design of business models. They further allow forest owners to learn about the future effects of different management options in the provision of FES, and to identify an optimal, marketable combination (Tóth et al., 2010).

In sum, the diversification of both FES suppliers and demanders, together with new IT options and innovative governance formats, creates a fertile ground for both policies and bottom-up innovations that aims to ensure diversified supply and demand can meet.

3.2. Money for everything? Rising demand and diversifying forest enterprises may lever innovations in regulating and cultural FES

In recent years there has been an increase in innovations relating to the supply of regulating and cultural FES (Section 3.1). On the side of landowners and managers, these innovations may also result from increasing climate change-related risks, unsteady prices, and the related pressure to diversify incomes away from an exclusive focus on wood. Innovative business models include, for instance, funeral forests or natural burials (Becher, 2022) which are now widespread in parts of Central and Western Europe, creating new cultural FES-related income possibilities for landowners (Mäntymaa et al., 2019; Tyrväinen et al., 2020), or innovations in the health sector, where small initiatives and businesses work with or in forests for targeted therapeutic or treatment interventions, social inclusion and rehabilitation, and health prevention with clinical assistance to promote people's health and well-being (Fraccaroli et al., 2021).

The data generated by the SINCERE-InnoForESt survey of European forest owners and managers indicates that the share of forest income related to provisioning FES grows from South-Western to North-Eastern Europe, while no similar geographical pattern could be observed for regulating and cultural FES (Torralba et al., 2020). In this survey, most innovations reported by forest owners and managers related to provisioning FES (mostly wood production). At the same time, forest owners and managers perceive their innovations for regulating and cultural FES as qualitatively being more innovative and promising. Reportedly, FES innovations are supported by organisational capacity, (e.g., leadership), by available knowledge, by cooperation among private actors, and by public financial support (Fig. 3).

In sum, societal demands towards a broad spectrum of FES have, to some degree, triggered innovations that also relate to FES other than wood, and which can serve as role models for further innovations. For this, exchange of knowledge and experiences among forest practitioners seems critical (Section 4.4).

3.3. Climate champions? Reconfirming the potential of forests to mitigate climate change

Forests can significantly contribute to climate change mitigation as carbon sinks and through substitution effects from forest products (Lindner et al., 2017; Brunet-Navarro et al., 2021). Although carbon sequestration in forests can be more (cost-) effective outside of Europe (e.g., in the tropics (Larjavaara et al., 2018)), European forests are also a significant carbon sink, especially when wood products and substitution effects are included. They store around 9% of the EU's Greenhouse Gas Emissions annually (Janssens et al., 2003: Lindner et al., 2017), albeit possibly with a declining trend (Nabuurs et al., 2013), especially considering recent large-scale droughts and disturbances.

With the Farm-to-Fork Strategy approved in May 2020, the EC is committed to implement the Carbon Farming Initiative aimed at the generation of tradable carbon certificates to be sold in the European Trading System (ETS). The New EU Forestry Strategy, approved in July 2021, clarified that forest investments will be included in the Carbon Farming Initiative. This is a significant change in EU forest policy considering that in 2003 the potential inclusion of forestry into the ETS was categorically dismissed: "forest activities when used as C credits do not bring technology transfer, they are inherently temporary and reversible, and uncertainty remains about the effects of emission removal by carbon sink" (Advisory Group on Forestry and Cork, 2003; Sotirov et al., 2021).

Following that historic decision, carbon forest investments have only grown in the voluntary markets until now, i.e., through private initiatives and spontaneous action by member states (e.g., Woodland Carbon Code, UK, or Label Bass Carbon scheme, France), and through regional and local authority initiatives (e.g., Carbomark scheme, Italy). The institutionalisation of these voluntary initiatives follows the mandate defined by the Paris Agreement on the involvement of "non-Party stakeholders" in developing carbon markets, a line of policy action confirmed by the outcomes of the Glasgow CoP26 of the UNFCCC, where the implementation of carbon markets was enhanced.

Still several technical issues must be clarified in this pilot phase (permanency and risk management, leakage, additionality, monitoring, carbon sequestration in wood products, relation to other FES), and regulation may be needed to resolve conflicts and avoid potential failures. Yet, the EC is committed to make a certification system for forest carbon removal operational by 2023. With ETS carbon prices reaching 96 €/t $C0_2$eq (August 2022), boosted by the very ambitious EU decarbonisation targets (−55% by 2030; zero emissions by 2050), carbon sequestration could become an economically attractive objective in European forest management.

In sum, the increasingly institutionalised forest carbon market in Europe holds potential for forest owners and managers to generate value from forests' climate mitigation potential.

4. Policy pathways for the future

This section introduces four main EU policy pathways responding to the challenges and opportunities described, in view of incentivising the provision of multiple FES across the continent. The pathways follow different and complementary modes of governance: pathway 1 emphasises information as a basis for policy design and innovation; pathway 2 a consistent (regulatory) policy framework; pathway 3 the economics of FES provision through a European PES system; and pathway 4 bottom-up participation, dialogue, and networking to achieve locally adapted FES provision and spread innovative knowledge and ideas. Importantly, the four pathways are not mutually exclusive, but are often complementary parts of a larger policy framework, each of them corresponding to one or more of the stated challenges, and considering the opportunities presented, as we detail below.

4.1. Better information: Monitor FES supply and demand broadly

Governing Europe's forests for multiple ecosystem services requires monitoring systems to ensure that policymakers, but also the wider spectrum of FES providers and demanders, have access to spatially explicit information about the potential supply and demand of relevant types of ecosystem services. Importantly, this should include regulating and cultural services that are rising in importance but are less covered by current forest monitoring systems (Section 2.4); Knoke et al., 2021). In addition, better information about forest owners' increasingly diverse preferences, capacities, and behaviour regarding management for FES (Section 3.1) is an important knowledge base for developing targeted policy instruments (Weiss et al., 2019b; Tiebel et al., 2021). Although data acquisition is challenging, the conceptual and methodological tools to create a European-wide FES database are already largely available, while different strategies exist to make such an effort effective and cost-efficient. The previous EU Biodiversity Strategy (Target 2 and Action 5) required member states to map and assess ecosystems and the economic value of their services in their national territory, with the assistance of the European Commission. This included integrating these values into accounting and reporting systems at EU and national level by 2020 (European Commission, 2011). An analytical framework and a common typology of ecosystem services to support the accounting have been developed, with the last technical methodological report published in 2019 (European Commission, 2019). Examples of forest ecosystem account assets include the extent of temperate deciduous forests, the level of fragmentation, or the amount of timber produced. However, there is a strong need to go beyond the assessment of data already provided by National Forest Inventories and relevant EU policies (e.g., monitoring of Natura 2000 protected area sites) to account for the multiple values of the full range of forest ecosystem services (Nelson et al., 2022). New mapping strategies should lean on advances in remote sensing and environmental modelling, featuring fine-scaled information for the supply of multiple FES (Orsi et al., 2020). To assess the demand for and access to FES, socio-cultural assessment methods, such as online Public Participation GIS (PPGIS) mapping tools, can show where and how forests can contribute to human wellbeing (Baumeister et al., 2020), and results from environmental economics can support spatial assessment of values (e.g., Bakhtiari 2018). Also, the use of emerging technologies like virtual environments, automated workflows, human behaviour analyses and machine learning can improve ecosystem services assessments including information from social media and mobile tracking applications (Nitoslawski et al., 2021). The interpretation and contextualisation of FES assessments require diverse, interdisciplinary teams, including expertise about different FES categories and heterogeneous European forestry contexts.

An assessment of the entire spectrum of FES could, in principle, be conducted at any scale, from local to EU. To achieve comparability, inform EU forest-related policies, and allow regional priority setting, the gathering of basic FES-related data could be done at the EU level. In this context a common definition of FES indicators would allow standardised monitoring and comparison of the quality and quantity of FES in different regions (Wolfslehner and Vacik, 2011; Linser et al., 2018). At the same time, specific FES-related information could be gathered nationally or sub-nationally, responding to specific demands and conditions. Providing the information about potential FES supply could support the collaborative design of business models between landowners and various interest groups. Specifically, the integration and interpretation of FES demand and supply into forest management may require a landscape perspective. Operationalised through "integrated landscape management", landscape approaches strive to harmonise the use of forests and other natural resources for food and fibre production, biodiversity, and other ecosystem services for the improvement of human well-being. A landscape perspective considers complementarities and competition between such objectives at the landscape scale (Plieninger et al., 2020). Such a perspective departs from traditional sectorial approaches by emphasizing adaptive management, stakeholder involvement, and multiple objectives (Sayer et al., 2013). A landscape perspective is of particular relevance for Europe, where relatively small land parcels, high populations densities, and multiple societal demands require high levels of multifunctionality in land management (Mann et al., 2018). Yet, implementing monitoring from a landscape perspective will also require that sectoral actors agree on common definitions on how to quantify and monitor ecosystem services across land use systems.

The supply and demand of FES are not fixed over time. Instead, they are sensitive to management interventions, climate change and disturbances, and context-related social-ecological changes. For this reason, any assessment effort must be accompanied by a monitoring strategy. Such a strategy could capitalise on citizen science methods for environmental education (Conrad and Hilchey, 2011; European Commission, 2020a), articulated through a network of regional FES observatories that harmonise and synthesise the data collected.

It is obvious that new monitoring activities will come with additional costs, as well as questions related to the legal basis, responsibilities, and competency. Therefore, expert and policy dialogues are needed to ensure that monitoring schemes are cost-effective (inter alia by combining alternative data gathering strategies ranging from remote sensing to on-the-ground information), that they do not put too much burden on public budgets, and that they deliver the politically and societally required information regarding FES supply and demand.

4.2. Policy integration: Coherently align EU forest objectives and policy instruments

Forests, at the EU and national policy levels, are subject to a striking diversity of societal demands (Section 2.1 and 2.6), translating into (sectoral) policy areas that formulate distinct, and partially rivalling, objectives (Sections 2.2 and 2.3). The new EU Forest Strategy has advanced EU forest policy development with a clear catalogue of objectives and concrete instruments, but its effectiveness will critically depend on the implementation through policy areas such as environment and agriculture, and EU member states' willingness to engage (Aggestam and Pülzl, 2018; Wolfslehner et al., 2020). Recent studies on EU forest policymaking leave doubts about to what extent in particular forest-rich member states will support implementation, given the ongoing ideological polarisation between forest use and conservation interests (Sotirov et al., 2021). This could result in conflicts, even a blockage situation, and may hamper the possibilities of advancing policies that provide strong incentives for forest owners and managers to provide multiple FES for societies across Europe.

This pathway aims to support dealing with mixed policy objectives promoted by different policy instruments at European and national levels. The main idea is to achieve policy integration, hence, to ensure that forest policy not only sets policy objectives but also embodies concrete processes for dealing with trade-offs, (e.g., by involving all major concerned societal groups and representing a range of different and partially conflicting actor perspectives in goal formulation and implementation (Aggestam and Pülzl, 2020)). Science can play an important role here by providing the knowledge basis for understanding the synergies and trade-offs between different FES, and options to achieve the provision of FES bundles, instead of narrowly targeting single goals (Tóth et al., 2010).

Policy consistency is thereby linked to horizontal and vertical integration within a given time span and involves the necessity to align different types of instruments (e.g., subsidy schemes that complement regulation and address the entire spectrum of policy objectives). To be clear, policy integration does not require all goal conflicts in European forest policy to be resolved at the EU level, but that the policy framework across policy levels is consistent in supporting multiple objectives, with transparent procedures in place to set priorities in the case of irresolvable goal conflicts that can be adopted/put into practice at national or local levels.

To achieve such a policy framework, we highlight the following principles:

- Give all forest related societal groups access to policymaking processes at the relevant scale and context and ensure transparent decision making. This should facilitate the development of a shared understanding of the different objectives for forest management, acknowledging different views and interests in the various contexts and scales, thus reflecting multiple, contextualised views on the potential supply and demand for FES within the policymaking system. As forest policies and strategic planning is conducted at different scales, the leading policy and planning institutions at the respective policy levels must develop such participatory processes.
- Align policy objectives with instruments to ensure that objectives are "backed up" by regulatory, but importantly also financial, policy instruments, and provide for flexibility to achieve regional priority setting in integration, reflecting specific regional or national socio-economic demands in a manner that is transparent and inclusive for the respective policy stakeholders and societal groups.
- Ensure that policies, policy instruments and their implementation are monitored through the collection of reliable and up-to-date information regarding key targets, and are adapted as needed.

Access to the policymaking process by various forest-related interest groups, and by groups that are affected by policies, and whenever possible society at large, policy objectives that are well translated into policy instruments, and a transparent flow of information on the supply of multiple FES, seem a robust basis for integrated EU forest policies, and the basis for governing Europe's forests well for the supply of multiple FES.

4.3. Payments for ecosystem services: Towards a European PES system?

A mismatch between FES demand and possibilities for forest owners and managers to gain profits from FES supply has been described as a key challenge for an EU policy to incentivise the supply of multiple FES (Section 2.1). PES are seen as a tool to incentivise the supply of FES in cases where other policy instruments such as regulation may not be feasible or appropriate (Section 2.4), especially designed to bridge trade-offs across stakeholders' interests (Wunder, 2015). An EU-wide PES system – or policy framework to enable PES schemes at various spatial levels – might potentially be a powerful component of a future integrative EU forest policy approach. However, both pros and cons can be raised vis-à-vis establishing such a system at the EU scale.

In terms of arguments in favour of a European PES system, some 85% of EU forests are available for wood production, yet nearly 90% are also accessible for Europe's citizens demanding recreational FES, and many provide further unpaid provisioning, regulating and cultural FES to societies (Fig. 1). Externalities and trade-offs between multiple management goals are thus omnipresent, which PES are a customised tool to address. Especially global or aggregate-scale FES, such as climate mitigation and biodiversity protection, are in society's focus; a PES system may be an elegant way to collect the needed resources to remunerate forest owners for prioritising these services to a sufficient degree. Arguably, forest owners would carry significant costs of FES supply if, for instance, (strict) protection for biodiversity purposes is planned to be enlarged on private lands. Making these cost burdens remunerated might thus make good sense. Finally, many environmental outcomes in Europe are affected by large agricultural subsidies through the CAP; an equivalent EU-wide forest PES scale may thus be an effective sectoral counterpart towards a landscape-level policy mix of productive and protective functions.

On the other hand, counterarguments also exist. Legal competency for forest issues in the EU remains more nested at the national than at the EU level, and the legal contexts vary greatly among EU countries. This makes it potentially difficult to define comparable "baseline standards" of FES supply, which could result in situations where forest owners in one country receive payments for the same FES measure that in another country forest owners are legally obliged to provide without payment, thus resulting potentially in a competitive advantage for the former (Section 2.3). Furthermore, club-good FES, such as watershed or recreational benefits, are better targeted by PES systems that are locally financed. The financing of an EU-wide PES system is also an open question: would member states be willing to co-fund it? Would Europe's citizens be willing to pay for FES, given a long tradition of seeing FES supply as a public sector responsibility of assuring legal compliance?

Moreover, for some global FES supply, European forests may have lower natural supply potential compared to forests in the tropics: carbon sequestration in Europe is climatically constrained (Section 3.3.), and tropical forests harbour more biodiversity than European forests. However, the site of FES provision matters for people's valuation of ES, and hence for the efficiency of policies (see e.g., Bakhtiari et al., 2018 or Dallimer et al., 2015). Finally, a large share of European forest owners are smallholders, potentially leading to high transaction costs of PES contracting and monitoring.

Therefore, if an EU-wide PES system were to be developed, it may need to adhere to some principles:

- Agree upon systemic objectives: A shared vision seems critical for a PES system to get political support from different sectors (i.e., conservation and forestry, Section 2.2 and 2.3) and levels (i.e., EU and country level). Inter alia, this includes the definition of the scope of a PES system (forests, or landscapes including different types of land use – calling for a larger systematic reform of the way land use subsidies are spent in the EU) and key FES to be supported (for instance biodiversity provision, climate mitigation and cultural FES).
- Clarify sources of finance: There is a necessity to earmark sufficient EU resources. Co-funding at the member state level (national to regional) would ensure sufficient national/regional government commitment. Participation should, as in all PES programmes, be guided by the principle of voluntariness.
- Scale innovative design: There may be trade-offs between ambition (i.e., how much does the system demand from participating landowners) and flexibility (i.e., how far can the system adapt to contextual forest owner demands). Yet, innovative contracting mechanisms (e.g., reverse or forward auctions, as practiced in the

SINCERE and NOBEL projects, where forest owners competed on price and biodiversity protection actions (Lundhede et al., 2022; Bingham et al., 2021)), can be one cost-effective way to achieve ambitious targets while keeping implementation flexible. More publicly funded, larger-scale experiments are needed, however, to adapt such instruments to each regulatory context for cost-effective supply. Experimenting with new formats will need some courage though; here it is important to note that in both the US and in Australia, auctions have become commonplace in the contract allocation of public PES programmes (Stoneham et al., 2003; Whitten et al., 2017).
- Set concrete FES foci: With a huge variety of forest management practices and featured ecosystem services across Europe (Section 2.6), a PES system needs to have transparently pre-identified what FES matter and to whom. A combination of a participatory societal process involving the general public, business sectors profiting from the services, and science-based assessments of FES supply potentials may help determine FES priorities at regional levels.
- Adopt generous time horizons: In forestry, long-term durations and changes of environmental and economic cycles are a key challenge. The system should prioritise measures that have a sufficiently long-term perspective and commitment for impact. For instance, there would be little value in forest biodiversity conservation contracts relating to the retention of deadwood or habitat trees that run for just half a dozen years.
- Focus on priority areas: Considering limited budgets, priority geographical areas may need to be identified where PES schemes should be developed first. These could be areas where they are most likely to bring about social welfare gains from better alignment between landowners' decisions and societal objectives, but also areas of special societal or environmental importance. Examples include:
  - Biodiversity hotspots, i.e., forest (landscapes) with specifically high conservation value, and/or forestland protected under Natura 2000.
  - Ecosystem services demand hotspots, i.e., forest landscapes with high societal FES demand (e.g., peri-urban areas, key nature-based tourism destinations) and/or the highest discrepancy between societal demand and current supply of ecosystem services. As flagged above: when objectives are highly conflictive, PES can help to soften hard trade-offs.
  - Adaptation hotspots and forest landscapes that are specifically affected by climate change related disturbances or where there is the highest adaptation pressure, combined with the greatest potential to restore resilient and diverse ecosystems that deliver multiple FES (Section 2.5).

Finally, solid monitoring, sanctioning of non-compliance, and accompanying research that evaluates impact are needed for an effectively implemented system: without a manifested conditionality mechanism, PES systems will tend to lose their credibility (Wunder et al., 2018). Easy "self-assessment" tools by forest owners to evaluate their environmental performance can increase transparency and acceptance, but contract compliance and environmental additionality eventually need to be transparently measured.

4.4. Bottom-up participation: Enable participation and encourage learning among FES innovators

Engaging with stakeholders across sectors and policy levels is key for supporting innovations for the supply of multiple FES, as well as for implementing integration at landscape level to help overcome the ideological differences stemming from competing objectives (Section 2.2.). The opening up of spaces that facilitate participatory, bottom-up processes at the regional and local levels allows to better explore and understand the underlying factors and values affecting FES prioritisation (Section 2.6). Moreover, it also allows the promotion of learning and helps to develop stakeholders' skills and capacity regarding FES demand-driven partnerships between forest owners and managers, business, society, policymakers, and scientists.

Despite growing research addressing FES, there is still a gap in how to integrate cultural and socio-economic assessments of different FES into traditional tools for forest planning (Vacik and Lexer, 2014). Understanding and unveiling the underlying values at play in different decision-making processes concerning FES is crucial also for raising social awareness, considering that FES face competing demands that are expected to be exacerbated in the future due to increased pressure on forests in the context of climate change. An integrative approach is needed to elicit landowners and stakeholders' diversifying preferences (Section 3.1), socio-economic and cultural values of FES, and to make better-informed choices.

While most FES valuations are performed at a national or regional scale (Bryce et al., 2016), participatory bottom-up processes could focus on a local scale to integrate local differences, values, and preferences into decision-making in a forestry context. Moreover, a participatory planning approach challenges the inherent power asymmetry in expert-based planning of local contexts, and therefore enhances local acceptability of FES-related decisions. Within the NOBEL project, participatory scenario modelling was used to explain how different management options influence the provision of FES, and to generate debate about how future forests in the municipality might look. Within the SINCERE project, following the EU principles of a multi-actor approach, a participatory interaction process was conducted at the level of local FES innovations which, as its evaluation has shown, has been considered beneficial by stakeholders for the development of customised local solutions to handle FES supply. Moreover, local participatory processes involving a broad spectrum of actors (beyond the "usual suspects") have proven to significantly improve mutual trust, understanding, and reduce historically rooted conflicts frequently associated with competing local demands for FES (Devente et al., 2016; Idrissou et al., 2013).

Scientists can support this by advancing understanding of how different types of forest management affect the supply of different FES, which is an essential basis for advancing a European forest policy that incentivises FES supply. Understanding the basic interconnections is necessary for designing management interventions (and policies to support them) at all levels, and knowledge needs to be accessible for all concerned stakeholders – those directly involved in forest management and planning, and those who benefit from FES directly or indirectly. Trade-offs between different outcomes and values need to be clearly articulated and discussed to reach consensus or to find a compromise about different forest management options in a specific context. Participatory action research led by social scientists can support collective learning about the different views and values regarding forests and FES and can establish clear linkages between potential PES and ecosystem service supply. Moreover, European scale research can also build important connections across regions and cases, to enable learning between the increasing number of FES innovators across country borders (Section 3.2).

5. Conclusions

Above we have introduced selected relevant findings on the supply and demand of FES in Europe, assessing challenges and opportunities, and outlining possible pathways for EU policy to support the supply of multiple FES in Europe. We selectively focused on key challenges and opportunities, and possible actions. Under our four suggested main pathways (and eventually beyond), further elements not covered in this paper could be important, for instance looking into the importance of innovation policies (Weiss et al., 2021), participatory policy approaches specifically for public forestlands (Buchy and Hoverman, 2000; Maier et al., 2014), or regulation, for instance in relation to protected areas and forest management standards. Nevertheless, we think that the pathways can offer guidance for EU forest policy, corresponding to the evidenced challenges and opportunities. Moreover, given the current momentum in European forest policy in relation to the European Green Deal, and the environmental and socio-economic challenges for EU forests, the time seems right for advancing these pathways, hoping to contribute to an EU framework for a future forest policy that governs Europe's forests for a better demand-aligned multifunctional FES supply.

Author statement

The idea for this manuscript was developed by Georg Winkel (first author, conceptualization). The first outline and main structure was collectively developed by all authors (conceptualization, writing of original draft). The data contributing to the paper arose from contributions of different co-authors (Data curation), as referenced in the paper. The writing (original draft) was done collectively by all co-authors, with the first author leading the writing process. The revisions were conducted mainly by the first author, with all authors commenting and contributing when necessary (review and editing).

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Acknowledgements

The research leading to these results has received funding from the European Union Horizon 2020 under Grant Agreement number 773702, SINCERE project (Spurring INnovations for forest eCosystem sERvices in Europe). The research has also received funding from the project NOBEL (Novel business models to sustainably supply forest ecosystem services), supported under the umbrella of ERA-NET Co-fund ForestValue. ForestValue has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement number 773324. The contributions by the CLEARINGHOUSE project were funded by the European Horizon 2020 Research and Innovation programme under the Grant Agreement number 821242.

References

Advisory Group on Forestry and Cork, 2003. Information on Directive 2003/87/EC of the European Parliament and of the Council of 13 October 2003, 11th of February 2003, Brussels.

Aggestam, F., Pülzl, H., 2018. Coordinating the uncoordinated: the EU Forest strategy. Forests 9 (3), 125. https://doi.org/10.3390/f9030125.

Aggestam, F., Pülzl, H., 2020. Downloading Europe: a regional comparison in the uptake of the EU Forest action plan. Sustainability 12 (10), 3999. https://doi.org/10.3390/su12103999.

Amici, A., Beljan, K., Coletta, A., Corradini, G., Constantin Danila, I., Da Re, R., Ludvig, A., Marčeta, D., Nedeljković, J., Nichiforel, L., Nonić, D., Pettenella, D., Posavec, S., Riedl, M., Sisak, L., Stojanovska, M., Vidale, E., Weiss, G., Živojinović, I., 2020. Economics, marketing and policies of NWFP. In: Vacik, H., Hale, M., Spiecker, H., Pettenella, D., Tomé, M. (Eds.), Non-Wood Forest Products in Europe – Ecology and Management of Mushrooms, Tree Products, Understory Plants and Animal Products. Books on Demand, Norderstedt, Germany, pp. 125–202.

Anderson, J.C., Gomez, C., McCarney, G., Adamowicz, W.L., Wiktor, N. Chalifour, Weber, M., Elgie, S., Howlett, M., 2010. Ecosystem Service Valuation, Market-Based Instruments, and Sustainable Forest Management: A Primer. Sustainable Forest Management Network, p. 5.

Angelstam, P., Elbakidze, M., Axelsson, R., Khoroshev, A., Pedroli, B., Tysiachniouk, M., Zabubenin, E., 2019. Model forests in Russia as landscape approach: demonstration projects or initiatives for learning towards sustainable forest management? Forest Policy Econ. 101, 96–110. https://doi.org/10.1016/j.forpol.2019.01.005.

Bakhtiari, F., Jacobsen, J.B., Thorsen, B.J., Lundhede, T.H., Strange, N., Boman, M., 2018. Disentangling distance and country effects on the value of conservation across national borders. Ecol. Econ. 147, 11–20. https://doi.org/10.1016/j.ecolecon.2017.12.019.

Barlagne, C., Melnykovych, M., Miller, D., Hewitt, R.J., Secco, L., Pisani, E., Nijnik, M., 2021. What are the impacts of social innovation? A synthetic review and case study of community forestry in the Scottish highlands. Sustainability 13 (8), 4359. https://doi.org/10.3390/su13084359.

Baumeister, C.F., Gerstenberg, T., Plieninger, T., Schraml, U., 2020. Exploring cultural ecosystem service hotspots: linking multiple urban forest features with public participation mapping data. Urban For. Urban Green. 48, 126561 https://doi.org/10.1016/j.ufug.2019.126561.

Becher, C., 2022. Becoming a tree: exploring the entanglement of bodies, soil, and trees in natural burials. Green Lett. 1-12 https://doi.org/10.1080/14688417.2022.2029717.

Bingham, L.R., Da Re, R., Borges, J.G., 2021. Ecosystem services auctions: the last decade of research. Forests 12 (5). https://doi.org/10.3390/f12050578.

Boon, T.E., Meilby, H., Thorsen, B.J., 2004. An empirically based typology of forest owners in Denmark – improving the communication between authorities and owners. Scand. J. For. Res. 19 (Suppl. 4), 45–55. https://doi.org/10.1080/14004080410034056.

Brunet-Navarro, P., Jochheim, H., Cardellini, G., Richter, K., Muys, B., 2021. Climate mitigation by energy and material substitution of wood products has an expiry date. J. Clean. Prod. 303, 127026 https://doi.org/10.1016/j.jclepro.2021.127026.

Bryce, R., Irvine, K.N., Church, A., Fish, R., Ranger, S., Kenter, J.O., 2016. Subjective well-being indicators for large-scale assessment of cultural ecosystem services. Ecosyst. Services 21, 258–269. https://doi.org/10.1016/j.ecoser.2016.07.015.

Buchy, M., Hoverman, S., 2000. Understanding public participation in forest planning: a review. Forest Policy Econ. 1 (1), 15–25. https://doi.org/10.1016/S1389-9341(00)00006-X.

Buttoud, G., Kouplevatskaya-Buttoud, I., Slee, B., Weiss, G., 2011. Barriers to institutional learning and innovations in the forest sector in Europe: markets, policies and stakeholders. Forest Policy Econ. 13 (2), 124–131. https://doi.org/10.1016/j.forpol.2010.05.006.

Conrad, C.C., Hilchey, K.G., 2011. A review of citizen science and community-based environmental monitoring: issues and opportunities. Environ. Monit. Assess. 176 (1), 273–291. https://doi.org/10.1007/s10661-010-1582-5.

Dallimer, M., Jacobsen, J.B., Lundhede, T.H., Takkis, K., Giergiczny, M., Thorsen, B.J., 2015. Patriotic values for public goods: transnational trade-offs for biodiversity and ecosystem services? BioScience 65, 33–42.

De Koning, J., Winkel, G., Sotirov, M., Blondet, M., Borras, L., Ferranti, F., Geitzenauer, M., 2014. Natura 2000 and climate change—polarisation, uncertainty, and pragmatism in discourses on forest conservation and management in Europe. Environ. Sci. Pol. 39, 129–138. https://doi.org/10.1016/j.envsci.2013.08.010.

Devente, J., Reed, M.S., Stringer, L.C., Valente, S., Newig, J., 2016. How does the context and design of participatory decision making processes affect their outcomes? Evidence from sustainable land management in global drylands. Ecol. Soc. 21 https://doi.org/10.5751/ES-08053-210224.

Edwards, P., Kleinschmit, D., 2013. Towards a European forest policy—conflicting courses. Forest Policy Econ. 33, 87–93. https://doi.org/10.1016/j.forpol.2012.06.002.

Engel, S., Pagiola, S., Wunder, S., 2008. Designing payments for environmental services in theory and practice: an overview of the issue. Ecol. Econ. 65 (2008), 663–674.

European Commission, 2011. Our life insurance, our natural capital: an EU biodiversity strategy to 2020. COM(2011) 244 final. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52011DC0244&from=EN. Accessed date 15 September 2022.

European Commission, 2019. Natural Capital Accounting: Overview and Progress in the European Union Natural Capital Accounting.6th Report – May 2019. https://ec.europa.eu/environment/nature/capital_accounting/pdf/MAES_INCA_2019_report_FINAL-fpub.pdf.

European Commission, 2020. EU Biodiversity Strategy for 2030. Bringing Nature Back Into Our Lives. COM(2020) 380 Final. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52020DC0380. Accessed date: 20 January 2020.

European Commission, 2020a. Best Practices in Citizen Science for Environmental Monitoring Commission Staff Working Document. Available at: https://ec.europa.eu/environment/legal/reporting/pdf/best_practices_citizen_science_environmental_monitoring.pdf. Accessed date: 15 February 2022.

European Commission, 2021. New EU Forest Strategy for 2030. {SWD(2021) 651 final} – {SWD(2021) 652 final}. COM(2021) 572 final. Available at: https://ec.europa.eu/info/sites/default/files/communication-new-eu-forest-strategy-2030_with-annex_en.pdf. Accessed date: 15 January 2022.

Ezzine-de-Blas, D., Corbera, E., Lapeyre, R., 2019. Payments for environmental services and motivation crowding: towards a conceptual framework. Ecol. Econ. 156, 434–443. https://doi.org/10.1016/j.ecolecon.2018.07.026.

Fraccaroli, C., Soer, A., Doimo, I., De Vreese, R., Devisscher, T., Humer, M., Öllerer, B., Mühlberger, D., Van Den Bosch, M., 2021. Forest-based care market outlook. In: Erasmus+ Green4C project, Deliverable 3.4: EU Market Outlook.

Geitzenauer, M., Blondet, M., de Koning, J., Ferranti, F., Sotirov, M., Weiss, G., Winkel, G., 2017. The challenge of financing the implementation of Natura 2000-empirical evidence from six European Union member states. Forest Policy Econ. 82, 3–13. https://doi.org/10.1016/j.forpol.2017.03.008.

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

Haukeland, J.-V., Fredman, P., Siegrist, D., Tyrväinen, L., Lindberg, K., Elmahdy, 2021. Trends in nature-based tourism. In: Fredman, P., Haukeland, J.-V. (Eds.), Nordic Perspectives on Nature-based Tourism: From Place-based Resources to Value-added Experiences. Edward Elgar Publishing, pp. 16–32. https://doi.org/10.4337/9781789904031.

Hernández-Morcillo, M., Torralba, M., Baiges, T., Bernasconi, A., Bottaro, G., Brogaard, S., Plieninger, T., 2022. Scanning the solutions for the sustainable supply of forest ecosystem services in Europe. Sustain. Sci. 1–17.
Hetemäki, L., Hanewinkel, M., Muys, B., Ollikainen, M., Palahí, M., Trasobares, A., 2017. Leading the way to a European circular bioeconomy strategy. From Science to Policy Vol.5. European Forest Institute. Available at. https://efi.int/sites/default/files/files/publication-bank/2018/efi_fstp_5_2017.pdf (Accessed date: 20 March 2022).
Huber, P., Hujala, T., Kurttila, M., Wolfslehner, B., Vacik, H., 2019. Application of multi criteria analysis methods for a participatory assessment of non-wood forest products in two European case studies. Forest Policy Econ. 103, 103–111.
Hurmekoski, E., Lovrić, M., Lovrić, N., Hetemäki, L., Winkel, G., 2019. Frontiers of the forest-based bioeconomy–a European Delphi study. Forest Policy Econ. 102, 86–99. https://doi.org/10.1016/j.forpol.2019.03.008.
Idrissou, L., van Passen, A., Aarts, N., Vodouha, S., Leuwis, C., 2013. Trust and hidden conflict in participatory natural resources management: the case of the Pendjari national park (PNP) in Benin. Forest Policy Econ. 27, 65–74. https://doi.org/10.1016/j.forpol.2012.11.005.
Jacobsen, J.B., Hanley, N., 2009. Are there income effects in global willingness to pay for biodiversity conservation? Environ. Resour. Econ. 43, 137–160. https://doi.org/10.1007/s10640-008-9226-8.
Janssens, I.A., Freibauer, A., Ciais, P., Smith, P., Nabuurs, G.J., Folberth, G., Schlamadinger, B., Hutjes, R.W.A., Ceulemans, R., Schulze, E.-D., Valentini, R., Dolman, A.J., 2003. Europe's terrestrial biosphere absorbs 7 to 12% of European anthropogenic CO2 emissions. Science 300 (5625), 1538–1542. https://doi.org/10.1126/science.1083592.
Knoke, T., Kindu, M., Schneider, T., Gobakken, T., 2021. Inventory of Forest attributes to support the integration of non-provisioning ecosystem services and biodiversity into Forest planning—from collecting data to providing information. Curr. Forestry Rep. 7 (1), 38–58. https://doi.org/10.1007/s40725-021-00138-7.
Roux, J.-L., Konczal, A., Bernasconi, A., Shonil, A., De Vreese, R., Doimo, I., Govigli, V., Kašpar, J., Kohsaka, R., Pettenella, D., Plieninger, T., Shakeri, Z., Shibata, S., Stara, K., Takahashi, T., Torralba, M., Tyrväinen, L., Weiss, G., Winkel, G., 2022. Exploring evolving spiritual values of forests in Europe and Asia – a transition hypothesis towards re-spiritualization of forests. Ecol. Soc. (unpublished).
Kraxner, F., Fuss, S., Verkerk, P.J., 2017. Is there enough forest biomass available to meet the demands of the forest-based bioeconomy? In: Winkel, G. (Ed.), Towards a sustainable European forest-based bioeconomy – Assessment and the way forward. What Science Can Tell Us 8. European Forest Institute, Joensuu, Finland, pp. 53–66.
Larjavaara, M., Kanninen, M., Gordillo, H., Koskinen, J., Kukkonen, M., Käyhkö, N., Larson, A.M., Wunder, S., 2018. Global variation in the cost of increasing ecosystem carbon. Nat. Clim. Chang. 8 (1), 38–42. https://doi.org/10.1038/s41558-017-0015-7.
Lawrence, A., Wong, J.L., Molteno, S., 2020. Fostering social enterprise in woodlands: challenges for partnerships supporting social innovation. Forest Policy Econ. 118, 102221 https://doi.org/10.1016/j.forpol.2020.102221.
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 (7), 1737–1749. https://doi.org/10.1007/s10980-019-00864-1.
Levers, C., Verkerk, P.J., Müller, D., Verburg, P.H., Butsic, V., Leitão, P.J., Kuemmerle, T., 2014. Drivers of forest harvesting intensity patterns in Europe. For. Ecol. Manag. 315, 160–172. https://doi.org/10.1016/j.foreco.2013.12.030.
Lidestav, G., Bogataj, N., Gatto, P., Lawrence, A., Stjernström, O., Wong, J., 2017. Forests in common and their contribution to local development. In: Carina, H., Keskitalo, H. (Eds.), Globalisation and Change in Forest Ownership and Forest Use - Natural Resource Management in Transition. Palgrave Macmillan, London, UK, pp. 261–302. https://doi.org/10.1057/978-1-137-57116-8_8.
Lidestav, G., Weiss, G., Živojinović, I., 2019. Changes in forest ownership. In: UNECE and FAO, Who owns our forests? Forest ownership in the ECE region. ECE/TIM/SP/43. United Nations, Geneva, Switzerland, pp. 43–60. Available at. https://unece.org/fileadmin/DAM/timber/publications/SP-43.pdf. Accessed date: 20 March 2022.
Lindner, M., Hanewinkel, M., Nabuurs, G.J., 2017. How can a forest-based bioeconomy contribute to climate change adaptation and mitigation? In: Winkel, G. (Ed.), Towards a sustainable European forest-based bioeconomy – Assessment and the way forward. What Science Can Tell Us 8. European Forest Institute, Joensuu, Finland, pp. 77–85.
Linser, S., Wolfslehner, B., Bridge, S.R.J., Gritten, D., Johnson, S., Payn, T., Prins, K., Rasi, R., Robertson, G., 2018. 25 years of criteria and indicators for sustainable Forest management: how Intergovernmental C&I Processes Have Made a difference. Forests. 9 (9).
Loft, L., Mann, C., Hansjürgens, B., 2015. Challenges in ecosystem services governance: multi-levels, multi-actors, multi-rationalities. Ecosyst. Services 16, 150–157.
Lovrić, M., Da Re, R., Vidale, E., Prokofieva, I., Wong, J., Pettenella, D., Verkerk, P.J., Mavsar, R., 2020. Non-wood forest products in Europe–a quantitative overview. Forest Policy Econ. 116, 102175 https://doi.org/10.1016/j.forpol.2020.102175.
Luck, G.W., Harrington, R., Harrison, P.A., Kremen, C., Berry, P.M., Bugter, R., Dawson, T.P., De Bello, F., Díaz, S., Feld, C.K., Haslett, J.R., 2009. Quantifying the contribution of organisms to the provision of ecosystem services. Bioscience 59 (3), 223–235. https://doi.org/10.1525/bio.2009.59.3.7.
Ludvig, A., Wilding, M., Thorogood, A., Weiss, G., 2018. Social innovation in the welsh woodlands: community based forestry as collective third-sector engagement. Forest Policy Econ. 95, 18–25. https://doi.org/10.1016/j.forpol.2018.07.004.
Lundhede, T., Wunder, S., Katila, P., Thorsen, B.J., 2022. Deliverable 4.1 assessing the upscaling potential of SINCERE IAs using a theory of change structure., H2020 project no.773702 RUR-05-2017. In: European Commission, 36 pp. Available at. https://sincereforests.eu/wp-content/uploads/2020/04/D1.4.pdf (Accessed date: 19 January 2022).
Maier, C., Winkel, G., 2017. Implementing nature conservation through integrated forest management: a street-level bureaucracy perspective on the German public forest sector. Forest Policy Econ. 82, 14–29. https://doi.org/10.1016/j.forpol.2016.12.015.
Maier, C., Lindner, T., Winkel, G., 2014. Stakeholders' perceptions of participation in forest policy: a case study from Baden-Württemberg. Land Use Policy 39, 166–176. https://doi.org/10.1016/j.landusepol.2014.02.018.
Mann, C., Garcia-Martin, M., Raymond, C.M., Shaw, B.J., Plieninger, T., 2018. The potential for integrated landscape management to fulfil Europe's commitments to the sustainable development goals. Landsc. Urban Plan. 177, 75–82.
Mann, C., Loft, L., Hernández-Morcillo, M., 2021. Assessing forest governance innovations in Europe: needs, challenges and ways forward for sustainable forest ecosystem service provision. Ecosyst. Services 52, 101384.
Mann, C., Loft, L., Hernández-Morcillo, M., Primmer, E., Bussola, F., Falco, E., Geneletti, D., Dobrowolska, E., Grossmann, C.M., Bottaro, G., Schleyer, C., Kluvankova, T., Garcia, G., Lovrić, M., Torralba, M., Plieninger, T., Winkel, G., 2022. Governance innovations for forest ecosystem service provision – insights from an EU-wide survey. Environ. Sci. Pol. 132, 282–295. https://doi.org/10.1016/j.envsci.2022.02.032.
Mäntymaa, E., Tyrväinen, L., Juutinen, A., Kurttila, M., 2019. Importance of forest landscape quality for companies operating in nature-based tourism areas. Land Use Policy 107, 104095. https://doi.org/10.1016/j.landusepol.2019.104095.
Messier, C., Bauhus, J., Sousa-Silva, R., Auge, H., Baeten, L., Barsoum, N., Bruelheide, H., Caldwell, B., Cavender-Bares, J., Dhiedt, E., Eisenhauer, N., 2021. For the sake of resilience and multifunctionality, let's diversify planted forests! Conserv. Lett. 15 (1), e12829 https://doi.org/10.1111/conl.12829.
Meyer, M.A., Schulz, C., 2017. Do ecosystem services provide an added value compared to existing forest planning approaches in Central Europe? Ecol. Soc. 22 (3), 6. https://doi.org/10.5751/ES-09372-220306.
Muys, B., Angelstam, P., Bauhus, J., Bouriaud, L., Jactel, H., Kraigher, H., Müller, J., Pettorelli, N., Pötzelsberger, E., Primmer, E., Svoboda, M., Thorsen, B.-J., Van Meerbeek, K., 2022. Forest biodiversity in Europe. In: Science to Policy 13. European Forest Institute, Joensuu, Finland (in press).
Nabuurs, G.J., Lindner, M., Verkerk, P.J., Gunia, K., Deda, P., Michalak, R., Grassi, G., 2013. First signs of carbon sink saturation in European forest biomass. Nat. Clim. Chang. 3 (9), 792–796. https://doi.org/10.1038/nclimate1853.
Navare, K., Muys, B., Vrancken, K.C. Van, Acker, K., 2021. Circular economy monitoring–how to make it apt for biological cycles? Resour. Conserv. Recycl. 170, 105563 https://doi.org/10.1016/j.resconrec.2021.105563.
Nelson, G.L., Jutras-Perreault, M.-C., Gobakken, T., Ørka, H.O., Vacik, H., 2022. Comprehensive set of indicators and potential data sources supporting the Common International Classification of Ecosystem Services, under review Ecological Indicators.
Nichiforel, L., Keary, K., Deuffic, P., Weiss, G., Thorsen, B.J., Winkel, G., Avdibegovic, M., Dobsinska, Z., Feliciano, D., Gatto, P., Mifsud, E.G., Hoogstra-Klein, M., Hrib, M., Hujala, T., Jager, L., Jarsky, V., Jodlowski, K., Lawrence, A., Lukmine, D., Malovrh, S.P., Nedeljkovic, J., Nonic, D., Ostoic, S.K., Pukall, K., Rondeux, J., Samara, T., Sarvasova, Z., Scriban, R.E., Silingiene, R., Sinko, M., Stojanovska, M., Stojanovski, V., Stoyanov, N., Teder, M., Vennesland, B., Vilkriste, L., Wilhelmsson, E., Wilkes-Allemann, J., Bouriaud, L., 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.
Nikinmaa, L., Lindner, M., Cantarello, E., Jump, A.S., Seidl, R., Winkel, G., Muys, B., 2020. Reviewing the use of resilience concepts in forest sciences. Curr. Forestry Rep. 6 (2), 61–80. https://doi.org/10.1007/s40725-020-00110-x.
Nitoslawski, S.A., Wong-Stevens, K., Steenberg, J.W.N., Witherspoon, K., Nesbitt, L., Konijnendijk van den Bosch, C.C., 2021. The digital Forest: mapping a decade of knowledge on technological applications for Forest ecosystems. Earth's Future 9 (8).
Onida, M., 2020. Forest and forestry policy between the EU and its member states. ELNI Rev 22-30. https://doi.org/10.46850/elni.2020.004.
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. https://doi.org/10.1016/j.landusepol.2020.104840.
Pagiola, S., Bishop, J., Landell-Mills, N., 2002. Selling Forest Environmental Services. Market-Based Mechanisms for Conservation and Development, Earthscan, London.
Plieninger, T., Muñoz-Rojas, J., Buck, L.E., Scherr, S.J., 2020. Agroforestry for sustainable landscape management. Sustain. Sci. 15 (5), 1255–1266.
Primmer, E., Paloniemi, R., Similä, J., Barton, D.N., 2013. Evolution in Finland's forest biodiversity conservation payments and the institutional constraints on establishing new policy. Soc. Nat. Resour. 26 (10), 1137–1154. https://doi.org/10.1080/08941920.2013.820814.
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., 2021. Mapping Europe's institutional landscape for forest ecosystem service provision, innovations and governance. Ecosyst. Services 27, 101225.
Pülzl, H., Hogl, K., 2013. Forest governance in Europe. Forest governance. In: Pülzl, H., Hogl, K., Kleinschmit, D., Wydra, D., Arts, B., Mayer, P., Palahí, M., Winkel, G., Wolfslehner, B. (Eds.), European Forest Governance: Issues at Stake and the Way Forward. What Science Can Tell Us 2. European Forest Institute, Joensuu, Finland, pp. 11–18.
Pülzl, H., Wydra, D., Hogl, K., 2018. Piecemeal integration: explaining and understanding 60 years of European Union Forest policy-making. Forests 9 (11), 719. https://doi.org/10.3390/f9110719.

Pülzl, H., Aggestam Prokofieva, I., Lukina, V.N., Sotirov, M., Pecurul-Botines, M., Tebenkova, N.D., Widmark, C., Rosinger, C., 2021. Re-Imagining Nature Communication: The Role of Societal Values for Forest Ecosystem Services. SSRN. https://doi.org/10.2139/ssrn.3972031.

Rametsteiner, E., Weiss, G., 2006. Innovation and innovation policy in forestry: linking innovation process with systems models. Forest Policy Econ. 8 (7), 691–703. https://doi.org/10.1016/j.forpol.2005.06.009.

Ranacher, L., Lähtinen, K., Järvinen, E., Toppinen, A., 2017. Perceptions of the general public on forest sector responsibility: a survey related to ecosystem services and forest sector business impacts in four European countries. Forest Policy Econ. 78, 180–189. https://doi.org/10.1016/j.forpol.2017.01.016.

Ranacher, L., Sedmik, A., Schwarzbauer, P., 2020. Public perceptions of forestry and the forest-based bioeconomy in the European Union. In: Knowledge to Action 3. European Forest Institute, Joensuu, Finland.

Roitsch, D., Derks, J., Rosinger, C., De Vreese, R., Jin, J., Lovrić, M., Pülzl, H., Zhang, C., Kronenberg, J., Basnou, C., Tyrväinen, L., da Schio, N., Haase, D., Konczal, A., Winkel, G., 2022. Deliverable 1.3 Societal perceptions and demands towards UF-NBS in China and Europe. H2020 project CLEARING HOUSE. agreement no. 821242. [unpublished].

Roux, J.-L., Lovrić, M., Winkel, G., 2020. Deliverable 3.2 Demand for policy support report. H2020 project no.773702 RUR-05-2017 European Commission, 76pp. Available at. https://sincereforests.eu/wp-content/uploads/2020/04/D1.3.pdf.

Sayer, J., Sunderland, T., Ghazoul, J., Pfund, J.L., Sheil, D., Meijaard, E., Buck, L.E., 2013. Ten principles for a landscape approach to reconciling agriculture, conservation, and other competing land uses. Proc. Natl. Acad. Sci. 110 (21), 8349–8356.

Seidl, R., Thom, D., Kautz, M., Martin-Benito, D., Peltoniemi, M., Vacchiano, G., Wild, J., Ascoli, D., Petr, M., Honkaniemi, J., Lexer, M.J., Trotsiuk, V., Mairota, P., Svodoba, M., Fabrika, M., Nagel, T.A., Reyer, C.P.O., 2017. Forest disturbances under climate change. Nat. Clim. Chang. 7 (6), 395–402. https://doi.org/10.1038/nclimate3303.

Sheppard, J.P., Chamberlain, J., Agúndez, D., Bhattacharya, P., Chirwa, P.W., Gontcharov, A., Sagona, W.C.J., Shen, H.L., Tadesse, W., Mutke, S., 2020. Sustainable forest management beyond the timber-oriented status quo: transitioning to co-production of timber and non-wood forest products—a global perspective. Curr. Forestry Rep. 6 (1), 26–40. http://hdl.handle.net/2263/74718.

Sotirov, M., Winkel, G., Eckerberg, K., 2021. The coalitional politics of the European Union's environmental forest policy: biodiversity conservation, timber legality, and climate protection. Ambio 50 (12), 2153–2167. https://doi.org/10.1007/s13280-021-01644-5.

Sousa-Silva, R., Verbist, B., Lombab, Â., Valent, P., Suškevičs, M., Picard, O., Hoogstra-Klein, M.A., Cosofret, V.-C., Bouriaud, L., Ponette, Q., Verheyen, K., Muys, B., 2018. Adapting forest management to climate change in Europe: linking perceptions to adaptive responses. Forest Policy Econ. 90, 22–30. https://doi.org/10.1016/j.forpol.2018.01.004.

Stoneham, G., Chaudhri, V., Ha, A., Strappazzon, L., 2003. Auctions for conservation contracts: an empirical examination of Victoria's bush tender trial. Aust. J. Agric. Resour. Econ. 47 (4), 477–500. https://doi.org/10.1111/j.1467-8489.2003.t01-1-00224.x.

Tiebel, M., Mölder, A., Plieninger, T., 2021. Small-scale private forest owners and the European Natura 2000 conservation network: perceived ecosystem services, management practices, and nature conservation attitudes. Eur. J. For. Res. 140 (6), 1515–1531.

Torralba, M., Lovrić, M., Bottaro, G., Gatto, P., Pettenella, D., Winkel, G., Plieninger, T., 2020. Deliverable 1.3 Analysis and relationships between Forest ecosystem Services supply and demand, and Innovative mechanisms across Europe. In: H2020 project no.773702 RUR-05-2017 European Commission, 76pp. Available at. https://sincereforests.eu/wp-content/uploads/2020/04/D1.3.pdf (Accessed date: 19 January 2022).

Tóth, S.F., Ettl, G.J., Rabotyagov, S.S., 2010. ECOSEL (2010): an auction mechanism for Forest ecosystem services. Math. Comput. For. Nat. Resour. Sci. 2, 99–116.

Tyrväinen, L., Plieninger, T., Sanesi, G., 2017a. How does the forest-based bioeconomy relate to amenity values? In: Winkel, G. (Ed.), Towards a Sustainable European Forest-Based Bioeconomy – Assessment and the Way Forward. What Science Can Tell us 8. European Forest Institute, Joensuu, Finland, pp. 92–100.

Tyrväinen, L., Sievänen, T., Konu, H., Aapala, K., Pellikka, J., Reinikainen, M., Lehtoranta, V., Ojala, O., Pesonen, J., Tuohino, A., 2017b. New ways to develop nature-based recreation and tourism in Finland. Prime minister's office. Valtioneuvoston selvitys- ja tutkimustoiminnan julkaisusarja 88/2017, p. 29. In Finnish with english summary.

Tyrväinen, L., Mäntymaa, E., Juutinen, A., Kurttila, M., Ovaskainen, V., 2020. Private landowners' preferences for trading forest landscape and recreational values: a choice experiment application in Kuusamo. Finland. Land Use Pol. 107, 104478 https://doi.org/10.1016/j.landusepol.2020.104478.

Vacik, H., Lexer, M.J., 2014. Past, current and future drivers for the development of decision support systems in forest management. Scand J Forest Res. 2014 (29), 2–19.

Vacik, H., Hale, M., Spiecker, H., Pettenella, D., Tomé, M., 2020. Non-Wood Forest Products in Europe, Ecology and management of mushrooms, tree products, understory plants and animal products. Outcomes of the COST Action FP1203 on European NWFPs. Books on Demand, Norderstedt, Germany, 416pp.

Vedel, S.E., Jacobsen, J.B., Thorsen, B.J., 2015. Forest owners' willingness to accept contracts for ecosystem service provision is sensitive to additionality. Ecol. Econ. 113, 15–24. https://doi.org/10.1016/j.ecolecon.2015.02.014.

Watson, J.E., Evans, T., Venter, O., Williams, B., Tulloch, A., Stewart, C., Thompson, I., Ray, J.C., Murray, K., Salazar, A., McAlpine, C., Potapov, P., Walston, J., Robinson, J.G., Painter, M., Wilkie, D., Filardi, C., Laurance, W.F., Houghton, R.A., Maxwell, S., Grantham, C., Samper, C., Wang, S., Laestadius, L., Runting, R.K., Silva-Chavez, G.A., Ervin, J., Lindenmayer, D., 2018. The exceptional value of intact forest ecosystems. Nature Ecol. Evol. 2 (4), 599–610. https://doi.org/10.1038/s41559-018-0490-x.

Weiss, G., 2000. Evaluation of policy instruments for protective forest management in Austria. Forest Policy Econ. 1 (3–4), 243–255. https://doi.org/10.1016/S1389-9341(00)00017-4.

Weiss, G., 2013. Innovation in forestry: new values and challenges for traditional sector. In: Carayannis, E.G. (Ed.), Encyclopaedia of Creativity, Invention, Innovation, and Entrepreneurship, Springer Science and Business Media, pp. 964–971. https://doi.org/10.1007/978-1-4614-3858-8_441.

Weiss, G., 2019. Innovation in forestry: New values and challenges for a traditional sector. In: Carayannis, E. (Ed.), Encyclopedia of Creativity, Invention, Innovation and Entrepreneurship. Springer, New York, USA.

Weiss, G., Ollonqvist, P., Slee, B., 2011. How to support innovation in the Forest sector: Summary and conclusions. In: Weiss, G., Pettenella, D., Ollonqvist, P., Slee, B. (Eds.), Innovation in Forestry: Territorial and Value Chain Relationships. CAB International, Oxfordshire, UK, pp. 303–320.

Weiss, G., Sarvasova, Z., Hermoso, V., Brotons, L., Sotirov, M., 2017. Funding of Natura 2000 in forests. In: Sotirov, M. (Ed.), Natura 2000 and Forests: Assessing the State of Implementation and Effectiveness. What Science Can Tell us 7. European Forest Institute, Joensuu, Finland, 16pp.

Weiss, G., Ludvig, A., Asamer-Handler, M., Fischer, C., Vacik, H., Živojinović, I., 2019a. Rendering NWFPs innovative. In: Wolfslehner, B., Prokofieva, I., Mavsar, R. (Eds.), Non-wood Forest Products in Europe: Seeing the Forest around the Trees. What Science Can Tell Us 10. European Forest Institute, Joensuu, Finland, pp. 77–98.

Weiss, G., Lawrence, A., Hujala, T., Lidestav, G., Nichiforel, L., Nybakk, E., Quiroga, S., Sarvasova, Z., Suarez, C., Zivojinovic, I., 2019b. Forest ownership changes in Europe: state of knowledge and conceptual foundations. Forest Policy Econ. 99, 9–20. https://doi.org/10.1016/j.forpol.2018.03.003.

Weiss, G., Emery, M.R., Corradini, G., Zivojinović, I., 2020. New values of non-wood Forest products. Forests. 11 (2), 165. https://doi.org/10.3390/f11020165.

Weiss, G., Hansen, E., Ludvig, A., Nybakk, E., Toppinen, A., 2021. Innovation governance in the forest sector: reviewing concepts, trends and gaps. Forest Policy Econ. 130, 102506 https://doi.org/10.1016/j.forpol.2021.102506.

Whitten, S.M., Wünscher, T., Shogren, J.F., 2017. Conservation tenders in developed and developing countries – status quo, challenges and prospects. Land Use Policy 63 (Supplement C), 552–560. https://doi.org/10.1016/j.landusepol.2016.09.029.

Wiersum, K.F., Wong, J.L.G., Vacik, H., 2018. Perspectives on non-wood forest product development in Europe. Int. For. Rev. 20 (2), 250–262. https://doi.org/10.1505/146554818823767546.

Winkel, G., 2007. Waldnaturschutzpolitik in Deutschland. Bestandsaufnahmen, Analysen und Entwurf einer Story-Line. Remagen-Oberwinter, Dr. Kessel (Freiburger Schriften zur Forst- und Umweltpolitik 13), 561pp.

Winkel, G., 2013. Forest and conservation policy in a changing climate. Forest Policy Econ. 36, 1–97.

Winkel, G., 2017. Policy conclusions. In: Winkel, G. (Ed.), Towards a sustainable European forest-based bioeconomy – Assessment and the way forward. What Science Can Tell Us 8. European Forest Institute, Joensuu, Finland, 153pp.

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: Government Pol. 34 (3), 496–514. https://doi.org/10.1068/c1356j.

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. https://doi.org/10.1080/19460171.2011.628002.

Winkel, G., Aggestam, F., Sotirov, M., Weiss, G., 2013. Forest policy in the European union. In: Pülzl, H., Hogl, K., Kleinschmit, D., Wydra, D., Arts, B., Mayer, P., Palahí, M., Winkel, G., Wolfslehner, B. (Eds.), European Forest Governance: Issues at Stake and the Way Forward. What Science Can Tell us 2. European Forest Institute, Joensuu, Finland, pp. 52–63.

Wolfslehner, B., Vacik, H., 2011. Mapping indicator models: from intuitive problem structuring to quantified decision-making in sustainable forest management. Ecol. Indicators 2011 11 (2), 274–283.

Wolfslehner, B., Prokofieva, I., Mavsar, R. (Eds.), 2019. Non-wood forest products in Europe: Seeing the forest around the trees. What Science Can Tell Us 10, 116. European Forest Institute, Joensuu, Finland.

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 Governance Post-2020. From Science to Policy 10. European Forest Institute, Joensuu, Finland, 52pp.

Wunder, S., 2015. Revisiting the concept of payments for environmental services. Ecol. Econ. 117, 234–243. https://doi.org/10.1016/j.ecolecon.2014.08.016.

Wunder, S., Brouwer, R., Engel, S., Ezzine-de-Blas, D., Muradian, R., Pascual, U., Pinto, R., 2018. From principles to practice in paying for nature's services. Nature Sustain. 1 (3), 145–150. https://www.nature.com/articles/s41893-018-0036-x.

Wydra, D., 2013. The legal context of European forest policy-making. In: Pülzl, H., Hogl, K., Kleinschmit, D., Wydra, D., Arts, B., Mayer, P., Palahí, M., Winkel, G., Wolfslehner, B. (Eds.), European Forest Governance: Issues at Stake and the Way Forward. What Science Can Tell us 2. European Forest Institute, Joensuu, Finland, pp. 29–36.

Zivojinovic, I., Weiss, G., Wilding, M., Wong, J.L.G., Ludvig, A., 2020. Experiencing forest products - an innovation trend by rural entrepreneurs. Land Use Policy 94, 104506. https://doi.org/10.1016/j.landusepol.2020.104506.