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SOCIOECONOMIC CHANGES AND CHALLENGES IN THE FOREST SECTOR: ACKNOWLEDGING THE ROLE OF MANAGERIAL ECONOMICS AND ACCOUNTING

Prague, Czech Republic | May 13-16, 2025

Czech University of Life Sciences, Faculty of Forestry and Wood Sciences

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PREFACE

Forests are at the center of global efforts to balance economic development with environmental sustainability. Climate change, market fluctuations, and policy uncertainties increase the demand for more efficient and resilient management strategies. Addressing these challenges requires innovative approaches in managerial economics and accounting, which offer essential tools for financial planning, risk assessment, strategic decision-making, and improving financial stability in forestry.

The International IUFRO Conference in Prague (May 13–16, 2025) provided a platform for discussing the socioeconomic changes and challenges in the forest sector, with a particular focus on economic decision-making and financial planning.

The event was organized by the Department of Forestry and Wood Economics, Faculty of Forestry and Wood Sciences, Czech University of Life Sciences Prague and programme took place in the university campus. The conference brought together researchers from 9 countries, including non-European participants. Organizing team prepared a conference program starting with a get-together evening, followed by 2 conference days with presentations and excursion to Lázeňské lesy a parky (spa forests and parks) in Karlovy Vary to see the attitude towards provisioning and managing multiple forest ecosystem services with focus on recreation. Opening speeches were followed by two invited lectures on topics of The intersection of socioeconomics and ecology in the management of biological invasions in forests and European Union's green economy and policies enabling the Circular and Bioeconomy transitions. Then, the programme was divided into 4 sessions with interesting contributions and fruitful discussions. Through interdisciplinary dialogue and knowledge exchange, the conference contributes to the development of effective strategies that support the economic viability and sustainability of the forest sector in an increasingly complex global landscape.

We would like to express our gratitude to all supporters who made this event possible. Thanks go to the Faculty of Forestry and Wood Sciences, CZU Prague and its employees who were involved in organization, to Lázeňské lesy a parky Karlovy Vary for organizing a wonderful excursion programme. We are grateful to all invited speakers for their opening speeches and keynote speakers Andrew „Sandy" Liebhold and Nataša Lovrić for the scientific enrichment of the conference. Thanks to reviewers, session chairs and IUFRO for supporting communicating the event and of course, to all authors and participants.

Organizing team, FLD CZU Prague

KEYNOTE SPEECHES

EUROPEAN UNION'S GREEN ECONOMY AND POLICIES ENABLING THE CIRCULAR AND BIOECONOMY TRANSITIONS

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Abstract:

The European Union (EU) is currently at the forefront of global efforts to transition towards a sustainable bioeconomy, promoting the efficient use of biological resources while addressing environmental and climate change challenges. Green policies and innovation play a leading role in enabling this transition by fostering technologies, processes, and business models that enhance the circular use of biomass, reduce reliance on non-renewable resources, and minimize waste. This presentation shows the key drivers, EU strategies and various enablers of green innovation in the EU, including policy frameworks. It highlights mapping successful innovation projects (Lovrić, N., 2020), where green innovation has unlocked new value chains, contributed to green job development, and strengthened Europe's global competitiveness in bio-based industries. Moreover, their analysis underscores the importance of multi-actor collaboration in aligning the diverse interests of stakeholders such as industry, academia, government, and civil society. By advancing green innovation, the EU not only accelerates its bioeconomy transition but also supports broader environmental objectives, including climate mitigation, biodiversity preservation, and the creation of resilient, sustainable economies. The presented studies findings emphasize the need for continued investment in research, education, transformational and paradigm change, as well as and infrastructure update to overcome existing barriers and fully realize the potential of the bioeconomy in contributing to a green, climate resilient and circular future.

Keywords:

EU Bioeconomy, green transition, economic, paradigm change, policy

THE INTERSECTION OF SOCIOECONOMICS AND ECOLOGY IN THE MANAGEMENT OF BIOLOGICAL INVASIONS IN FORESTS

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Abstract:

Globally, forests are increasingly affected by non-native organisms, especially plants, insects and tree pathogens. The main driver behind most biological invasions is international trade and travel, which facilitates the accidental transport of organisms. Establishment of many of these species has transformed forest functions, reduced biodiversity and productivity, caused high levels of tree mortality, and altered ecosystem services, often resulting in substantial monetary losses. Knowledge of socioeconomic factors, such as drivers of international trade and travel, are key to understanding and predicting invasions. Invasions often have complex socioeconomic impacts and quantifying these impacts is crucial to identification of the value of mitigation measures. Selection of strategies for managing invasions requires balancing the costs and benefits of these measures and is crucial for identification optimal timing of management early or late in the invasion process. More socioeconomic research is thus needed to more effectively manage the problem of biological invasions in forests.

Keywords:

invasive species, impacts, costs, management, optimization

SCIENTIFIC PAPERS

THE EUROPEAN FOREST ACCOUNTS HANDBOOK 2024: A NEW FRAMEWORK FOR HARMONIZED FOREST DATA REPORTING

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Abstract

The European Forest Accounts (EFA) provide a framework for assessing forest resources, timber stocks, and the economic contributions of the forestry sector within the EU and EFTA countries. As part of the Environmental-Economic Accounts and the National Accounts, EFA includes natural and monetary data, supporting policymaking in areas such as climate strategies and the bioeconomy transition. The recently published European Forest Account Handbook 2024, which is introduced in this presentation, entails standardized methodologies and reporting guidelines for EFA data compilers to improve data quality, harmonization and comparability across countries. Though the Handbook helps to improve methodology, implementation and comparability within and across countries may still be impeded by data gaps, varying national definitions, limited technical capacities and time restrictions. Nevertheless, EFA data serve as an important information source for policymakers, researchers, and forest sector stakeholders, enabling informed decision-making for sustainable forest management and economic planning.

Keywords

European Forest Accounts, reporting guidelines, forest asset valuation, methodological standardization, forestry statistics

1 Introduction

The European Forest Accounts (EFA), depict forests and their primary product timber as a resource, covering aspects from area and stock to value, utilization, and processing within the timber industry at state level. As a vital component of international reporting, EFA are a part of the Environmental-Economic Accounts of Member States of the European Union (EU) and European Free Trade Association (EFTA). Further, they complement National Accounts by integrating natural and monetary data on the forest sector, providing insights into the interactions between economic and household activities and the environment (Bormann et al., 2006). With this, EFA provides important data for EU forest-related policies, climate strategies, and the transition to a bio-based economy. As forests play a crucial role in carbon sequestration and sustainable biomass production, EFA data can help policymakers to evaluate the balance between forest management, timber harvesting, carbon stocks ecosystem services and rural development.

Initially developed in the late 1990s/early 2000s, the then so-called European Economic Accounts for Forestry (EAF) were introduced as a satellite system to the European System of Accounts, capturing material flows and income specific to forestry production (Sekot, 2007). In 1999, the EAF was substituted by the Integrated Environmental and Economic Accounting for Forests (IEEAF), which were further revised in 2014 to become the EFA. This latest revision aimed to simplify reporting tables and align data collection with emerging data needs (Rosenkranz et al., 2019). Eurostat, in collaboration with Member States and international organizations, has continuously refined the EFA over the years to improve data harmonization and comparability and ensure consistency with the System of Environmental-Economic Accounting (SEEA), the System of National Accounts (SNA), the European System of Accounts (ESA) and the Joint Forest Sector Questionnaire (JFSQ) (European Commission et al., 2009; Eurostat 2013; Eurostat et al., 2021; United Nations 2014, 2021). Until 2024, EFA reporting has been voluntary for EU Member States, however, following the amendment of Regulation 691/2011, Member States of EU and EFTA, as well as candidate countries, will be required to submit data for EFA on a mandatory basis from reporting year 2023 (EU, 2024). In Germany, the Thünen-Institute of Forestry annually compiles EFA data on behalf of the German Federal Statistical Office.

Ten years after the development of the EFA table framework, the European Forest Account Handbook 2024 (Eurostat, 2024) was composed on behalf of Eurostat, in collaboration the Expert Group on Forestry Statistics. This was done in response to increasing demands from the Member States for methodological guidance, standardization of definitions and concepts and comparability of results as well as to evolving EU data needs. The EFA-Handbook replaces the IEEAF guidance document (Eurostat 2002) and aims to serve as a key reference document for compiling harmonized and comparable forest accounts across Europe.

Being the newest standardized compilation of method for forest accounting on state level, the EFA Handbook shall be introduced here. The presentation aims to give an overview over exemplary methods and data sources for the mandatory tables (and table A2b; see Table 1), as an outcome of our work in the Eurostat Expert Group on Forestry Statistics, and to briefly discuss value and use of the EFA-Handbook. This is complemented by a short description of the current state of methodologic uses and revisions in Germany.

2 Account structure

The EFA framework consists of ten interconnected tables, five of which are now mandatory for reporting. The table framework includes four key components: 1) asset accounts for wooded land, 2) asset accounts for timber stocks, 3) economic accounts for the forestry and logging sector, and 4) tables depicting the supply and use of wood in the rough. They always refer to a single reference year (t-2) (Table 1).

Table 1: Table structure of the European Forest Accounts

Category	Table no.	Table name	Reporting
Assets	A 1a	Area of wooded land, in 1000 ha	Mandatory
	A 1b	Area of wooded land, in million national currency	Voluntary
	A 2a	Timber on wooded land, in 1000 m³ over bark	Mandatory
	A 2b	Timber on wooded land, in million national currency	Mandatory
Economy	B 1	Economic aggregates of the forestry and logging industry (excluding other industries), in million national currency	Mandatory
	B 2	Output of the forest and logging industry by type	Mandatory
	B 3a	Supply of wood in the rough by all industries, in million national currency	Voluntary
	B 3b	Use of wood in the rough by all industries, in million national currency	Voluntary
Material flow	C 1a	Supply of wood in the rough by all industries, in 1000 m³ over bark	Voluntary
	C 1b	Use of wood in the rough by all industries, in 1000 m³ over bark	Voluntary

The asset accounts for forest land (1) and timber stock (2) contain information on area/timber stock, and area/timber stock changes for the area categories Forests Available for Wood Supply (FAWS), Forests Not Available for Wood Supply (FNAWS), Other Wooded Land (OWL) and Other Land with Tree Cover Available for Wood Supply. The economic tables (3) provide information on output, intermediate consumption, value added, net entrepreneurial income, capital formation, imports and exports and labour input for the forestry and logging industry. The physical supply and use tables (4) in turn outline the material flow of wood in the rough across all industries, including imports, exports, and final uses.

3 Methods

3.1 Data sources and methodology for physical and monetary forest area accounts

The asset accounts for forest land (Table A1a and A1b) follow the basic structure:

Opening area + changes through afforestation - changes through deforestation +/- changes through statistical reclassification = Closing area.

The forest area categories are defined according to the FAO Forest Resources Assessment 2025 (FAO FRA, 2025). Countries may adjust these definitions but must explain any deviations in the metadata sheets (Eurostat, 2024). The estimates for forest area can be based on either a single data source or a combination of sources. The primary source for physical forest area data in many countries are the National Forest Inventories (NFI) which are typically updated every 5 to 10 years. Further, data from continuously maintained cadasters, spaceborne or airborne remote sensing, land use survey data, forest management data or agricultural surveys can be used to achieve complete area coverage (Eurostat, 2024). Information on afforestation and deforestation, as the key factors influencing changes in areas of wooded land, can also be taken from NFIs, however they are hardly available on an annual basis. Option for data calculation is either the interpolation of NFI-data or the building of a time series by means of an indicator series. Further the comparison of cadastral registers may help to give an overview of forest area but is rather time consuming. Also, remote sensing data, providing maps of wooded land at regular intervals, can be used as a basis for estimating increases and decreases in forest area. Statistical reclassifications, such as changes from FAWS to FNAWS by land set-aside, could also be taken from NFIs. As annual data is also not available for this position, expert interviews can be used to fill the gaps between NFI intervals (Eurostat, 2024). In Germany, NFI data is used for estimating the opening stock forest area (FAWS and FNAWS) as well as changes in forest area between NFI. In a next step, the interpolated NFI data is aligned with annual data on afforestation and deforestation areas from the Greenhouse Gas Reporting, which is raised by a combination of remote sensing and cadastral data. Statistical reclassification (land set aside areas) is determined by an annual survey of the German Federal Ministries responsible for forestry.

The monetary value in Table A1b refers to the value of bare forest land, without the value of the timber stock or other biological capital, and should reflect prices for ownership transfer in the reporting year (Eurostat, 2024). Three methods can be used for estimation: 1) the direct method, which uses transaction data on bare wooded land to calculate an average price per hectare, and extrapolates this to the total wooded land area; 2) the residual method, in which the total value of forest land including timber stock is calculated and then the value of the timber stock (based on stumpage prices) is deducted; and - if this kind of data is unavailable - 3) the Faustmann method in which value of the forest land is calculated based on the entire expected future income from timber harvests less production, silvicultural and administrational costs (Eurostat, 2024). In Germany, the Faustmann method is applied, however, this has been subject to many discussions, as, due to the low profitability of raw wood production from main tree species - with internal rates of return around 0.4% for oak, pine, and beech, and approximately 1.7% for spruce (Staupendahl et al., 2020) - combined with high fixed costs, the Faustmann formula can in some years results in negative land values, particularly for low-yield tree species.

3.2 Data sources and methodology for physical and monetary timber stock accounts

The asset accounts on timber stocks (Table A2a and A2b) follow the basic structure:

Opening stock + net increment - removals - irretrievable losses +/- changes through statistical reclassification = Closing stock.

The same forest area categories apply as for the tables on wooded land. Timber stocks are defined in accordance with the SEEA CF (UN 2014) as the total volume of trees, both living and dead, that can be used for timber or fuel, including components such as stem wood and bark, stumps above ground, and large branches. A threshold of 0 cm at breast height is applied and strongly encouraged. However, minimum diameters of stems and branches vary across countries mainly due to different management and survey practices (Eurostat, 2024).

The main data sources for compiling timber stock accounts are NFIs - again often used as the primary source - along with forest management data, remote sensing, forestry production and income statistics, forest industry surveys, and related databases. When estimating the volume and volume changes of timber stock, a differentiation for forest stands with different tree species, age classes, etc., for the forest area categories, is encouraged. Timber volume calculations should further be based on the same wooded land classifications as those used for area related tables, which is typically ensured with NFI data, but may require careful adjustment when using cadastral or spatial datasets (Eurostat, 2024). To create a time series of the timber stock, interpolation and extrapolation of (NFI) data can be done. Deviations due to large scale primary or secondary forest dieback, should be determined with the support of forest management experts. Changes in the timber stock (increment) can also be determined using NFI data or growth models. Removals can be estimated either by using a residual method (= change in timber stock - net increment - felling residues) or by tracking the flow of wood products and ensuring that estimates of removals and fellings align with data on total roundwood use, including international trade and inventory changes (Eurostat, 2024), which is done in Germany, based on the Estimations of Fellings (Jochem et al., 2015)

To value the timber stock, in line with ESA and SNA, indirect valuation methods should be used. If possible, a distinction should be made for valuing the removals and the remaining timber stock. For calculating timber prices, four methods are suggested by Eurostat (2024): 1) the stumpage value method, in which an average stumpage price is projected to both, the standing timber volume and the harvested timber. 2) The consumption value method in which the stumpage values are calculated for different age and diameter classes, therefore allowing for differentiation of remaining and felled timber. 3) The net income method in which a discounted stumpage price is calculated for different age classes by adjusting the current stumpage price using an appropriate discount factor. And 4) The age constant method in which the expected felling value for each age class is determined using the net income method, adjusted by an age factor. To ensure consistency to the National Accounts for Forestry, the stumpage value method is used in Germany, which is based on differentiated timber prices for different assortments and calculated for both forest enterprises and forest service providers.

3.3 Data sources and methodology for the economic accounts

The table on the economic accounts for the forestry and logging industry (B1) includes the following positions (Eurostat, 2024):

1) Total output (= Goods characteristic of the forestry and logging activity + Services characteristic of the forestry and logging activity + Other products from connected secondary activities in the local KAU + Other products),
2) intermediate consumption (=Goods input + services input + Other goods and services used as inputs)
3) Gross value added (= Total output - Intermediate consumption)
4) Net value added (=Gross value added - Consumption of fixed capital)
5) Factor income (= Net value added - Taxes on production + Subsidies on production)
6) Net operating surplus (= Factor income - Compensation of employees)
7) Net fixed capital formation (= Consumption of fixed capital - Gross fixed capital formation)
8) Changes in inventories
9) Capital transfers
10) Labour input in 1000 annual work units (AWU)

EFA Table B1 covers the economic units classified under NACE Rev. 2.1, Division 02 (forestry and logging). This includes all kind-of-activity units (KAUs) performing activities within this classification, including secondary activities undertaken by these KAUs. However, secondary forestry and logging production by KAUs not part of NACE Div. 02 are excluded. Where it is feasible and corresponding data exists, separate KAUs should be created and coded to NACE 02 (Eurostat, 2024).

The forestry and logging industry primarily produces timber, which can be managed in two ways: cultivated (actively managed) or natural (minimally managed). In cultivated forestry, output is recorded progressively as the timber stock grows, whereas in natural forestry, output is only recorded at harvest. Logging output, in both contexts, is recorded based on wood removals (Eurostat, 2024).

A key challenge in forestry accounting is aligning long production cycles with annual reporting requirements, particularly for cultivated forests where timber growth must be estimated each year. In contrast, natural forests do not generate recorded output until harvest, so their economic contribution may be underestimated in annual accounts. Additionally, forestry output (growing timber stock) and logging output (harvested wood) must be carefully distinguished (Eurostat, 2024).

The main data source of Table B1 are the National Accounts. If data in the detailed level required for EFA is missing in the National Accounts, business surveys, input-output tables or supply-use tables, forestry surveys, annual reports, production and price statistics and finance statistics as well as household surveys and labour force surveys can be used to estimate data. In regard to alignment of EFA and National Accounts the Handbook encourages close cooperation between data compilers (Eurostat, 2024).

Table B2 compiles the data of table B1 by type of output and contains the following positions: Output of basic prices, divided in the positions own final use, market, non-market, total and of which households. Estimating the data for Table B2 is challenging due to limited direct data availability. Total output at basic prices should and own final use estimates, can be taken from Table B1. Household removals for personal use should also be considered, but will likely require household and energy surveys for accurate estimation. Market output is typically calculated as total output minus own final use, except when non-market output exists, such as forestry-related government services. While output classification for all forestry products is conceptually possible, data compilers should focus on the most significant products, that is wood in the rough (Eurostat, 2024).

4 Discussion

The new EFA Handbook primarily serves as a guidance document for data compilers but also as an informational document to other interested entities. It promotes standardized reporting guidelines for the first time since the establishment of the EFA tables and aims to provide a framework for collecting and reporting the EFA tables and to thus ensure good quality, harmonization and comparability across data-providing States. It further aids countries in meeting new legal requirements of data reporting e.g., due to Regulation 691/2011 (EU, 2024). By providing a standardized reporting framework, it offers guidance on complex estimations, helping data compilers to find appropriate calculation methods and provides assistance to dealing with missing data. Additionally, the Handbook provides guidance to improve the compatibility with other international datasets, striving for better possibilities of cross-sectoral analyses.

In reality, however, differences in national definitions, methodologies, measurement and reporting practices will still lead to inconsistencies. Data gaps, irregular survey intervals, and variations in inventory methods, such as sampling techniques, periodicity, and biomass conversion factors, create inconsistencies that complicate cross-country comparisons. One example is the instruction to use a threshold of 0 cm BHD for calculating all stock related data. NFIs often apply different thresholds, which directly affects timber stock estimates and complicates cross country comparisons. Although links to methods for converting national thresholds to 0 cm BHD are given in the Handbook, EFA data compilers may not have access to all data necessary for the conversion, as often data compilers are not also the primary producers of data.

Furthermore, some national data providers lack the technical capacity for advanced modeling techniques, such as satellite-based forest monitoring, impacting the completeness and accuracy of reported data. Further, the Handbook often requires rather detailed data compilations and research (e.g., expert consultations for determining changes of timber volume by biotic or abiotic calamities) which are rather time consuming. As data compilers often have other duties apart from EFA, this will either lead to lack of time or compromises in data quality.

Additionally, Europe's diverse forest ecosystems and management practices may also impact comparability, as might differences in political frameworks and economic and ecological accounting approaches. Whereas some countries focus on non-market forest functions like biodiversity and recreation, EFA mainly focuses on timber value and forest-related employment, making direct comparisons difficult. And last but not least, the intention to provide several methods for each calculation step, so that all countries can choose the method best applicable, is understandable on the one hand. On the other hand, different methods most certainly lead to different results, again hindering comparability.

5 Conclusion

The drafting of the European Forest Account Handbook 2024 is an important step toward ensuring the quality of forest-related economic data across Europe. By providing methodological guidance, harmonized terminology and definitions, and alignment to international standards, it provides a valuable tool for EFA data compilers, statisticians, researchers working in the forestry and bioeconomy sector and all others interested in details of the accounts. The Handbook enhances consistency and comparability across data-providing countries and helps to align EFA data with other accounting systems, thereby improving the reliability of forest-related economic assessments and supporting policymakers and stakeholders in making informed decisions for affecting forest management. However, challenges related to data availability, valuation uncertainty, comparability due to a wide range of methods and regional differences must be kept in mind when analyzing and comparing EFA data.

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THE GERMAN FOREST ACCOUNTANCY DATA NETWORK (FADN): NEEDS ANALYSIS AND CONCEPTUAL DEVELOPMENT

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Abstract:

The Forest Accountancy Data Network (FADN) of the Federal Ministry of Food and Agriculture is the most important data source for assessing the economic situation and development of German forestry. In an ongoing research project for the further development of the FADN, we have carried out a needs analysis and identified initial approaches for the conceptual development of the FADN. A central result of our needs analysis was that all FADN key figures collected currently collected are used in numerous (nationwide) analyses and reports, and the data requirements will tend to increase in the future. For example, ecosystem services have been identified as an additional topic. Based on a scoping review, we identified possible indicators that cover this topic. These indicators were then assessed in terms of their feasibility by forest enterprises and their suitability by ecosystem service experts. For this purpose, an online survey was conducted.

Keywords:

Forest Accountancy Data Network, ecosystem services, data collection, indicators, economic situation

1 Introduction

The Forest Accountancy Data Network (FADN) is a meaningful data base for assessing the economic situation and development of forestry. If a continuous, long-term series of operational data is available, forestry with its long production periods can be analyzed in a well-founded manner. In Central Europe, only a few countries, such as Germany, Austria, or Switzerland (D-A-CH-region), operate a FADN at the national level (Bürgi et al. 2016), which is probably due to the high costs for the network operators and participating forest enterprises (Toscani 2016).

The German FADN was initiated in 1951 to document and analyze accounting data of forest enterprises and to monitor their development. Since 1976, it has been the responsibility of the Federal Ministry of Food and Agriculture (BMEL) and is operated by the federal and state governments. The federal states are responsible for collecting data from the forest enterprises and checking the plausibility of the data. The federal government is responsible for data management, data analysis, reporting, and documentation (Lohner et al. 2016).

In the FADN, state, corporate, and private forest enterprises with a forest area of 200 ha or more report their operating results annually on a voluntary basis. Due to the voluntary participation, the FADN can be characterized as an “assessment sample”. Based on the BMEL implementation instructions, the operational data is collected using a survey form comprising nine tables. This survey form contains 608 key figures, 428 of which must be reported directly by the forestry enterprises. The individual operation data is checked with a plausibility check program (FsnPlausi). The individual enterprise results are aggregated in five defined product areas: 1. production of wood and other forest products, 2. protection and restoration, 3. recreation and environmental education, 4. services for third parties, and 5. sovereign and other official tasks (DFWR 1998; BMEL 2017; Hartebrodt et al., 2022; Müller et al. 2024). The collected individual enterprise data are extrapolated using projection factors based on the “Free extrapolation”, taking into account the sample stratification groups: ownership type (private, corporate, state forest), federal state and size class (200-500 ha, 501-1000 ha and >1000 ha) (Seintsch et al. 2017).

The FADN results are published in the annual report “The economic situation of forest enterprises” (BMEL 2024). The current report, as well as 11 standard evaluation tables, the implementation instructions, the forestry survey form, the plausibility check program, and an archive with the accounting results of previous reporting years, are available online on the BMEL website.[1]

In addition to this direct reporting of FADN results, the FADN data are used for numerous other reports and reporting obligations at federal level, such as the national Economic Accounts for Forestry (e.g. Rosenkranz et al. 2024), the (German) European Forest Accounts (e.g. Rosenkranz et al. 2019), the Federal Government's reporting obligation under § 41 (3) Federal Forest Act on the situation and development of forestry (e.g. Dög et al. 2016; BMEL 2021) or for scientific evaluations, e.g., by the Thünen Institute for federal policy advice (e.g. Regelmann et al. 2023). A systematic recording of the user groups of the FADN data and their data needs at the level of the individual FADN key figures is not available yet.

Although the FADN can look back on a long success story, it also faces major challenges. The biggest current challenge is the sharp decline in the number of forest enterprises participating. With 353 forest enterprises in 2012 and 171 forest enterprises in 2022, this number has declined by more than half in recent years. One reason for this is the high data collection effort required to provide the numerous key figures, which exceeds the direct benefit for the participating enterprises. In order to alleviate the effort for forest enterprises, but also to meet new data needs of different user groups, due to current developments such as climate change, new business areas, additional reporting obligations, and changing social demands on the provision of ecosystem services, it is necessary to regularly review the suitability of the FADN survey.

Against this backdrop, the aim of the current joint project “Further development of the German Forest Accountancy Network (FADN²)” is to comprehensively analyze the FADN and develop options for further development.[2] In the sub-projects of the Thünen Institute of Forestry (TI-WF), the following research questions, among others, should be answered:

i.) Which data needs do the main data users of the FADN have?

[1] https://www.bmel-statistik.de/landwirtschaft/testbetriebsnetz/testbetriebsnetz-forst-buchfuehrungsergebnisse

[2] https://www.thuenen.de/de/fachinstitute/waldwirtschaft/projekte-liste/weiterentwicklung-forstbetrieblicher-kennzahlenvergleich

ii.) How can the provision of ecosystem services be conceptually integrated into the FADN?

2 Methods

2.1 Survey of main data users and their data needs according to FADN key figures

To answer the first research question, a mix of methods was used to identify the main data users and their data needs for TBN key figures (Müller et al. 2024): i.) A request was sent to the BMEL regarding internal needs and external requests for FADN data (e.g., BMEL 2024). Additionally, BMEL provided an overview of the FADN website views. ii.) As the TI-WF is one of the main users of the FADN indicators the FADN key figures used in TI-WF statement, individual calculation and reporting systems were systematically recorded through a document analysis. iii.)In addition, expert interviews were conducted with the forest expert service of the Federal Agency for Real Estate, with the FADN state officers, and with the operators of forest enterprise comparisons, benchmarking rings, and regional FADNs. In the last two groups, the interest of the participating forest enterprises in FADN key figures for operational comparisons and benchmarking was surveyed in particular.

2.2 Conceptual integration of ecosystem services

To answer the second research question, the method was divided into three parts: i.) First, the ecosystem services (ES) relevant to forest policy were identified through a document analysis and in order to adapt the integration of the ES to the structure of the FADN and to ensure an easy understanding of the ES, these were grouped into so-called: Forest Ecosystem Service units (FES units). ii.) In a second step, a scoping review on possible indicators to represent the identified FES units was conducted. iii.) Finally, a two-part survey to evaluate the indicators' feasibility and suitability was carried out. This paper focuses on the third part.

Most indicator evaluation schemes include the following key aspects: Indicators should be generally accepted, comprehensive but thrifty, understandable, sensitive, useful, and feasible (Harger & Meyer 1996; Doran 1981; Rice 2003; Lebacq et al. 2013; Schliep et al. 2014; van Oudenhoven et al. 2018). We assume that the indicators identified through the scoping review already meet these criteria, as some form of assessment scheme must have been applied for their development and validation. However, for inclusion in a FADN, the criterion of feasibility by forest enterprises is particularly important. Furthermore, since most indicators are not specifically developed for the operational level, it is necessary to determine if they are suitable at an operational level.

To evaluate the criteria of feasibility and suitability, two surveys were conducted. These were carried out from February to March 2025 using the online survey tool "Limesurvey". One part of the survey targeted experts in the field of ecosystem services and aimed to assess the suitability of the indicators selected in step 2, when applied at an operational level. Experts were asked to rate the suitability of the indicators at the forest enterprise level on a three-level Likert scale as high, medium, or low. Both main indicators and any necessary sub-indicators for their calculation were identified in the scoping review. For research efficiency, experts only evaluated the main indicators for the respective FES units.

The second part of the survey targeted managers or owners of forest enterprises and aimed to estimate the effort required to collect the indicators within the forest enterprise. The survey of forestry enterprises focused on the sub-indicators, as these are necessary to calculate the main indicators. Here, the survey was limited to sub-indicators not collected through the forest inventory. Besides estimating the effort to collect the indicators, the forest enterprises were asked if they had a forest inventory system. If a forest inventory system is in place, we assume that the indicators collected therein are readily available. For the surveyed indicators, the estimated time required by the forest enterprises to provide the indicators was queried. Time was used as a proxy for effort. The scale ranged from “available in the enterprise” to “2-3 working days” or more, and also included the option of “no response” if no information on the indicator was available.

3 Results

3.1 Data users and their data needs

- **Identification of main user groups**

As main user groups of the FADN key figures were identified i.) the federal government (federal policy, ministries and forestry departmental research), ii.) the federal states (state policy, ministries and forestry research), iii.) forest expert service for forest valuation and iv.) the forest enterprises for benchmarking (Müller et al. 2024).

- **Documentation of the current data needs**

The FADN-key figure needs of the main user groups were assigned to the individual accounting positions of the total of 608 key figures in the nine tables of the forestry survey form. As almost all FADN key figures are published in the annual BMEL report “The economic situation of forest enterprises” (BMEL 2024), the federal government's data requirements were differentiated into “Federal government with BMEL report (w.r.)” and “Federal government without BMEL report (w/o.r.)”. In table 1 the result of this assignment is shown illustratively for the table “Felling rate, timber harvest and timber sales” of the forest survey questionnaire. A key result of these needs analyses is that almost all FADN key figures are used by the main user groups and only a small number of the current key figures (the all-white fields in table 1) are not used (Müller et al. 2024).

Table 1: FADN- forestry survey form: Used key figures in m³ without bark (w.b.) of felling rate, timber harvest and timber sales for the identified data users

Feeling rate, timber harvest, timber sales

1		2	3	4	5	6	7	8
Description	Code	Oak	Beech and other hardwoods	Hardwood total	Spruce, fir, douglas fir	Pine, larch and other conifers	Conifers total	In total
		m³ w.b.	m³ w.b.	m³ w.b.	m³ w.b.	m³ w.b.	m³ w.b.	m³ w.b.
Utilizaation rate / Cutting rate	3001							
Harvested timber	3002							
Harvested other usable wood	3003							
Harvested unusable wood	3004							
Total wood harvest	3005							
Of which: Sold standing / Self-harvesters (ohne unverwert-bares Holz)	06							
Contractor	07							
Own management	08							
Energy wood (additional information)	3010							
Total wood sold	3011							
Currently not occupied	3012							
Unsold wood from harvests of the reporting year	3013							
Wood removed for own use	3014							

Plausibility check

3005 - 3004 = 3011 + 3013 + 3014

Federal government (w.r.)
Federal government (w/o.r.)
Federal states
Forest enterprises
Forestry appraiser

- **Identification of unused FADN key figures**

A surprising result of the needs analysis was that only a relatively small number of FADN key figures are currently not used by the main user groups. The unused key figures can be assigned to the following accounting items of the data entry form: i.) total natural removals of hardwood, softwood, and wood in total, ii.) calculated expenses (total of cost types), iii.) expenses unrelated to the accounting period (total of cost types), iv.) consumption of own products under the item local and higher authority administration expenses, v.) consumption of own products under the item own machinery and vehicle fleet and vi.) comparative value of forestry use (Müller et al. 2024)

- **Identification of additional future data needs**

As additional future data needs were identified for the following topics: i.) ecosystem services, ii.) climate change and forest disturbance (impact and consequences), iii.) reduced yields or additional expenses due to the protective and recreational function of the forest, iv.) alternative business areas, v.) operational framework conditions and socio-economic operational data, and vi.) timber harvest and timber sales. The inclusion of additional key figures on i.) ecosystem services in the future was considered particularly important given the increased remuneration of these services and the associated revenues for German forest enterprises. (Müller et al. 2024).

Conceptual integration of ecosystem services

In strategies from the federal government, EU, and UN, 41 ecosystem services (ES) were identified. To reduce complexity, the identified ES were combined into FES units according to the idea of Boyd and Banzhaf (2007). These units are: i.) wood provision, ii.) non-timber forest products, iii.) biodiversity, iv.) air quality regulation, v.) protection against natural hazards, vi.) drinking water, vii.) culture, health, and recreation, ix.) economic, science, and education. During the scoping review, 31 articles dealing with indicators for ES were identified. Indicators were found for 38 of the 41 ES. Overall, there were many similar indicators for the individual ES, and there were significant differences in the number of indicators per ES or FES unit, as well as in the differentiation of the indicators concerning ES or FES unit.

A total of 173 forest enterprises and 51 experts participated in the surveys for the further evaluation of the identified indicators. The responses from both experts and forestry enterprises were divided into three categories. For experts, the categories were high, medium, and low suitable; for forestry companies, the categories were easy, moderate, difficult, and not collectible. The overall evaluation was based on the frequency of the respective responses. The category that encompassed the most responses (but at least 40% of them), formed the overall evaluation.

From the perspective of the forest enterprises, the assessment of the feasibility of the indicators was relatively clear-cut. For the majority of the surveyed forest enterprises, the indicators were either easy or difficult to collect. The category "moderate" did not play a significant role.

Table 2: Indicators of the FES unit "drinking water supply" with description, reference value, sources, and evaluation by forest enterprises and experts

indicator	sub-indicator	description	ref. value	original sources	feasibility	suitability
tree-specific sizes					green	green *d
	tree species (name)	names of tree species occuring in the area	species name	[4][1], [10], [24], [30]	green	
	tress species (number)	average number of trees per hectar	(n) ha^{-1}	[4][1], [30]	green	
	tree age	average tree age for every tree species in stand	Ø in years	[30]	green	
	tree hight	average tree hight for every tree species in stand	Ø in m	[30]	green	
	breast high diameter (BHD)	average DBH for every tree species in stand	Ø in cm	[30]	green	
growing season		duration of growing season	in months	[30]	green *b	yellow *d
leaf area index		ratio of one-side leaf area to one unit of soil (Watson, 1947)		[30]	green *ab	yellow
stock-specific sizes					green	yellow
	tillering level	average tillering level per tree species per hectar	Ø ha^{-1}	[4][1], [30]	green	
	forest stratification	predominant stratification of the stands		[8]	green	
management form		type of management on the predominant area		[30]	green	yellow
forest soil					yellow	yellow
	humus type	predominant soil type of the entire forest area		[4][1], [30]	yellow	
	soil type	predominant humus type on the entire forest area		[4][1], [30]	green *c	
	infiltration rate	calculation according to the TUB-BGR method (Wessolek et al., 2008)	mm a^{-1}	[4][1], [8]	green *ab	
catchment area drinking water production plant		area used for drinking water production	% of total	[4][2], [10]	green	green
total amount of drinking water		estimated total available amount of drinking water on the total area	Tsd.m^3 ha^{-1}	[3], [11], [14], [27]	red	green
floodplaines		floodplaines according to § 76 WHG[5]	% of total	[4][2,3], [10]	green	green
area and type of designated areas				[4][2], [7][4], [10], [14]	green	green
	names	all areas that have a legal protection status, are subject to legal restrictions on use or have been voluntarily taken out of use	name	[4][2], [7][4], [10], [14]	green	
	percent of total area	all areas that have a legal protection status, are subject to legal restrictions on use or have been voluntarily taken out of use	% of total	[4][2], [7][4], [10], [14]	green	

[1] Bastian et al., (2012): Verfahrensansätze der Landschaftsökologie zur Erfassung und Bewertung von Ökosystemdienstleistungen
[2] Bürger-Arndt, (2012): Kategorien, Indikatoren und Datenlage der Waldfunktionkartierung
[3] Ontrup, (2012): Waldfunktionenplanung in Rheinland-Pfalz: Forstliche Abwägung und planerische Konsequenzen
[4] Schäfer (2013): Ökonomische Bewertung von Biodiversität und Ökosystemleistungen in Wäldern
[5] Water Resources Act of Germany

*a calculable with available data
*b derivable from statistics or literature
*c easy to collect only with site mapping
*d adjusted

green: easy / high
yellow: hard / middle
red: not feasible / weak

Table 2 exemplarily shows the results of the evaluation for the FES unit "drinking water supply". The first four columns are the result of the literature analysis. Column 5 contains the literature sources[3]. Columns 6 and 7 display the results of the forest enterprise and expert surveys using a traffic light system. Overall, ten indicators were identified for the FES unit "drinking water supply," some of which can be further broken down into sub-indicators. In regard to feasibility, most of the indicators were rated as easy to collect by the forest enterprises. Only one sub-indicator and, consequently, the indicator itself were rated as difficult to collect. Additionally, one indicator cannot be collected by forest enterprises at all. In regard to suitability, from the experts' perspective, only half of the indicators are highly suitable for describing the FES unit at the operational level, including the indicator rated as not collectible by the forest enterprises. The other indicators were rated as moderately suitable.

[3] The table is taken from the as yet unpublished original article, so no direct sources for the key figures are available here.

For use in the FADN, indicators that are rated as easy to collect and highly suitable are particularly promising. These are the tree-specific properties and the designated area categories in this example. Indicators that are either not collectible or only weakly suitable are not considered for use. In this example, this includes the quantity of available drinking water under the forest area.

4 Discussion and conclusion

FADNs are a central data source on the economic situation and development of forestry for enterprises, associations, administration, science and politics. In the central European D-A-CH region (Germany, Austria, and Switzerland), these FADNs can be regarded as successfully established since they have now been in existence for over five decades (Toscani 2016).
FADNs are, however, associated with considerable costs for the participating forest enterprises and network operators, and the availability of public funding for their continuation is always uncertain. The success of the FADN depends heavily on the perceived cost-benefit for all FADN participants and data users. Due to the high internal data collection effort for the FADN data reports, this applies in particular to the voluntarily participating forest enterprises. The existing FADN must therefore be continuously reviewed and further developed, and the existing FADN data must be used in the best possible way (Toscani 2016; Bürgi 2023).

With our needs analysis, we attempted to systematically record the data users and their data needs for Germany. Since we only recorded the "active and regular" FADN data users as "main data users", it is possible that we did not identify other important data users who only use the BMEL-internet offers or publications on the FADN "passively and unregular" (e.g., timber industry, banks or insurance enterprises).

Our survey of the current need for individual FADN key figures shows that almost all of the key figures are used. A reduction in the number of key figures would only be possible by prioritizing the information needs of the individual main data user groups. Possible approaches for such prioritization are shown by Müller et al. (2024). In this context, Toscani (2016) points out that the scientific approach of FADN follows Popper's "bucket theory", according to which empirical data is accumulated "in a bucket" and only used later to form hypotheses. Following this reasoning, FADN data is partly collected in advance, and the full information content is generally not utilized on an ongoing basis.
Another aim of our needs analysis was to identify additional FADN data needs for the future. The topics of ecosystem services, alternative business areas, climate adaptation, and forest disturbance or timber harvesting and sales are likely to provide important information for benchmarking. An intensification of benchmarking appears to be a promising approach for improving the cost-benefit ratio of the FADN for participating forest enterprises (e.g., Bürgi 2023). Benchmarking also requires a sufficient number of participants to be able to form suitable and relevant forest enterprise comparison groups (Müller et al. 2024). Concerning an expansion of the FADN key figure catalog to include further subject areas, the main issue is the effort required by forest enterprises to provide the data. The decisive factor for the effort involved is also likely to be whether the key figures are already available in the forestry operation independently of the FADN or would have to be determined separately for this purpose.

New figures should both fulfil the need for information and at the same time be easy to collect at the operational level. The indicators developed for various ecosystem services are not necessarily suitable for application within the accountancy network frame.

By involving forest enterprises and experts, we were able to evaluate indicators for ecosystem services identified from the literature in terms of their suitability for use in the FADN. Particularly, indicators that are rated as easy to collect by forestry enterprises and highly informative at the forestry

enterprise level by experts are candidates for inclusion in the FADN. Indicators that are either not collectible or poorly suited should not be included in the FADN. For indicators that are rated as difficult to collect but highly informative, or as easy to collect but at least moderately informative, a discussion on whether they should be included may be warranted.
Our work focused solely on indicators that have already been discussed in the literature. If there is a need for expanded information within the FADN, the development of new indicators to map ecosystem services or other possible focal points could be considered. Such new developments should involve both forestry enterprise experts and experts in the in the affected area to ensure the feasibility and suitability.

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SOCIOECONOMIC CHANGES AND CHALLENGES IN THE FOREST SECTOR: THE INTERPLAY OF EU AND CZECH LAW

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Abstract:

The forest sector is undergoing significant socioeconomic changes driven by evolving economic structures, demographic shifts, and environmental challenges. Paper explores the key transformations affecting forestry, including labor market dynamics, the shift towards sustainable forest management, and the increasing role of digitalization and bioeconomy. The research focuses on the interplay between these socioeconomic factors and the legal framework governing the forest sector at both the EU and national level. The study analyses relevant EU regulations, such as the EU Deforestation Regulation (EUDR), the Forest Strategy 2030, and biodiversity protection directives, examining their impact on national legislation and forest governance. Additionally, it assesses the challenges associated with the transposition of EU law into Czech legal frameworks, highlighting potential conflicts between economic interests, environmental protection, and social sustainability. The paper concludes with recommendations for harmonizing legal frameworks, improving policy coherence, and enhancing the resilience of the forest sector in response to contemporary socioeconomic challenges.

Keywords:

forest sector, socioeconomic changes, sustainable forest management, EU law, Czech law

1 Introduction

European forest governance is increasingly driven by supranational regulations aimed at promoting environmental sustainability and climate resilience (Imbrenda et al., 2023; Forest Europe, 2024). Legal acts such as the EU Deforestation Regulation (EUDR) and the Forest Strategy 2030 impose new requirements on Member States that change national forest legislation and administrative practices. In the Czech Republic, where more than a third of the territory is covered by forests and forestry plays an important role in regional economies, these changes pose legal and socio-economic challenges (Perunová & Zimmermannová, 2023). This article aims to explore the intersection of EU legal frameworks and Czech legislation on forest management and to assess how the implementation of EU policies affects the national legal system and the wider forest-dependent society. The Czech Republic, as a member of the European Union, must comply with a number of directives and regulations related to forestry. Key ones include the Habitats Directive (92/43/EEC) and the Birds Directive (79/409/EEC) – aimed at the protection of natural habitats and wild species. In the field of forestry, this is primarily the Timber Regulation (EU No. 995/2010) – which combats illegal logging by requiring the legal origin of timber placed on the EU market. The Czech Republic is also a party to several international agreements, such as the Carpathian Convention, which promotes sustainable forest management in the Carpathian region, the UN Resolution on Forests and the Ministerial Conference on the Protection of Forests in Europe (Forest Europe). All these commitments also have socio-economic impacts on economic development. Compliance with international forest regulations leads to sustainable management, thereby contributing to long-term economic benefits (stable supply of wood, support for investments and projects). Sustainable management also creates jobs in forestry, nature conservation and related sectors. International law supports biodiversity and ecosystem services that benefit local communities (water regulation, soil protection, climate change mitigation). Legal acts such as the EU Deforestation Regulation (EUDR) and the Forest Strategy 2030 impose new requirements on Member States that change national forest legislation and administrative practices. In the Czech Republic, where more than a third of the territory is covered by forests and forestry plays an important role in regional economies, these changes bring legal and socio-economic challenges. The main research questions include: (1) How are EU legal instruments in the field of forestry transposed into Czech law? (2) What legal conflicts or ambiguities arise in this process? (3) What are the socio-economic impacts of these changes on Czech forestry actors?

2 Methods

This research uses an interdisciplinary approach of comparative legal analysis. The legal documents analysed include the EUDR (Regulation (EU) 2023/1115 of the European Parliament and of the Council), the EU Forest Strategy to 2030, Act No. 289/1995 Coll., on forests, and related environmental legislation (Cícha & Boháč, 2021; Heredero & Blome, 2022). Secondary data are drawn from scientific literature, policy documents, and reports of state institutions. Methods used were legal-analytical method which identify legal inconsistencies and assess compliance between EU law and Czech legislation and comparative method which compare implementation in the Czech Republic and EU.

3 Results

The Czech Republic has started transposing EU forest legislation through amendments to the Forest Act and related legislation. Key areas include several legislations. One of them is compliance with the EUDR, Czech authorities are responsible for verifying the origin of wood and ensuring that products do not come from areas where deforestation has occurred after 2020. Implementation has required adjustments to forest certification and monitoring. Other important document is Forest Strategy 2030 which means that Czech adaptation emphasizes multifunctionality, sustainable management and increasing forest resilience through species diversification. Despite progress, some challenges remain and are mentioned in documents. Definitely is used of unclear terminology. In Czech Republic is the insufficient enforcement capacity. Especially at the municipal level, enforcement of new obligations is limited by a lack of staff and technical equipment. Legislative changes significantly affect forest owners and rural economies. Private forest owners (approx. 20% of Czech forests) face increasing administrative demands related to wood traceability and certification. Public forest enterprises, such as Lesy České republiky, are under pressure to modernize and comply with European standards. Rural employment is declining due to mechanization, digitalization and the decline of traditional forestry professions.

The following *Fig. 1* and *Fig. 2* clearly show that forest law in the European Union and the Czech Republic, despite being partially interconnected, differs in its structure, level of competence and method of implementation. The European Union does not have a uniform forest law or a common forestry policy – the main responsibility therefore remains with the individual Member States. However, the EU uses sector-specific legislative instruments (e.g. in the field of timber trade, biodiversity or climate objectives), which significantly influence national legal frameworks. The Czech Republic responds to these European regulations by transposing them into national legislation – in particular through the Forest Act (No. 289/1995 Coll.) and the Nature Conservation Act (No. 114/1992 Coll.). Strategic documents such as the Climate Strategy or the Rural Development Programme also play an important role. The tables thus clearly capture the multi-level governance of forestry in the EU and confirm that the future effectiveness of forest policy will depend on the ability to align European objectives with national conditions, especially with regard to sustainable management, nature conservation and the economic viability of the forest sector.

Law - area	EU law	Czech law
General Forest Legislation	No unified EU forest law – national competence	Forest Act No. 289/1995 Coll.
Illegal Logging / Timber Trade	EU Deforestation Regulation (EUDR, 2023); previously EUTR	Incorporated through EUTR/EUDR enforcement
Biodiversity Protection	Habitats Directive (92/43/EEC), Birds Directive (2009/147/EC)	Nature and Landscape Protection Act No. 114/1992 Coll.
Climate Regulation	LULUCF Regulation (EU 2018/841), EU Climate Law	Climate Protection Strategy, participation in EU LULUCF framework
Renewable Energy Use	Renewable Energy Directive (RED II/III)	Act on Supported Energy Sources, implementation of RED
Subsidies and Rural Development	CAP – Common Agricultural Policy (incl. RDP)	Act on Agriculture, National Rural Development Programme
Environmental Impact and Protection	Environmental Impact Assessment (EIA) Directive	Environmental Protection Act No. 17/1992 Coll., EIA Act
Forest Monitoring and Planning	Forest Information System for Europe (FISE), reporting obligations	Forest Management Plans, NFI oversight
Protected Areas	Natura 2000 network (based on Habitats/Birds Directives)	National network of protected areas, Natura 2000 transposition

Figure 1. Comparison of legal areas

Area	EU	Czech Republic
Competence	No common EU forestry policy; Member States define their own policies	National laws and strategies – primary responsibility
Timber Trade	Regulation of timber import and trade via EUDR	Transposition of EUDR into national control and enforcement
Biodiversity	Natura 2000 (Habitats and Birds Directives)	Transposed through Act No. 114/1992 Coll. and management of protected areas
Climate Regulation	LULUCF regulation and carbon targets	National strategies aligned with EU climate goals
Energy	RED III – conditions for use of biomass	Act on Supported Energy Sources
Subsidies	Common Agricultural Policy (CAP)	RDP (Rural Development Programme) + national support schemes
Monitoring	EU systems (FISE, Copernicus)	National forest inventories (NFI, Forest Management Plans - LHP)

Figure 2. Summary of Main Differences Between EU and Czech Forestry Legislation

Figure 3 shows the main pillars of European forestry policy and legislation. Given that the EU does not have a common forestry policy, the map focuses on the tools that the EU uses to influence forestry: strategic documents (e.g. EU Forest Strategy), legislation (e.g. EU Deforestation Regulation - EUDR), funding (CAP, LIFE) and international cooperation (e.g. FLEGT). The map illustrates the complexity of the links between environmental, climate and economic objectives.

Figure 4 depicts key national documents, laws and institutions that form the framework of forestry in the Czech Republic. The core is the Forest Act and the Forest Policy of the Czech Republic until 2030. Institutions such as the Ministry of Agriculture, the National Forestry Institute (formerly ÚHÚL) or the state enterprise Lesy ČR are also highlighted. The map also considers the influence of European funding and the emphasis on monitoring (e.g. LHP, inventory).

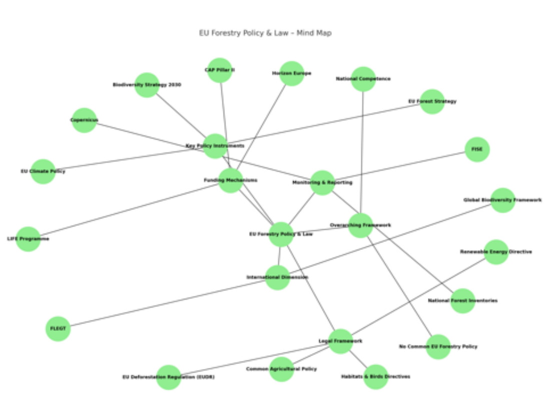

Figure 3.

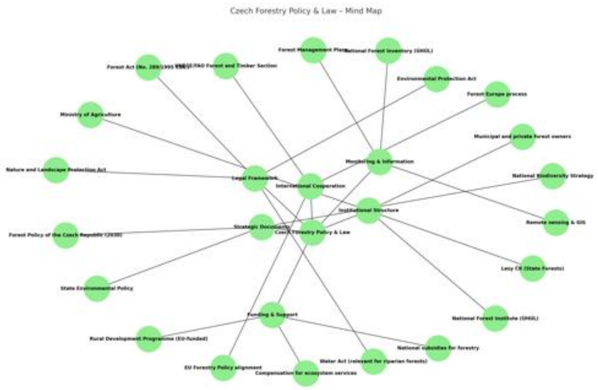

Figure 4.

The following *figure 5* connects both levels – European and national – and shows how the EU influences the forest policy of the Member States in a general way. Branches representing strategic documents, legislative framework, financing and international relations both at the EU level and in the Czech Republic branch out from the central node. The map allows a comparable view of both levels and helps to understand how European policy is reflected in Czech legislation and practice.

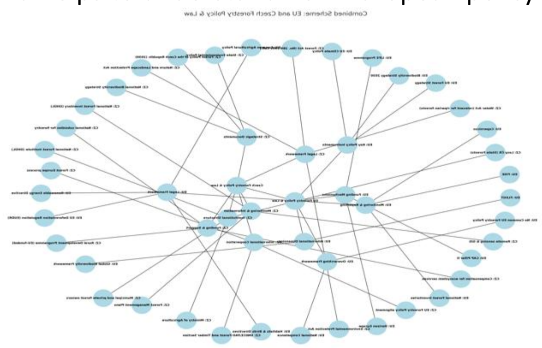

Figure 5. European and national levels combined

The timeline at *Figure 6* provides an overview of the main milestones in the field of forest policy and legislation at EU and Czech level from the 1990s to the present. It starts with the Habitats Directive (Natura 2000), continues with key European strategies and regulations (EUTR, EUDR), and also presents Czech legislative and institutional changes (e.g. the Forest Act, the establishment of the Forestry and Forestry Agency and its renaming). This overview shows the development and interconnection of policies over time.

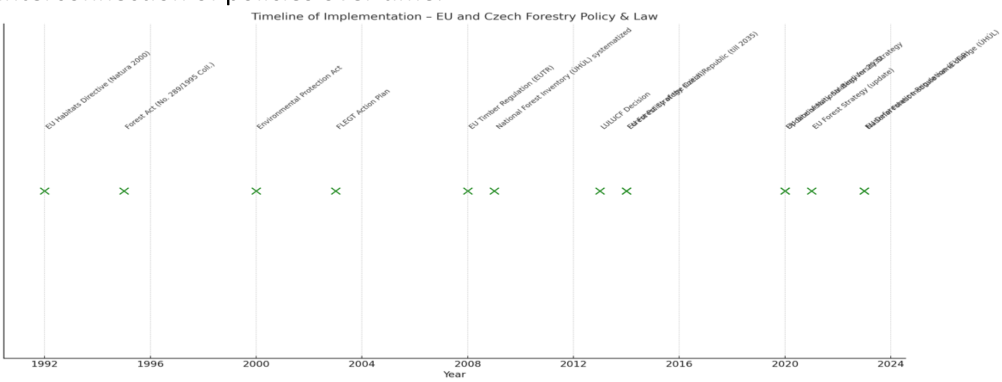

Figure 6. Overview of the main milestones in the field of forest policy and legislation

Aspect	EU Forestry Policy	Czech Forestry Policy
Strategic Policy	EU Forest Strategy (2021), Biodiversity Strategy 2030	Forest Policy of the Czech Republic 2030
Main Legal Framework	EUDR, Natura 2000, RED III, LULUCF Regulation	Forest Act (No. 289/1995), Nature Protection Act
Sustainability Focus	**Yes** – Sustainable Forest Management (SFM)	**Yes** – Defined in forest plans and legal obligations
Biodiversity Protection	**Yes** – Natura 2000, Biodiversity Strategy	**Yes** – Protected areas, NATURA 2000 sites
Climate Focus	**Yes** – Carbon sinks, LULUCF, Green Deal	**Yes** – Reforestation, forest health, erosion control
Funding Mechanisms	CAP, LIFE, Horizon Europe	National subsidies, RDP (EU-funded)
Monitoring Systems	FISE, Copernicus, national reports	Forest Inventories, LHP, ÚHÚL monitoring
Institutions Involved	European Commission, DG ENV, DG AGRI	Ministry of Agriculture, National Forest Institute, Lesy ČR
International Commitments	FLEGT, UNFCCC, Convention on Biological Diversity	EU obligations, Forest Europe, FAO
Implementation Level	Policy coordination, support and regulation	National legislation and practical enforcement

Figure 7. European and Czech forest policy

Legal Area	EU Law / Regulation	Czech Law
General Forest Legislation	No unified EU forest law – national competence	Forest Act No. 289/1995 Coll.
Illegal Logging / Timber Trade	EU Deforestation Regulation (EUDR, 2023); previously EUTR	Incorporated through EUTR/EUDR enforcement
Biodiversity Protection	Habitats Directive (92/43/EEC), Birds Directive (2009/147/EC)	Nature and Landscape Protection Act No. 114/1992 Coll.
Climate Regulation	LULUCF Regulation (EU 2018/841), EU Climate Law	Climate Protection Strategy, participation in EU LULUCF framework
Renewable Energy Use	Renewable Energy Directive (RED II/III)	Act on Supported Energy Sources, implementation of RED
Subsidies and Rural Development	CAP – Common Agricultural Policy (incl. RDP)	Act on Agriculture, National Rural Development Programme
Environmental Impact and Protection	Environmental Impact Assessment (EIA) Directive	Environmental Protection Act No. 17/1992 Coll., EIA Act
Forest Monitoring and Planning	Forest Information System for Europe (FISE), reporting obligations	Forest Management Plans, NFI oversight
Protected Areas	Natura 2000 network (based on Habitats/Birds Directives)	National network of protected areas, Natura 2000 transposition

Figure 8. European and Czech forest legislation

The *figure 7* and *figure 8* presented clearly summarize the main differences and points of contact between European and Czech forest policy and legislation. From the first overview, it is clear that both the EU and the Czech Republic declare a commitment to sustainable forest management, biodiversity protection and taking climate goals into account. However, while the European Union operates primarily at the level of strategic documents, support programs and legal frameworks with an impact on the Member States, the Czech Republic ensures practical implementation through national legislation and forest planning. From a legal perspective, a fundamental difference is that the EU does not have a uniform forest law, and forest policy therefore remains largely the responsibility of the Member States. However, direct and indirect regulation of forestry through regulations, directives and strategies – especially in the areas of biodiversity, climate and timber trade – is increasingly influencing national forest legislation. The Czech Republic is responding to these challenges by adapting laws such as the Forest Act and the Nature and Landscape Protection Act, but the process of transposing and enforcing European regulations brings with it a number of practical and administrative complications. The figures also show that although financing and monitoring tools exist at both levels, the effectiveness of their use depends on the capacity of national institutions, the degree of coordination and the ability to reconcile environmental objectives with the economic reality of forestry practiceOverall, it can be said that there is a high degree of interconnectedness between EU and Czech forest policies, but its implementation in national conditions encounters structural, economic and institutional barriers that require targeted strategic and legislative efforts.

4 Conclusion

The economic side of forest management is fundamentally influenced by legislative and political conditions. While some instruments, such as national subsidies (e.g. the Rural Development Programme, support for recovery after disasters), provide financial stability, others – such as restrictive regulations on the species composition of stands or logging bans – can worsen the economic situation of owners. An example is the state's response to the bark beetle disaster (2017–2022), when there was a significant drop in wood prices. Although the state provided some support, larger entities with higher administrative capacity in particular had a real chance of fully drawing on the subsidies. Small owners often did not even manage to cover basic costs. At the same time, legislative uncertainty (e.g. debates on the ban on clear-cutting or the introduction of no-intervention zones) increases investment risk and can discourage long-term afforestation plans. Forestry policy affects not only the economy but also the lifestyle of owners. A specific issue is the restriction of owners' user rights. The obligation to allow public access to the forest (unless explicitly prohibited) sometimes leads to conflicts (e.g. damage to the stands, littering, disturbance of game), which the owners perceive as a depreciation of their work and property. In many regions, especially in the border regions or the Highlands, forestry is a key employer and economic pillar. Policies that limit logging or force owners to green without adequate compensation can lead to a decrease in local incomes, job losses and the decline of rural communities. A special place is occupied by traditional family forests, the management of which is often passed down from generation to generation. Strict regulation and economic uncertainty can disrupt intergenerational continuity and lead to the sale of land to larger entities or speculators, thereby gradually emptying the landscape and cultural ties. The EU's external pressure is a key factor. Strategies such as the European Green Deal, the Biodiversity Strategy to 2030 or the draft Nature Restoration Law call for a fundamental rethinking of forest management objectives. Adapting to climate change (e.g. shifting to species-rich, more resilient stands) is costly and returns on investment over a period of several decades are not guaranteed. This is particularly true for smallholders who do not have access to expert advice or sufficient capital. Forestry laws and policies significantly shape the conditions for forest management. From the perspective of forest owners, especially small-scale ones, the following should be highlighted:

- Ensure equal access to subsidies and reduce administrative burdens, e.g. through digitalisation and targeted advice.
- Consider the social and cultural dimensions of forest ownership, not just environmental objectives.
- Strengthen owners' participation in policy-making so that proposals reflect their experiences and needs.
- Create long-term legal frameworks that provide stability and predictability for forest investments.
- Increase owners' awareness of climate and legal changes, for example through local forestry centres.

Otherwise, the good intentions of environmental policies risk leading to negative social consequences, loss of trust and erosion of traditional forest management.

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FOREST GIFT TAX DEDUCTIBILITY IN INCOME TAXATION FOR PROMOTING TRANSFERS TO THE NEXT GENERATION

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Abstract:

Inheritance and gift taxation affects family forest transfers to the next generations. In Finland, the gift taxation starts from property fair value of 5,000 euros and inheritance taxation from 20,000 euros, with two progressive tax rate classes dependent on closeness of family relationship. *Forest gift deduction* is an instrument established in 2017 for gift tax alleviation. It makes a part of paid gift tax deductible in forest income taxation. According to the Finnish Family Forest Owner 2020 survey, forest owners were mostly aware of the forest gift deduction. However, the instrument and its very strict applicability seemed to be unclear. The number of users of the forest gift deduction has remained low. Approximately 20% of forest properties belong to owners who could according to the Income Tax Act potentially use the forest gift deduction. Among these properties, it seems that only a clear minority will utilize the deduction.

Keywords:

family forestry, inheritance and gift taxation, transfer to the next generation, tax instrument

1 Introduction

Inheritance and gift taxation affects family forest transfers to the next generation by increasing the fixed costs of forestry and violating the going concern principle. In cases, where roundwood sales incomes or other finances to cover tax payments are inadequate, inheritance or gift tax may also force the next generation to sell the forest property.

In Finland, the gift taxation starts already from property fair value of 5,000 euros measured as accumulated sum in three years. The inheritance taxation starts from fair value of 20,000 euros. Both taxes have two progressive tax rate classes depending on the closeness of family relationship. In the gift taxation, taxable fair values are taxed at rates of 8-17% or 19-33%, respectively. E.g. for a property of 200,000 euros the gift tax would be 22,100 or 53,450 euros.

As in many countries applying inheritance and gift taxation, Inheritance and Gift Tax Act in Finland includes also a tax exemption in agricultural and family business transfers, based on economic and employment policy objectives. This tax exemption can be applied also to forestry business part of a farm or a company. This exemption requires, however, that the next generation will carry on agricultural or forest industrial production at least five years after the transfer.

Because the number of agricultural farms has decreased rapidly in Finland, the inheritance and gift tax exemption has become all the time less applicable in family forestry. Nowadays only some 10 % of family forest properties are owned by agricultural farms (Karppinen et al 2020), compared to some 80-90 % still in the 1960's (Leppänen et al. 2017).

In forestry terms, the Finnish gift taxation may start already from a forestland gift less than one hectare. For instance, in 2024, the mean forestland prices per hectare were from 6,683 euros (standard deviation 3,284 euros) in Southern Finland province Kanta-Häme to 1,791 euros (standard deviation 1,540 euros) in Northern Finland province Lapland (National Land Survey, property price statistics, 2025).

The Finnish forestry sector has had some success to develop alternative tax instruments to support family forest transfers, especially by appealing to needs to promote roundwood supply in forest policy. Forest deduction when buying forest was adopted from Sweden in the income tax reform of 1993. It has become an important transfer instrument not only for open market but also for intra-family forest property transfers. The forest deduction is based on a part of the payment for the forest property purchase. The deduction can be made from forest incomes.

Forest gift deduction (FGD) is a tax instrument in force since 2017 to alleviate gift tax on forest property. The objective of the FGD is to increase the size of forest properties, promote entrepreneurial forestry and increase the roundwood supply. The instrument design has similar features with forest deduction, but in a much more complicated form. The basic idea of the instrument is to make a part of paid gift tax deductible in forest income taxation. According to the Income Tax Act, the partial compensation of paid gift tax is possible only for such forest property gifts, that fulfil 'taxation value' exceeding 30,000 euros, or, if not fulfilled, forestland exceeding 100 hectares. An ownership share, given or received, must fulfil this requirement, too.

The number of annual FGD beneficiaries is reported by the Finnish Tax Administration (Table 1). However, the annual beneficiaries are partly the same over years, as the use of forest gift tax deduction from forest incomes requires typically several years after the property transfer. There is a 15-year limit for FGD use in forest taxation. So, table 1 does not reveal the total number of individual beneficiaries, except for the first year 2017.

Table 1: Number of annual beneficiaries and deduction values of the forest gift deduction (FGD). Source: Finnish Tax Administration. tax statistics (2025).

Year	Number of beneficiaries	FGD, euros	Mean of FGD, euros/ beneficiary	Median of FGD, euros/ beneficiary
2017	54	980,858	18,164	8,549
2018	141	2,189,386	15,528	9,370
2019	150	1,879,707	12,531	7,554
2020	163	2,144,882	13,159	8,000
2021	172	2,340,061	13,605	8,970
2022	207	2,445,742	11,815	8,158
2023	252	3,229,600	12,816	7,942

The applicability of FGD tax instrument to family forest owners has not been studied earlier, *ex post*. The aim of this article is to use the Finnish Family Forest Owner 2020 survey to find out:

- What kind of knowledge family forest owners have on the FGD tax instrument?
- How probably family forest owners will use the FGD tax instrument?

2 Material and methods

In the Finnish Family Forest Owner 2020 survey (Karppinen et al 2020), the survey population consisted of forest properties defined within a province, owned by natural persons, heirs and tax partnerships. Sampled forest properties had to have forestry land at least five hectares in Southern Finland provinces, ten hectares in the provinces of Central Ostrobothnia, North Ostrobothnia and Kainuu, and at least twenty hectares in the province of Lapland.

The forest properties by provinces were selected by systematic sampling from the information system of the Finnish Forest Centre. The survey was carried out in the beginning of 2019. The sample of the survey was 15,750 forest properties. The survey questionnaire contained a common part and three sub-sample theme parts.

The final response percentage of the survey was 42.4, i.e. a total of 6,542 responses were received. The information on the forest gift tax deduction was asked in the common part of the questionnaire. The responses were analyzed with statistical methods (SPSS). The question on the knowledge and considerations on the forest gift tax deduction was asked as follows:

> *Do you know the forest gift deduction?*
> *(1) I don't know (2) I have heard of it (3) I have familiarized myself with it*
>
> *Would you consider sometime in future to use the forest gift deduction?*
> *(1) No (2) I need further information (3) Yes (4) I don't know*

In the analysis, the responses were associated by employing cross tabulations with forest property and forest owner information received in the survey and as a Finnish Forest Centre register data. To evaluate the hypothesis that the percentage distributions are not equal, Pearson X^2 test was employed for percentage distributions. The corresponding hypothesis on roundwood sale means was tested by employing one-way analysis of variance (ANOVA). Unfilled responses to the questions were included in the analysis as 'no response'.

3 Results

In the first phase, the forests properties were divided into four groups according to the Income Tax Act conditions set for the use of forest gift deduction (FGD). These groups are later referred in Tables 2 and 3:

1. Forest property does not fulfil the conditions for FGD, because the taxation value or forest area is too small
2. Forest property does not fulfil the conditions for FGD, because it is owned by several forest owners, leading to too small taxation value or forest area of an individual ownership share
3. Forest property fulfils the conditions for FGD, but it is a part of agricultural property, eligible for an inheritance and gift tax exemption
4. Forest property fulfils the conditions for FGD, and the owners are not carrying out agriculture on the property.

The responses to knowledge question indicated that forest owners were mostly aware of the forest gift deduction (Table 2). In total 55 % of forest properties responding 66 % of forestry area had heard of or familiarized themselves with the FGD. Approximately 20 % of forest properties corresponding 42

% of forestry area could potentially use the FGD. These potential forest properties are described in the group 4.

Table 2: Forest owners' knowledge on forest gift deduction. Distributions (%) are depicted both by groups in rows and by responses in columns. Roundwood average sales (m^3 over bark/ha/a) are only by responses.

	I don't know	**I have heard of it**	**I have familiarized myself with it**	**No response**	**Average Total**
% of forest properties/owners (% of forestry area)					
Forest property groups regarding the possibity for FGD (n=6,542*)**					
1. No, taxation value or forest area is too small	76 (49) 50 (48)	56 (27) 38 (39)	46 (18) 9 (10)	69 (38) 3 (3)	63 (32) 100
2. No, too small taxation value or forest area of an individual ownership share	9 (11) 35 (35)	12 (10) 48 (48)	12 (8) 15 (15)	8 (8) 2 (2)	10 (10) 100
3. Yes, but eligible for inheritance and gift tax exemption	3 (10) 22 (19)	9 (17) 55 (51)	10 (22) 20 (26)	7 (22) 3 (4)	7 (16) 100
4. Yes, the owners are not carrying out agriculture on the property	12 (30) 26 (23)	23 (46) 51 (52)	32 (52) 21 (23)	16 (32) 2 (2)	**20 (42)** 100
Total	100 42 (31)	100 **42 (48)**	100 **13 (18)**	100 3 (3)	100 100
Average roundwood sales volume in years 2016-2018 (n=6,298)***					
m^3 (o.b.)/ha/year	2.6	3.7	**4.7**	1.8	3.5

**** = P value < 0.001, ** = P value < 0.01, * = P value < 0.05.*

Table 3: Forest owners' considerations to use forest gift deduction. Distributions (%) are depicted both by groups in rows and by responses in columns. Roundwood average sales (m^3 over bark/ha/a) are only by responses.

	No	**I need further information**	**Yes**	**I don't know**	**No response**	**Average Total**
% of forest properties/owners (% of forestry area)						
Forest property groups regarding the possibility for FGD (n=6,542*)**						
1. No, taxation value or forest area is too small	64 (32) 12 (11)	64 (33) 27 (26)	54 (23) **16 (17)**	67 (38) 39 (40)	69 (42) 6 (6)	63 (32) 100
2. No, too small taxation value or forest area of an individual ownership share	9 (8) 11 (10)	10 (10) 27 (28)	12 (9) **22 (23)**	10 (10) 36 (35)	8 (8) 4 (4)	10 (10) 100
3. Yes, but eligible for inheritance and gift tax exemption	5 (13) 10 (9)	8 (19) 32 (32)	9 (20) **26 (31)**	5 (11) 27 (23)	7 (18) 6 (5)	7 (16) 100
4. Yes, the owners are not carrying out agriculture on the property	21 (47) 13 (13)	18 (38) 25 (24)	25 (48) **24 (27)**	18 (41) 33 (32)	16 (32) 5 (4)	20 (42) 100
Total	100 12 (11)	100 **27 (26)**	100 **19 (24)**	100 36 (34)	100 6 (5)	100 100
Average roundwood sales volume in years 2016-2018 (n=6,298)***						
m^3 (o.b.)/ha/year	3.6	3.6	**4.1**	3.0	2.4	3.5

**** = P value < 0.001, ** = P value < 0.01, * = P value < 0.05.*

When looking the considerations to use the FGD (Table 3), the instrument and its very strict applicability seemed to be mostly unclear for forest owners. Even those forest owners, whose properties did not fulfil the requirements of the FGD, were considering the instrument. Over the groups, the variation in 'yes' responses was between 16-26 % among forest owners. All groups indicated strong further information needs, too.

In Tables 2 and 3, the roundwood sales were highest in, firstly, among those present forest owners, who indicated the best knowledge ('I have familiarized myself with it') on the FGD, and secondly, among those who considered the use ('yes') of FGD sometime in future. This result may reflect the FGD conditions, that require considerable roundwood sales by the next forest owner generation.

Table 4: Group 4 forest property owners' considerations for potential use of forest gift deduction (FGD) by intended way to transfer the property to the next generation.

4. Forest property fulfils the conditions for FGD, and the owners are not carrying out agriculture on the property	**No**	**I need further information**	**Yes**	**I don't know**	**No response**	**Total Average**
% of forest properties/owners						
Intended way to transfer the forest property to the next generation (n=1,290*)**						
By inheritance, without a will	15	26	18	36	5	100 20
By a will	16	24	25	30	5	100 22
By a gift	11	30	**41**	16	2	100 **10**
I shall sell the property	17	23	27	30	3	100 17
I shall merge the property to a jointly owned forest	..	..	..	..	..	100 1
I shall change the property form to a partnership/company	6	31	34	26	3	100 3
By other way	26	29	19	26	0	100 2
I don't know	8	24	22	43	3	100 25
Total (n=1,359)						
Average	13	25	**24**	33	5	100
Average roundwood sales volume in years 2016-2018 (n=1,301)***						
m^3 (o.b.)/ha/year	3.4	3.5	**4.1**	2.9	2.3	3.4

**** = P value < 0.001, ** = P value < 0.01, * = P value < 0.05.*

In group 4 – where the forest properties most probably fulfilled the conditions for FGD – the forest owner intentions to transfer the property were very similar to forest owner intentions in general (Korhonen et al 2024). In group 4, 20 % of the present forest owners were intending to let the property be transferred by inheritance, without a will. 22 % were intending to make a will. Only 10 % were intending to transfer the forest property by a gift – essential for the use of FGD – to the next generation. 17 % were intending to sell the forest property. One percent of forest owners was intending to merge the property to a jointly owned forest, a forest ownership form with special legislation in Finland. Three percents were intending to change the property ownership form to a partnership or company. Two percents had other intentions. 25 % didn't have any intended way to transfer the property.

When looking forest owners considering a transfer by gift in group 4 in further details, 1/3 of them were intending to transfer the property to a single person, 1/3 to be shared to several persons and 1/3 to a 'joint ownership'. The question 'Do you know the forest gift deduction' or 'Would you consider sometime to use the forest gift deduction?' did not have statistical differences in response distributions among these three transfer by a gift intentions. So, the final share of potential users of the FGD may remain as low as 20 % (proportion of group 4) x 10 % (transfer by a gift in group 4) x 1/3 (gift to a single person in group 4) of all forest properties. That would result in a final potential FGD target population magnitude of only a percent of or in numbers only few thousands forest properties in Finland.

4 Discussion and conclusion

The forest gift deduction (FGD) is a tax instrument that came into effect in 2017 and promotes the transfer of forest ownership to the next generation, especially on non-agricultural forest properties. The FGD is based on forest policy objectives, while the inheritance and gift tax exemption applied for agriculture and family business are based on economic and employment policy objectives.

According to the Finnish Tax Administration, use of the FGD has remained very low compared to its objectives. The Finnish Family Forest Owner 2020 survey results reveal that only 20 percent of forest properties or 42 percent of the forestry land area may meet the FGD requirements, provided that the property transfer is made as a gift, and the gift is given to a single recipient. However, only a small part of forest owners is intending to transfer their forest to the next generation by a gift, and even less as a gift to a single recipient. In the long term, the FGD may therefore be a real option for only a few thousand forest properties in Finland.

Despite this, owners of forest properties that do not meet the conditions have heard about, become familiar with and partly consider using the FGD in the future. These results indicate, therefore, more the general interest of forest owners in the transfer of ownership and the factors affecting it than the potential future use of the FGD.

There are various instruments in Finland to transfer the forest property to the next generation and alleviate inheritance and gift taxation in family forestry. However, as the example of forest gift deduction shows, the reality can be very complex for many forest owners and properties. There has been every now and then discussion in Finland to fully give up inheritance and gift taxation, lastly in winter 2025. However, these discussions are usually suppressed very early on by references to opposing studies that completely exclude family forestry issues.

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FOREST EDUCATIONAL TRAILS: A PATH TO ECONOMIC AND SOCIAL BENEFITS

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Abstract:

Forest Educational Trails (FETs) provide educational, environmental, physical and psychological benefits. While their impact on cognitive and physical development is well documented, their economic value remains unexplored. This study assesses the economic value of the educational and sustainability benefits of 78 Slovenian FETs. The benefits include increased environmental awareness, promotion of sustainability and behavioural change. After classifying FETs into three categories based on their interpretive potential, visitor numbers were assessed, and costs and benefits were monetised and compared. Although 43.6% of FETs had a negative cost-benefit ratio, the average benefits exceeded costs by almost 50%, highlighting significant social benefits, especially for well-equipped FETs. Considering construction costs over 30 years and applying a social discount rate of 5%, the overall internal rate of return is 19.4% and the net present value is 3.97 million €, indicating an appropriate educational and tourist product with the potential to promote sustainable practices and stimulate regional economic development.

Keywords:

cost-benefit analysis, economic analysis, Slovenia, educational benefits, sustainability benefits

1 Introduction

One of the important cultural ecosystem services (ES) is the educational ES (Mocior and Kruse, 2016). The long-term effects of formal and informal educational activities include the increase of environmental awareness, improved understanding of scientific knowledge and building social trust for foresters' professional activities (Mocior and Kruse, 2016; Chrzanowski, 2016 cited by Uglis et al., 2019; Korcz and Janeczko, 2022). A large part of outdoor learning takes place on Forest Educational Trails (FETs). FETs are trails that are equipped with information tables for visitors to learn about forests, forestry, nature, culture, history and other features along the path (Lesnik, 1995; Nevrelová and Ružicková, 2019; Kentelky et al., 2023). Despite the name, they ought to be found also elsewhere than forests, such as other ecosystems, landscapes, and even in virtual environments (Lesnik, 2006; Vassiljev and Bell, 2023).

There is a long tradition of FETs in Slovenia, as the first two FETs were opened to the public back in 1974. Since then, the knowledge and societal demand increased and diversified, bringing novel requirements for FET design. Some of these requirements include attractive content, elaborated interpretation, didactical compliance and additional *in situ* facilities (Lesnik, 2006; Prah in Kolnik, 2007). Especially the content of information tables and guides tends to be rather demanding for most visitors (Tempesta and Vecchiato, 2018; Nevrelová and Ružicková, 2019; Janeczko et al., 2021). On the other hand, the true advantage and benefit of FETs lies exactly in the ease and capacity to transfer knowledge and educate people in an attractive way. The effects of education and learning often go beyond an individual experience and ought to have wider, multiplier social impacts (e.g. Žoncová et al., 2013). Thus, the potential educational and sustainability benefits of FETs can be assessed with several methods and approaches from economic literature, including cost-benefit analysis (CBA).

Despite the increasing recognition of non-market valuation methods to assess cultural ES (e.g. Romanazzi et al., 2023), there is little empirical evidence to quantify their contributions in economic terms. Economic valuation is often more difficult, but expressing values in monetary terms is relevant for advocating and justifying project investments, supporting forest policy or education-related decision-making processes, and planning regional economic development. This study aims to fill this gap by not only assessing the educational benefits, but also providing an economic valuation of Slovenian FETs.

2 Materials and Methods

2.1 FET survey and interpretative potential

In order to assess the FETs, we downloaded the basic information and *.gpx files from maPZS website https://mapzs.pzs.si/search/trails?trailTypes=10&lang=en. The process of surveying the FETs began in November 2023 and ended in October 2024. During this time the website was updated several times, yet in our research we opted to include and analyse 78 FETs that were registered at the maPZS website on 1.5.2024.

We personally visited all 78 FETs and collected data on each FET conditions according to three criteria, namely a) interpretative ability, b) functionality, and c) attractiveness. Several indicators were assigned for each criterion and collected during the visit. In this paper we focus on two indicators that are considered crucial for the process of identifying the *interpretative potential* (IP), namely the presence of informational tables and other didactical tools, and the existence of an FET guide (e.g. handbook, website, …). The IP concept shares some similarity with the concept *education potential*, i.e. the interpretative and clarity quality of information tables for pedagogical use (Nevrelová and Ružicková, 2019). We define the IP as the ability to provide sufficient interpretation with *in situ* equipment and tools to allow independent visit (Leban, 2023). The IP categories reflect the level of experience and learning on an FET and are as follows:

- **First category** – **high IP**: fully equipped FETs with 3 or more information tables or other didactical tools and an online or hardcopy guide.
- **Second category** – **medium IP**: FETs equipped with 2 or less information tables, without didactical tools, or an online or hardcopy guide.
- **Third category** – **low IP**: FETs with no information tables, didactical tools nor a guide whatsoever.

2.2 Estimation of visitor number

As literally no data exists on the number of FET visitors, we estimated the number of FET visitors based on few field-gathered information and several assumptions. First, we assumed that FETs with the highest IP are more frequently visited than FETs with lower IP. Second, we assumed that the newest or renovated FETs were more attractive and more frequently visited as older. The reasoning behind is that first the interpretation is often much better on newer FETs than on older. Finaly, we assumed that the size and vicinity of bigger cities plays an important role in defining the frequency of visits, since FETs closer to cities attract more daily people and the bigger the city, the higher the likelihood of visit. We estimated the number of visitor-days for each IP category separately and multiplied it with the corresponding weighted value of the each assumed criteria. The weights assigned for city vicinity diminish from 2 to 0.5 with the diminishing distance from city centre to the beginning of the FET. The weights for city population increases from 0.5 to 3 with the increase city population.

2.3 Cost-benefit analysis

CBA is a social appraisal of investment project in ways that correct for market failure (Perman et al., 2003). The CBA framework applied in this study encompass 1) identification and monetarization of costs, 2) identification and monetarization of benefits, 3) comparing costs and benefits, 4) economic and sensitivity analysis, 5) reporting.

The costs considered are annual maintenance costs and opportunity costs. The opportunity costs (OPPORT) relate to the lost opportunity of growing trees for timber production. For this we estimated that every 20 meters one tree would grow along the FET, and that a net gain would be 20 € per tree. Annual maintenance costs (MAINT) were calculated based on a fixed estimated value per kilometre for each IP category: high IP were assigned a value of 1.000 €, medium IP a value of 500 € and low IP a value of 200 € per kilometre. Building costs were not included in CBA calculation as the FETs are already built and we wanted to assess the costs and benefits from today, thus not including the past costs and benefits. Nevertheless, building costs were taken into account in the economic analysis (see next section).

The benefits considered for this study were willingness to pay for education (WTP), sustainability behaviour benefits (BEHAVIOUR), and avoided costs from environmental damage (AVOID). WTP is derived from similar educational programs (i.e. guided tour in Ljubljana marsh nature park costs 6 €/person) as an approximation of the FETs educational value. FETs with high IP obtained 50%, medium IP 25% and low IP 12.5% of the reference value. BEHAVIOUR includes benefits arising from changes in behaviour, namely reduced waste. We estimated these benefits for FETs with high IP by assuming a 5% decrease in waste production per visitor, thus leading to a 6.6 kg less produced waste annually (on average a person in Slovenia produces 132 kg of waste annually), which means an annual reduction of costs for waste management for 1.29€ (with a price of 0.196 €/kg). FETs with medium IP obtained 50% and FETs with low IP obtained 25% of the value for FET with high IP. AVOID relates to an assumption that FETs foster better environmental stewardship, including water management. Thus, we calculated avoided costs from less water consumption (leading to less generally environmental degradation). We assumed that each visitor would reduce personal water consumption for 1%, which means 0.61 m^3 of water (with an annual average being 61.0 m^3 per person). With a given price of 2.17 €/m^3 of water, the value amounts to 1.32 € per person for FETs with high IP, 50% and 25% of that value for FETs with medium and low IP, respectively. Table 1 summarizes the benefits, costs and estimated visitors.

Table 1: Parameter values used for the calculation of costs and benefits.

IP category	BENEFITS WTP (€/person)	BEHAVIOUR (€/person)	AVOID (€/person)	COSTS MAINT (€/km)	OPPORT (€/km)	VISITOR DAYS DAYS (days)	VISITORS (n/day)
High IP	3.00	1.29	1.32	1,000		144	15
Medium IP	1.50	0.65	0.66	500	400	136	10
Low IP	0.75	0.16	0.33	200		116	5

2.4 Economic and sensitivity analysis

In order to estimate the net present value (NPV) and the internal rate of return (IRR) we included the estimated building costs of FETs. These costs were calculated per kilometre and then multiplied with the length of each FET. The costs included expenses for design (5,000 €/km), materials (4,360 €/km), service (3,000 €/km) and labour (3,446 €/km). For each kilometre of a trail, we planned 3 wooden tables with benches, 20 informational tables, leaflet prints, and other promotion materials. The purpose of this economic analysis was to assess the viability of building additional FETs and at the same time consider the costs and benefits. A 5% social discount rate and a project length of 30 years was chosen to perform the economic analysis. The building costs equals 50% of total building costs in year 0, 30% in year 1 and 20% in year 2. Finally, to verify the robustness of the results, we conducted a sensitivity analysis with varying the discount rate, building costs and applying the 95% confidence interval bounds to all benefits (Tavárez and Barriga, 2023). All the analyses described above were performed in MS Excel 365®.

3 Results

The average FET is 3.26 km long and has 8 tables in total of which 5 are interpretative tables. Almost 60% of FETs does have an online or printed guide. Following the IP criteria, forty-three FETs (55.2%) were classified as FET with high IP, twenty FETs (25.6%) with medium IP and fifteen FETs (19.2%) with low IP.

The number of visitors was estimated individually for each FET, as the varying distance to the closest city and city population was used as a proxy. The average estimated annual visit amounts to 2.271 (median equals 1.620) visitors per FETs. On an annual level, the total number of visitors of 78 analysed FETs is 177.135. The minimum visit is estimated to 270 (*FET Polana*) and the maximum visit to 12.960 (*Mestni gozd Celje*).

The average annual benefit on an FET is estimated to 10,789.71 € (median 6,066.71 €) and the average costs to 2,363.73 € (median 1,675.00 €). On average, the value of benefits and costs equals to 3,312.59 € and 1,752.70 € per kilometre, respectively. In absolute terms, the total value of benefits is estimated to 841,597.35 € and the costs to 438,431.00 €, leading to an annual net benefit of 403,166.35 €. This translates to an average net balance of 2.28 € per visitor annually. The benefit-cost ratio equals 1.92, meaning that the current FET network in Slovenia provides at least almost twice as many benefits than costs.

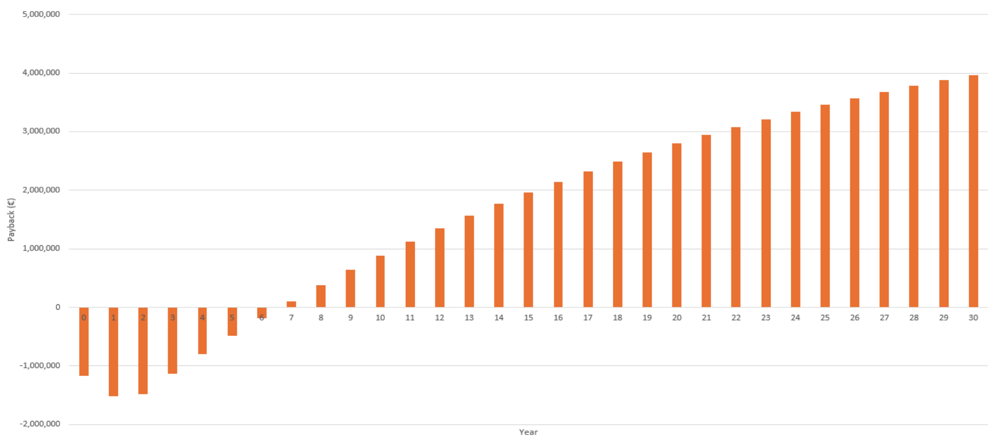

Figure 1. Payback (cumulative present value) as the result of the economic analysis.

The results of the economic analysis with building costs included shows that the NPV reaches 3,970,837.76 € in 30 years. The cumulative present value indicates viability and positive paybacks of the project starting at year seven (Figure 1). The IRR amounts to 19.44% and represents a decent, yet medium-risk investment. The sensitivity analysis also suggests that the project is economically viable, when building costs not exceeds 32,966.89 €. The benefit-cost ratio decreases to 1.78 and increases to 2.06 on the lower and upper confidence intervals, respectively.

4 Discussion and conclusion

This study was the first attempt to assess the economic value of 78 Slovenian FETs and used an economic analysis to determine the economic viability under the assumption that the 78 FETs would be built from scratch. Today, FETs have evolved significantly in both quantitative and qualitative terms, responding to societal demands for educational spaces in forests and to advances in science. Nevrelová and Ružicková (2019) proposed and implemented a methodology to evaluate the educational potential of existing educational trails. In our study, we construct a simpler index to indicate the interpretive potential for an individual. Despite conceptual differences between both studies, we emphasise the importance of such a quantitative approach for evaluation of educational trails and support its further development.

The results for 78 existing Slovenian FETs show that they generate a positive annual net balance, even though almost 44% of the FETs individually show a negative benefit-cost ratio. The average annual net benefit of one kilometre of FET is 1,586.89 €, or 2.28 € per visitor. Tempesta and Vecchiato (2018) found that the benefits of maintaining and improving the hiking trail network in northern Italy are worth 12,260 € per kilometre or an estimated 3.46 € per visitor. On the other hand, Széchy and Szerényi (2023) estimated the value of recreational ES in a biosphere reserve to be 7.56 € and 13.15 € per visitor for a half-day or full-day trip, respectively. We conclude that the results of our study, despite methodological and conceptual differences, are within the range of values found in other studies.

Our results also show that investing in new EFTs is profitable, even though the costs and benefits considered, the estimated number of visitors and other assumptions made in this study may not be entirely realistic. As pointed out by Tavárez and Barriga (2023), profits are not observed until several years after the start of the project. In our case, the benefits start to appear in the seventh year. However, it is the multiplier effect that should be observed and taken into account in decision-making. Investments in FETs promote pro-environmental behaviour, increase environmental awareness, strengthen local tourism and contribute to regional economic development (Žoncová et al., 2013; Nevrelová and Ružicková, 2019; Kentelky et al., 2023).

The main limitations of this study are the uncertain estimate of visitor numbers and the limited consideration of benefits and costs. Having better estimates or real values and using different methodologies could lead to slightly different results. In general, the results are robust to the given inputs, which is also confirmed by the sensitivity analysis. Furthermore, we assume that the benefit-cost ratio is even higher in practice, as not many FETs are regularly maintained, so that maintenance costs converge to zero. We suggest that future studies consider additional benefits, costs and other methods to assess them, collect more direct data from visitors, conduct a comparative study among countries or holistic research for a region, and assess additional ecosystem services beyond education, such as health and biodiversity conservation. By doing so, the broader value proposition of FETs could be even better articulated, justifying further integration into environmental, tourism, and educational strategies in Slovenia and beyond.

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APPRAISING NON-MARKET ECOSYSTEM SERVICES OF THE CZECH FORESTS: A PERSONAL COST AND LIFE CYCLE ASSESSMENT APPROACH

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Abstract:

Non-market forest ecosystem services are provided alongside wood production but are rarely valued economically in the Czech Republic. This study evaluates selected non-wood forest services, i.e., berry collection, game management, recreation, relaxation, and sports, by estimating their economic value using the personal cost approach and comparing them to wood production based on the 2022 data from the Forest Enterprise of the Czech University of Life Sciences Prague. Furthermore, environmental impacts were also assessed using the Life Cycle Assessment (LCA) method. The LCA followed ISO 14040 and 14044 standards using SimaPro software. Forest berry collection showed the highest estimated economic value, followed by relaxation and wood production. In contrast, relaxation had the highest environmental impact, followed by berry collection. Game management had the lowest, while sports showed moderate impacts. These results contribute to the understanding of non-market forest benefits and aim to support forest management strategies by integrating ecosystem services into decision-making tools.

Keywords:

life cycle assessment, non-market forest ecosystem services, environmental impact assessment

1 Introduction

Many policy frameworks aim to maximize social well-being, which is strongly supported by non-market ecosystem services (Czajkowski et al., 2014). The introduction of payment schemes for these services is expected to incentivize supply, helping the service availability more closely with societal demand (Engel et al., 2008). However, the true value of these non-market services remains underexplored. While wood production is assessed in economic terms, non-market ecosystem services, such as forest berry foraging and recreational use in Czech forests are still largely undervalued. Traditionally, opportunity cost and cost-benefit analysis have served as proxy indicators to estimate the value of non-marketable goods. More recently, environmental impact assessments have also been applied to evaluate these services. Therefore, this study aims to assess selected non-market forest ecosystem services in the Czech Republic using both the personal cost approach and environmental impact analysis.

2 Methods

The Czech Republic, located in Central Europe, was selected as the study site. Forest area in the country has been increasing annually, currently covering approximately 34% of the total land area. Around 75% of these forests are managed primarily for timber production, highlighting the emphasis on provisioning ecosystem services. The Czech Republic also holds a leading position in log exports (Ministry of Agriculture of the Czech Republic (MoA), 2020); FAO 2021). Norway spruce currently dominates Czech forests, covering 46.8% of the total forested area, followed by Scots pine at 16.0%. Among deciduous species, European beech is the most common (9.6%), while summer and winter oaks together account for 7.8%. In terms of ownership, the majority of forests are state-owned (54.6%), followed by private individuals (approximately 19%) and municipalities or cities (17.2%) (MoA, 2020).

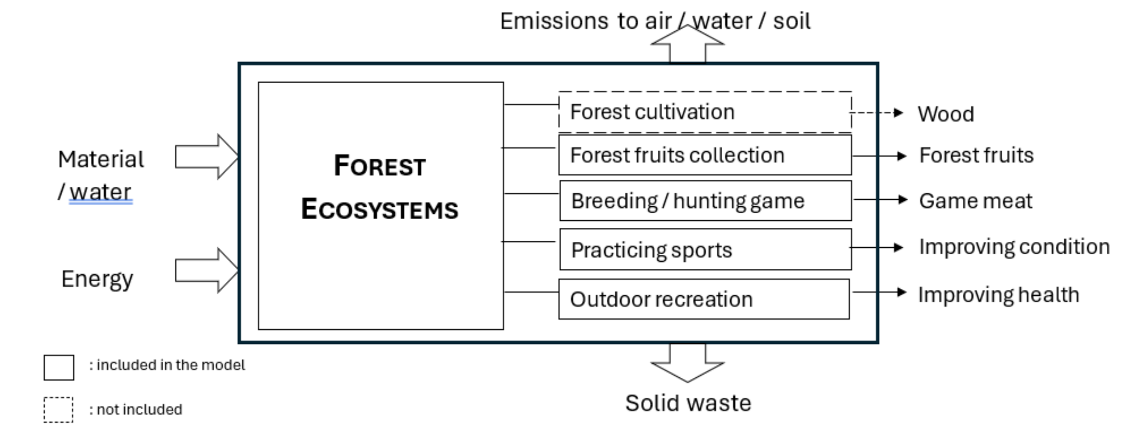

Figure 1. Study framework of wood and non-market forest ecosystem services (modified from Hájek et al., 2025, under review)

2.1 Boundaries of the system and the declared unit of LCA

This study focused on forest ecosystem services that are commonly used in the Czech Republic and for which enough data were available to conduct a life cycle assessment (LCA). These include collecting forest fruits, relaxing, sports, hunting, and general recreation. The analysis only looked at activities over a specific time period—100 years, which represents the average lifespan of a forest stand (Hájek et al., 2024). Other stages of the ecosystem services' life cycle were not considered. Therefore, the services are reported based on 1 hectare of forest over a 100-year rotation. For this reason, a declared unit was used instead of a functional unit.

2.2 Impact category of LCA

The chosen methodological procedure is based on the ISO 14040 and 14044 standards (ISO 14040:2006 Environmental management — Life cycle assessment — Principles and framework and ISO) and the specialized computer software SimaPro (PRé Consultants B.V., Amersfoort, The Netherlands.). The basic method of the Centrum voor Milieuwetenschappen Leiden-Industrial Assessment (CML-IA), which is the most common model for impact assessment, was used for the calculations and formulation of the categories (Center of Environmental Sciences-Leiden University 2016).

The CML-IA baseline V3.09 methodology was used to calculate the results of the impact category indicators. The selected environmental impact categories included in this study are depletion of material and energy raw materials, global warming, damage to the ozone layer and the formation of photooxidants.

2.3 Data characteristics of selected forest ecosystems

Primary data of accounting report from the Forest Enterprise of the Czech University of Life Sciences Prague for personal costs and LCA were collected in 2022. This year was chosen because there were minimum external disturbances like bark beetle outbreaks or wildfires (Hlásny et al., 2021; Mohammadi et al., 2022).

The basis of determination of individual forest-related activities in this study is based on the work of Šišák and Pulkrab (2008), which summarizes results from an annual questionnaire survey conducted by the Centre for Public Opinion Research with around 1,100 respondents. Data on forest crop collection were also obtained from this long-term sociological research, covering both public and private sectors. The surveys focus on the types and quantities of forest products collected. Since 1994, these findings have been processed at the Czech University of Life Sciences Prague and published annually from 1998 onwards. They are regularly used by the Ministry of Agriculture and other scientific and management institutions.

Data on hunting activities were sourced from the annual Report on the State of Forestry in the Czech Republic, which provides essential information but does not include figures from hobby or professional breeding.

Information on recreational and leisure activities was collected through extensive research by the Czech University of Life Sciences Prague (Šišák and Pulkrab, 2009; Šišák et al., 2002). These results are supported by expert estimates, purchase records, and reports from thousands of individual collectors across the Czech Republic. The assessment of relaxation activities focused on transportation to the forest edge (unmodified catchment sites). The activity itself involved walking in the forest, without using any motorized transport. Sports activities followed the same pattern as relaxation, where visitors moved through the forest on foot. The joint cost effect was analyzed based on the frequency and number of visits, which were then converted using personal costs. Other activities are restricted by the Forest and Road Act. The product system includes transportation by private car to and from the forest, and the time spent in the forest. This is the same for relaxation, sports, and recreation (Figure 2).

The monitored activities included the collection of mushrooms, blueberries, raspberries, blackberries, cranberries, and elderberries. Data on fruit collection was estimated by recalculating the number of forest visitors and their average travel distance within the Czech Republic. This estimate was then converted into hours per visitor. For transport, the most commonly used vehicle, namely Škoda passenger car, was selected as the reference (Figure 2). The assessed product system includes travel to the forest by car, the actual collection of forest fruits, and the return journey.

Game management was evaluated based on actual yield data per game species and per hectare of forest land, as provided by the national statistical office. The rental costs for individual hunting grounds were also considered. Entry into the forest for hunting purposes was accounted for through legal exceptions granted to hunting ground users for activities such as animal care, feeding, hunting, and equipment maintenance (Figure 2). All activities and inputs were standardized to one hectare per year. The product system includes animal care (e.g., feed, salt), construction of basic hunting infrastructure (e.g., perches, feeders), transportation by private car to the forest, and the hunting of game.

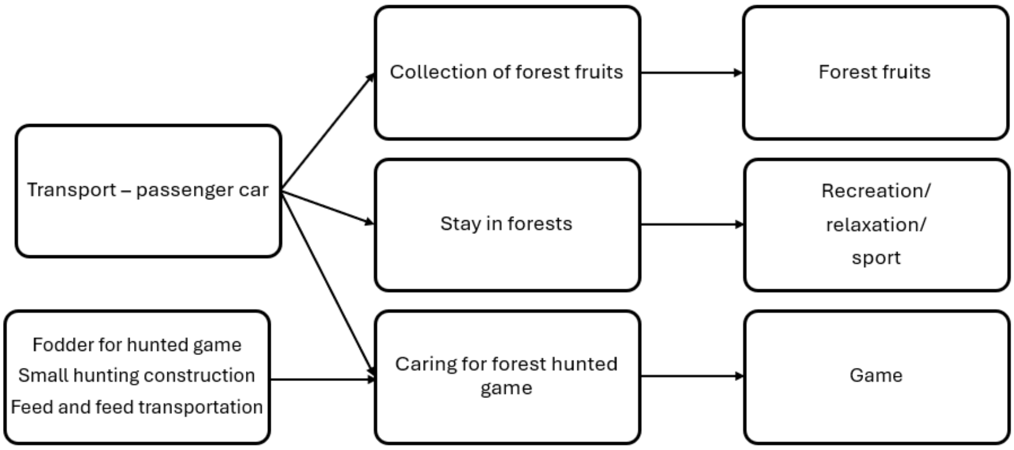

Figure 2. Assessment diagram of life cycle in non-market commodities (modified from from (Hájek et al., 2025, under review)

3 Results

The research protocol and analysis was done following the analysis of wood production ecosystem services (Hájek et al., 2024). Furthermore, in Table 1, a comparison between individual ecosystem services is presented.

Table 1: Outputs/value of products from 1 ha for a period of 100 years (modified from from (Hájek et al., 2025, under review)

Services	**Yield quantity**	**Technical unit**	**Revenues (€)**	**The price of products expressed in personal cost terms (€)**	**Total calculated Yields (€)**
Wood production	808.0	m^3	59,732.02		59,732.02
Forest berries	3,609.8	kg	26,355.61	84,406.47	110,762.08
Relaxation				94,621.72	94,621.72
Sport				8,869.39	8,869.39
Game management	46.7	kg	207.05	1,819.36	2,026.41
Recreation				29,079.97	29,079.97

Explanations:

- personal costs - wages + statutory contributions (health and social insurance), as direct costs
- direct costs listed for individual activities as the sum of personal costs per 1 hectare

- revenues - all sales from individual activities, basically expressed as the sum of personal expenses, for hunting and gathering forest fruits are further increased (sum of personal expenses + sales for fruits or game and rents) by individual sales for these commodities.
- Total calculated yields = revenues + personal costs
- 1 € = 24.57 CZK (using exchange rate in 2022)

Table 2: Environmental impact categories based on LCA (modified from from (Hájek et al., 2025, under review)

Impact category	**Forest fruits**	**Relaxation**	**Sport**	**Game management**	**Recreation**	**Units**
Extraction of mineral resources	0.39	0.58	0.13	0.04	0.11	kg Sb eq
Extraction of fossil fuels	108,486.35	162,227.44	35,090.73	11,149.95	29,898.44	MJ
Global warming (100a)	8,092.27	12,098.95	2,617.07	1,017.92	2,229.82	kg CO2 eq
Depletion of the ozone layer	8.07E-04	1.21E-03	2.61E-04	1.11E-04	2.22E-04	kg CFC11 eq
Photochemical oxidation	9.49	14.19	3.07	0.86	2.61	kg C2H4 eq

Among all the forest functions assessed, relaxation had the greatest environmental impact in the mineral resource extraction category, followed by forest fruit collection (Table 2). In both cases, the main contributor was the transport of visitors to the forest, including fuel consumption, vehicle wear and tear, and maintenance. The actual time spent in the forest was not included in the assessment. Similarly, in the fossil fuel depletion category, relaxation again showed the highest impact, followed by fruit collection. Greenhouse gas emissions were also highest for relaxation and lowest for hunting. The results from the CMl-IA baseline method revealed a similar pattern across all impact categories for the selected ecosystem services. Wood production was excluded from Table 2 to avoid the misleading impression that its impacts are disproportionately high compared to other forest functions.

4 Discussion and conclusion

Although forests provide a wide range of ecosystem services (Stohr, 2013), this study focused on five key services based on the availability of reliable data. These selected services align with current public preferences (Hochmalová et al., 2022; Purwestri et al., 2023), although such preferences can differ across countries. A 100-year assessment period was chosen to match the typical forest rotation cycle (Hájek et al., 2024). This timeframe also helps address difficulties in estimating the lifespan of individual ecosystem services. A technical unit of 1 hectare was used, referred to as a declared unit (DU), since the focus was on the production or extraction phase of biotic resources rather than the full life cycle.

The data collection was based on a previous study describing individual forest ecosystem services (Šišák and Pulkrab, 2008), along with supporting financial records. A comparison of yields from wood production was also included (Table 2). The results show that forest fruit collection had the highest yield, followed by relaxation, with wood production coming in third. This pattern aligns with findings from Lipa and Hájek (2014) and Liu et al. (2023).

Life Cycle Assessment (LCA) results revealed that fruit collection and relaxation also had the highest environmental impacts. These insights are important for guiding forest management decisions. For example, tools that support ecosystem services could be adjusted to focus on those with greater environmental impact based on the LCA findings.

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CARBON AND COST TRADE-OFFS IN DECOMMISSIONED BEECH FORESTS IN GERMANY

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Abstract:

This study evaluates the decommissioning of timber use in beech (Fagus sylvatica) commercial forests as a climate protection measure in Germany using a simulation model. Two scenarios are analyzed over a 200-year horizon: a managed business-as-usual (BAU) scenario and an unmanaged decommissioning (DCM) scenario. The study incorporates climate-sensitive survival probabilities for two emission pathways (RCP 4.5 and RCP 8.5) to assess impacts on timber and carbon stocks, including aboveground biomass, belowground biomass, and coarse woody debris. Under the DCM scenario, additional carbon storage is projected at 740 t CO_2 ha^{-1} under RCP 4.5 and 700 t CO_2 ha^{-1} under RCP 8.5. Opportunity costs for carbon sequestration are low in the short to medium term but increase as the rate of sequestration declines over time. The findings provide critical insights for policymakers and stakeholders in forest conservation and carbon management in Central Europe.

Keywords:

decommissioned forests, carbon sequestration, climate change mitigation, opportunity costs

1 Introduction

The transition toward greenhouse gas neutrality by 2050 and the EU's binding climate targets emphasize the critical role of the Land Use, Land-Use Change, and Forestry (LULUCF) sector. The 'Fit for 55' package mandates that EU Member States offset land use and forestry emissions through equivalent CO_2 removals, aiming to reduce net emissions by 55% by 2030 and achieve climate neutrality by 2050 (EU COM 2021). The EU 2024/3012 regulation establishes a Union framework for CO_2 certification, facilitating voluntary carbon markets (EU Parliament 2024b). One notable example is the "Graf von Westphalen Forest Carbon Project", certified under the Verified Carbon Standard, where 80% of growth increments are marketed as certificates over a 30-year period on a 769-hectare estate (Gerst et al. 2024). In Germany, the Climate Protection Act (KSG 2021) sets ambitious reduction targets of at least –25 Mt CO_2-eq by 2030, –35 Mt by 2040, and –40 Mt by 2045. Complementary initiatives include the Action Program for Natural Climate Protection and federal funding programs such as 'Climate-Adapted Forest Management' and 'Climate-Adapted Forest Management PLUS' (BMUV 2023; BMEL 2022). These programs for private and communal landowners incorporate Criterion 12, which mandates natural forest development on 5% of forest areas exceeding 100 ha, reinforcing the national wilderness and protected area's goal of 10% strict conservation.

EU legislation and the Biodiversity Strategy 2030 also emphasize the conservation of old-growth forests due to their high carbon stocks and biodiversity value (EU COM 2020; Regelmann et al. 2023). The strategy mandates legal protection for at least 30% of EU land area, with strict protection for one-third of these zones, including all remaining primary and old-growth forests (EU COM 2020). The Nature Restoration Law further promotes the development of native old-growth forests by ceasing timber harvesting and enhancing natural ecosystem dynamics (EU Parliament 2024a). In Central Europe, particularly in Germany, old beech forests hold significant ecological and carbon sequestration value. Consequently, political commitments, such as the 2021 coalition agreement between SPD, Grünen, and FDP, have enacted a logging ban in old, near-natural beech forests on federal lands (SPD/Grüne/FDP 2021). Efforts are also underway to establish voluntary alliances with states and provide financial incentives for municipal and private forest owners.

This study[4] evaluates the impacts of forest decommissioning on CO_2 sequestration and its associated opportunity costs using an enhanced Forest Economic Simulation Model (FESIM). The research examines how decommissioning affects aboveground biomass, belowground biomass, and coarse woody debris (CWD), assessing trade-offs between increased carbon storage and lost timber production. Germany serves as a case study due to its extensive operational data from the Forest Accounting Data Network (FADN) and its central role in the EU's climate and biodiversity policies (FADN 2023). Accordingly, this paper asks following research question: *What are the carbon and cost trade-offs of decommissioning beech forests in Germany?*

2 Methods

2.1 Scenarios

Two scenarios are evaluated: Business as Usual (BAU) and Decommissioning (DCM). The BAU scenario serves as a baseline by continuing conventional forest management practices in German beech-dominated forests. It is based on the control parameters of the Basis scenario of the "German Forest Development- and Timber Volume Modeling" (Oehmichen et al. 2018; Rosenkranz et al. 2017). It features moderate thinning, natural regeneration, and a long, gradual timber harvesting and rejuvenation phase. BAU provides insight into the expected trajectory of forests if current practices persist.

In contrast, the DCM scenario assumes a complete cessation of management activities, allowing forests to undergo natural succession through all developmental stages. This scenario highlights the differences from traditional management by comparing the outcomes of decommissioned forests with those under BAU.

[4] The present article presents the partial results of the study by Regelmann et al. (2025): "Balancing Carbon and Cost: Unveiling the Carbon Sequestration Potential and Opportunity Costs of Beech-Dominated Forest Lands Decommissioned from Forestry Use." European Journal of Forest Research (under review).

2.2 Model Framework

FESIM is a deterministic simulation model incorporating a biological-technical production module based on yield tables, a partially dynamic area module, and an economic evaluation module, all built on operational and inventory data, which is used for long-term simulation. Documented in previous studies (Rosenkranz et al. 2014; Dög et al. 2016; Regelmann et al. 2023; Rosenkranz et al. 2023), FESIM simulates forest management over periods up to 200 years with a five-year time step. Four tree species—beech, oak, pine, and spruce—are modelled as idealized pure stands.

2.3 Model Enhancements

Several improvements were integrated into FESIM to address our research aim:

1. A biological growth model tailored for decommissioned forest areas based on control-plot experimental data, following Pretzsch et al. (2023).

2. Incorporation of climate-sensitive survival probabilities using an area-weighted arithmetic mean derived from the dataset of Brandl et al. (2020) using the method of Fuchs et al. (2022) for two emission scenarios (RCP 4.5 and RCP 8.5).

3. Implementation of a carbon accounting framework that tracks carbon in aboveground biomass, belowground biomass, and coarse woody debris (CWD) based on the official reporting standards (Röhling et al. 2016).

For set-aside forests, natural growth indicators such as total volume production, standing volume, and total volume increment are modeled using continuous growth functions computed at five-year intervals. Excess biomass, beyond the maximum stock, is treated as density-dependent mortality and added to the CWD pool.

2.4 Carbon Accounting and Economic Valuation

Carbon stocks are calculated as the sum of aboveground, belowground, and CWD pools. Changes in these stocks over time yield a flow measure of carbon sequestration. A simple negative exponential decay model, based on Rock et al. (2008), is used to simulate the decomposition of dead coarse woody debris.

For economic evaluation, we assess opportunity costs using Contribution Margin I (CM I), defined as timber revenues net of harvesting and forwarding costs. CM I is calculated for each simulation period and discounted over time, with the terminal value included. Carbon sequestration costs (CSC) are derived by comparing the CM I from BAU to the additional carbon stored under DCM.

2.5 Forest Accountancy Data Network (FADN)

Data from 23 private and corporate forest enterprises (with at least 75% beech in accordance to Bolte et al. (2022)) from FADN (2011–2021) were aggregated to create idealized pure stands (FADN 2023). This data underpins the simulation and economic analysis, with adjustments made for the five-year time step and age-class divisions in FESIM. The framework simplifies tree diversity into four species groups and assumes idealized pure stands without interspecies transitions, in part due to limitations in available FADN data.

3 Results

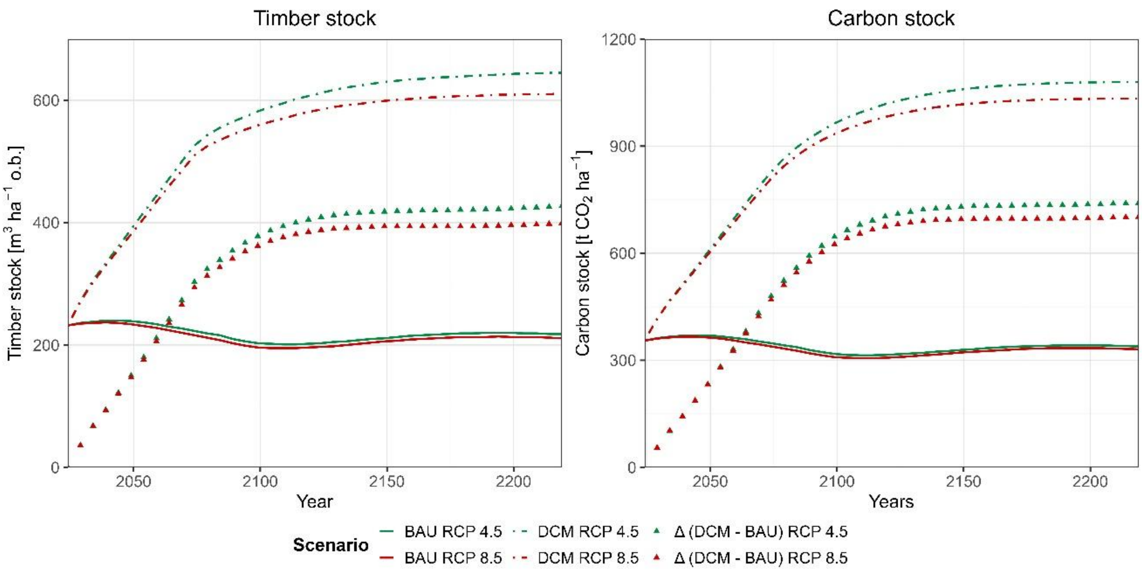

Figure 1. Timber stock (on the left) and carbon dioxide stock (on the right) with deltas for the BAU- and DCM-Scenario for RCP 4.5- and RCP 8.5-survival probabilities. The green colour corresponds to the RCP 4.5 scenario, whereas the red colour represents the RCP 8.5 scenario. The solid line represents the BAU scenario, while the dot-dash line represents the DCM scenario. The lines with triangles each indicate the delta from DCM to BAU, representing the differences between these two scenarios. It should be noted that the timber stock plot (on the right) represent only aboveground standing volume with diameters above 7 cm, whereas the carbon stock plot (on the left) encompasses all three assessed carbon pools of aboveground biomass, belowground biomass and CWD.

3.1 Timber Stock Development

In the managed scenario (BAU), timber stock initially declines from approximately 232 m^3 ha^{-1} to around 200 m^3 ha^{-1}. This early decrease is primarily due to the initial model effect and the routine removal of timber through harvesting. For the first 100 years, the timber stock remains relatively stable under BAU, after which it gradually increases, reaching roughly 220 m^3 ha^{-1} by the end of the simulation. The impact of survival probabilities in this scenario is minimal, as the regular harvesting and salvage practices continually remove timber, limiting any significant variation caused by differing survival rates.

In contrast, the unmanaged scenario (DCM) exhibits a consistently upward trend in timber stock. Starting from the same initial level of 232 m^3 ha^{-1}, the timber stock steadily increases over time without the intervention of harvesting. As the forest develops naturally, the accumulated biomass reaches near-equilibrium levels significantly higher than in the BAU scenario—approximately 645 m^3 ha^{-1} under the RCP 4.5 emission pathway and about 611 m^3 ha^{-1} under the RCP 8.5 pathway. Notably, during the first 100 years, the DCM scenario experiences a marked increase in timber stock, followed by a saturation effect as the forest approaches its maximum stocking capacity, reflecting the inherent limitations of natural growth dynamics.

3.2 Carbon Stock Dynamics

Carbon stock dynamics in the two scenarios reveal a similar divergence to that of timber stocks. Both scenarios begin with a baseline carbon stock of 355 t CO_2 ha^{-1}. Under the BAU scenario, carbon stocks decline over time, eventually reaching around 314 t CO_2 ha^{-1} under RCP 4.5 and 306 t CO_2 ha^{-1} under RCP 8.5. This reduction is largely attributed to the initial decline in timber stock caused by harvesting and the corresponding removal of biomass, compounded by the model's initialization effect. Conversely, the DCM scenario shows a pronounced accumulation of carbon. Carbon stocks rapidly increase in the early stages of the simulation as the forest matures without interference, eventually stabilizing near mid-simulation before reaching high terminal values. By the end of the simulation, carbon stocks under DCM reach approximately 1080 t CO_2 ha^{-1} under RCP 4.5 and 1033 t CO_2 ha^{-1} under RCP 8.5. The substantial difference in carbon accumulation between DCM and BAU is primarily driven by aboveground biomass, which contributes about 75% of the extra carbon, while belowground biomass and coarse CWD account for roughly 13% and 12%, respectively. The rapid initial carbon uptake gradually diminishes as the forest approaches a natural saturation point, with increment rates declining from an early peak of approximately 11 t CO_2 ha^{-1} per year to less than 1 t CO_2 ha^{-1} per year towards the end.

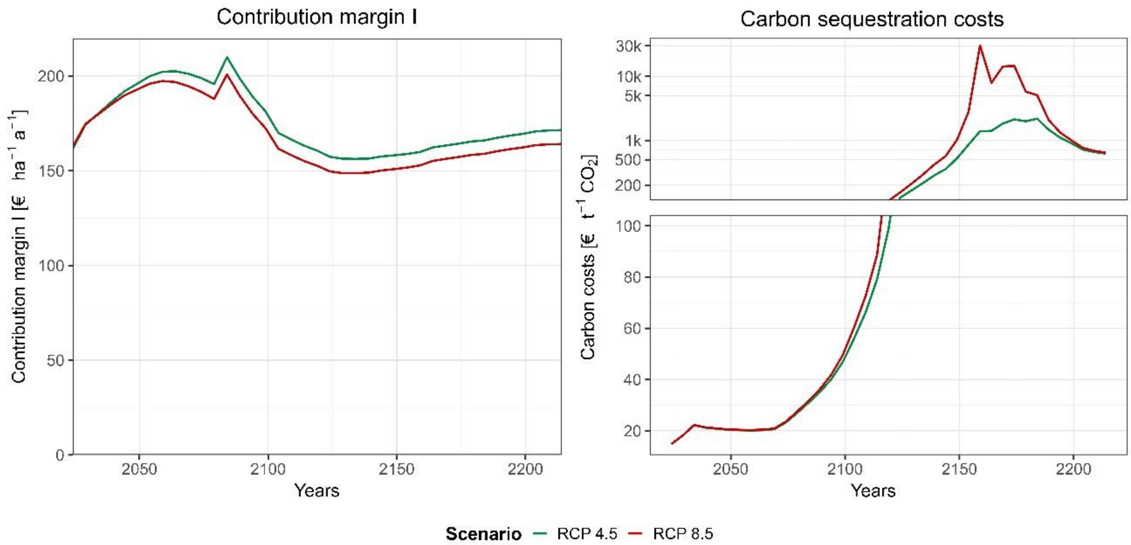

Figure 2. Contribution margin I of the BAU Scenario (on the left) and carbon sequestration costs of BAU to DCM Scenario (on the right) for RCP 4.5- and RCP 8.5-survival probability. The carbon sequestration costs have a regular y-scale in the lower half of the Plot and a log-scale in the upper part.

3.3 Opportunity Costs

Opportunity costs, expressed through the foregone Contribution Margin I (CM I) from not harvesting timber, display a distinct temporal pattern. Initially, the economic loss in the BAU scenario is moderate, with CM I starting at around €162 per hectare per year. This value increases to a local peak—approximately €202 ha^{-1} a^{-1} under RCP 4.5 and €197 ha^{-1} a^{-1} under RCP 8.5—before declining to a local minimum in the mid-simulation period. In the later stages, there is a slight stabilization in these costs. The small discrepancies between emission scenarios indicate that damage to the managed forest is limited, allowing for salvaged timber to continue generating revenue despite lower prices.

When evaluating carbon sequestration costs—the ratio of foregone timber revenues to the additional carbon stored—the results indicate that these costs start relatively low, between €15 and €20 per ton of CO_2, but increase over time. In the later part of the simulation, costs frequently exceed €10000 per ton of CO_2, especially under the RCP 8.5 pathway, reflecting an intensifying economic trade-off between timber production and enhanced carbon storage as the forest matures and natural saturation effects become more pronounced.

4 Discussion and conclusion

4.1 Discussion of Methods and Limitations

The simulation framework used in this study, FESIM, combines dynamic biological-technical production with a static economic assessment. While it effectively models forest growth through discrete time periods connected via Markov chains, its static economic module assumes constant timber prices extrapolated from current FADN data and expert assessments. This method restricts our opportunity cost analysis to the managed (BAU) scenario, as the decommissioned (DCM) scenario does not yield cash flows. Consequently, we rely on scenario deltas rather than conventional approaches such as the Faustmann model. Furthermore, the initial stock data are less granular than that of the National Forest Inventory, and natural regeneration is assumed to occur at zero cost—an optimistic scenario that may overestimate carbon storage in DCM.

Additional limitations emerge from the model’s partial climate sensitivity. While it incorporates climate-sensitive survival probabilities (following Brandl et al. (2020)), it does not integrate climate-sensitive growth dynamics nor does it include updated data reflecting recent forest damage; the Brandl et al. (2020) dataset only extends to 2018 and does not account for the significant forest damages in Germany between 2018 and 2022 (Möhring et al. 2022). Consequently, we assume that our survival probabilities are more optimistic. The carbon accounting module, which calculates biomass and carbon stocks in aboveground biomass, belowground biomass, and coarse woody debris, omits soil and litter pools due to significant uncertainties. Despite these limitations, the study’s simplified, empirically driven approach facilitates a comparison of BAU and DCM scenarios over a 200-year period.

4.2 Discussion of Results

Our findings demonstrate a clear divergence between managed and unmanaged scenarios. In the BAU scenario, timber stocks initially decline—primarily due to the initial model effect—and later stabilize with minimal influence from survival probabilities, as continuous harvesting limits biomass accumulation. Conversely, the DCM scenario shows a steady increase in timber stocks, reaching substantially higher equilibrium levels. Carbon dynamics mirror these trends: while BAU exhibits a gradual decline in carbon stocks over time, the DCM scenario achieves significant accumulation, primarily driven by aboveground biomass, with notable contributions from belowground biomass and coarse woody debris. Economic analysis indicates that initial opportunity costs, measured as foregone timber revenues, are moderate but accelerate sharply as additional carbon is sequestered—exceeding €100 per ton CO_2 in later simulation phases, particularly under more severe climate scenarios.

5 Conclusion

In summary, our study highlights that decommissioning of beech-dominated forests substantially enhances long-term carbon storage while markedly altering timber stock dynamics. Although the BAU scenario maintains relatively stable timber levels, the unmanaged approach significantly increases both timber and carbon stocks, albeit with accelerating opportunity costs over time. These results underscore the trade-offs between timber production and carbon sequestration. For policymakers and stakeholders, the findings emphasize the need for integrated strategies that balance the economic value of timber with the environmental benefits of enhanced carbon storage. While decommissioning may offer viable short- to medium-term climate protection benefits, the long-term economic feasibility is challenged by rising sequestration costs, suggesting that future forest management policies must carefully weigh these ecological and economic trade-offs.

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VALUING FOREST GENETIC RESOURCES FOR ECOSYSTEM SERVICES: EXPERT-BASED INSIGHTS FOR FUTURE MANAGEMENT PRACTICES, POLICYMAKING AND ACCOUNTING INITIATIVES ACROSS EUROPE

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Abstract:

Forest resources are central to many European Union (EU) policies, with biodiversity conservation and Forest Genetic Resources (FGR) essential for enhancing forest resilience and sustaining ecosystem services (ES). However, FGR's role in ES provision remains underexplored and largely absent from economic and accounting frameworks. The EU-funded OptFORESTS project assesses FGR diversity's contribution to ES under climate change through a Delphi survey involving around 50 experts - including geneticists, ecologists, socioecologists, economists, and decision-makers- across six EU countries. The study evaluates FGR management practices, their ES impacts, and related risks and opportunities under current and Nature Futures Framework (NFF) scenarios. Preliminary findings reveal expert perception differences along a North-South gradient and across disciplines, despite Delphi rounds aiming for convergence. These insights highlight challenges in integrating FGR into management, policy, and accounting. Research results will inform future strategies to enhance the recognition of FGR value within European forest governance and economic frameworks.

Keywords:

ecosystem services, assessment, expert-based, risks, opportunities, forest reproductive materials, forest management

1 Introduction

Forest restoration and biodiversity conservation are central to the EU's climate agenda, with Forest Genetic Resources (FGR) playing a key role in forest resilience and adaptation. FGR—the heritable material in trees and woody plants—and associated Forest Reproductive Material (FRM), such as seeds and seedlings, underpin forests' capacity to adapt to stressors like climate change and pests. In turn, they support the delivery of essential ecosystem services (ES) that sustain human well-being (FAO, 2025). FGR conservation and improvement generate both use and non-use values, offering commercial benefits for the forestry sector (e.g., Jansson et al., 2017) and broader ecological gains through enhanced ES provision and resilience (Soliño et al., 2020). Yet, despite their significance, FGR remain largely overlooked in current economic models and accounting systems. Due to different conceptual and methodological challenges (Potschin et al., 2013), existing research in Europe has traditionally focused on improving the use value of forests related to wood production (Bosselmann et al., 2008) in specific Nordic regions, e.g., Scandinavia (Jansson et al. (2017). This narrow focus has largely overlooked other ES. Although a variety of FGR management practices have been proposed to enhance genetic diversity under current conditions (Ratnam et al., 2014), empirical or expert-based studies that quantify how these practices could influence ES over future ecological, socioeconomic, and political trajectories are still missing. To address these critical gaps, the Horizon Europe-funded OptFORESTS project assesses FGR diversity's contribution to ES under climate change via a Delphi survey focussing on four research questions (RQ):

RQ1: Which FGR management practices can contribute to improving ES supply currently and in the future in selected EU countries and at the overall EU level? **RQ2:** What are the impacts of adopting these FGR management practices on the provision of ES in the selected EU countries and at the EU scale? **RQ3:** How might these impacts change under alternative future scenarios? **RQ4:** What potential environmental, economic-technological, and sociopolitical (legal) risks are associated with adopting FGR management practices to improve ES supply, and what mitigation strategies could address these risks in the selected countries and across the EU?

2 Methods

The research consists of a multiple-steps and expert-based study conducted through the Delphi method (Hurmekoski *et al*., 2019). It is targeted at five expert categories (Geneticists, Ecologists, Economists, Socioecologists, and Decision Makers) across six EU countries (Italy, France, Denmark, Finland, Romania, and Slovenia) and at the EU scale. The main steps are briefly reported below.

2.1 Identification of targeted ES

A list of ES for the analysis was identified based on a literature review and through a harmonization exercise among existing ES classification systems (Table 1). This was done to ensure that the list is both comprehensive and concise enough to be manageable during surveys, avoiding confusion or redundancies while minimizing respondent fatigue.

Table 1: list of FES

Provisioning	**Regulating**	**Cultural**
Genetic materials	Air quality	Aesthetics
Water quantity	Carbon storage	Education and research
Food (wild plants)	Genetic pool protection	Outdoor recreational/sporting activities
Firewood	Habitat for plants and animals	Mushrooms and other wild plants picking
Timber	Human health	Hunting
Game and trophies	Natural hazard protection	Spiritual value
	Noise reduction	Traditional/local culture/knowledge
	Soil quality	
	Temperature regulation	
	Water quality	

2.2 Identification of FGR management practices, the levels of genetic diversity management and FRM

The final lists of practices (Table 2), the levels of genetic diversity management and associated FRM (Table 3) were developed through a literature review and internal consultation among OptFORESTS project partners (experts).

Table 2: list of FGR management practices

1. Novel low-input breeding strategies *i.e.,* implementing (participatory) breeding programs (with limited or no use of advanced genomic or propagation techniques) to 1) select trees according to their phenotypes and 2) to develop new seed sources with high level of genetic diversity adapted to local conditions.	***6. Silviculture of genetically mixed stands*** *i.e.,* intra-specific mixtures (genotypes) or population mixtures (species) forest stands.
2. High intensity breeding i.e., Using advanced techniques like genomics selection, biotechnology, and clonal propagation to study and enhance forest genetic resources.	***7. Selective thinning*** e.g. selective logging in place of, or in addition to, natural selection
3. Seed/Gene banks e.g. Storing seeds and genetic material under controlled conditions to preserve genetic diversity	***8. Rescue of declining forests*** e.g. enrichment plantings (when natural regeneration fails)
4. Conservation seed orchards/clonal archives e.g. 1) establishing seed orchards for seed production to conserve and maintain specific genotypes or origins. 2) Maintaining collections of clones for conservation and breeding purposes.	***9. Restoration of devastated areas*** e.g. restoring degraded or deforested areas using native tree species that have high genetic diversity (including afforestation and reforestation)
5. Selected seed stand e.g. identifying designated area of forest where the trees have been selected based on certain desirable genetic and phenotypic traits.	***10. Landscape-scale genetic heterogeneity management*** e.g. maintaining or restoring connectivity between forest habitats to promote gene flow and enhance genetic diversity, agroforestry, rewilding, protected areas.

Table 3: levels of genetic diversity management and associated FRM

Level	FRM
1. *Populations*	***1.*** *Seeds*
2. *Species*	***2.*** *Plants*
3. *Individual Trees*	***3.*** *Part of plants*
4. *Individual trees*	***4.*** *Other (local reproductive material)*
5. *Genes*	***5.*** *Mix*
6. *Mix*	

2.3 Design of three future scenarios

Future trajectories of human-nature relationships may influence the effectiveness of FGR management practices in supplying FES. Building on the Nature Futures Framework (NFF) (Paz-Duran et al., 2023), combined with IPCC (IPPC, (2020) and IPBES scenarios on climate change and biodiversity loss (IPBES-IPCC, 2021), three pathways have been developed considering the potential for climate change adaptation and mitigation by 2050. These alternative futures for forests and human society differ in the types of values people assign to nature: intrinsic (“nature for nature” = NN), instrumental (“nature for society” = NS), or relational (“nature for nature, culture and society” = NN-NC-NS).

2.4 Survey design

The OptFORESTS Delphi process follows a classical Delphi iteration logic with controlled feedback. The entire process involves three rounds of expert consultations, each structured into three blocks exploring the link between FGR management practices and (i) forest provisioning, (ii) regulating and (iii) cultural ES, respectively. Each block consists of four sections, presented to each expert at the national (i.e., their country of residence) and the EU level. **Section 1** aims to identify the most promising management practices (Table 2) to enhance the protection and sustainable use of FGR, FRM (Table 3), while ensuring the delivery of FES. **Section 2** aims to select and rank the ES (Table 1) whose supply would increase through the implementation of the FGR management practices and the use of FRM identified in Section 1 under current environmental, socio-political, economic and technological conditions. **Section 3** aims to do the same as Section 2 by considering three alternative pathways of future relations between human society and forest ecosystems. **Section 4** investigates the environmental, socio-political, and economic-technological risks associated with the FGR management practices, along with corresponding mitigation strategies. The third block of the first Delphi Round also includes Section 5, which collects personal information about the experts that will be relevant for analysing the responses and survey data. The overall structure and answer options of Sections 3 and 4 will remain the same across the three rounds, while Sections 2 and 4 include some variations (e.g., dichotomic answer options vs Likert scale).

2.5 Survey pilot test and experts panel identification

The survey was pre-tested with a panel of experts selected within the project partnership. Then a panel of experts to run the Delphi was developed through a snowball sampling approach.

3 Results

This section presents some aggregated results from the OptFORESTS Delphi Round 1. Due to space limitations, results in subsections 2.3 and 2.4 are explicitly reported (Figure 3 and Table 4) only at the EU-level. However, specific country-level insights are provided in the discussion section.

3.1 The composition of the panel of experts

At the end of the first round, 47 experts had fully completed all three survey blocks. Figure 1 shows the composition of the panel after round 1.

Country / Category	Geneticists	Ecologists	Socioecologists	Economists	Decision makers	Total
Italy	5	8	0	3	1	17
France	4	2	2	1	2	11
Slovenia	1	0	2	0	1	4
Finland	3	3	2	0	2	10
Romania	2	0	0	1	1	4
Denmark	1	0	0	0	0	1
Total	16	13	6	5	7	47

Figure 1. The composition of the panel of experts

The panel is strongly unbalanced both in terms of countries and expert categories. Italy is the most represented country, with 17 experts, while Denmark has only one expert. As regards expert categories, the distribution is more homogeneous, with Geneticists being the most represented category (16 experts), and Economists the least represented (5 experts). Some combinations of country and category are missing.

3.2 FGR management practice at country and EU level

Figure 2 shows the frequency percentages for each FGR management practice (column headers) selected at country and EU levels (row headers) during the First Round. To facilitate visualization, the intensity of the cell background colour increases with higher values.

Block 1: Provisioning ES												
Country	1. NL-IBS	2. HIB	3. SGB	4. CSO/CA	5. SSS	6. SGMS	7. ST	8. RDF	9. RDA	10. LSGHM	11. O	Total
Denmark	33.33%	0.00%	0.00%	0.00%	0.00%	33.33%	0.00%	33.33%	0.00%	0.00%	0.00%	100.00%
Finland	14.81%	11.11%	11.11%	3.70%	0.00%	22.22%	3.70%	11.11%	0.00%	22.22%	0.00%	100.00%
France	12.12%	9.09%	3.03%	15.15%	15.15%	15.15%	9.09%	3.03%	0.00%	12.12%	6.06%	100.00%
Italy	6.12%	0.00%	14.29%	4.08%	8.16%	10.20%	6.12%	8.16%	22.45%	20.41%	0.00%	100.00%
Romania	25.00%	0.00%	0.00%	16.67%	16.67%	0.00%	16.67%	8.33%	8.33%	8.33%	0.00%	100.00%
Slovenia	9.09%	0.00%	0.00%	0.00%	9.09%	9.09%	18.18%	9.09%	18.18%	27.27%	0.00%	100.00%
EU	13.14%	6.57%	9.49%	9.49%	12.41%	9.49%	8.03%	6.57%	10.95%	13.14%	0.73%	100.00%
Block 2: Regulating ES												
Country	1. NL-IBS	2. HIB	3. SGB	4. CSO/CA	5. SSS	6. SGMS	7. ST	8. RDF	9. RDA	10. LSGHM	11. O	Total
Denmark	50.00%	0.00%	0.00%	0.00%	50.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	100.00%
Finland	14.81%	11.11%	7.41%	7.41%	7.41%	22.22%	7.41%	3.70%	3.70%	14.81%	0.00%	100.00%
France	3.13%	3.13%	0.00%	15.63%	6.25%	28.13%	3.13%	18.75%	12.50%	6.25%	3.13%	100.00%
Italy	8.33%	2.08%	8.33%	6.25%	4.17%	16.67%	4.17%	14.58%	18.75%	16.67%	0.00%	100.00%
Romania	25.00%	0.00%	0.00%	16.67%	16.67%	0.00%	8.33%	8.33%	8.33%	16.67%	0.00%	100.00%
Slovenia	0.00%	0.00%	0.00%	12.50%	12.50%	25.00%	25.00%	0.00%	25.00%	0.00%	0.00%	100.00%
EU	8.40%	6.87%	5.34%	6.11%	6.11%	12.98%	2.29%	14.50%	19.85%	17.56%	0.00%	100.00%
Block 3: Cultural ES												
Country	1. NL-IBS	2. HIB	3. SGB	4. CSO/CA	5. SSS	6. SGMS	7. ST	8. RDF	9. RDA	10. LSGHM	11. O	Total
Denmark	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	50.00%	50.00%	0.00%	0.00%	100.00%
Finland	7.14%	0.00%	7.14%	14.29%	0.00%	10.71%	7.14%	14.29%	17.86%	21.43%	0.00%	100.00%
France	7.41%	0.00%	3.70%	7.41%	3.70%	25.93%	3.70%	7.41%	14.81%	22.22%	3.70%	100.00%
Italy	6.25%	0.00%	8.33%	4.17%	4.17%	6.25%	6.25%	14.58%	25.00%	25.00%	0.00%	100.00%
Romania	0.00%	0.00%	10.00%	0.00%	10.00%	10.00%	10.00%	20.00%	20.00%	20.00%	0.00%	100.00%
Slovenia	0.00%	0.00%	0.00%	0.00%	0.00%	28.57%	0.00%	14.29%	42.86%	14.29%	0.00%	100.00%
EU	4.72%	0.79%	7.87%	3.15%	3.94%	10.24%	2.36%	18.90%	24.41%	23.62%	0.00%	100.00%

Note to Figure 2*: 1. NL-IBS: Novel low-input breeding strategies; 2. HIB: High intensity breeding; 3. SGB: Seed/Gene banks; 4. CSO/CA: Conservation seed orchards/clonal archives; 5. SSS: Selected seed stand; 6. SGMS: Silviculture of genetically mixed stands; 7. ST: Selective thinning; 8. RDF: Rescue of declining forests; 9. RDA: Restoration of devastated areas; 10. LSGHM: Landscape-scale genetic heterogeneity management; 11. O: Other*

Provisioning services: At the EU level, the leading practices are LSGHM (13.1 %), NL-IBS (13.1 %) and SSS (12.4 %). France, Italy and Finland distribute their selections rather heterogeneously, sharing an emphasis on LSGHM and SGMS. Romania and Slovenia's selections are relatively more concentrated, with NL-IBS and LSGHM being the top choices, and a common preference for ST. HIB remains marginal everywhere except in Finland. **Regulating services**: At the EU level, RDA (19.8 %) and LSGHM (17.5 %) are the top two practices. Among countries, France (28.1 %), Slovenia (25 %, along with ST and RDA), and Finland (22.2%) share a highest frequency for SGMS, which is also highly selected in Italy. Additionally, Italian experts show a high preference for RDA (18.7 %) and LSGHM (16.7 %). Romania strongly emphasises NL-IBS (25%). **Cultural services:** At the EU-level, RDA (24.4%) and LSGHM (23.6%) increase their prominence, accounting for nearly half of the total selections, with RDF (18.9 %) ranking third. All countries, except Denmark, include LSGHM among their top two preferences. RDA (42.9% in Slovenia, 25% in Italy), RDF (20% in Romania), and SGMS (28.6% in Slovenia and 25.9% in France) complete the picture of the most selected practices.

Overall, across all three ES groups, the panel has mostly selected restoration-oriented and landscape-scale options (e.g. RDA) while generally excluding more high-technology (i.e., HIB, SGB, CSO/CA) and precision-oriented practices (e.g., ST).

3.3 Ecosystem services at the EU-level

Figure 3 shows the frequency percentages for the positive impacts of each provisioning ES (row headings) for each FGR management practice (column headings) selected at the EU-level during the First Round. To facilitate the visualization, the intensity of the cell background colour increases as the values increase.

EU-level											
Provisioning ES	**1. NL-IBS**	**2. HIB**	**3. SGB**	**4. CSO/CA**	**5. SSS**	**6. SGMS**	**7. ST**	**8. RDF**	**9. RDA**	**10. LSGHM**	**11. O**
1. Genetic materials	34.69%	32.00%	48.15%	48.00%	31.48%	18.33%	21.43%	17.65%	21.43%	18.82%	50.00%
2. Water quantity	4.08%	4.00%	14.81%	4.00%	5.56%	11.67%	14.29%	17.65%	20.00%	17.65%	0.00%
3. Food (wild plants)	8.16%	8.00%	18.52%	4.00%	11.11%	18.33%	14.29%	17.65%	14.29%	18.82%	0.00%
4. Firewood	16.33%	16.00%	0.00%	12.00%	12.96%	16.67%	21.43%	13.73%	10.00%	12.94%	0.00%
5. Timber	30.61%	36.00%	18.52%	28.00%	29.63%	16.67%	23.81%	17.65%	18.57%	15.29%	50.00%
6. Game and trophies	6.12%	4.00%	0.00%	4.00%	9.26%	18.33%	4.76%	15.69%	15.71%	16.47%	0.00%
Total	**100.00%**	**100.00%**	**100.00%**	**100.00%**	**100.00%**	**100.00%**	**100.00%**	**100.00%**	**100.00%**	**100.00%**	**100.00%**
Regulating ES	**1. NL-IBS**	**2. HIB**	**3. SGB**	**4. CSO/CA**	**5. SSS**	**6. SGMS**	**7. ST**	**8. RDF**	**9. RDA**	**10. LSGHM**	**11. O**
Air quality	7.02%	11.11%	4.55%	6.67%	8.51%	7.53%	0.00%	7.94%	8.46%	9.73%	0.00%
Carbon storage	19.30%	22.22%	9.09%	16.67%	14.89%	17.20%	37.50%	14.29%	10.95%	11.89%	0.00%
Genetic pool protection	15.79%	13.89%	27.27%	23.33%	12.77%	12.90%	25.00%	7.94%	8.96%	11.89%	0.00%
Habitat for plants and animals	10.53%	5.56%	13.64%	3.33%	14.89%	16.13%	0.00%	13.49%	11.44%	11.89%	0.00%
Human health	8.77%	8.33%	9.09%	13.33%	6.38%	5.38%	0.00%	7.94%	9.45%	9.19%	0.00%
Natural hazard protection	15.79%	11.11%	9.09%	10.00%	12.77%	11.83%	25.00%	11.90%	11.44%	9.73%	0.00%
Noise reduction	5.26%	5.56%	4.55%	6.67%	4.26%	1.08%	0.00%	4.76%	7.46%	5.95%	0.00%
Soil quality	5.26%	8.33%	13.64%	6.67%	12.77%	12.90%	0.00%	11.90%	11.44%	10.27%	0.00%
Temperature regulation	8.77%	5.56%	4.55%	6.67%	6.38%	7.53%	12.50%	10.32%	9.95%	9.19%	0.00%
Water quality	3.51%	8.33%	4.55%	6.67%	6.38%	7.53%	0.00%	9.52%	10.45%	10.27%	0.00%
Total	**100.00%**	**100.00%**	**100.00%**	**100.00%**	**100.00%**	**100.00%**	**100.00%**	**100.00%**	**100.00%**	**100.00%**	0.00%
Cultural ES	**1. NL-IBS**	**2. HIB**	**3. SGB**	**4. CSO/CA**	**5. SSS**	**6. SGMS**	**7. ST**	**8. RDF**	**9. RDA**	**10. LSGHM**	**11. O**
Aesthetics	11.11%	0.00%	7.69%	12.50%	11.11%	18.57%	18.18%	16.80%	16.32%	16.57%	0.00%
Education and research	44.44%	25.00%	25.64%	25.00%	22.22%	18.57%	18.18%	16.00%	15.26%	15.38%	0.00%
Recreational/sporting activities	0.00%	25.00%	7.69%	6.25%	11.11%	11.43%	18.18%	15.20%	13.68%	14.79%	0.00%
Mushrooms /wild plants picking	22.22%	0.00%	12.82%	6.25%	11.11%	17.14%	18.18%	13.60%	14.21%	12.43%	0.00%
Hunting	0.00%	0.00%	5.13%	6.25%	5.56%	11.43%	0.00%	10.40%	12.11%	14.20%	0.00%
Spiritual value	0.00%	25.00%	20.51%	18.75%	16.67%	11.43%	18.18%	14.40%	14.21%	12.43%	0.00%
Traditional/local culture/knowledge	22.22%	25.00%	20.51%	25.00%	22.22%	11.43%	9.09%	13.60%	14.21%	14.20%	0.00%
Total	**100.00%**	**100.00%**	**100.00%**	**100.00%**	**100.00%**	**100.00%**	**100.00%**	**100.00%**	**100.00%**	**100.00%**	0.00%

Note to Figure 3*: 1. NL-IBS: Novel low-input breeding strategies; 2. HIB: High intensity breeding; 3. SGB: Seed/Gene banks; 4. CSO/CA: Conservation seed orchards/clonal archives; 5. SSS: Selected seed stand; 6. SGMS: Silviculture of genetically mixed stands; 7. ST: Selective thinning; 8. RDF: Rescue of declining forests; 9. RDA: Restoration of devastated areas; 10. LSGHM: Landscape-scale genetic heterogeneity management; 11. O: Other*

From Figure 3, it is possible to gather insights into the kind of trade-off analysis, both within and between ES categories, that will be performed at the end of the Delphi process. Indeed, each FGR management strategy is associated with the positive supply of specific ES. For example, according to the results of the first Delphi round at the EU-level, the implementation of RDA is strongly associated with the provisioning of genetic materials and water resources, while much less with noise reduction and air quality regulation. On the other hand, NL-IBS shows a strong positive impact on education and research activities, but no impact on recreation and sport. In addition, across practices, the preliminary results show that for provisioning ES, genetic materials (on average 31.1%) and timber (on average 25.9%) are the most positively impacted, while game and trophies (8.6%) ranks lowest. For regulating ES, carbon storage (15.8%) and genetic pool protection (14.5%) rank first and second, while noise reduction (4.1%) ranks last. For cultural ES, education and research (20.5%) and hunting (5.9%) show respectively the highest and lowest frequencies.

3.4 Future scenarios at the EU-level

Figure 4 shows the frequency percentages for each future scenario (row headings) for each FGR management practice (column headings) selected at the EU-level during the First Round. To facilitate visualization of the results, the intensity of the cell background colour increases as the values increase.

EU-level											
Provisioning ES											
Scenario	1. NL-IBS	2. HIB	3. SGB	4. CSO/CA	5. SSS	6. SGMS	7. ST	8. RDF	9. RDA	10. LSGHM	11. O
NN	0.00%	0.00%	11.11%	0.00%	0.00%	0.00%	9.52%	0.00%	8.57%	9.41%	0.00%
NN-NC-NS	67.35%	56.00%	70.37%	64.00%	61.11%	76.67%	71.43%	76.47%	77.14%	69.41%	100.00%
NS	32.65%	44.00%	18.52%	36.00%	38.89%	23.33%	19.05%	23.53%	14.29%	21.18%	0.00%
Total	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
Regulating ES											
Scenario	1. NL-IBS	2. HIB	3. SGB	4. CSO/CA	5. SSS	6. SGMS	7. ST	8. RDF	9. RDA	10. LSGHM	11. O
NN	0.00%	0.00%	14.29%	0.00%	12.50%	5.88%	0.00%	10.53%	7.69%	13.04%	0.00%
NN-NC-NS	72.73%	33.33%	42.86%	50.00%	37.50%	70.59%	33.33%	63.16%	69.23%	69.57%	0.00%
NS	27.27%	66.67%	42.86%	50.00%	50.00%	23.53%	66.67%	26.32%	23.08%	17.39%	0.00%
Total	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	0.00%
Cultural ES											
Scenario	1. NL-IBS	2. HIB	3. SGB	4. CSO/CA	5. SSS	6. SGMS	7. ST	8. RDF	9. RDA	10. LSGHM	11. O
NN	0.00%	0.00%	10.00%	0.00%	0.00%	0.00%	0.00%	0.00%	3.23%	3.33%	0.00%
NN-NC-NS	83.33%	0.00%	70.00%	100.00%	60.00%	84.62%	100.00%	87.50%	90.32%	86.67%	0.00%
NS	16.67%	100.00%	20.00%	0.00%	40.00%	15.38%	0.00%	12.50%	6.45%	10.00%	0.00%
Total	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	0.00%

***Note to Figure 4**: 1. NL-IBS: Novel low-input breeding strategies; 2. HIB: High intensity breeding; 3. SGB: Seed/Gene banks; 4. CSO/CA: Conservation seed orchards/clonal archives; 5. SSS: Selected seed stand; 6. SGMS: Silviculture of genetically mixed stands; 7. ST: Selective thinning; 8. RDF: Rescue of declining forests; 9. RDA: Restoration of devastated areas; 10. LSGHM: Landscape-scale genetic heterogeneity management; 11. O: Other*

On average, across ES categories, the NN-NC-NS scenario (63.5%) was selected as the most functional for increasing the future supply of ES at the EU-level. The NS scenario (26.8%) ranks second, showing its highest mean frequency for regulating services (35.8%). On the other hand, the NN scenario received limited selections, with an average score of 3.6% across ES categories, and only 1.5% associated with provisioning services. On average, despite some specific patterns (see paragraph 4.3), the results at the country-level show similar trends.

4 Discussion

4.1 FGR management practice at country and EU level

In general, after the first round, clear differences in the selection of FGR management practices, between the three ES groups, can be observed.

The selection for **Provisioning ES** is the most diverse, ranging from breeding strategies to landscape-scale activities. Among them, NL-IBS, SGMS, RDF, LSGHM are highly selected in most countries. These practices act at genetic, stand and landscape levels, highlighting the need for action across all scales to manage genetic diversity while positively impacting provisioning ES. Furthermore, specific country-level patterns have emerged. For instance, Italy and Slovenia show a high frequency for RDA, potentially reflecting their recent loss of large forest areas due to storms (e.g., Vaia), bark-beetle outbreaks, and wildfires. Overall, at the EU scale, the picture appears less polarised than within individual countries, however, the need for a multilevel approach still strongly emerges. The choices for **Regulating ES** are less dispersed, being concentrated on landscape and stand-level options, especially mixed stands. RDA and LSGHM represent the top two practices at the EU-level, indicating general agreement that large-scale restoration and management measures are most effective in delivering regulating ES. The choices associated with **Cultural ES** are the most homogeneous, with higher frequencies on stand and landscape-scale practices, which are largely dominant in every country and at the EU level. This highlights that cultural ES are mostly connected to heterogeneous, well-preserved forest landscapes. It is worth noting that HIB has generally received very little selection, suggesting limited support for advanced biotechnological strategies.

4.2 Ecosystem services at the EU-level

As regards **provisioning ES**, genetic materials and timber are the two most frequently selected services. If firewood is considered too this confirms that woody biomass is the leading provisioning ES. This emphasis remains even when geneticists are excluded from the panel. Timber's result is consistent with the literature and with EU bio-economy policies that promote wood products as low-carbon substitutes. Country rankings are largely similar, but some local characteristics can be identified (e.g., Italy for water and edible non-wood forest products, and Slovenia for non-wood forest products in general). In both countries, these products have historical, cultural, economic, recreational and even "identity" value. Italy is Europe's largest consumer of such products, and Slovenia has one of the highest rates of household collection (WildFood, 2022). Carbon storage and genetic-pool protection are the most selected **regulating ES**, followed by natural-hazard protection and habitat for plants and animals. The high score for genetic-pool protection may reflect the growing policy focus on habitat quality and biodiversity (e.g. EU Biodiversity Strategy (EC, 2020), Nature Restoration Law (EC, 2022)). On the other hand, carbon storage may reflect the importance of the EU climate-mitigation strategies and measures such as the EU "Fit-for-55" package and the forthcoming Carbon Removal Certification framework. Among countries, natural-hazard protection stands out in France, Romania and Italy, all characterized by extensive mountain areas. For **cultural services**, selections are mostly consistent across countries, with two clear indications: education and research have the highest share, while hunting has the lowest (in line with the low score for game-and-trophies in the first block). Traditional/local culture and knowledge ranks second and is closely associated with landscape aesthetics. Slovenia is the only country with a frequency that differs significantly from the general pattern.

4.3 Future scenarios at the EU-level

The NN-NC-NS scenario received most of selections. This may reflect a general preference for a multifunctional approach driven by the interests of various stakeholders. Hence, experts' opinions appear more aligned with the IPBES concept of "nature's contributions to people" than with a purely utilitarian (economic) perspective of ecosystem services. At the country-level, across ES categories, a recurring pattern has emerged. NN-NC-NS is predominant in Finland, France and Slovenia, NS in Denmark and Romania, while NN leads the ranking in Italy.
This interesting result may reflect Italy's long-standing inclination toward "close-to-nature" silviculture, characterised by light interventions and low harvest levels, now reinforced by the EU guidelines for closer-to-nature forest management.

5 Conclusions

In conclusion, despite the limitation of an unevenly distributed panel across countries and expert categories, the first round of the OptFORESTS Delphi provides a snapshot of expert opinions on the current and future impact of FGR management practices on FES at multiple scales. The results of the second and third rounds, by refining the analysis, can offer valuable insights for informing future strategies aimed at enhancing the recognition of FGR value within European forest governance and economic frameworks. In this context, building on the Delphi results, a desirable way forward to better associate socioeconomic benefits with FGR management practices might be represented by the spatially explicit, physical and monetary, assessment of key FES at local and regional scales.

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ASSESSING THE IMPACT OF EUROPEAN POLICIES ON FOREST GENETIC RESOURCES AND FOREST REPRODUCTIVE MATERIAL: POLICY GAPS AND ECONOMIC IMPLICATIONS

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Abstract:

While policy research on forest genetic resources (FGR) and forest reproductive material (FRM) tends to focus on forestry and biodiversity, there is a lack of studies investigating broader institutional structures. This study, conducted within OptFORESTS project, examines the impact of European policies on FGR and FRM in 2025 and 2050. Through desktop research we identified 48 documents and assessed them through expert panel consultation and SWOT analysis. Approximately half of identified documents was assessed as having positive impacts, currently and in the future. A SWOT analysis highlighted strengths (i.e. afforestation incentives), weaknesses (i.e. the lack of explicit FGR and FRM focus), opportunities (i.e. collaborations), and threats from practices (i.e. land use pressures). Economic incentives, such as afforestation grants and research funding, were identified as crucial to promoting sustainable forest management and the bioeconomy, while it was recognised that more economic opportunities are needed in terms of cross-border FRM trade and the potential economic benefits of diverse tree species. Interestingly 87% of experts was unaware of financial opportunities and mechanisms prescribed by economic policies that declare certain categories of aid in the agricultural and forestry sectors (e.g. Commission Delegated Regulation (EU) 2022/126, Regulation (EU) No 1305/2013, etc.). Limited awareness of economic policies among stakeholders can hinder the effective implementation of sustainable forest management practices, potentially leading to missed opportunities for leveraging economic incentives and achieving long-term ecological and economic benefits. Such findings underscore the need for improved policy coordination to effectively address existing gaps in FGR and FRM governance. To effectively translate available economic policy instruments into practice, it is essential to enhance policy awareness and build capacity among stakeholders. Application of the Better Regulation Agenda (2023) should lead to a more rigorous evaluation of policy options before their adaption.

Keywords:

policy impact assessment, biodiversity conservation, framework conditions, institutional structures, forestry

1 Introduction

Forest Genetic Resources (FGR) and Forest Reproductive Materials (FRM) are essential for biodiversity and ecosystem services across Europe. Despite numerous initiatives aimed at their conservation and sustainable use, significant policy gaps remain, primarily due to inadequate frameworks and poor implementation (Pecurul-Botines et al., 2023; Potter et al., 2023). These gaps are exacerbated by a lack of coordination across sectors and countries, hindering effective conservation efforts, particularly in response to challenges such as climate change and emerging pests (Maniak-Huesser et al., 2021). Moreover, FGR and FRM considerations are often not fully integrated into broader policy frameworks, including agriculture, energy, and trade, despite their indirect relevance (Graudal et al., 2020; Lefèvre et al., 2024). This oversight results in fragmented efforts and missed opportunities for policy synergies that could drive transformative changes in forest sustainability (Graudal et al., 2020; Hoban et al., 2021).

Economic considerations play a critical role in the implementation of FGR and FRM policies, especially through financing mechanisms. Policies that incentivize afforestation, reforestation, and forest-based bioeconomy could contribute significantly to sustainable forest management but simultaneously face challenges such as capacity of FRM production, suitability of species, and approval of certain management practices, such as assisted migration (Haase and Davis, 2017). Further on, financing mechanisms often lack clear integration with FGR conservation and FRM production goals (Lefèvre et al., 2024; Potter et al., 2023). For instance, afforestation incentives primarily focus on increasing forest cover which may inadvertently overlook genetic diversity concerns (Ivetić and Devetaković, 2017). Additionally, policies supporting forest-based bioenergy can inadvertently encourage monoculture plantations, undermining long-term resilience (Ibid.).

While the FGR and FRM policy research and practice tended to focus mostly on the policies from forestry, and biodiversity, there seems to be a lack of studies that investigate the interaction of policies from broader domains (energy, trade, innovation, social cohesion, etc.) with FGR or FRM policies. This can lead to a lack of prioritisation of FGR conservation and management within broader forest policy and planning processes (Hoban et al., 2021; Graudal et al., 2020; Fady et al., 2016). There are even fewer projects or studies that take into consideration and analyse a wide set of FGR-related policies vis a vis transformative potential of policy instruments. In this way, the previous research might miss identifying structural policy gaps that could be used as potential deep leverage points for strategic adaptation and innovation interventions. Focusing on policy gaps, our aim is to identify policy and governance gaps that hamper sustainable conservation, management and use of FGR on the European level. For fulfilling our aim, we answer on two research questions (RQ):

> RQ_1: What policies influence sustainable conservation, management and use of FGR on the European level, currently and in the future?
>
> RQ_2: How selected policies influence sustainable conservation, management and use of FGR on the European level, currently and in the future?

2 Methods

To answer our research questions, we conducted exploratory-explanatory study. To assess the influence of European Union policies on FGR and FRM we designed Excel Template for European Policy Identification and Assessment. The questionnaire template consisted of seven sheets, one of which explains the terminology, and six of which are dedicated to specific policy domains. Policy domains group sets of policies that predominantly relate to the respective domains. The domains include 'agriculture and forestry' (11 policy documents); 'environment' (14 policy documents); 'market and trade' (nine policy documents); 'energy and climate' (three policy documents); 'research and innovation' (four policy documents); and 'financing' (seven policy documents). The template was pre-tested by five experts and refined to improve functionality. Then, in period March – May 2024, it was shared with 15 internal experts from the OptFORESTS project partners.

11 out of 15 invited experts (specialists in forest genetics, FRM, forest and environmental policy, and forest management) provided comprehensive assessments of policies vis-à-vis FGR and FRM. The experts self-assessed their knowledge of the policy, assessed policy influence of each policy on FGR and on FRM, currently and in 2050 and indicated the relevance of each policy for in-depth analysis. Weighed scores were calculated from the expert evaluations of policy influence currently, and in the future, valuing the categories "Very negative", "Negative", "Neutral", "Positive" and "Very positive" respectively from -5, -3, 0, +3 and +5. Open ended expert responses were summarised using Chat GPT 4o-mini, which included elements such as the influence of legislation on FGR and FRM, SWOT elements, policy enabler or barrier, and the need for in-depth analysis, and cross-checked and revised by research team.

3 Results

For each policy document, the experts indicated their respective level of familiarity. For eight of the policy documents, none of the experts indicated to be aware. With 11 experts indicating awareness levels for 48 policy documents (Table 1), thus administering 528 votes, 59% of the votes were distributed to categories corresponding to "Less than aware", and a remaining 41% of the votes being distributed to categories corresponding to "Aware" (31%), "Functional knowledge" (9%) or "Policy author/contributor" (1%, 3 documents with at least one vote).

The experts indicated most awareness – as the sum of votes awarded to the categories "Aware", "Functional knowledge" and "Policy author/contributor" - related to the policies comprised in the policy theme "Agriculture and Forestry", followed by "Environment", then "Markets and Trade".

Table 1: Distribution of the expert 'votes' of awareness per policy theme, for all policy documents in each policy category

Policy theme	Nothing selected	Unaware	Aware	Functional knowledge	Policy author /contributor
ALL	8%	51%	31%	9%	1%
1. AGRICULTURE & FORESTRY	0%	43%	40%	13%	3%
2. ENVIRONMENT	5%	45%	41%	8%	0%
3 MARKET & TRADE	11%	44%	32%	12%	0%
4 ENERGY & CLIMATE	9%	52%	36%	3%	0%
5 RESEARCH & INNOVATION	18%	45%	27%	0%	9%
6 FINANCING	17%	82%	1%	0%	0%

Source: Own elaboration

3.1 Policies influencing FGR and FRM

The majority vote represents the influence category most frequently assigned to a given policy by the experts, based on evaluations using a weighted scale. Almost all policy documents were evaluated by most experts to have a neutral to positive impact both now and in the future. The top ten rated policies influencing FGR (Figure 1) and FRM (Figure 2) are ranked from highest to lowest based on their average scores.

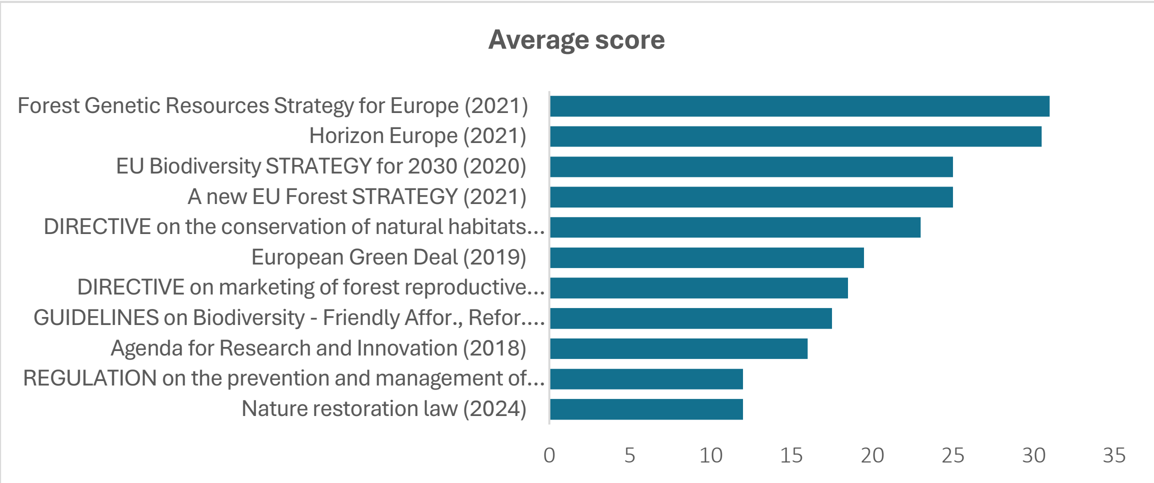

Figure 1. Policy documents with top 10 average scores influencing FG; 11 policies is shown due to the tie of two ranked policies with score 12 (Own elaboration)

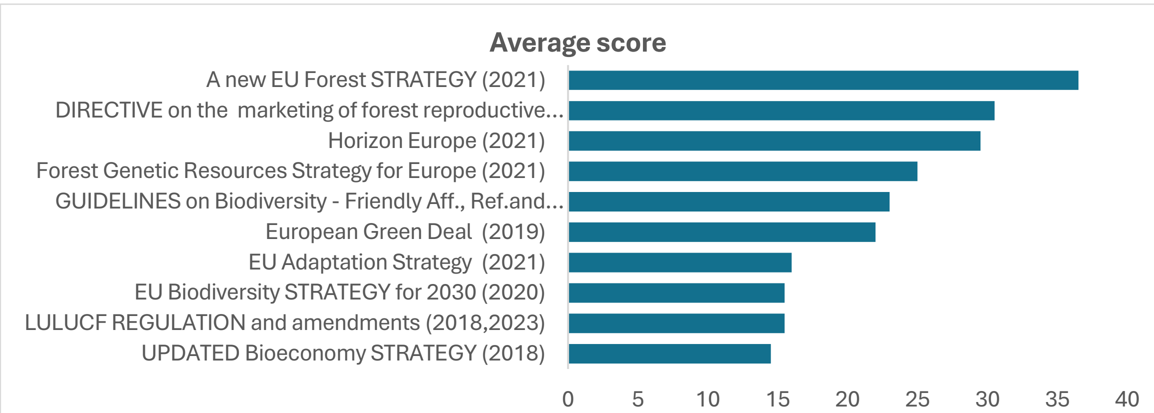

Figure 2. Policy documents with top 10 average scores influencing FRM (Own elaboration)

These policies together form a complex landscape for FGR conservation, highlighting the need for further integration and coordination across sectors. One policy document, the *Legislative proposal on plants obtained by certain new genomic techniques (COM(2023)411*)[5], was considered by a majority of experts with low current and possibly negative future influence.

Internal experts also provided qualitative answers on how polices influence FGR and FRM, as well as the reasons for in depth analysis. Based on full answers and justification of need for in-depth analysis per policy, SWOT analysis in summary format for all policies was developed. Table 2 below provides summary of SWOT analysis. Common Reasons Internal experts listed for in-depth analysis included:

1. Clarification of FGR and FRM relationships: Many policies mention FGR and FRM without clarifying their relationship. An in-depth analysis is needed to understand how these elements interact and how policies can ensure their coordinated management for long-term sustainability.
2. Addressing gaps in regulatory frameworks: Although many polices are relevant for sustainable forest management, they do not address FGR and FRM explicitly. Thus, those policies lack detailed frameworks or fail to offer specific mechanisms for FGR conservation and management and/or FRM deployment. In-depth analysis can identify missing elements like funding mechanisms, organizational structures, and enforcement strategies.
3. Evaluating the long-term impact on genetic diversity: While some policies acknowledge the importance of genetic diversity, many focus on short-term goals (e.g., carbon sequestration, bioenergy) without considering the long-term impacts on FGR. In-depth analysis could assess whether FGR are being adequately protected and integrated into long-term planning.
4. Ensuring comprehensive climate change adaptation: Some policies focus on improving forest resilience to climate change, but may overlook the role of FGR or suitability of FRM in this process. Further analysis can identify how FGR conservation and management and/or FRM deployment could be integrated into adaptation strategies to ensure forest resilience.
5. Risk of overexploitation or neglect: In some cases, policies may inadvertently encourage practices that lead to overexploitation of certain tree species or a lack of attention to less commercially viable but ecologically valuable species. In-depth analysis would examine these risks and recommend solutions to balance ecological and economic goals.
6. Understanding the impacts of emerging technologies: The potential role of new genomic techniques and other biotechnologies in forestry is an emerging area of concern. In-depth analysis would assess how these technologies could affect FGR and forest management practices, particularly in the context of climate adaptation.
7. Monitoring and assessing cross-border coordination: Policies often mention cross-border cooperation but lack the detailed mechanisms needed for effective implementation. In-depth analysis would evaluate if there are prescribed coordination mechanisms across countries applicable to FGR and FRM.
8. Strengthening collaboration and knowledge sharing: While many policies encourage collaboration, there is a need to deepen the exchange of best practices and research findings. In-depth analysis would focus on how policies can better foster collaboration between member states, researchers, and forest managers to improve the management of FGR and FRM.

[5] Not on the Figure, as evaluated with low current and potential negative influence.

Table 2: Summary of SWOT analysis*

STRENGHTS	WEAKNESSES
• **Support for FGR and FRM:** Many policies prioritise or at least indirectly support the conservation and sustainable use of FGR and FRM, through various mechanisms (e.g., EUFORGEN), afforestation incentives, and restoration efforts. • **Actionable Measures:** Several strategies include concrete proposals, such as increasing FRM production, enhancing forest resilience to climate change, and fostering cross-border cooperation to ensure the sustainable management of forest resources. • **Alignment with Climate Goals:** Many policies highlight the role of forests in climate adaptation and mitigation, emphasizing the importance of selecting climate-resilient tree species and sustainable forestry practices. • **Promote Research and Innovation:** There is a support for funding and innovation in forestry research (e.g., Horizon Europe), contributing to long-term improvements in FRM and FGR management.	• **Lack of Direct Focus on FGR and FRM:** A key issue across several policies is the insufficient focus on FGR and FRM, which are either not explicitly addressed or only mentioned in passing. • **Voluntary and Non-Enforceable Measures:** Many strategies, such as those dealing with FGR conservation, rely on voluntary compliance, which can reduce their effectiveness and lead to inconsistent implementation across member states. • **Insufficient Specificity:** Many documents provide high-level strategies without delving into the specifics needed for successful implementation, particularly around organizational structures, funding mechanisms, or clear regulatory frameworks. • **Potential Conflicts:** Policies focusing on broad objectives like carbon sequestration or bioenergy production sometimes overlook the importance of genetic diversity, risking overexploitation or neglect of genetic resources in favour of short-term economic goals.
OPPORTUNITIES	**THREATS**
• **Improved FGR and FRM Integration:** Policies can be better aligned to integrate genetic diversity and FRM conservation into broader biodiversity and forestry goals, including climate change adaptation and ecosystem services. • **Innovation in Genetic Resources:** There is potential for innovation in forestry genetics (i.e. the use biodiversity friendly forest management practices, advanced genomic techniques, better-suited FRM for climate adaptation, etc.) • **Collaboration and Cross-Border Coordination:** Strengthening cross-border collaboration and enhancing research cooperation could improve the consistency and effectiveness of forest management practices across Europe. • **Sustainable Land Use:** Incorporating stronger FGR and FRM considerations into land-use planning and forest management, especially in the context of bioenergy, restoration projects, and agroforestry, could help ensure long-term sustainability.	• **Risk to Genetic Diversity:** Overreliance on certain species or the introduction of non-native species for climate adaptation (e.g., assisted migration) could reduce genetic diversity and undermine long-term forest resilience. • **Potential for Monocultures:** Some policies may inadvertently encourage monoculture plantations, leading to reduced biodiversity and resilience in forest ecosystems. • **Climate Change Uncertainties:** The unpredictability of climate change impacts on forest ecosystems could lead to challenges in selecting the right FRM, with potential long-term consequences for forest health and genetic conservation. • **Insufficient Enforcement:** The voluntary nature of many policies, along with gaps in regulatory enforcement, may lead to ineffective implementation and missed opportunities for preserving forest genetic resources.

*Summary was produced by Chat GPT 4o-mini and revised by two researchers

4 Discussion and conclusion

Our study underscores significant policy gaps that hinder the sustainable conservation, management, and use of FGR and FRM in Europe. Despite efforts to address these issues through various European policies, the lack of coordinated and integrated policy frameworks remains a primary barrier (Hoban et al, 2023; 2021). The fragmented policy landscape limits the effectiveness of conservation efforts, particularly in light of challenges such as climate change, invasive species, and forest degradation (Pecurul-Botines et al., 2023; Kaufer, 2023).

Expert assessments reveal that many policies have a neutral to positive influence on FGR and FRM both now (2025) and in the future (2050). Policies often target specific sectors such as climate change, biodiversity, and forest management but fail to address the interconnected nature of FGR and FRM (Lefèvre et al., 2013). The majority of policies suffer from insufficient specificity, often lacking clear actionable measures or effective enforcement mechanisms (*Ibid*.). This lack of detail limits their practical impact, as the voluntary nature of many measures results in uneven implementation across member states (Hoban et al., 2021). Notably, the results highlighted that while Horizon Europe was recognized as an important funding mechanism, a significant gap exists in the awareness of other financial instruments, such as those provided through agricultural aid and forestry-specific regulations (e.g., Commission Delegated Regulation (EU) 2022/126, Regulation (EU) No 1305/2013). These funding mechanisms might be underutilized due to limited awareness among stakeholders, which could impede the effective implementation of sustainable forest management practices (Haeler et al., 2023). The analysis also identified opportunities for greater cross-border collaboration and innovation in forest genetics, areas where policy frameworks could be strengthened. However, there is a significant risk that economic pressures, such as those associated with bioenergy and monoculture plantations, could undermine genetic diversity, a critical component of forest resilience (Ivetić and Devetaković, 2017).

Such findings emphasize a crucial role that financing mechanisms play in advancing sustainable forest management (Potter et al., 2017). While Horizon Europe was recognized by experts as pivotal in funding research and innovation in forestry, many other funding opportunities remain overlooked. This highlights the importance of integrating financial support with long-term strategic goals for FGR and FRM conservation. However, the low awareness of funding mechanisms particularly tied to agricultural and forestry regulations suggests that the potential of these financial tools might be underexploited (Mammides and Kirkos, 2020). The lack of awareness could prevent stakeholders from fully leveraging available economic incentives, hindering the effective implementation of policies aimed at sustainable forest management.

To address this gap, it is essential to enhance knowledge of financial instruments such as EU regulations on agricultural aid, which can support forest-related activities, including FGR and FRM management. Increasing awareness and building capacity around these funding mechanisms would help stakeholders access the resources necessary for implementing sustainable forestry practices (Potter et al., 2017; Mammides and Kirkos, 2020). Furthermore, ensuring that funding policies are better aligned with FGR and FRM goals will help bridge the gap between financial incentives and ecological objectives (Potter et al., 2017). Strengthening the integration of financing into broader forest policy frameworks can ensure that economic incentives are fully leveraged to support long-term sustainability and resilience in European forests.

While the panel's assessments provide valuable insights into the influence of these policies, it is essential to acknowledge the limitations of this exercise. First, the reliance on expert judgment to assess the influence of policies could introduce biases, as the experts' perspectives and knowledge may differ, especially concerning policies with which they are less familiar. Additionally, the subjective nature of evaluating policy effectiveness, especially when projecting future impacts (e.g., for 2050), presents challenges in ensuring consistency and accuracy. The expert assessments also reflect a snapshot in time, and future evaluations may yield different results as new policies emerge or existing ones are updated. As such, the results should be taken as indicative rather than replicable, providing a general sense of policy influence but not absolute certainty regarding their implications.

In conclusion, the study reveals that while progress has been made by adopting policy frameworks for FGR and FRM conservation, the lack of detailed, actionable measures and sufficient financial support mechanisms remains a significant obstacle. Improving coordination, increasing policy specificity, and raising awareness of financial opportunities will be crucial for overcoming these barriers. Enhancing the mobilization of financial resources and incentives would have important economic implications, strengthening the case for investing in genetic diversity and supporting the long-term resilience and sustainability of European forests.

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REGIONAL ANALYSIS OF BIOMASS POTENTIAL FOR ENERGY USE IN SLOVAKIA: CALCULATION, FORECAST, AND IMPACT OF ENVIRONMENTAL POLICY

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Abstract:

The study examines the potential of forest biomass for energy use in the Slovak Republic, focusing on regional disparities and the influence of environmental policy. Utilizing data from the Forestry and Hunting Information System, we determined the current and projected volumes of available biomass in various districts across Slovakia. The analysis contrasts the existing biomass potential with that which would be available if logging were completely halted in protected areas (designated as degree of nature protection 3 and above). Furthermore, the study calculates the potential financial consequences of reducing the energy potential of biomass for individual districts of Slovakia. Regional differences in the potential of biomass for energy use are significant. The greatest decrease in potential under the influence of environmental policy is expected in the districts of Snina, Liptovský Mikuláš and Rožňava.

Keywords:

fuelwood, biomass, renewable resources, Slovak forests, potential

1 Introduction

The use of biomass for energy purposes contributes to achieving the climate and energy goals of the European Union. Slovakia had a target for renewable sources in 2020 of at least 14 %. According to Eurostat data, the share in gross final consumption in 2020 was 17.35 % (Eurostat, 2020). There is a discussion on further increasing the share of renewable energy sources. The updated Integrated National Climate and Energy Plan, which is to present a key conceptual document in the field of energy, set the share of renewable energy sources in the final energy consumption of the Slovak Republic at 23% by 2030. Forest biomass plays an important role as a source of bioenergy. The determination of the potential of wood for energy use is being addressed by authors in various countries of the world on all continents (Bhattacharya et al., 2003; Lauri et al., 2014; Van Holsbeeck et al., 2020; Nord-Larsen, Talbot, 2004; Stolarski et al., 2020; Pfeiffer, Thrän, 2018; Šafařík et al., 2021).

According to registration data published by the Ministry of Agriculture and Rural Development of the Slovak Republic (Green Report, 2022), the total annual consumption of solid fuel biomass in Slovakia averaged 3 million tons per year between 2016 and 2022. This included fuel wood, residues from wood processing and handling, briquettes, and pellets. Direct supplies of the fuel wood assortment from forestry amounted to approximately 0.8 million tons annually.

Environmental policy goals and objectives will influence biomass's potential for energy use. Increasing forest protection reduces the volume of wood assortments offered on the market and, at the same time, increases their prices (Bolkesjø et al., 2005). In the Slovak Republic, five levels of nature protection (SOP) apply to territorial nature and landscape protection, which are defined in Act No. 543/2002 Coll. on Nature and Landscape Protection. Timber harvesting has been regulated since the 3rd SOP, and in the 5th SOP, harvesting is strictly prohibited. In recent years, the process of zoning national parks with the exclusion of harvesting has been underway, or is underway, even in areas where it was previously possible. Stricter environmental policy associated with the hypothetical complete exclusion of timber harvesting in SOP 3 will impact the volume of biomass potential for energy use in the future.
The scientific article aims to determine the regional potential of biomass for energy use by districts of the Slovak Republic based on data from the Forest Management Information System (FMIS). We calculate the potential under the unchanged current situation and compare it under a regime of stricter environmental policy with the complete exclusion of timber harvesting in SOP 3 - 5. Based on calculations, we will assess the resulting impact of these economic changes.

2 Methods

To determine the potential of energy biomass, we collected data from detailed stand data (timber on stumps) and used the available FMIS data. The data sources used in the analysis are planned intentional timber harvesting in forest stands on forest lands in valid Forest Management Programs (FMP) for individual forest spatial distribution units.
Available wood biomass is bound for defined territorial units on stumps in forest stands depending on the actual categorization of forests (commercial, protective, special purpose) or current levels of nature protection. It is the calculated potential in standing living wood in forest stands, of which we expect to use only a certain part for energy purposes (100% quality class VI - firewood, 25% quality class - pulpwood). From a methodological point of view, we first determined the volume of available and subsequently planned harvesting until 2035.
The available harvesting was calculated based on the harvesting regulations for individual tree species per decade according to the valid (FMP), and the recorded harvesting of all tree species carried out to date according to the Forest Management Records (FMR).
The forecasted harvesting was derived from the current decennial harvesting regulations in FMP. The average annual planned harvesting was derived from the decennial harvesting with a coefficient of 0.1. In the various forecast alternatives to 2035, two options were considered:

1. The planned harvesting remains unchanged across all stands – business as usual.
2. Planned harvesting will be the same as currently in stands outside the 3rd and higher SOP, none will be planned in protected areas - impact of environmental policy.

The volume of forecasted annual harvesting in FMIS is given in m3. We transformed the volume through wood density coefficients by tree species to the biomass value in tons at model zero wood moisture: biomass dry matter. The core of the work is the summary of data on the forecasted annual potential of energy biomass by districts in overview maps (the forecast maps are supplemented by a map showing the difference in energy-usable biomass between the analysed variants). The annual biomass potential in the Slovak Republic is estimated based on ownership type (state and non-state) and tree species composition (coniferous and broadleaves). This estimation covers the current state as well as forecasts extending to 2035, reflecting both the business as usual variant and the environmental policy impact variant. At the same time, the annual value of this potential is calculated from an economic point of view, which allows for the assessment of the financial impact of the environmental policy.

3 Results

The total current potential of annual biomass available for energy use in Slovakia's forests, as derived from FMIS data and expressed in dry matter, reaches 1.31 million tons (equivalent to 2.62 million tons in a fresh state at 50% relative humidity). Nearly three-quarters of this biomass is found in non-state forests, while the remaining quarter is located in state forests. Currently, coniferous biomass accounts for only 13% of the total biomass available for energy purposes across all of Slovakia's forests. According to forecasts based on processed data from FMIS, the annual extraction of energy-usable biomass for the entire country is projected to be 1,054 thousand tons of dry matter in the business as usual variant and 972 thousand tons in the environmental policy impact variant by 2035. The share of coniferous biomass in these forecasts for all of Slovakia's forests is expected to increase to around 25% by that time. From an economic perspective, the total annual value of this biomass is anticipated to decline from approximately €78 million to €60 million, assuming current conditions prevail. If harvesting were to cease in SOP 3+, the annual value of energy biomass would drop to roughly €50 million.

Table 1: Amount of current and forecasted biomass for energy use in the Slovak Republic (The value of biomass in million € is given in brackets)

Period	Wood species	State forest *thousand t dry matter / year (mil.€)*	Non-state forest *thousand t dry matter / year (mil.€)*	Total *thousand t dry matter / year (mil.€)*
Current period 2022	Coniferous	16.1 (0.6)	151.7 (5.4)	167.8 (6.0)
	Broadleaves	327.7 (20.9)	809.7 (51.5)	1137.4 (72.4)
	Total	343.8 (21.4)	961.4 (57.0)	1305.2 (78.4)
Forecast 2035 unchanged status	Coniferous	95.9 (3.4)	170.1 (6.1)	266.0 (9.5)
	Broadleaves	323.9 (20.6)	464.4 (29.5)	788.4 (50.2)
	Total	419.8 (24.0)	634.5 (35.6)	1054.3 (59.7)
Forecast 2035 Impact of environmental policy	Coniferous	74.2 (2.7)	155.7 (5.6)	229.9 (8.2)
	Broadleaves	302.0 (19.2)	439.8 (28.0)	741.8 (47.2)
	Total	376.2 (21.9)	595.5 (33.6)	971.6 (55.4)

Regarding biomass availability, it is important to determine the potential by region. Fig. 1 and 2 show the forecasted available biomass (variant business as usual and variant environmental policy impact) suitable for energy use by districts of the Slovak Republic. Fig. 3 shows the difference between the variants of biomass use for energy purposes.

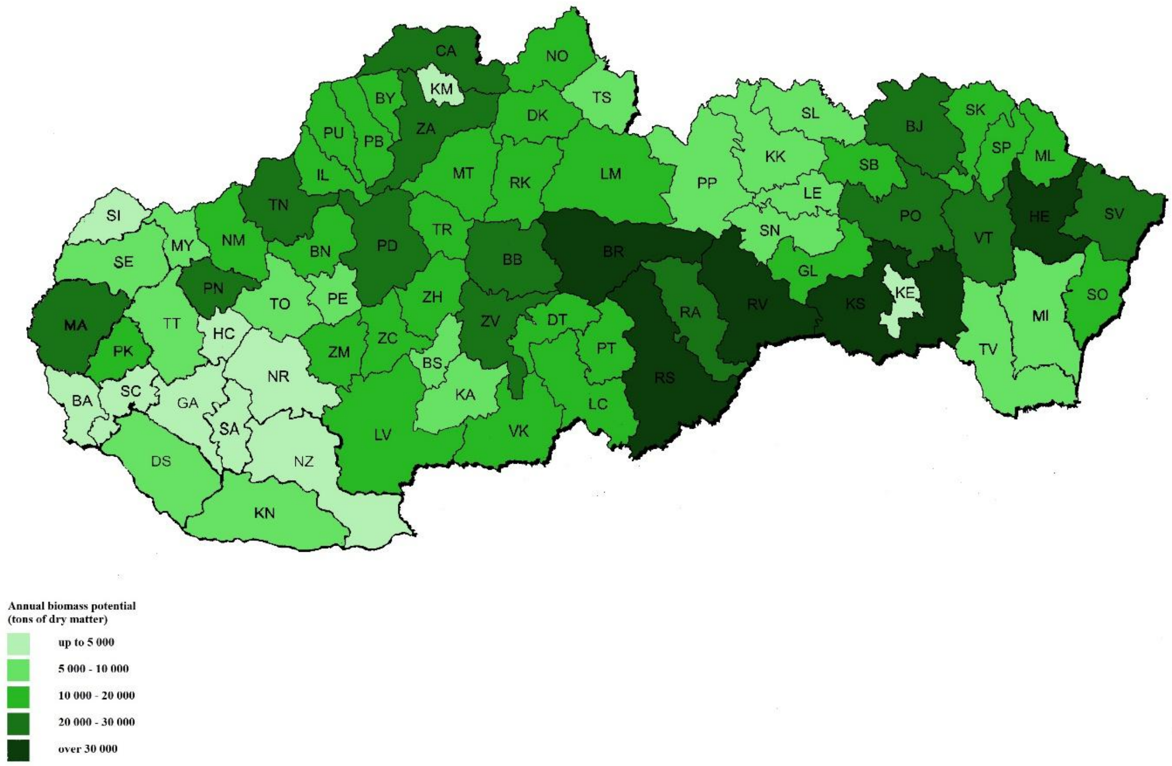

Figure 1. Distribution of annual biomass potential for energy use by districts - business as usual variant, forecast 2035.

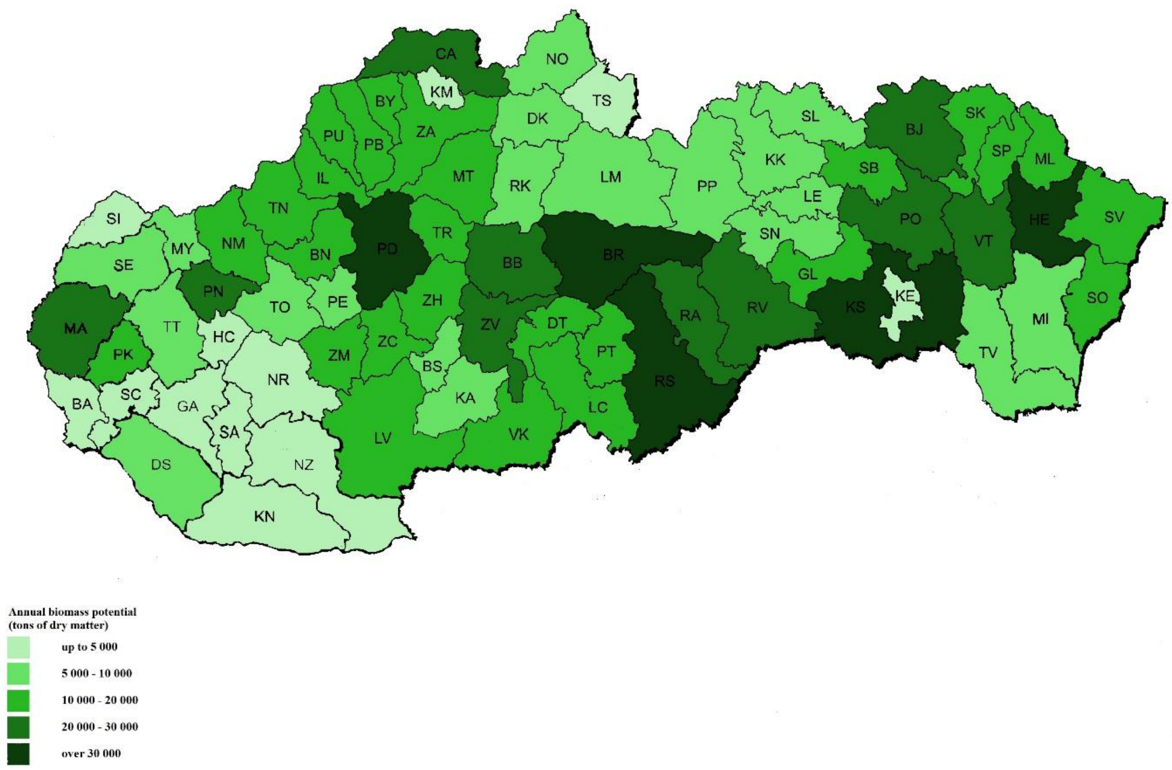

Figure 2. Distribution of annual biomass potential for energy use by districts - variant impact of environmental policy, forecast 2035.

From a regional perspective, the most available biomass for energy use with an annual potential of over 30,000 t of dry matter in the forecast period until 2035 is in the districts of Košice, Rimavská

Sobota, Humenné and Prievidza. The lowest volumes of biomass for energy use in the forecast period are in the urban districts of Bratislava and Košice. In addition to urban districts, these are districts that are in lowlands with low forest cover and predominant agricultural production (Šaľa, Senec, Galanta, Hlohovec, Piešťany). The difference between the business-as-usual scenario and the environmental policy impact scenario (as illustrated in Fig. 3) indicates how the potential for biomass will be influenced by stricter nature protection regulations and the prohibition of timber harvesting in SOP 3 to SOP 5.

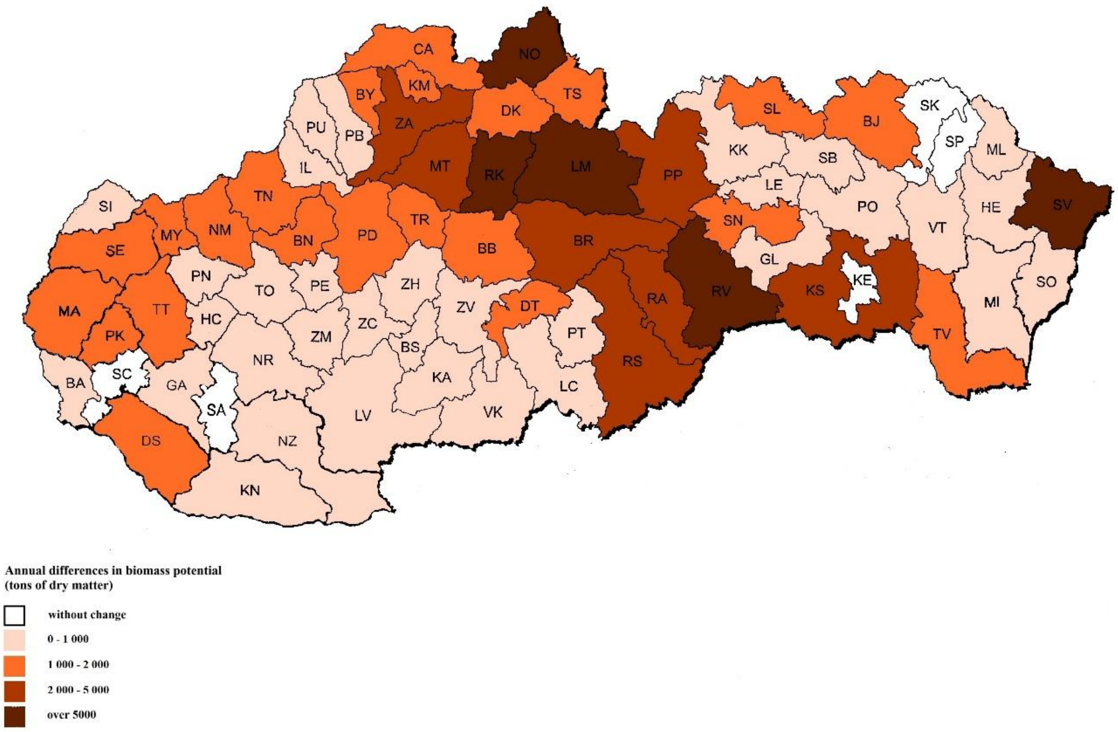

Figure 3. Differences between business as usual and the impact of environmental policy variant

The total difference between the two variants is 83 thousand tons of biomass expressed in dry matter per year (166 thousand tons in fresh state). The highest difference of almost 15 thousand tons of dendromass dry matter per year is forecasted in the Snina district (Poloniny National Park). Other districts where the potential of biomass for energy purposes will be reduced due to nature protection (5 - 11 thousand tons of dry biomass per year) can be included in the districts with the largest national parks of the Slovak Republic (Liptovský Mikuláš, Rožňava, Ružomberok, Námestovo, Martin, Brezno Poprad and Revúca).

4 Discussion and conclusion

The total annual biomass potential for energy use in Slovak forests, derived from the FMIS data expressed in dry matter, reached 1.35 million tons. Suppose we convert the mass of dry matter biomass to biomass in the fresh state (2.7 million tons). The results correspond to the data from the work of Trenčiansky-Kicko (2022) and Oravec et al. (2022). Trenčiansky-Kicko (2022) states that the energy biomass potential of fuelwood and residues after harvesting reaches 2.48 million tons per year. Oravec et al. (2022) forecast the annual usable potential of forest fuelwood biomass from 2020 to 2035 in the range of 2.77 to 2.80 million tons of fresh raw material per year.

The presented study provides a comprehensive analysis of the potential of forest biomass for energy use in the Slovak Republic, with an emphasis on regional differences and the potential impact of stricter environmental policy. Based on extensive data from FMIS, the current annual available biomass

potential was determined at 1.35 million tons of dry matter. Forecasts until 2035 indicate this potential decreased to 1.09 million tons of dry matter under the business-as-usual variant.
The key finding is the significant impact of environmental policy, specifically the hypothetical exclusion of harvesting in areas with the 3rd and higher nature protection level, which could further reduce the annual potential of energy biomass by 83 thousand tons of dry matter. The study quantified these changes not only in physical units but also from an economic point of view, pointing to a potential decrease in the annual value of biomass from approximately 78 million € to 60 million € in the business-as-usual scenario and up to € 50 million if harvesting in protected areas is stopped.
The analysis of regional differences revealed that the most significant available biomass potential is characterized by the districts of Košice, Rimavská Sobota, Humenné and Prievidza. At the same time, the lowest volumes were recorded in urban districts of cities and lowland districts with predominant agricultural production. The expected tightening of environmental policy would most significantly affect the potential in the districts of Snina, Liptovský Mikuláš and Rožňava.
The results of the study provide a valuable overview of the current and future potential of forest biomass for energy use in Slovakia and emphasize the importance of taking into account environmental policies and regional specificities when planning in the field of renewable energy sources.

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ASSESSING THE IMPACT OF MANAGEMENT RISK ON THE ECONOMIC EFFICIENCY OF FOREST ENTERPRISES

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Abstract:

The economic efficiency of forest enterprises is influenced by a variety of economic, social, political, and natural conditions. A key revenue source remains wood sales, but climate change has increased management risks, notably through rising incidental fellings. It is necessary to analyze, quantify, and incorporate risk into forest land management models. This paper analyzes the impact of such risks on economic performance. The Sibyla growth simulator is used to model the development of wood structure and volume in selected forests. Based on the outputs, costs and revenues are calculated, followed by the evaluation of the economic efficiency using indicators such as Net Present Value (NPV), profit as the equivalent of annual rent, and the economic value of forest property. Results show that incorporating risk into planning leads to reduced revenues, increased costs, and lower overall efficiency. These outcomes highlight the importance of integrating risk factors into long-term forest management.

Keywords:

forest enterprises, economic efficiency, risk, climate change

1 Introduction

The progression of climate change, including both its causes and consequences, is currently a highly relevant topic, not only in numerous research projects but also as an important part of the agenda for governments of nation states and international political organizations. Forest ecosystems represent a vital component of the landscape, contributing to the stability of the environment. Forests occupy approximately 41% of Slovakia’s territory, with the development of forest stands showing a positive trend—since the year 2000, forest area has increased by 14,115 hectares. The results of a long-term survey on the health of Slovakia's forests indicate a stabilization in recent years; however, the overall condition of the forests still falls short of the European average. Based on the defoliation indicator, the situation is more favourable for deciduous tree species, whereas a significant deterioration has been recorded for conifers, particularly in recent years. The current tree species composition of forests is significantly shaped by long-term human activity, with only about 40–45% of forests classified as natural. Forests with unnatural species composition are particularly sensitive to climatic factors such as strong winds, frost, heavy and prolonged snow cover, or extended periods of drought, as well as to biotic threats, especially bark beetles and wood-boring insects. A major anthropogenic factor negatively affecting forest ecosystems is commercial forestry. Increasing pressure is also observed from sports and recreational activities, including the construction of large-scale recreational facilities and the expansion of ski resorts. Air pollution (emissions) represents another factor that adversely impacts forest ecosystems in Slovakia.

Modeling the impacts of climate change on forest ecosystems and the ecosystem services they provide should fundamentally account for the following phenomena:

- Uncertainty in forest production (changes in climatic and natural conditions, variations in atmospheric CO_2 concentrations, nitrogen deposition in the soil, etc., leading to alterations in growth rates and tree species composition).

- Increasing specific risks in forest land management (growing occurrence of extreme weather events, windstorms, droughts, forest fires, insect and fungal pathogen outbreaks, etc.).

- Changes in the functional effects of forest ecosystem services (e.g., alterations in production and multifunctional roles of forests).

A clear manifestation of specific risk factors is the occurrence of incidental fellings. According to available models (Konôpka et al. 2016; Konôpka and Konôpka 2007), a trend of increasing volume of salvage logging has been identified, with extreme annual values further intensifying this trend. By 2030, the average annual volume of salvage logging is expected to reach approximately 2.5 million m³ (Fig. 1). However, it must be emphasized that this is more of an estimate based on historical data rather than a precise forecast. Actual values will depend on weather developments, which are inherently unpredictable.

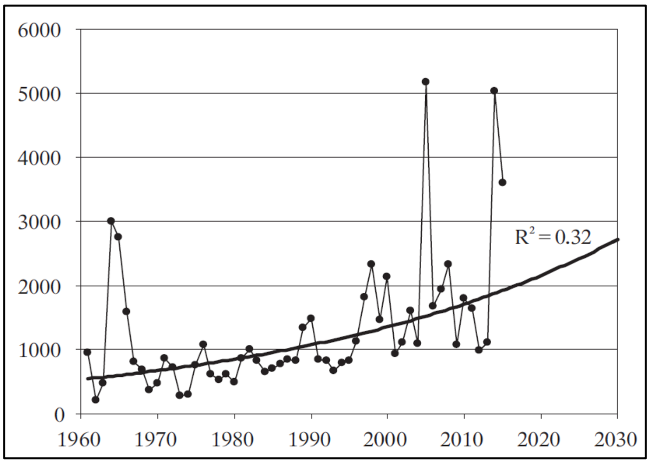

Figure 1. Trends in Accidental Logging Since 1960 and Projected Developments Until 2030 (Konôpka et al., 2016)

2 Methods

The methodological approach to assessing the economic impact of specific management risks on forest land is based on procedures applied in the works of Holécy and Hanewinkel (2006), Holécy (2009), Giertliová (2011), and Holécy, Korená Hillayová (2020). Stand growth simulations were conducted using the Sibyla growth simulator (Fabrika, 2005), in its current version SIBYLA – Triquetra. Its application provided detailed input data regarding the development of structure, volume, and quality of timber production, biomass, ecological stability, and forest biodiversity. The model outputs represent technical units that subsequently required objective valuation.

To calculate expected revenues (and subsequently the capital value of the forest), average market prices of raw timber assortments were adopted from data provided by the general directorate of LESY SR for the year 2024. The cost structure for forest land management was derived from operational analyses supplied by the state enterprise LESY SR, š. p.. The structure of direct costs corresponds to the costing base used by the enterprise and includes:

- Silvicultural costs (artificial forest regeneration, weed control, game protection, protection against browsing and bark stripping, thinning — categorized into pre-commercial and cleaning thinning — and other silvicultural activities),
- Harvesting costs (timber felling, skidding, processing at roadside depots and sorting yards, transportation, and related maintenance and repairs),
- Property taxes,
- Overhead costs.

The input for risk quantification, expressed as the probability of incidental fellings, was based on a 20-year database from the National Forest Centre detailing the volume and structure of salvage logging in Slovakia. Risk was then determined using point probability estimates, which represent the likelihood that one hectare of a given tree species at age (t) will be destroyed by a damaging agent within one decade. The calculation is based on the following relationship:

$$\hat{p}(t) = k \cdot \Delta\hat{F}(t).\hat{f} \quad /1$$

And

$$\Delta F(t) = \hat{F}(t) - \hat{F}(t-1) \quad /2$$

The symbol *k* denotes the number of assumed age classes *j*, where each age class spans 10 years. In this sense, each *p(j)* denotes the probability of stand destruction within a 10-year period. The longest assumed rotation period in this analysis was 150 years. The variable represents the relative frequency of incidental fellings in the studied area, while the theoretical distribution was modeled using the Weibull probability distribution *W(c,γ)*.

The soil expectation value *SEV(u)* was chosen as the criterion for project feasibility. To evaluate the impact of fire risk on this metric, two types of measures were proposed:

- The deterministic risk-adjusted forest soil expectation value *SEVj(u)* calculated using the standard Faustmann formula:

$$SEV_J(u) = [NPV\ (u) * (1+p)^u]/[(1+p)^u - 1] \quad /3$$

  The Net Present Valure NPV(u) indicates the present value of a series of cash flows generated by a forest management project over the assumed rotation period uuu, using an interest rate of 1.0% annually, as recommended for forestry investments in Slovakia (Holécy, 2011).

- The computation of the **risk-free capital value** of forest land used **transition probability matrices *P***, as described by Kouba (1989, 2002). Matrix elements $p_{i,j}$ represent the probability of forest stands transitioning from a lower to the next higher age class. Elements $p_{1,j}$ denote the probability of premature stand destruction or harvesting in the *j*-th age class and its return to the first age class. Mathematically, the probability matrix ***P*** can be written as (Kouba, 2002):

$$P = \begin{vmatrix} p_{11} & p_{12} & \dots & 0 \\ p_{21} & 0 & \dots & 0 \\ p_{n-1,1} & 0 & \dots & p_{n-1,n} \\ 1 & 0 & \dots & 0 \end{vmatrix}$$

The initial vector $p^{(0)}$ = [1, 0, 0,…, 0] describes the stand's age structure at the beginning of the project. Elements of vectors *p(i)* multiplied by the respective destruction probabilities *p(j)* and evaluated through estimated costs and revenues of a forestry project, provide the expected cash flows for each decade in the infinite rotation cycle. The algorithm was terminated when the increment of the risk-free *NPV(nu*) of this project for the last *n*-th rotation period *u* fell belove 0.001 EUR. This result was then considered as the sought value of $SEV_f(u)$.

This methodological approach was applied to a selected forest stand located within the LESY SR, š.p., organizational unit Poľana. The stand consists of a mixed composition of spruce–fir–beech and covers an area of 3.17 hectares. The species composition is 50% spruce, 20% fir, and 30% beech, with a current age of 60 years and a planned rotation age of 120 years.

3 Results

The specific management risk on forest land was assessed based on the probability of incidental fellings. The development of damage or destruction risk for the analyzed tree species—Norway spruce (*Picea abies* L.), silver fir (*Abies alba* Mill.), and European beech (*Fagus sylvatica* L.)—is presented in Figure 2. The modeling results confirmed the highest sensitivity to risk in spruce.

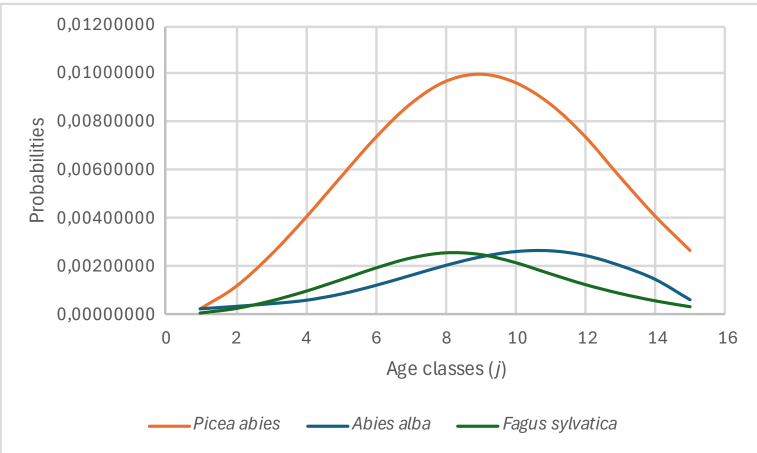

Figure 2. Probabilities of investigated tree-species destruction for 10-year period

The impact of incidental fellings resulting from climate change is further summarized in Table 1, which presents the derived values of SEVj(u) (deterministic) and $SEV_f(u)$ (risk-free) for individual tree species and for the stand as a whole.

Table 1: Resulting values of $SEV_j(u)$ and $SEV_j(u)$ for the individual tree species and the mixed stand

Species	***Picea abies***		***Abies alba***		***Fagus sylvatika***		***Mixed Stand***	
Age (t)	**$SEV_j(u)$**	**$SEV_f(u)$**	**$SEV_j(u)$**	**$SEV_f(u)$**	**$SEV_j(u)$**	**$SEV_f(u)$**	**$SEV_j(u)$**	**$SEV_f(u)$**
(years)	**($EUR.ha^{-1}$)**	**($EUR.ha^{-1}$)**	**($EUR.ha^{-1}$)**	**($EUR.ha^{-1}$)**	**($EUR.ha^{-1}$)**	**($EUR.ha^{-1}$)**	**($EUR.ha^{-1}$)**	**($EUR.ha^{-1}$)**
10	-52 247,43	-24 403,21	-92 935,83	-47 127,58	-57 885,57	-11 789,72	-62 076,56	-25 164,04
20	-42 585,22	-28 279,48	-73 256,70	-52 816,53	-32 177,44	-30 936,21	-45 597,18	-33 983,91
30	-22 645,26	-17 888,44	-47 371,58	-40 627,77	-21 696,67	-16 434,43	-27 305,94	-22 000,10
40	-11 288,16	-9 557,17	-29 765,28	-27 360,63	-16 203,97	-614,33	-16 458,33	-10 435,01
50	-2 739,31	-2 748,49	-15 101,10	-16 450,21	-11 265,80	-3 563,72	-7 769,61	-5 733,40
60	2 531,34	-1 695,24	-8 120,57	-16 353,22	-2 782,65	-2 538,44	-1 193,24	-4 879,79
70	4 336,17	885,09	-158,29	-35,08	1 520,26	1 370,70	2 592,51	846,74
80	5 952,31	2 575,26	1 061,27	498,51	7 241,21	2 755,75	5 360,77	2 214,06
90	6 181,35	2 872,32	2 091,42	1 055,11	9 367,18	7 441,74	6 319,12	3 879,70
100	6 593,46	3 165,95	6 017,41	3 136,97	10 687,16	10 496,79	7 706,36	5 359,41
110	6 477,84	3 213,77	8 418,91	4 534,72	11 138,48	9 540,33	8 264,25	5 375,93
120	8 402,65	4 479,14	11 071,65	6 121,56	10 109,03	6 543,30	9 448,37	5 426,87
130	7 826,20	4 020,53	9 042,42	5 043,45	8 998,89	4 048,54	8 421,25	4 233,52
140	7 383,68	3 830,42	7 316,46	4 920,83	7 809,26	2 421,81	7 497,91	3 625,92
150	6 602,13	3 535,13	5 790,10	3 267,06	6 268,98	5 239,22	6 339,78	3 992,74

As shown in Table 1, incorporating risk into the valuation process significantly reduces the soil expectation value across all species and stand ages. The greatest sensitivity to risk is observed in Norway spruce, especially at higher age classes, where the divergence between deterministic and risk-adjusted values becomes most pronounced. European beech shows relatively more stable values, reflecting a higher degree of resilience. These results demonstrate the importance of integrating risk factors into long-term economic planning for forest management.

4 Discussion and conclusion

The results presented in Table 1 clearly demonstrate that accounting for risk—expressed as the risk-adjusted soil expectation value $SEV_f(u)$—leads to a substantial decrease in the profitability of forest stand cultivation for all evaluated tree species as well as for the stand as a whole. The observed difference of approximately 2 347,04 EUR per hectare represents the economic risk borne by forest managers in the form of potential income loss due to the impacts of climate change.

The disparities become even more pronounced when considering different climate scenarios. Norway spruce, which constitutes the dominant share of the stand, exhibits a more than 26% increase in the probability of damage or destruction in advanced age classes (age class 8 and above). According to Minďáš and Škvarenina (2000) and Holécy et al. (2023), Norway spruce and European beech are the most climate-sensitive tree species in Slovak forests. This heightened vulnerability results from the synergistic effects of multiple damaging agents and climate extremes—particularly drought and irregular precipitation patterns—contributing to a decline in forest health across several regions of Slovakia. For Norway spruce, risk levels peak in the higher age classes (8 and 9), which coincide with the maturity and planned harvest age. Incidental fellings in these older stands significantly undermine management efficiency by reducing timber revenues and increasing harvesting and regeneration costs.

The findings also provide a basis for evaluating the suitability of current rotation lengths for similar stands. A long-standing debate in forestry concerns the need to shorten rotation periods for selected species. This study supports such a shift, particularly for European beech, which achieves maximum profitability at 110 years of age—and even 10 years earlier when risk is considered. This is largely due to declining wood quality with age, especially due to the formation of false heartwood. Nevertheless, any modification to rotation age must be approached with caution to ensure the continued provision of essential ecosystem functions and the long-term sustainability of forest ecosystems.

Finally, forest management and harvesting strategies must adapt to the dynamic behavior of forest ecosystems. This will require the broader application of proven adaptive management practices and technologies, along with a revised definition of standard forest management. This definition should incorporate realistic criteria for ecological stability and resilience to ensure the provision of ecosystem services under changing environmental conditions. Achieving and promoting such a shift will depend on increasing awareness among forest owners and managers regarding the risks and potential losses associated with inadequate adaptation to climate change.

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ROTATION PERIOD AND ITS INFLUENCE ON FOREST VALUATION IN SLOVAKIA

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Abstract

One of the fundamentals for calculation of forest value is the rotation period. Although the topic of determination of optimal rotation has a long history, there is no clear answer and several practices for its estimation have been proposed. For instance, the rotation period currently used in Slovakia is a combined one (based on the average increment method) in which the economic portion dominates. However, the rotation period has grown over time, which significantly affects, for example, the possibility of logging or forest valuation. The objective of this paper, therefore, is to review the role of the rotation period in forest valuation and its historical context. We used textual exegesis that involves reading and interpretation of historical economic texts on forest valuation. Especially, the influence of different schools of thought - the school of net forest yield and the school of net land yield – plays a crucial role in understanding how forest valuation practices have developed.

Keywords:

rotation period, forest valuation, Faustman formula, Slovakia

1 Introduction

One of the fundamentals required for calculations of forest value is the rotation period. Although the topic on determination of the optimal rotation period has a long history (Pearse, 1967, Hartman, 2018), there is no clear answer and several practices for its estimation were proposed (Helmedag, 2008, 2018). Generally, the rotation period refers to the time span from the establishment of a forest until its final harvesting. It is typically expressed as the average age at which the forest is harvested to allow a new crop to grow. There are several criteria for determining the optimal rotation period (Helmedag, 2002): (a) maximum total average increment, (b) maximum total value of production (school of net forest yield), (c) maximum internal rate of yield of the forestry project, (d) maximum net present value of the forestry project, or (e) maximum capital value of forest land (school of net land yield).

In Slovakia, the rotation period is defined as the framework production period of the forest stand. It is calculated based on cutting maturity, which is a state in which trees and vegetation reach the characteristics determined by the objectives of forestry and in which it is advantageous to harvest them (Act No. 537/2021 Coll. on forest management and forest protection). The method currently used for calculation of cutting maturity is combined cutting maturity (Table 1). As the rotation period in Slovakia is increasing, it significantly affects the possibility of logging or valuation of forests. For instance, the average rotation period increased between 1950 and 1970 from 98 to 105 years (coniferous forests 104.5 years, broadleaved forests 105.9 years) (Hromada, 1978) and has currently reached 122 years. Particularly in commercial forests it is 108 years (e.g. spruce 70-110, fir 90-120, pine 90-100, beech 100-120, oak 120-160, poplar 15-30 years), in special purpose forests it is 116 years and in protective forests 193 years due to optimal fulfilment of the required functions.

Table 1: Types of cutting maturity of trees (in sensu Halaj, 1988, Halaj et al., 1990)

Types	Characteristics of cutting maturity types	Summary
Natural	Natural dying off (physical and physiological)	-
Quantitative	Stands reach a maximum average annual volume production (age of culmination of average total production increment/age at which total average increment and total current increment become equal). It depends only on the tree species, side class and stand density.	It considers maximum production in terms of volume.
Technical	Growth at the age at which the maximum average annual production of the target assortments is achieved - at the age of culmination of the total average increment of the target assortment. The difference between technical and value cutting maturity is only that value cutting maturity is derived from all basic assortments, technical maturity only from target assortments.	It aligns the requirements of the national economy for target product ranges with the production capabilities of the forestry
Value based	Growth reaches the highest average annual increment in the value of annual production (the age of culmination of the total average value increment). Value is monetary expression of total production.	It considers the maximum production in terms of quantity, quality and value
Economic	Stands at the age at which the maximum average annual net income is achieved: economic maturity I - age at which total average increment culminates and economic maturity II - yield minus the costs of growing and harvesting activity.	It synthesizes most of the components of cutting maturity: maximum production (quantity, quality, value) and economic criteria (costs of cultivation)
Shortened	The age at which the descending part of the total current increment curve of the actual low-productive stand intersects the culmination level of the target stand.	Optimizes the age of reconstruction of low-productive stand to target stand
Non-prod.	Stands with optimal fulfilment of specified non-production forest functions (e.g., water management, soil protection, recreation).	
Combined	Stands at an age at which the total loss compared to the maximum values of all considered cutting maturity criteria is minimal.	Deduces (optimizes) the age of combined technical, economic and value cutting maturity

The rotation period is not only important for forest management but also for forest valuation. While valuation is related to developing concepts or methods for estimating the value of goods or services, appraisal is the application of these concepts or methods to come up with the specific value of goods or services to a particular individual (Davis and Johnson, 1986). The valuation could be undertaken for several reasons such as valuation of forest property for purchase or for sale, valuation for taxation purposes, valuation in connection with land division, or valuation due to damages (Petrini, 1953). Two approaches to providing the value evolved: (i) the school of net forest yield and (ii) the school of net land yield. However, during the period of socialism, different approaches for forest valuation were developed and even today forest valuation in Slovakia echoes these methods. In this respect, the aim of the paper is to provide a historical overview of forest valuation approaches in general, particularly in Slovakia.

2 Methods

To review economic thoughts in the literature were identified various research methods. Specifically, Marcuzzo (2008) classified these methods among textual exegesis, rational reconstruction, and historical reconstruction. These categories help organize the study of the history of economic thought, providing distinct approaches to understanding how economic ideas have developed and evolved. With a special focus on Slovakian case, in the paper was applied textual exegesis that involves reading and interpretation of historical (review) economic texts. Particularly were reviewed articles or textbooks with special focus on forest valuation. The focus was on understanding the ideas, arguments, and theories within their original written forms and the intentions of the economists who created them. Although textual exegesis can be applied across different types of historical economic thought research, in this context, it specifically refers to an approach focused on "making sense" of text (Emmett, 2003, Marcuzzo, 2008).

3 Results

3.1 The school of net land yield and trends in forest valuation

The school of net land yield (also called school of rentability or netto school) is based on the idea of forest production like agricultural production. More precisely, forest production begins on bare land and the funds spent are viewed as an investment in afforestation and forest management, which is to be repaid at the end of the rotation period (Papánek, 1951, Hromada, 1978, Holécy, 2019). A net yield (sum of business profit, land rent) is obtained from the managed forest stand once during the rotation period. The forest stand appears to be circulating capital, and the basic capital appears to be only the land (Papánek, 1951). Thus, in terms of the Faustman equation (1849), the value of stump wood is equivalent to (i) the invested capital that is interest-bearing over the life of the stand, and (ii) the retained, accumulated and interest-bearing net yield from the land.

3.2 Faustman formula and its evolvement

The school of net land yield builds on Faustmann formula in search of rotation period at which the value of forest land reaches its maximum. In the economics of forestry and natural resources, it is commonly perceived that the Faustmann formula was discovered in 1849 and that the Faustmann rule or Faustmann-Pressler solution of the optimal rotation period was derived from it a decade later by Pressler (Viitala, 2015). While many studies have examined the development of basic forest economic principles almost exclusively in space several decades after Faustmann and Pressler, more recent studies (e.g., Scorgie, 1996, Helles and Liddal, 1997, Viitala, 2013, 2016, Müller and Hanewinkel, 2019) have identified the origins of the Faustmann deeper in time. Already in the early 17th century, the question of maximizing the value of forest land by choosing the optimal felling period dominated. In England, Houghton (1683, 1701) had already compared the value of a forest with the value of other land uses in the sense of the opportunity cost approach, that is, in the sense of modern capital and investment theory. In presenting these economic comparisons, Houghton (1683, 1701) approached the basic principle of Faustmann rule, which states that it is optimal to harvest a forest when its marginal value growth falls below the marginal cost of forest capital consisting of stumpage and bare land (Viitala, 2013, 2016). Based on these findings, Richards (1730) described the application of the calculation of perpetual annuity in relation to the valuation of forests. He was the first economist do discover the principles of the Fuastmann formula and capture the capital character of forest in the English tradition (Scorgie, 1996, Viitala, 2013, Müller and Hanewinkel, 2019).

Also in Denmark, Reventlow (1810) made calculations of the optimal rotation period of oak and beech with a marginal approach, but without considering the opportunity costs of bare land. Given that Danish forestry was closely connected with Germany, the question remains whether the economic ideas promoted by Reventlow (1810) were without credit presented in the German forestry literature? (Helles and Liddal, 1997).

In the 18th century in Germany, Nördlinger (1805) proposed that the net income from a forest should be considered as the interest on forest capital, and the value of a forest should be calculated based on the expected future utility it provides, that is, the income it brings over an infinite number of years (Viitala, 2016). In the appendix to Nördlinger´s (1805) article, Hossfeld (1805) showed from a mathematical point of view how the value of a forest can be obtained not only within the framework of eternal annual series but also within the framework of periodic series of income (periodic rent). He was the first to capture the capital character of forests in German tradition, the idea which appeared again in Faustmann (1849), Pressler (1860) or Fisher (1906) publications. Moreover, he was able to avoid the shortcomings of his colleagues from forestry and agricultural economics (e.g., Thünen, 1826, 1863) who evaluated young forests only by multiplying timber volume by their prices. Hossfeld (1805) also concluded that rotation period of most of tree species should be much longer than conventionally assumed. Using differential calculus to derive the most advantageous rotation period was new in forestry (Vittala, 2016, Müller and Hanewinkel, 2019). Although König (1813) did not present any algebraic formulas for determining value of bare land and forests, he correctly split the value of forest into value of standing timber and value of bare land. The first represents the capitalized value of the timber income from the first rotation, and the second, the capitalized value of the net income from all subsequent rotations. He considered regeneration costs only once, at the beginning of the first rotation, while Faustmann (1849) used a series of regeneration costs and discounted them (Vittala, 2016). Moreover, Pressler´s (1860) indicator percent relied on incremental analysis like König (1813) who as a first one promoted value increment percent when he analysed optimal rotation period (a measure that utilizes the marginal method but discards the opportunity cost of bare land).

The above studies suggest that some scholars, such as Reventlow (1810), Thünen (1826, 1863), König (1813, 1835, 1842), Pfeil (1823), Hundeshagen (1826) or property owners were aware of the capital character of stump wood (Viitala, 2016, Müller and Hanewinkel, 2019). Probably building on these ideas of the time value of money and the discount rate, Faustmann (1849) later formulated the equation for determining the yield value of land (LEV) as the value that the forestry use of land can be expected to maintain forever (Müller and Hanewinkel, 2019):

$$LEV = \frac{E_t + \sum_{i=1}^{j} D_i . w^{t-t_i} - C . w^t}{w^t - 1} - A \qquad (1)$$

where C describes cultivation costs incurred at the beginning of the rotation period, D_i describes contribution margins from j thinning at time t_i, E defines the contribution margins from the final use of the stand at the end of the rotation period at time t, w describes interest rate, and A means net present value of annual administrative costs. *LEV* is special case of net present value (*NPV*); it is perpetual series of *NPV*.

3.3 Faustman formula and its application

Although both Faustmann and Pressler outlined optimal rotation period for a single stand, it was Ohlin (1921) who formulated a direst-order optimality criterion using the Faustmann equation (1) to maximize the existing value of forest land as well as to determine the optimal rotation period (Löfgren, 1983, Brazee, 2006, Müller and Hanewinkel, 2019). In this case, the problem of determining the interest rate for forestry projects is crucial. The higher the yield rate chosen, the shorter the optimal rotation period and vice versa (Holécy, 2019).

Forestry economic thinking, aligned with modern capital and investment theory, experienced a significant revival only after the publication of Samuelson's work in 1976. Samuelson (1976) with simplifying premise of Faustmann formula (1849) was able to support the basic idea (determination of the value of forest land in the sense of a capital value assessment under the premise of profit maximization) without questioning the basic idea of the theory. As a result, by 2002 (150 years since Faustman (1849) 313 articles were published on the topic of optimal rotation (Newmann, 2002), and in the subsequent 21 years, already 513 articles were published (McIntosh and Zhang, 2024). Issues such as ecosystem services (e.g., carbon sequestration, recreation), risk and uncertainty, or climate change entered the scientific debate (Newman, 2010, Amacher, 2012, Müller and Hanewinkel, 2019, McIntosh and Zhang, 2024) with following outcomes. Firstly, national economic interests had not been taken into consideration. This theory led to the introduction of too low rotation periods, did not guarantee the permanence of the yield, nor the uniformity of the yield (Matejíček and Zádrapa, 2014). Secondly, Faustmann formula (1849) is currently only one of many elements of forest valuation because the profit maximization as the limiting principle of Faustmann's theory, is of decreasing importance for forest economics. Particularly, it has limited application in valuing non-production forest functions (Kant, 2013, Detten and Wolf, 2016). This is not surprising, since the main goal of most researchers investigating optimal rotation period is to identify a method to maximize profit given a set of different circumstances and variables. Most of Faustmann´s theory applications, such as finding the optimal rotation period, optimal investments in forestry under different market prices, interest rates, tree species, or risk and uncertainty, were to maximize the value of forest and profit (e.g., Tahvonen and Viitala, 2006).

3.4 The school of net forest yield and trends in forest valuation

In reaction to the school of net land yield was developed the school of net forest yield (also called school of productivity or brutto school). It is based on two main principles, (a) the principle that forest is characterized by all age groups and it is assumed that the first forest manager has come to already existing forest stand and only continues to use what nature has given him, and (b) the principle that the forest soil and the forest stands form a mutually inseparable whole, which is the basic spatial framework of forest production (Papánek, 1951, Hromada, 1978, Holécy, 2019). A net yield (sum of capital interest, business profit, land rent) is obtained from the managed forest regularly annually. Thus, the funds are spent on forest management every year and these costs are not understood as a capital investment payable at the end of the rotation period, but only as a production cost of the current year. Therefore, the net yield from the whole forest is the difference between the value of stump wood, and between afforestation and management costs (Papánek, 1951, Hromada, 1978, Pulkrab at al., 1987, Matejíček and Zádrapa, 2014):

$$r = A_u + \sum D - (c + u.v) \qquad (2)$$

where r is the net annual yield from the forest, calculated and summed by tree species, A_u is value of felling (of forest stands at age *u*) after deducting the felling costs, *D* is thinning value after deducting harvesting costs, *c* is costs of afforestation, respectively costs of ensuring forest, *v* is average annual administrative costs per unit area, and *u* is rotation time of individual tree species in a normal economic group. The period *u* in which *r* is at its maximum corresponds to the period of the highest net forest yield, as Korf (1955) states: The period of the highest net forest yield corresponds to the age limit in which the sum of income from the economic group, reduced by the sum of all expenses in the economic group, is at its maximum. This concept, which contains many correct elements of a purely forestry perspective, has led to high rotation periods and to the retention of mature, clear-cutting-capable stand stocks. In contrast, it allows for the permanence of the income and pays less attention to the interest in the capital invested in the forest. Put it differently, the forest owner is interested above all in a permanent and balanced and as high as possible annual income - forest rent, and the rate of interest on forest capital is less important to him (Matejíček and Zádrapa, 2014).

3.5 Trends in forest valuation in Slovakia

Historical trends before 1990

The valuation of forests in Slovakia began in the 15th century, when the first instruction for estimating the value of forests was developed. It was based on four age and forest value curves, the value of which ranged from 3-50 silver marks (Kavuliak, 1942). Later, forest valuation was influenced by the school of net land yield and the school of net forest yield. Since the 1950s new theoretical and methodological approaches emerged which significantly differed from the forest valuation under capitalism (e.g., Papánek, 1951, Hromada, 1978, Pulkrab, 1988, Pelcner and Tutka, 1984). In other words, during socialism a doctrine of so-called free use of nature was applied and only such resources that were subjects of socially recognized useful labour were focuses of valuation (in sensu of general labour theory of value) (Tutka et al., 2003). Forest valuation was driven by a large group of Soviet, Polish, Czech (e.g., Pulkrab, 1988, Šišák, 1990) and Slovak economists (e.g., Papánek, 1972, 1978, Zachar, 1988, Tutka, 1989). Specifically, the valuation of forest natural resources was based on economic categories such as (Pelcner and Tutka, 1984): the amount of the socially necessary costs of production or making available, net return per unit area or space of a natural resource, land rent, and economic effects of use.

As only one category of ownership by the state, respectively cooperative ownership existed, before 1990 there was no objective need for forest valuation in Slovakia. Thus, the price of the forest land was fixed. More precisely, a political decision was made to set the range of official forest land values (Table 2), where the maximum price of forest land could reach half of the highest basic price of agricultural land (Matejíček and Zádrapa, 2014).

Table 2: Historical overview of legislation dealing with forest valuation in Slovakia

Year	Law	Summary
1875	Slovak Commercial Act of XXXVII/1875	Valuation standard (determination of actual market prices as of the inventory date)
1921	Government regulation No. 53/1921 Coll. by which regulations binding for the determination and calculation of the acceptance price for confiscated property taken over by the land state are issued	First valuation regulation for forest valuation considering side class, type and tree species composition, the area and age of the stand, and stand density, including binding price scale for assessing compensation for seized property taken over by the state
1940	Government regulation No. 206/1940 Coll.on the determination of the estimated price of real estate purchased according to Act No. 46/1940 Coll.	Forest valuation considering quality of side class, type and tree species composition, the area and age of the stand, and stand density
1949	Government Act on valuation No.65/1949 Coll.	Valuation of agricultural and forest land is uniform according to the principles laid down by government regulation
1969	Decree No. 47/1969 Coll. on the prices of privately owned buildings and on compensation for the expropriation of real estate	Valuation of agricultural and forest land (0.40 Kčs/m^2)

1988	Decree No. 205/1988 Coll. on the prices of buildings, land, permanent vegetation, payments for the establishment of the right of personal use of land and on compensation for temporary use of land	Determination of price of forest land (0.40 Kčs/m^2). Decree amended in 1990 (No. 289/1990 Coll.) and price of forest land adjusted (3 Kčs/m^2)
1991	Decree No. 465/1991 Coll. on the prices of buildings, land, permanent vegetation, payments for the establishment of the right of personal use of land and compensation for temporary use of land	Determination of minimal value of forest land (0,30 Skk/m^2)
1996	Decree No. 18/1996 Coll. on the prices	Law on price determination in general
2004	Decree No. 492/2004 Coll. on the determination of the general value of assets	Determination of minimal value of forest land (0,40 Skk/m^2 which equals to 0,13278 Eur/m^2) - average prices equal to circa 0,10 Eur /m^2 of forest land and 0,50 Eur/m^2 of forest stand

Forest valuation after 1990

After 1990, the legitimization and equalization of ownership relations conditioned activities connected with determining forest value (Tutka, 2000). The first methodology for assessing the value of forests and their functions was developed in the Czech Republic by Matějíček a Skoblík (1993), and in Slovakia by Tutka (1992), Zachar et al., (1992). Forest valuation combined the data of three areas of expertise – legal, forestry and economic. Various methods and ways of forest valuation emerged (e.g., Pulkrab et al., 2007, Matejíček and Zádrapa, 2014): the yield method (the oldest method based on the school of net land yield or the school of net forest yield), the cost method, the comparative method, or their combination. Nevertheless, currently used methods defined in decree No. 151/1997 Coll on property valuation in Czech Republic and in decree No. 492/2004 Coll. on the determination of the general value of property in Slovakia still reflect the approaches developed before 1990. The method of positional differentiation is the most used method for determining the value of forest property in Slovak practice. The general value of forest property is the sum of the results of the two separate procedures determining (i) the general value of forest land and (ii) the general value of forest stands:

The general value of forest land ($VŠH_{LPOZ}$) in € is determined as the product of the unit general value of forest land ($JVŠH_{LPOZ}$) and the area of the forest land (M) in ha or m^2 (Pic. 3).

$$VŠH_{LPOZ} = M \,.\, JVŠH_{LPOZ} \qquad (3)$$

The unit general value of forest land ($JVŠH_{LPOZ}$) in €/ha or €/m^2 is determined as the product of the unit initial value of forest land (VHL_{POZ}) and the positional differentiation coefficient (k_{PD}) (Pic. 4). The coefficient of locational differentiation is determined as the product of the coefficient of the general situation of demand for the benefits of forest functions (k_S), the coefficient of forest property utilization (k_V) and coefficient of forest cover of a part of the country (k_L). The coefficient K_S is determined based on the population density per km^2 at the district level in which the forest land is located. Coefficient k_V is determined based on the forest category, forest stand age and productivity of the site. The coefficient k_L is based on the forest cover at the district level.

$$JVŠH_{LPOZ} = VH_{LPOZ}.\, k_{PD} \qquad (4)$$

The unit initial value of a forest land (VH_{LPOZ}) in €/ha or €/m^2 is determined as the sum of the basic value of the forest land for the target tree species composition (H_{LPOZ}) and the value of the position factor (f_p) depending on the average skidding and hauling distance (Pic. 5).

$$VH_{LPOZ} = H_{LPOZ} + f_p \qquad (5)$$

The value of the position factor (f_p) in €/ha or €/m^2 is determined as the sum of the products of the total growing stock of stumpage production of the target tree species in the rotation period (*k*) and the j-th stand class in the rotation period per hectare ($Z_{cuk,j}$), the target tree species representation ($C_{zstk,j}$) and the sum of the unit rates of the position factor (H_{v1}, H_{v2}) (Pic. 6).

$$f_p = \sum_{k=1}^{n} Z_{cu_{k,j}} . C_{zst_{k,j}} . (H_{v_1} + H_{v_2}) \quad (6)$$

In the case of the general value of forest stand ($VŠH_{LPOR}$), the price is set for the actual stand that grows on the forest land at a given time. It is determined in €/ha as the product of the unit general value of forest stand ($JVŠH_{LPOR}$) and the area of forest land (*M*) in ha or m^2 (Pic. 7).

$$VŠH_{LPOR} = M \, . JVŠH_{LPOR} \quad (7)$$

The unit general value of forest stand ($JVŠH_{LPOR}$) in €/ha is determined as the product of the unit initial value of forest stand (VH_{LPOR}) and the positional differentiation coefficient (k_{PD}). The positional differentiation coefficient is determined in the case of determining the general value of forest land (Pic. 8).

$$JVŠH_{LPOR} = VH_{LPOR} . k_{PD} \quad (8)$$

The unit initial value of forest stand (VH_{LPOR}) in €/ha is determined as the sum of the product of the basic value of forest stand according to tree species (*k*) and their actual representation, site class (*j*), age (*i*), stand density (*z*) and the coefficient of forest stand damage (*kp*) in % and the value of the position factor (*fp)* (Pic. 9).

$$VH_{LPOR} = H_{LPOR_{k,j,i}} . (1 - k_p) + f_p \quad (9)$$

The value of the position factor (f_p) in €/ha is determined as the product of the united rates of the position factor of the forest stand for skidding (H_{v1}) and haul of (H_{v2}) timber and actual stand stock in m^3 per ha ($Z_{sk,j,i}$) (Pic. 10).

$$f_p = \sum_{k=1}^{n} Z_{s_{k,j,i}} . (H_{v_1} + H_{v_2}) \quad (10)$$

As the decree No. 492/2004 Coll. on the determination of the general value of forest property in Slovakia has not been updated for last 20 years, the cost and revenue prices used for current official forest valuation are obsolete. For this reason, work has been underway in recent years to prepare an update of this decree to bring the value of forest land and stand closer to current market values (Kovalčík et al., 2020; Merganič et al., 2024). As part of the updates to the decree (i), the total production of tree thickness, the value of forest stands, location factors, costs of silviculture has been recalculated, as well as (ii) adjustments to the coefficient for converting the basic value of the stand of determining tree species to the value of assigned tree species has been made. Based on calculations with current prices, the impact of updating the published prices on current prices will cause an increase in the value of forest property by approximately 2.66 times (Merganič and Bahýľ, 2024). Furthermore, the development of rotation periods appears in conflict with developmental tendencies (e.g., in the use of raw materials such as wood, ongoing climate change). Generally, the average rotation period in Slovakia had been circa 10-30 years longer in comparison to other countries of Europe (e.g., Holuša et al., 2021), which will cause search for new possibilities or more decision space concerning rotation period (e.g., Korená et al., 2020, Korená at al., 2022).

4 Discussion and conclusion

A historical overview shows that the school of net land yield and the Faustmann formula was originally intended to solve specific practical forestry problems. The first in this context is the valuation of forest land, which was an important issue in Faustmann's time. Considerations of the investment theory of Faustmann (1849) followed later, especially to determine the optimal rotation period or the maturity of the stand (e.g., Pressler, 1860, Ohlin, 1921, Worrel, 1953, Pearse, 1967) or to solve the problem of optimal thinning (e.g., Schreuder, 1971, Chen et al., 1980, Borchert, 2002, Pantic et al., 2015). Since Faustmann (1849) and Pressler (1860) probably drew on the thoughts of previous generations of forestry economists, their calculation of forest value under intermittent and sustained yield management using discounted cash flow to infinity is often referred to as König–Faustmann, Faustmann–Pressler, Faustmann–Wicksell, Faustmann–Pressler–Ohlin or Faustmann–Ohlin–Preinrich-Bellman-Samuelson formula (e.g., Heyer, 1871, Schwappach, 1888, Gane, 1968, Samuelson 1976, Johansson and Löfgren, 1985).

Applying the theory of the school of net land yield in practice led to short, almost extremely short rotation periods, while applying the school of net forest yield led to long rotation periods (Papánek, 1951, Hromada, 1978). Specifically, the school of net forest yield was established in response to the harmful consequences that the financial rotation period had for forestry. Generally, this school prescribed the owner to keep his capital invested in forestry, regardless of whether the profitability of this investment was satisfactory. However, also the school of net land yield was not consistent in interpreting the financial principle in forestry, because when calculating rentability according to the Faustman formula (1849), it used not the usual interest rate, but a lower, so-called forest interest rate (Papánek, 1951, Möhring, 2009, Matějíček and Zádrapa, 2014). Thus, the disputes between the two schools remained rather in the theoretical field. In forestry practice, there was no significant boundary between their application although foresters applied measures according to the principles of the school of net land yield (i) to produce as many trees as possible attractive for sale, (ii) to apply intensive thinning aimed at accelerating the growth of the main stand, or (iii) not to impose extremely long rotation periods (Papánek, 1951, Porubiak at al., 1987). However, due to general characteristics of forestry such as the length of the period under consideration, the school of net land yield has not found much application in the practice of Central European forestry due to their long rotation periods or significant fluctuations in timber prices (e.g., Möhring, 2001, Coordes, 2014, Müller and Hanewinkel, 2019) in comparison to Scandinavia or North America (Tahvonen et al., 2001, Amacher et al., 2011).

In summary, even today it is not clear what the optimal rotation period should be. The dispute does not concern the methodology (Müller and Hanewinkel, 2019). The differences are based on diverse assumptions about the lack of capital, although both schools assume a lack of land. The lack of capital, which is taken into account in the school of net land yield when using an interest rate above 0%, is therefore the only, as Möhring (2009) emphasized, important difference between the two schools, which leads to the fact that the rotation periods determined using the net forest yield theory are fundamentally higher than the rotation periods determined using the land yield theory. As a result, neither school of thought has yet gained ground in German forestry (Möhring, 2001, Moog and Borchert, 2001). Empirical studies rather show that forestry practice, when making decisions about the rotation period at an internal rate of interest of 1.3%, is positioned somewhere between the land yield theory and the net forest yield theory (Möhring, 2001). Particularly, methods of indirect price comparison are applied (Weimann, 1985).

Neither of these schools are applied in forestry practice in Slovakia. The reasoning behind these developments is that the forest valuation significantly differed under socialism in comparison to capitalism. Even current legislation (e.g., Decree No. 492/2004 Coll. on the determination of the general value of property) reflects methods developed before 1990. Specifically, via the method of positional differentiation forest property value as a sum of the general value of forest land and the general value of forest stands is determined. However, as the data for determining the value of property in the legislation is mostly valid for the years close to the publication of the given legislation, there is an urgent call for data adaptation to the real market situation. Several proposals already exist to deal with the issue (Barbierik, 2021). For instance, the coefficient development of average prices and costs could be based on the departmental statistics of the Ministry of Agriculture and Rural development of the Slovak Republic and on the development of the average domestic monetization of raw wood and total costs (Barbierik, 2021). Another proposal offers the possibility of connecting an update of values with average wages published by the Statistical Office of the Slovak Republic (e.g. various surveys and statistics on the development of the Slovak economy in long time series that also cover the period of enactment of older legislative regulations) (Merganič and Bahýľ, 2024). Yet, referring to historical developments, a political decision may well be made to set the range of official forest land values. These prices can be further adjusted by deductions. Given the still low share of land prices in the total price of the forest, so far, the use of official prices has been the easiest approach to valuing forest land (e.g., Matějíček and Zádrapa, 2014). The efforts of the practice are also directed towards simple methods for forest stand valuation that would reflect the value development of the stand with sufficient accuracy.

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HIDDEN COSTS OF HARMFUL SUBSIDIES TO THE ENVIRONMENT

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Abstract:

Over the past decades, it has become evident that many economic activities remain viable only through the support of public subsidies. However, these subsidies often promote practices that generate significant environmental harm, including pollution, resource depletion, and ecosystem degradation. Despite growing recognition of these negative impacts, environmentally harmful subsidies (EHS) continue due to their perceived role in supporting national competitiveness. This study systematically reviews peer-reviewed literature to assess the broader environmental consequences of such subsidies. The findings reveal persistent ecological degradation and limited progress in reforming subsidy systems. The results underscore the need to raise awareness among policymakers and society, encouraging the redirection of financial support toward sustainable practices. Promoting subsidy schemes that align with conservation, efficient resource use, and responsible management can contribute to environmental improvement, particularly in vulnerable regions and local communities.

Keywords:

economic incentives, environmental impacts, policy evaluation, public finance, natural resource management.

1 Introduction

For several decades, subsidies have been widely employed to stimulate growth in key economic sectors such as transportation, energy, agriculture, mining, and manufacturing. While often justified as tools to enhance national and regional competitiveness (OECD, 2005), many of these subsidies have been identified as environmentally harmful subsidies (EHS), as they promote practices that degrade ecosystems. These include pollution, inefficient resource use, biodiversity loss, and soil degradation (Koplow & Steenblik, 2022; Lehmann, 2012; OECD, 2022; Schlegelmilch, 2020).

A striking example is the Amazon region, where government-backed programs have indirectly fueled the expansion of livestock farming, agriculture, and logging—activities linked to deforestation and large-scale land conversion (De Area Leão Pereira et al., 2020; Portela & Rademacher, 2001). Rather than supporting sustainability goals, such subsidies perpetuate development models that harm ecosystems and natural resources.

Although various proposals have been put forward to reform or repurpose these subsidies toward environmentally beneficial practices (European Commission & VVA., 2022; OECD, 2022), implementation has been slow. One key barrier is the technical and political complexity involved in identifying and modifying so-called " environmentally harmful subsidies" (OECD, 2005).

This study conducts a literature review and qualitative content analysis to explore the environmental impacts of environmentally harmful subsidies. Specifically, it seeks to answer the question: What impact do EHS have on natural resources? Through content analysis, this research identifies how such subsidies affect different environmental dimensions. The term impact is defined as the positive or negative outcome resulting from a specific action, with environmental impact referring to the measurable alteration of environmental components, such as climate, air, soil, water, and biodiversity, caused by human activities (Bonilla, 2007).

Subsidies are considered environmentally harmful when they lead to excessive waste generation, emissions, or resource extraction beyond socially optimal levels across production and consumption cycles. These adverse effects may also contribute to health risks and accelerate the depletion of natural capital (Berg et al., 2010; OECD, 2005).

Understanding these environmental and social implications is essential to raise awareness, promote public engagement, and support the development of policy instruments that internalize environmental costs. Ultimately, this study aims to foster informed decision-making that encourages more sustainable production and consumption patterns.

2 Methods

Figure 1 shows the methodological framework applied in this study, which began with a literature review conducted on March 4, 2024, using three academic databases: Web of Science, Scopus, and ScienceDirect. The search focused on publications containing the keywords subsidies, market-based instruments, and environmental impact in the title, abstract, or keyword fields. Only peer-reviewed articles in English published between 1999 and 2023 were included. From an initial set of 759 records, duplicates were removed and exclusion criteria applied, resulting in a final sample of 103 articles selected for analysis.

2.1 Qualitative content analysis

The analysis followed the three-phase model of content analysis: preparation, organization, and presentation (Elo & Kyngäs, 2008). Coding was carried out using ATLAS.ti, which supported the segmentation and categorization of qualitative data. In the preparation phase, all texts relevant to the research question were compiled. The unit of analysis was defined as any segment of text, regardless of length, that addressed aspects of environmentally harmful subsidies.

During the organization phase, meaningful text segments were identified and coded. The coding scheme combined deductive categories based on the literature review with inductive codes emerging from the data. These codes captured recurring themes such as economic justification, environmental externalities, policy resistance, and reform proposals. A pilot test was conducted on a subset of articles to assess coding consistency. Discrepancies were reviewed and adjustments made to refine code definitions and ensure reliability.

In the presentation phase, results were organized into thematic categories derived from the coding process. The analysis revealed patterns in how environmentally harmful subsidies are conceptualized and critiqued. Findings were illustrated with textual examples to highlight the environmental impacts, policy drivers, and reform challenges discussed in the literature.

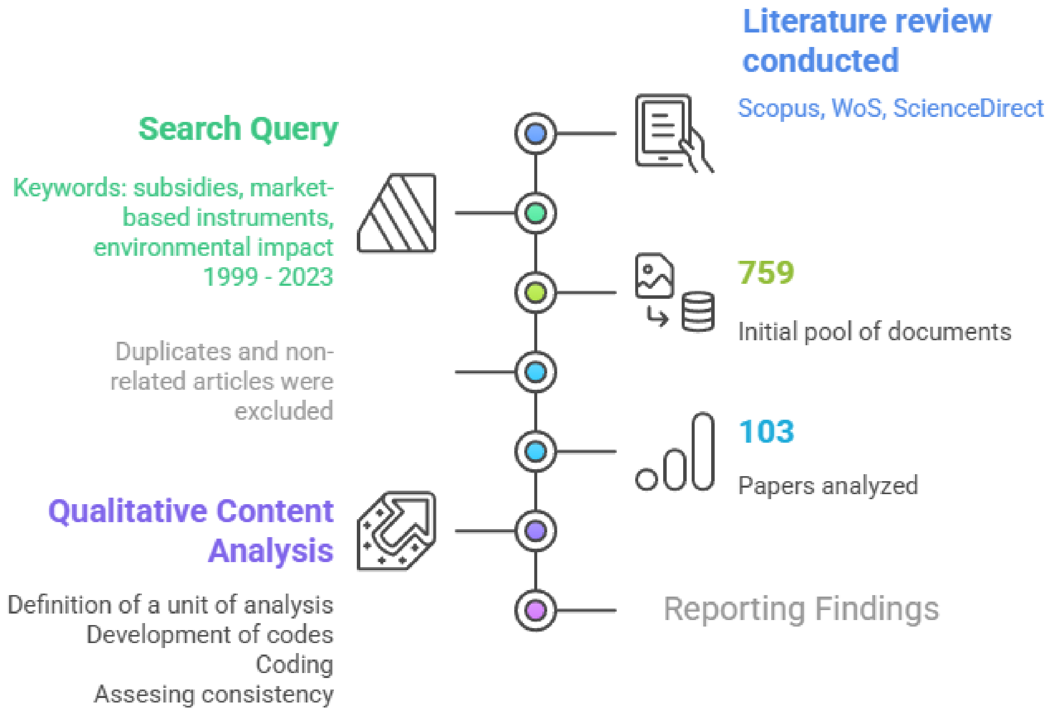

Figure 1. Study Methodological Framework

3 Results

The qualitative analysis was conducted on 2,788 citations extracted using Atlas.ti software directly relevant to the influence of HSE on the environment. Notably, several publications garnered the highest number of comments, including "Circular Economy and Environmental Sustainability: A Policy Coherence Analysis of Current Italian Subsidies" with 193 quotes (6.92% of the total comments), "Does Organic Farming Benefit Biodiversity?" with 175 quotes (6.28%), "Creation of Marine Reserves and Incentives for Biodiversity Conservation" with 145 quotes (5.20%), and "Biodiversity Policy Integration in Five Policy Sectors in Germany: How Can We Transform Governance to Make Implementation Work?" with 133 quotes (4.77%).

The findings of this study are presented through thematic categories that emerged from the qualitative content analysis of selected academic literature. These categories reflect recurring patterns and concerns regarding the design, implementation, and consequences of EHS across different economic sectors and policy contexts. Each subtheme is illustrated with representative quotations drawn directly from the reviewed sources, highlighting how subsidies contribute to environmental degradation, the challenges of reform, and the varied effectiveness of existing policy instruments.

3.1 Drivers of Environmentally Harmful Subsidies

Subsidies are often introduced as tools to promote economic development, but in practice, they tend to support activities that lead to environmental degradation. Many policies are historically rooted in objectives such as territorial control, food security, or economic growth.

"*The development of agriculture over the past 50 years... supported by state subsidy has allowed global food production to outstrip human population growth*" (Perkins et al., 2011).

"*Chile spent more than 4% of the GDP on fossil fuel subsidies… much higher than the 1% spent on environmental protection*" (Madeira, 2022).

"*The Commission also showed that there are many subsidies in the food, agriculture, fisheries, and energy sectors that are driving humanity in the wrong direction... allowing us to exploit resources, which are in turn causing serious damage*" (Haines, 2016).

3.2 Sectoral Impacts of Subsidies

Different sectors, agriculture, fisheries, energy, and forestry, experience specific environmental consequences due to poorly designed subsidies. These include deforestation, overfishing, biodiversity loss, and pollution.

"*Subsidies encouraged extensive cattle ranching… Cattle ranching activities account for most of the deforestation in Brazilian Amazonia*" (Portela & Rademacher, 2001).

"*Approximately 25% of global capture fisheries is wasted as by-catch… marine ecosystems and their biodiversity are being depleted for short-term gains*" (Duda & Sherman, 2002).

"*Subsidies for plantations… lead to loss of old growth forest and biodiversity*" (Gain & Watanabe, 2017).

3.3 Effectiveness of Conservation Subsidies

While some subsidy programs aim to protect the environment (e.g., agri-environmental schemes), their effectiveness is often questioned due to weak implementation, design flaws, or insufficient funding.

"*The 'greening' of EU agricultural policy through vast financial expenditure… has had limited success in reversing biodiversity losses*" (Perkins et al., 2011).

"*In Poland, higher support under the nature packages… does not contribute, in a tangible manner, to an increase in the area under protection*" (Brodzińska, 2015).

"*In Austria, agri-environmental measures were not sufficiently targeted to halt biodiversity loss. More spatially specific and goal-oriented incentives are needed to increase their ecological effectiveness*" (Wrbka et al., 2008).

3.4 Policy Failures and Missed Commitments

Despite international agreements to eliminate harmful subsidies, progress has been limited. Many governments have not identified or acted on these subsidies.

"*In 2010 world governments agreed to eliminate, phase out or reform incentives that harm biodiversity by 2020. Yet few governments have even identified such incentives…*" (Dempsey et al., 2020).

"*Resistance to subsidy reform stems from political interests, lack of transparency, and the influence of powerful lobbying groups, such as in the fossil fuel and agricultural sectors*" (Dempsey et al., 2020).

"*Brazil invested $158 million to fight deforestation, but simultaneously allocated $14 billion to activities that cause it, illustrating the contradiction between policy goals and financial practices*" (Dempsey et al., 2020).

3.5 Economic Instruments and Subsidy Reform

Subsidies can be reoriented to support conservation if aligned with well-designed policy mixes. Researchers stress the importance of transparency, environmental tax reform, and systemic thinking.

"*Subsidy reform should be accompanied by instruments such as environmental taxes and degressive aid. The European Commission recommends that harmful subsidies be phased out gradually to encourage investments in green technologies*" (Wilts & O'Brien, 2019).

"*Government subsidy policies, when scientifically and systemically designed, can guide farmers toward more sustainable crop choices, optimizing land use while reducing environmental impacts through targeted incentives*" (Ziliaskopoulos & Papalamprou, 2022).

"*While some energy and farming subsidies can support sustainability, others such as fossil fuel subsidies are regressive. Eliminating these could reduce GHG emissions by up to 10% by 2050*" (Wilts & O'Brien, 2019)

4 Discussion and conclusion

This study highlights the critical role of environmentally harmful subsidies in accelerating environmental degradation across diverse ecosystems. The literature review and qualitative content analysis findings reveal that government financial support often justified as mechanisms for economic development or sectoral competitiveness, continues to incentivize unsustainable practices in sectors such as agriculture, forestry, energy, and fisheries.

There is a clear and well-documented link between EHS and environmental harm. In tropical regions, particularly the Amazon, deforestation has intensified due to subsidies for livestock ranching, agriculture, and logging (Portela & Rademacher, 2001). Similarly, in marine environments, fishing subsidies have contributed to overexploitation, illegal practices, and widespread ecosystem decline (Duda & Sherman, 2002). These outcomes reflect a pattern in which short-term economic priorities are favoured over long-term ecological integrity.

In forestry, subsidies for improving productivity have led to adverse side effects such as forest homogenization, reduced resilience, and biodiversity loss (Gain & Watanabe, 2017). In energy and agriculture, subsidies continue to support fossil fuel consumption and intensive land-use, despite growing evidence that such practices accelerate soil degradation, water pollution, and greenhouse gas emissions (Madeira, 2022; OECD, 2022).

Despite international commitments such as Target 18 of the Global Biodiversity Framework and provisions under the Paris Agreement, implementation of subsidy reform remains limited. Political resistance, vested interests, and institutional fragmentation continue to obstruct meaningful change (Beers & Bergh, 2001; Dempsey et al., 2020). Many governments still lack transparency regarding the full extent of their subsidies and their impacts, complicating reform efforts.

Moreover, several studies emphasize the importance of aligning environmental taxation and subsidy reform. Instruments like carbon taxes and polluter-pays schemes can help internalize ecological costs but must be paired with the gradual elimination of subsidies that promote emissions-intensive and resource-depleting activities (OECD, 2021; Wilts & O'Brien, 2019).

Environmental policy must prioritize coherence, transparency, and adaptability to achieve real progress. Periodic review of subsidy programs, participatory policy design, and cross-sectoral coordination are essential for reducing adverse environmental externalities. This includes supporting context-sensitive transitions that ensure social equity and minimize disruption in vulnerable regions.

4.1 Policy Implications and Future Research Directions

This study underscores the urgency of phasing out environmentally harmful subsidies to safeguard ecosystems and advance sustainable development. The following policy implications and research priorities are proposed:

- Eliminate or reform subsidies that incentivize pollution, deforestation, and inefficient resource use, and redirect public funds toward sustainable practices and infrastructure.
- Establish transparent systems for monitoring the environmental impacts of subsidies, enabling evidence-based policy adjustments.
- Improve cross-sectoral governance, promoting consistency between national development goals and international environmental commitments.
- Provide transitional support for affected sectors to mitigate social and economic disruption during subsidy phase-outs.
- Encourage interdisciplinary and applied research on the effectiveness of subsidy reforms across different ecological and institutional contexts, including the role of fiscal instruments and regulatory innovation.
- Future studies should also explore the integration of environmental impact assessments into subsidy design processes and evaluate how local-level governance can support more sustainable subsidy frameworks.

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A STRATEGIC ASSESSMENT OF THE GAME MEAT VALUE CHAIN FACTORS

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Abstract:

This article offers a strategic assessment of the game meat value chain in the Czech Republic, using national-level data on game meat production dynamics, volumes, pricing trends, and value distribution. The context of the study includes a steady increase in ungulate culls and a rising incidence of browsing damage affecting forest regeneration, alongside stagnating buy-in prices for primary producers. Through a value chain analysis, the presentation identifies several persistent bottlenecks, including the seasonality of supply, limited processing and storage capacity, low consumer demand, regulatory complexity, logistical challenges, low profitability, and a declining number of hunters. The presentation illustrates the disparity in value added across the chain, with the most significant gains occurring beyond primary production—in processing, retail, and gastronomy. In response to these challenges, three strategic clusters are proposed, reflecting the diversity of territorial and market conditions: (1) local-level solutions prioritising affordability and simplified logistics; (2) district-level models involving small-scale processing, direct sales, and targeted consumer education; and (3) national and international approaches based on branding, added-value product development, and lifestyle positioning. The analysis builds on national sources and recent published studies to outline practical, regionally adaptable pathways for improving the efficiency and coherence of the game meat chain within the existing economic and ecological framework.

Keywords:

game meat, value chain, forest regeneration, market barriers, strategic clustering

1 Introduction

Ungulate browsing has become one of the most persistent biological constraints on forest regeneration throughout temperate-zone Europe. In the Czech Republic, the third National Forest Inventory (NIL3 2016-2020) recorded 31,8 % average browsing damage on advanced regeneration ≤ 1.3 m (Czech Forestry Institute, 2023), even though annual culls of red, roe and wild-boar populations have more than doubled since 2003 (CSO, n.d.). The ecological consequences are two-fold: (i) higher restocking costs for public and private forest managers and (ii) a structural shift towards browsing-tolerant tree species, with uncertain long-term impacts on biodiversity and carbon storage (Carpio et al., 2021; Gortázar & Fernandez-de-Simon, 2022).

However, game meat possesses nutritional (high-protein, low-fat, no hormones) and environmental credentials that align well with European “Farm-to-Fork” (European Commission, 2020)and climate targets (Fiala et al., 2020), International case studies show that when transparent provenance, product innovation and collective quality labels are in place, consumers are willing to pay premiums that can be channelled back to the forest sector (Gaviglio et al., 2018; Marescotti et al., 2019). Recent Czech research confirmed the latent demand—but also highlighted critical value-chain bottlenecks: fragmented supply, seasonality, expensive chilled logistics and weak brand communication (Němec et al., 2025; Němec, Riedl, et al., 2023; Riedl et al., 2024).

Paradoxically, larger cull quotas have not translated into more substantial economic incentives for hunters. Real carcass prices paid to small-scale suppliers have stagnated since the early 2000s (Němec, Skřivánková, et al., 2023), while cumulative consumer-price inflation approached almost 100 % in the period 2003 – 2024 (CSO, 2024). Coupled with the demographic decline of the hunting community and rising logistics costs, this price squeeze erodes the willingness of owners of smaller forest estates to organise the extra harvests that ecologists and silviculturists deem necessary (Němec, Skřivánková, et al., 2023).

This article aims to describe potential strategies for monetising game meat that increase the value captured by primary producers—forest owners and users—through a synthesis of original quantitative survey data and official statistical records. By grounding its marketing analysis in the practical needs of forest protection, the study seeks to identify where and how additional value can be transferred upstream to those whose culling effort underpins sustainable regeneration.

2 Methods

2.1 Desk research

Our empirical foundation rests, first, on an extensive desk-based review of secondary sources. We gathered long-term data on ungulate culls, carcass prices (2003-2024), and national consumer price indices to monitor real-price trends and margin erosion at the forest gate. The desk phase also covered EU hygiene and trade regulations that set the transaction-cost environment for small game-meat businesses. Particular attention was paid to government publications and market-research studies issued by the Czech Statistical Office (ČSÚ), the Ministry of Agriculture (MZe), the Czech Forestry Institute at Brandýs nad Labem (ÚHUL/NLI) and Forestry and Timber Fund (LDK). The web pages of game meat dealers were inspected to collect recent buy-in prices.

2.2 Qualitative research

A programme of qualitative interviews was undertaken between 2022 and 2024 in the Czech Republic and Slovakia (using the advantage of similar development and history between the Czech Republic and Slovakia), designed to identify the institutional and operational specifics of the game-meat sector that are not captured by secondary statistics. A purposive sampling strategy was adopted to encompass the principal nodes of the value chain: private and public forest landholders, lease-holding hunting associations, licensed processors, distributors, and representatives of retail and gastronomy. Semi-structured interviews offered the requisite balance between consistency and conversational latitude, permitting respondents to articulate their experiences in their own terms while ensuring coverage of core topics as described in (Němec et al., 2025).

3 Results

3.1 Ungulate culls dynamics

Between 2003 and 2023 the total recorded cull of ungulate game in the Czech Republic rose from 229,655 to 475,297 pieces (Czech Statistical Office, 2025), representing a cumulative increase of 107 % and an average compound annual growth rate of approximately 3.7 %. The data show a medium-term escalation of harvesting pressure, interrupted by bi-yearly downturns that reflect inter-annual variability rather than a sustained change of direction as smoothed in a 2-year average.

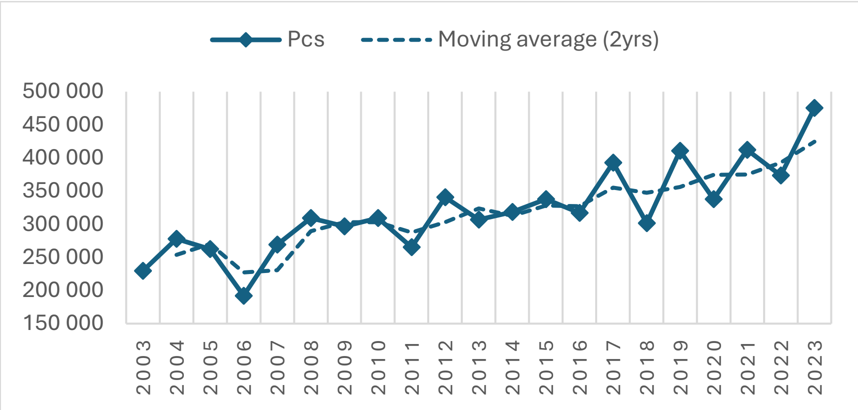

Figure 3. Ungulate culls 2003 - 2023 in CZ.

3.2 Hunters' population decrease

From 2003 to 2023, the registered hunting cohort contracted from 94,280 to 88,337 (Czech Statistical Office, 2025), a net reduction of 5,943 individuals, equating to a decline of about 6.3 per cent over the two-decade span. Across the entire interval, the compound annual growth rate is approximately – 0.30 per cent, underscoring a steady contraction as represented in Figure 2.

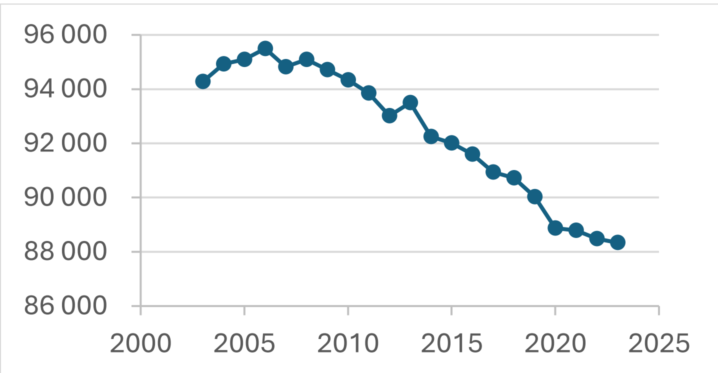

Figure 4. Declining population of hunters 2003-2023

3.3 Buy-in prices stagnation

Table 1 presents the current average buy-in prices for four principal game species, with the figures that would be expected had the 2003 baseline simply tracked cumulative consumer-price inflation to 2024 (CSO, 2024). Collectively, the data reveal that primary producers now receive between one-half and one-third of the purchasing power-corrected remuneration that would prevail if 2003 prices had simply been indexed to consumer inflation over the intervening twenty-one years.

Table 3: Average primary buy-in prices, CPI-adjusted projections, and price gaps

Prices/kg in EUR	**2003**	**2024**	**2024 CPI-Adjusted Price**	**GAP**
Roe deer	3.6	2.8	7.05	**4.25**
Red deer	2.2	2.2	4.31	**2.11**
Fallow deer	1.8	2.0	3.53	**1.53**
Wild boar	1.4	1.2	2.74	**1.54**

3.4 Hunting pressure

Between 2003 and 2023, the operational burden borne by Czech hunters intensified markedly. Although the national hunting workforce contracted by 6.3 % (from 94,280 to 88,337 individuals), the total area under game-keeping obligations expanded slightly (+1.8 % to 6.87 million ha). Consequently, the mean surface administered per hunter rose from 71.6 ha to 77.8 ha, an 8.6 % increase that alone indicates a heavier spatial responsibility. The escalation in culling requirements was still more pronounced: annual ungulate offtake more than doubled (+107 %), rising from 229,655 to 475,297 head. When normalised to human effort, this translated into a jump from 2.4 to 5.4 culled animals per hunter (+120.9 %). Taken together, the figures reveal a system in which fewer practitioners must supervise larger territories while simultaneously achieving substantially higher harvest quotas. Such a combination of declining manpower and expanding biological as well as administrative demands suggests growing pressure on voluntary hunting structures, with potential implications for sustainability, welfare standards and the long-term viability of population control strategies.

Table 4: Hunting intensity per hunter CZ

	2003	**2023**	**% Change**
Hunters (Pcs)	94 280	88 337	-6.3%
Hunting area (ha)	6 754 981	6 873 641	1.8%
Ungulates culls	229 655	475 297	107.0%
ha/Hunters	71.6	77.8	8.6%
Culls/Hunters	2.4	5.4	120.9 %

3.5 Value transfer in the value chain

The trajectory of economic valorisation along the Czech game meat supply chain is highly asymmetric, with the most significant proportion of price accretion occurring downstream of the forestry. At the point of primary production (in wild boar example)—the moment a carcass leaves the hunter—net meat revenue averages €2.77 kg^{-1} and is treated as the 100 % baseline. Once the carcass is eviscerated, inspected and dismembered in a certified facility, the unit price climbs to €4.86 kg^{-1} (≈ 157 % of baseline), reflecting the costs of hygiene compliance, refrigeration, trimming losses and the first layer of margin capture. A far steeper increment materialises at the following node: packaged frozen joints entering mainstream retail are priced at €9.88 kg^{-1}, more than trebling the baseline (≈ 321 %). The most substantial leap, however, is registered in the hospitality segment, where portioned cuts served as prepared dishes command the equivalent of €22.13 kg^{-1}, i.e. roughly a 7.2-fold multiplication of the producer's net value. These figures expose a pronounced downstream skew in value appropriation: while hunters bear the biological and ecological risks, over 85 % of the final consumer expenditure is captured beyond the forestry (primary production) —principally by food-service operators whose pricing power rests on labour, ambience and experiential attributes rather than on the intrinsic cost of raw venison.

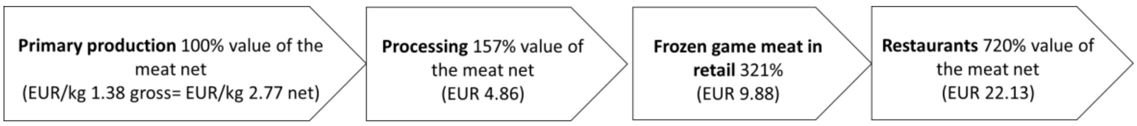

Figure 5. Sus Scrofa (2022) meat value transfer in the value chain

3.6 Qualitative research among key players

The qualitative enquiry revealed nine salient constraints relevant to the Czech (and Slovak) game-meat value chain.

Seasonality of supply.

The Czech (and Slovak) game-meat chain is fundamentally conditioned by the temporal rhythm of hunting legislation and wildlife biology, which concentrates the legally permissible cull into a narrow window (major exception is wild boar in the Czech Republic). Downstream distributors experience erratic volumes that hinder the negotiation of standing contracts with food retailers, while consumers confront sporadic availability that discourages habitual purchase behaviour.

Restricted processing and storage capacity.

Because most primary producers operate at a small spatial scale, chilled rooms and certified cutting facilities are scarce and geographically dispersed. When peak deliveries coincide, bottlenecks arise at the lairage and carcass-chilling stage, forcing hunters to accept lower primary production prices from the few processors that still maintain spare capacity.

Subdued consumer demand.

Survey data revealed that game remains coded as a "special-occasion" meat for most households. Price elasticity is high, willingness to experiment is inhibited by culinary unfamiliarity, and ethical reservations about hunting persist among younger urban cohorts. The resulting thin demand discourages retailers from allocating shelf space, which in turn perpetuates low visibility and reinforces consumer inertia—a self-referential loop that constrains scale at every node of the chain.

Complex regulatory environment.

Operators must navigate an intricate mosaic of veterinary, food-safety and environmental statutes whose compliance costs are proportional rather than progressive.

Insufficient refrigerated logistics.

Specialised vehicles remain in short supply and are costly to charter across sparsely populated hunting districts. Distributed smaller production requires a substantial period of accumulation for the transportation economy in a stabilised temperature chain.

Low profitability and depressed producer prices.

Interviewed landowners reported that nominal buy-in prices for venison have stagnated for over a decade, while input costs—fuel, ammunition, transport and carcass disposal—have followed the consumer-price index upwards. Gross margins at the hunting stage are therefore squeezed, weakening incentives for selective culling beyond the statutory minimum and limiting the ability of cooperatives to finance communal chilling facilities. Processors likewise operate on thin profit margins after accounting for the costs of hide removal, veterinary stamps and offal disposal.

Shortage of skilled hunters and plant personnel.

Demographic data show a gradual ageing of the licensed hunting community, with recruitment failing to offset retirements. Parallel shortages afflict deboning lines, where hygienic practice and carcass anatomy require specialised manual skills that are difficult to automate and unattractive to younger workers. Labour scarcity inflates overtime wages during peak season and constrains throughput, thereby reinforcing the seasonal mismatch between the available workforce and biological supply.

Variable carcass quality.

Processors emphasised the heterogeneity of field-dressed carcasses in parameters such as bullet damage, gastrointestinal leakage and time-to-chill. Inconsistent bleeding and contamination elevate microbial loads, necessitating rigorous trimming that reduces saleable yield and drives up unit processing costs. Quality variation also complicates standardised portioning, impeding the branding of game products as premium items with predictable sensory attributes.

Intrinsically low meat yield.

Unlike livestock breeds selected for high dressing percentages, wild ungulates allocate a substantial proportion of live weight to hide, viscera and bone. Average saleable yield seldom exceeds 55 %, and smaller species such as roe deer yield even less. The physiological ceiling on meat recovery magnifies the impact of all upstream inefficiencies—every kilogram lost to spoilage, regulatory trimming, or logistics failures carries a higher opportunity cost than in conventional red-meat sectors.
Other details, including qualitative research analysis, are mentioned in (Němec et al., 2025).

4 Discussion and conclusion

Qualitative triangulation of supply-chain mapping, long-run price series and 24 semi-structured stakeholder interviews shows that the widening gap between rising cull quotas and falling forest-gate prices cannot be bridged by a single, national marketing channel. Instead, the research supports three nested strategy clusters that internalise progressively more of the downstream margin.

First, a "local-economy" pathway links hunters directly with nearby households (≤ 10,000 inhabitants). Because buyers here prioritise affordability and social trust, carcasses are moved under the EU "for personal consumption" derogation. This arrangement keeps retail mark-ups near zero and can significantly lift producers' net receipts over current buy-in dealer prices.

Second, "district hubs" (10–100,000 inh.) rely on micro-butchery licences and proprietary click-and-collect logistics to supply trimmed cuts marketed on a price–quality narrative; consumer-panel work shows that tasting events and on-pack cooking guidance are decisive for this segment (Němec, Riedl, et al., 2023).

Third, a national / export cluster converts frozen stock into high-value charcuterie under a collective provenance label (e.g., *Czech Wild Venison*); brand storytelling and digital traceability allow list prices addressing premium segments while still competitive with other market premium proteins (Riedl et al., 2024).

Collectively, these clusters tackle the nine structural bottlenecks identified for the Czech and Slovak game-meat sector—seasonality, fragmented chilling, thin demand, stringent hygiene rules, costly cold-chain logistics, low producer margins, ageing labour, carcass heterogeneity and inherently low meat yield—by matching product form and regulatory regime to specific spatial markets. The research indicates that no single market outlet can fund the cull levels required for forest regeneration; instead, three spatially tiered business models—local direct-sale, district micro-butchery, and national/export premium branding—sequentially capture more downstream value and return it to hunters/forest owners. Together they can significantly raise primary producer revenues while simultaneously bypassing or mitigating the nine structural bottlenecks that constrain the Czech–Slovak game-meat chain, as mentioned also in (Němec et al., 2025; Němec, Skřivánková, et al., 2023; Riedl et al., 2024).

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