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Study Programme: Global Change Forestry

Analysis of Economic Instruments Implemented in the EU Stimulating Adaptation Measures of Forestry Climate Change Policies

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Ph.D. THESIS ASSIGNMENT

Diana Carolina Huertas Bernal

Global Change Forestry

Thesis title

Analysis of economic instruments implemented in the EU stimulating adaptation measures of forestry climate change policies.

Objectives of thesis

The dissertation is focused on economic instruments supporting adaptation measures of climate change policy. It aims to describe the impacts of climate change on forests and the economic instruments used in the EU forestry sector that contribute to adaptation to climate change. The most effective instruments to support adaptation measures are expected to be selected. Measures for changes to the current system of economic instruments in the forestry sector will be proposed to support practical application.

Methodology

The literature research will be based primarily on all instruments of environmental policy and their theoretical operation so as to guarantee the widest possible selection of appropriate instruments. Subsequently, the suitability of instruments to support adaptation measures in the European Union and the theoretical aspects of their use will be evaluated. This will be followed by data collection to assess the effectiveness of individual economic instruments, preferable with EUROSTAT being used as a data source.

Appropriate statistical methods will be used to evaluate the data and will be used to assess effectiveness. Based on the evaluation of suitable tools to support adaptation measures, a recommendation for a suitable tool mix usable in the conditions of the European Union will be proposed.

Schedule:

01/2021-08/2021 literature research

05/2021-10/2021 describe the impacts of climate change on forests in the EU and the adaptation measures used

09/2021-12/2021 data collection

01/2022-06/2022 describe the economic instruments implemented in the forest-based sector in the EU that contribute to the adaptation to climate change

07/2022-03/2023 evaluate the selected economic instruments to determine the efficiency of the instrument as an adaptation of climate change

04/2023-12/2023 describe how the selected economic instruments contribute to the adaptation to climate change in the forest-based sector

01/2024-03/2024 elaboration of the first version of the dissertation.

The proposed extent of the thesis

At least 80 standard pages

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environmental policy; effectiveness; forest ecosystem services; sustainability; instrument mix

Recommended information sources

AGRAWALA, S. and FANKHAUSER, S. (eds.) Economic Aspects of Adaptation to Climate Change: Costs, Benefits and Policy Instruments. Paris: OECD Publishing, Paris, 2008, https://doi.org/10.1787/9789264046214-en.

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STERN, Nicolas Herbert. *The economics of climate change : the Stern review.* Cambridge: Cambridge University Press, 2007. ISBN 0-521-70080-9.

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Prague on 22. 05. 2024

DECLARATION

I hereby declare that this dissertation, titled "Analysis of Economic Instruments Implemented in the EU Stimulating Adaptation Measures of Forestry Climate Change Policies," is entirely my own work based on consultations and recommendations of the supervisor. All sources used have been appropriately acknowledged and cited. I confirm this dissertation has not been previously submitted for any degree or qualification in any university or other institution.

I agree to the publication of the dissertation according to Act No. 111/1998 Coll. on universities as amended, regardless of the outcome of its defense.

Prague, 2024 Diana Carolina Huertas Bernal

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ABSTRACT

Economic instruments have established themselves as essential policy tools to internalize environmental costs and promote sustainability alongside regulations and other measures. However, some of these instruments have had adverse effects on the environment. This research focuses on identifying and analyzing the economic instruments available in the European Union forestry sector that align with climate change adaptation policies. Using mixed methods, a comprehensive understanding of the topic was obtained, ranging from identifying instruments in strategic documents regulating the EU forestry sector to analyzing case studies and the perceptions of forestry experts.

The research included the use of multiple panel regressions to evaluate the relationships between the use of economic instruments and the consumption of industrial wood, as well as the analysis of the effects of changes in land cover, SWOT analysis, in-depth interviews, surveys, analysis of forest ecosystem services, and spending on environmental protection. It was found that, despite the wide range of instruments available, forestry sector actors lack in-depth knowledge of them, and forest management does not take full advantage of available resources. Furthermore, current policies and regulations do not appear to impact domestic wood consumption significantly, and the current level of environmental taxes does not substantially affect consumption decisions. However, exports exert a positive and significant influence on domestic wood consumption.

Likewise, public perception of the role of forests in water supply is remarkably high, with more than half of respondents strongly agreeing that forests' water supply services are essential. The findings of this research highlight strengths and areas for improvement, providing a solid basis for policymakers to optimize the processes of use, implementation, dissemination, and access to financing mechanisms for sustainable forest management in the EU. These recommendations can help maximize environmental and economic benefits, promoting more effective and sustainable forest management.

Keywords:

Market-based instruments, SWOT analysis, foresters' opinions, multiple panel regressions, landcover change, roundwood consumption, and environmental expenditure accounts.

1. INTRODUCTION

The pursuit of efficiently allocating economic resources for sustainable development has been a central tenet of environmental programs since the declaration of Agenda 21 in 1992 (UNCED, 1992). Over the years, various economic instruments (EIs) have emerged as potent tools for internalizing environmental costs alongside regulations and other policy measures (Barde, 1994; OECD, 2020). However, these instruments have faced challenges and deviations from their initial purpose due to complex factors (Robinson et al., 2002). For instance, the valuation of ecosystem services often relies on inadequate economic metrics, such as production relations or opportunity costs, rather than comprehensive assessments of ecosystem degradation (Pirard, 2012). Hahn and Stavins argue that certain economic studies overlook the interplay between corporate profits, market dynamics, and environmental factors while neglecting transaction costs in their analysis (Hahn & Stavins, 1992).

Transitioning to the forest sector, forest management primarily relies on economic instruments like subsidies and taxes/charges to expand or maintain forest areas and quality and deter forest degradation (Barde, 1999; Cubbage et al., 2007). Within the forestry industry, key EIs include tax incentives for investments in equipment and machinery, reduced tax rates on income from forest product sales, and tax credits for sustainable forestry practices and certification (Institute for European Environmental Policy & European Commission, 2017; OECD, 2021b).

The evaluation of environmental policies and associated economic instruments has been a focal point of research since at least 1999, highlighting challenges such as integrating economic instruments with other policy approaches, data limitations for subsequent assessments, and the multiplicity of goals complicating outcome measurement (Barde, 1999). Recent studies continue to underscore the complexity of analyzing economic instruments and their environmental implications (Koplow & Steenblik, 2022; Mickwitz, 2003; Schlegelmilch, 2020).

Research on economic instruments often examines their role in development policies, accompanied by financing programs to enhance sector competitiveness and innovation. Studies assess policy effectiveness, acceptability, implementation, consumer trends, and long-term effects (Gómez-Baggethun & Muradian, 2015; Herzig et al., 2008; Mickwitz, 2003; Onofri & Nunes, 2020; Russi et al., 2016). Some focus on environmental components like water, air, soil, and biodiversity (Ansell et al., 2016; Barbier et al., 1997; Chobotová, 2013; Knowler, 2004; Schlegelmilch, 2020; UNEP, 1998; Zhou et al., 2020), while others analyze specific sectors such as energy, transport, agriculture, construction, and automotive (Bergek & Berggren, 2014; Farrell et al., 2015; OECD, 2000; Shahzad et al., 2021)

Examining public perception reveals gaps in awareness and understanding of available financial instruments, hindering the effectiveness of market-based approaches (Carattini et al., 2017; Dresner et al., 2006). However, understanding how forest actors perceive and utilize economic instruments remains unclear and vaguely documented due to industry complexity, long production cycles, interconnected products and services, and challenges in valuing logging's environmental impacts (De Bruin et al., 2015; Hurmekoski & Hetemäki, 2013).

Furthermore, this lack of attention has created a significant gap in understanding the influence of economic instruments on sustainable forest resource management. Utilizing a mixed methodology of qualitative and quantitative analyses, this study delves into the utilization, perception, and implications of economic instruments among forestry actors in the European Union (EU). Through in-depth interviews, surveys, SWOT, content analysis, and multiple panel regressions, the study identifies patterns, best practices, and areas for improvement, offering valuable insights for policymakers and forest managers. By integrating these findings into EU forestry strategies and enhancing stakeholder awareness, forest management can be more effectively supported by relevant programs and initiatives.

Examining the available economic instruments within the forestry sector will provide a comprehensive overview of the tools at hand and facilitate the identification of areas for enhancement and optimization. Such analysis enriches the existing knowledge base and lays the groundwork for more informed policy formulation and decision-making to advance sustainable forest sector management.

The choice of the research topic is based on the researcher's interest in thoroughly understanding the functioning of economic mechanisms, particularly in a highly regulated context such as the European Union. This understanding can shed light on addressing the environmental and economic challenges in Latin America, where the implementation of environmental legislation is often limited. The concern arises from phenomena such as financing for establishing oil palm crops and managing royalties from large oil and infrastructure projects in Colombia. These cases exemplify the need to fully explore existing economic instruments and their impact on environmental management. Given the magnitude of this problem at a global level, it was decided to study a specific case that offered essential lessons: the EU. With its developed economies, the EU provides an exciting model for understanding how economic instruments are used and perceived within the EU. This knowledge will allow its possible implementation to be projected in other regions of the world, thus contributing to more effective management of natural and economic resources at a global level.

2. OBJECTIVES AND HYPOTHESIS

2.1 Aim and Objectives

Economic instruments are designed to influence societal behavior regarding environmental resource usage. However, inadequately developed, or deficient instruments may adversely affect the environment and society. To mitigate these effects, this research aims to analyze the allocation of financial resources to adapt the European forestry sector, thereby stimulating adaptation to climate change. The study focuses on the following specific objectives and associated research questions:

Objective 1: Identify economic instruments that stimulate adaptation to climate change in the EU forestry sector.

Question 1: What specific economic instruments, including policies, incentives, and mechanisms, are effective in stimulating adaptation to climate change within the European Union forestry sector, and what are their intended outcomes?

Objective 2: Interpret how the use of economic instruments to facilitate the adaptation of the EU forestry sector to climate change is perceived.

Question 2: How do various stakeholders within the EU forestry sector perceive the effectiveness and accessibility of economic instruments and financing schemes intended to facilitate adaptation to climate change in forestry management and wood production?

Objective 3: Assess the impact of economic instruments on roundwood consumption in the EU to understand how these instruments affect market dynamics and resource utilization in the forestry sector.

Question 3: What are the multifaceted implications of utilizing economic instruments, including policies and incentives, on market dynamics, resource utilization, forest management practices, and socioeconomic aspects within the wood industry of the EU?

Objective 4: Analyze the implications of using economic instruments in water treatment and their effects on forest ecosystems in the Czech Republic.

Question 4: What effects does the use of economic instruments have on water quality, and what are its implications for the state of forests in the Czech Republic?

2.2 Hypothesis

By investigating the influence of various economic instruments, their utilization, and subsequent implications for the forest management and wood industry, this dissertation seeks to contribute to a deeper understanding of the crucial role played by economic mechanisms in sustainable forestry management. This thesis will test the following hypotheses:

Null hypothesis: There is no significant relationship between the implementation of economic instruments in the EU forestry sector and levels of climate change adaptation.

Alternative hypothesis: There is a significant relationship between the implementation of economic instruments in the EU forestry sector and levels of climate change adaptation, with economic instruments either positively or negatively influencing adaptation efforts.

3. LITERATURE REVIEW

This literature review aims to gain comprehensive insights into the research conducted on economic instruments, along with the policies and strategies implementing them to manage environmental resources, with a particular focus on the European Union and the forestry sector's adaptation to climate change. Scientific articles were systematically searched in databases such as Scopus, Scielo, ResearchGate, ScienceDirect, and Web of Science using keywords such as "economic instruments," "market-based," "policy," "in-depth interview," "panel regression," "payment for ecosystem services," "ecosystem services," "biodiversity," "harmful subsidies," among others, in various combinations. This exploration of existing research enables the comparison of methodologies and identification of relevant aspects to inform the development of this study. Additionally, gray literature from international organizations and institutions was reviewed, given their leadership in global environmental policy development and research, offering valuable insights for this investigation.

3.1 Economic Instruments

3.1.1 DEFINITION

Combining various definitions, economic instruments can be understood as fiscal and financial incentives (United Nations, 1997) used to internalize environmental costs, as initially described by Pigou in the early 1920s (Hahn & Stavins, 1992; UNEP, 2004). These instruments aim to achieve environmentally sustainable objectives (OECD, 2020, 2021a), by encouraging desired behaviors among producers and consumers (Mickwitz, 2003; UNEP, 2004; United Nations, 2015).

3.1.2 CLASSIFICATION

Economic instruments are typically classified based on their characteristics (Bouwma et al., 2015; Bräuninger et al., 2011; OECD, 2017; UNEP, 1995). This research adopts categories such as taxes and fees, tradable permits, environmentally motivated subsidies, and voluntary approaches. These categories have been selected due to the availability of information in open-access databases, facilitating the development of this research. Moreover, they represent the most commonly used instruments globally, with their usage notably increasing over the past three decades. They are employed to mitigate and adapt to climate change and play a significant role in shaping the price signals of the global economy. These features make them particularly suitable for comparison and analysis in this study.

TAXES AND FEES

The environmental taxes are all mandatory payments made by economic agents to the government. Tax rates are based on negative environmental impacts, such as pollution levels. Taxes are the revenues that finance public expenditure. At the same time, environmental fees are mandatory payments to the government charged in proportion to the services provided, such as the volume of water consumed (Bräuninger et al., 2011; Dresner et al., 2006; OECD, 2017). Taxes are the most used economic instruments globally. They are therefore widely studied to describe its potential, economic valuation, and options to redesign and improve their effectiveness (Andersen et al., 1997; Baranzini et al., 2000; Carattini et al., 2017; Cherry et al., 2012; Chiu et al., 2015; Clinch, 2002; Dresner et al., 2006; Ekins, 1999; Elliott & Fullerton, 2014; B. Lin & Li, 2011). Due to environmental problems that have arisen from the use of fertilizers, pesticides, abstraction, and discharge of water, landfills, among others, the need to comply with the principle of polluter pays through taxes to regulate the activities and discourage the use of polluting goods (ECOTEC et al., 2001). However, environmental taxes constantly have much opposition as the effects on the economy are not easily understood. Tax reforms are introduced to discourage goods or services, thereby increasing the tax (Dresner et al., 2006).

Taxes and charges for the use of fertilizers and pesticides have been analyzed through case studies. Some results indicate the tendency to substitute the useless, dangerous, and polluting alternatives because of the available incentives to reduce the harmful effects. Likewise, studies suggest that in the absence of subsidies for green fertilizers and pesticides, farmers resort to less sustainable but more economical techniques to maintain their farms (ECOTEC et al., 2001; N. Lin et al., 2019; Slunge & Alpizar, 2019). Regarding taxes for abstraction or discharge of water, investigations are identified on payments for the conservation of underground water, preservation of biodiversity associated with bodies of water, hydro-economic model, irrigation, etc (Ansell et al., 2016; Berbel et al., 2019, 2019; Blanco-Gutiérrez et al., 2011; Graveline, 2020, 2020). One of the studies model's groundwater extraction's economic and hydrological factors, identifying the effectiveness and profitability of taxes according to the context where the extraction is implemented and the environmental policies that regulate them. They conclude that increasing economic incentives through flexible taxes for water use can ensure a minimum extraction without affecting the demand for water, which is generally linked to market prices (Ansell et al., 2016). Another investigation uses the non-linear model of the point-of-material method to analyze the factors that affect groundwater extraction, the cost, and the effectiveness of environmental policies in this regard, finding that in the case study in a region of Spain, effective economic instruments are required to reduce water consumption and promote aquifer recovery (Blanco-Gutiérrez et al., 2011).

The emissions taxes imposed by the administrative authority were raised so that goods with high emissions content are more expensive and obtain less profit. The reduction of emissions is encouraged to be more competitive in the market. However, the tax bases and rates determine the final impact of the emissions. Carbon taxes differ markedly between countries (Baranzini et al., 2000). Hence the need to create emissions trading systems to regulate the market.

TRADABLE PERMITS

The tradable permits are permissions to assign pollution under a trading system. There are two types "cap-and-trade systems" and "baseline-and-credit systems." In the first, pollution limits are set, and permits are assigned by auction or free of charge according to established criteria. While the second type, no boundaries are set, and pollutants that reduce emissions over the standard can market their surplus to other polluting enterprises to achieve their goals (OECD, 2017).

Studies on cap-and-trade systems such as the EU ETS analyze the instrument through models to assess environmental policy (Barragán-Beaud et al., 2018; Brink et al., 2016; Chiu et al., 2015). The Brink study analyzes the current operation and proposes reforms designing the EU ETS and its possible consequences on prices of carbon, emissions of greenhouse gases (GHGs), and compliance costs in response to low prices reported since 2011 due to market uncertainties. It is finding that reducing the number of allowances offered or introducing variable taxes to keep a price floor can increase the value of the carbon market (Brink et al., 2016). Another study presents a scenario-based model to compare the most efficient mechanism that should be implemented in Mexico. According to political conditions, emissions trading provides greater profitability and lower distributional effects than a carbon tax (Barragán-Beaud et al., 2018). Another theoretical study identifies that the economic impacts of carbon taxes and emissions trading systems depend on the energy market structure linked. For this reason, it is essential to value the energy market when it comes to incorporating carbon taxes or ETS (Chiu et al., 2015).

SUBSIDIES

The environmentally motivated subsidies are payments made by the government to influence production levels and prices. As well as to control the creation of projects or activities that protect or restore the environment, can be grants or loans, tax exemptions or reductions, feed-in tariffs, price support, differential rates in credits, totally or partially financed guarantees, among others (Bräuninger et al., 2011; OECD, 2017).

Environmental protection expenditures are widely studied as they are mechanisms that facilitate the direct financing of initiatives to improve environmental quality (European Commission, 2011; Kierepka-Kasztelan, 2018). Since 1990, the need to develop environmental protection policies and collect information on expenditures has arisen. In this way, the System of Integrated Environmental and Economic Accounts surges. Which has been improving and standardizing processes to compare the resources each country allocates for environmental protection, given that environmental problems are not limited to the borders but appear transnationally and require joint efforts to be handled (Le Gallo & Ndiaye, 2021).

Likewise, there are studies on corporate environmental expenditure, where the consequences and trends in spending and environmental quality are explored. One investigation concludes that the environmental expenditures of some companies depend on the rigidity of each country's environmental policies and can negatively impact economic performance and pollution prevention (Singh et al., 2016). While another study identifies that larger companies with energy-intensive or export companies are more likely to spend resources on environmental issues (Haller & Murphy, 2012).

Moreover, there is national research assessing environmental protection expenditure, which suggests spending trends and exposes future needs to continue to improve environmental quality (Bobáková & Mihaliková, 2019; Hájek, 2003; Soukopova & Bakos, 2010; Soukopová & Struk, 2011).

VOLUNTARY APPROACHES

The voluntary approaches are all the other instruments seeking to improve environmental performance voluntarily, including agreements to enhance performance beyond the provisions of the regulations (OECD, 2017). This category includes payment for ecosystem services (PES), an incentive-based mechanism where users pay an ecosystem service to communities or individuals who manage resources so that ecosystem services are preserved over time (Derissen & Quaas, 2013; OECD, 2010; Xie et al., 2021).

In the last 20 years, interest in PES has been aroused. Studies have been presented for and against the mechanism, as well as specific studies in developing countries and analyzes on its implementation and possible environmental consequences when monetizing the environmental services provided by the forest (Barbier, 2007; Costanza et al., 1997; Daily & Matson, 2008; European Commission, 2015; Gómez-Baggethun & Muradian, 2015; Gretchen et al., 1997; Joint Research Centre et al., 2020; Li et al., 2017; Milder et al., 2010; Ruggiero et al., 2019). Some studies on payment for ecosystem services focus on analyzing the ecological and social consequences of initiatives that have been implemented throughout developing countries (Milder et al., 2010; Ruggiero et al., 2019).

The study of PES in the forests of Brazil reports a lack of continuous and rigorous impact evaluations that allow monitoring and improving the design of the mechanism, creating uncertainty about the effectiveness of the conservation tool. Additionally, the research demonstrated that the PES positively impacts forest cover; however, diversity and conservation of forest ecosystems are compromised. Likewise, it highlights that the mechanism's effectiveness is linked to the environmental legal framework that promotes conservation and sustainable development, which may lead to dependence on PES to achieve the objectives of native vegetation coverage (Ruggiero et al., 2019).

The most ecologically diverse and sensitive lands are in developing countries in low-income communities. A study identifies the potential to alleviate the poverty of these communities with PES; however, the challenges for implementation are uncertain, and other limitations are faced due to the political stability, economic and commercial interests that can distort the benefits of payment for ecosystem services (Milder et al., 2010).

The biodiversity strategy to halt biodiversity loss in the European Union is the political framework that supports all initiatives to conserve diversity and associated ecosystem services. The initiatives promoted under this strategy have made it possible to investigate, map and assess the state of the ecosystems and services that exist in the member states, as well as investing in and creating entities in charge of monitoring and monitoring the issues raised to achieve the objectives of the strategy (Joint Research Centre et al., 2020).

Since 2011, ecosystems have been identified based on standardized methodologies to compare the information obtained. With the use of geographic information systems, ecosystems have been delimited, and trend scenarios have been modeled. Additionally, pressures and factors that can influence ecosystems' functioning have been identified. It is part of the baseline to follow up on the implemented measures and initiatives to improve their functioning (Joint Research Centre et al., 2020).

Studies on mechanisms for the conservation of biodiversity are also popular and represent an excellent opportunity to propose initiatives that integrate the components of ecosystems. One of the studies analyzes the duration of compensation payments so that they are effective. The ecosystem services they represent are conserved, finding that for the specific study of conservation of butterflies in Germany, according to the ecological and economic parameters they have, medium contracts term is preferable rather than long term to make effective conservation (Drechsler et al., 2017).

3.1.3 ENVIRONMENTAL PROTECTION

In 2021, there were 3,680 economic instruments reported as being in use across more than 120 countries (OECD, 2021b). Therefore, this study will focus on economic instruments with environmental domains that directly mention forest resources or indirectly benefit the forest, such as water, landscape, soil, and biodiversity. Additionally, as economic instruments are associated with environmental protection expenditures (European Commission. Eurostat, 2010), it was necessary to identify the activities that promote the sustainable development of the forestry sector. For this, the Classification of Environmental Protection Activities (CEPA) and Classification of Resource Management Activities (CReMA) provide information on environmental activities and products that prevent, reduce, and eliminate pollution or degradation of the environment like protection and remediation of soil and water, protection of biodiversity and landscapes, wastewater management, and waste management (EEEA, 2020).

Furthermore, the EIs can be linked to measures to adapt to climate change because they provide direct or indirect payments that encourage activities to minimize impacts. They are usually national programs with local initiatives to assess the needs of forest owners and farmers to promote research and development of sustainable technologies through direct investment (Bräuninger et al., 2011). In this sense, some EIs have contributed to the improvement of the state and protection of critical environmental components of society, such as water (European Commission, 2019c; Stavins, 2003), soil (Knowler, 2004; Stavins, 2003), and air (Stavins, 2003), among others. However, some other economic instruments have generated adverse effects on the environment (Directorate-General for Energy (European Commission) et al., 2022; OECD, 2003), biodiversity (Pérez & Simonetti, 2022; Portela & Rademacher, 2001; Schlegelmilch, 2020), forests (Lehmann, 2012; OECD, 2022), and society (Koplow & Steenblik, 2022).

3.1.4 Environmental Regulation and Forestry

Throughout history, there has been an increasing acknowledgment of the imperative to safeguard and uphold the environment, stemming from the adverse impacts of human activities on nature. The earliest legislative endeavors to protect the environment trace back to the 19th century, predominantly focusing on conserving vital natural resources such as water and land. In 1872, the United States Congress ratified The Act of Dedication, establishing Yellowstone National Park as the world's first American national park. Subsequently, in response to widespread contamination of rivers and lakes from sewage and industrial waste discharge, Congress passed the Federal Water Pollution Control Act in 1948. By 1972, mounting public awareness and concerns regarding water pollution necessitated crucial legislative amendments (Downing et al., 2003). Similarly, in the United Kingdom following the Great Smog of 1952, Londoners increasingly grappled with curbing the toxic byproducts of industrialization, prompting the enactment of the British Clean Air Act of 1956.

International Conferences on the Environment have become critical events for establishing global agendas and fostering international cooperation on environmental matters, such as the United Nations Conference on the Human Environment in Stockholm in 1972 and the Earth Summit in Rio de Janeiro in 1992. Specifically, for the forestry sector, interest has been raised in compensation payments to forest owners and farmers and the creation of forest incentives and compensation mechanisms. Likewise, it has increased local and regional participation in decisions that promote sustainable forestry development and biodiversity conservation (Hrabanski, 2015; Schmithüsen & Zimmermann, 2001).

Since the mid-nineties, interest in evaluating environmental policies has been aroused. In the 6th Environmental Action Program for the European Union (1600/2002/EC), the parameters were established to improve the processes of environmental policy formulation through ex-ante and ex-post evaluations to compare scenarios with and without measures taken (Andersen et al., 1997; Krutilla, 2011; Mickwitz, 2003; Vaz & EEA, 2001).

The European Union stands as one of the global leaders in environmental policy (Burns et al., 2020; Kilian & Elgström, 2010), as well as in economic instruments and financing schemes facilitating the funding of environmental management plans and measures aimed at enhancing the condition and utilization of natural resources. Within this framework, the European Commission has devised sectoral policies and long-term action plans for research, technological development, and financial support to foster societal advancement. Below is a brief overview of the policies and programs.

- The EU's Common Agricultural Policy (CAP) has been operating since 1962 to support farmers and guarantee food security in Europe. It includes two financing funds, the European Agricultural Fund for Rural Development (EAFRD) and the European agricultural guarantee fund (EAGF) (European Commission, 2021c). The EAFRD is one of the main economic instruments for this research, is part of the category environmentally motivated subsidies, and is regulated by the EU Rural Development Regulation No 1698/2005.
- The Council of the European Community established a scheme for trading greenhouse gas emissions to meet the Kyoto Protocol's commitments on reducing the emissions of carbon dioxide (CO_2) and other greenhouse gases (Directive 2003/87/EC of the European Parliament and of the Council, 2003). In 2005, launched the EU Emissions Trading System (EU ETS) put a price on carbon and gave a financial value to each ton of emissions saved which promotes investment in clean and low-carbon technologies (European Commission, 2016). The most common method for allocating emission allowances is auctioning. Usually, its revenues are spent on renewable energy, energy efficiency, and sustainable transport (European Commission, 2020).
- The framework programs for research and innovation of the European Union are initiatives to promote and invest in cutting-edge research by supporting research projects and technological development, which is selected from the annual calls (European Commission, 2021b), is administered by The European Climate, Environment, and Infrastructure Executive Agency (CINEA) to achieve the European Green Deal. Includes LIFE Program, financing projects in nature and biodiversity, climate change mitigation, and adaptation. Horizon Europe on research and innovation to tackle global climate

challenges and the Innovation Fund to reduce greenhouse gas emissions (European Commission, 2021a).

- The financial means of The European Economic Area (EEA) and the Norwegian funds are used to finance projects to improve biodiversity, reduce pollution of air and water, and the creation and implementation of adaptation, and mitigation strategies to face climate change at the municipal level only applies to some European Union members (EEA, 2021).

3.1.5 Environmental Harmful Instruments

As mentioned above, if economic instruments have flaws in their interpretation and implementation, they can generate certain challenges to the environment and communities. For instance, Hrabanski's study sets out the arguments of scientists, NGOs, and local communities against using market-based instruments as biodiversity offsets. Statements include a lack of monitoring of biodiversity in projects that fail, governance problems, displacing biodiversity, and highlighting that offsetting biodiversity is permission to destroy rather than minimize or prevent loss of biodiversity (Hrabanski, 2015). Likewise, the regression model panel developed in China indicates that GDP growth generates environmental and low-efficiency degradation in the use of resources due to factors as industry structure, economic development, and land-use intensity. While the factors influencing the achievement of eco-efficiency are technical innovation and government regulation (Zhou et al., 2020).

On the other hand, economic sectors, including transportation, agriculture, mining, and manufacturing, rely on subsidies to sustain financial viability (OECD, 2003). They keep getting financial support despite knowing the environmental harm these activities cause. This support is often justified by claiming it boosts national and regional competitiveness (OECD, 2005). A clear example of this is seen in the Amazon rainforest, where livestock activities contribute to deforestation. Government-funded programs and subsidies unintentionally encourage large-scale livestock farming, agriculture, and logging, leading to extensive land clearing and conversion to pasture (Portela & Rademacher, 2001).

Additionally, a series of studies expose the failures and deviations of policy instruments, comparing the initial economic theories with the concepts and policy instruments implemented in practice. Indicating that the initial purpose of the internalization of environmental costs has been changed due to different factors that are complex to analyze;

for example, monetary values given to ecosystem services are not based on economic valuations but financial relations of production or opportunity costs. Questioning that analysis rarely includes all aspects of ecosystem degradation (Pirard, 2012). Hahn & Stavins report that some economic studies of policy instruments assume that all trading gains are achieved regardless of the market they develop, irrespective of the environment. Additionally, they indicate that static references are used to compare the instruments, limiting the analysis by not introducing transaction costs (Hahn & Stavins, 1992).

3.1.6 LIMITATIONS AND KNOWLEDGE GAPS

Some limitations that arise in studies related to environmental policies and economic instruments were identified.

- Forest environmental issues are complex due to external factors as organizational aspects, stakeholders, use of information technology, political decisions, international environmental agreements, and cultural norms, which are difficult to quantify and can only be described (Krutilla, 2011; Schmithüsen & Zimmermann, 2001; Soukopová & Struk, 2011).
- In practice, monetizing environmental benefits is complex due to uncertainties in economic analysis methods, and aesthetic, health and recreational services still do not have market prices (Onofri & Nunes, 2020; Soukopova & Bakos, 2010).
- The study of environmental policies and instruments is quite complex since it involves extended time frames, many stakeholders, and significant uncertainties. For example, environmental effects can occur in the same place where the damage is caused or far away, which makes it impossible to identify all the factors that cause a phenomenon (Mickwitz, 2003; Russi et al., 2016).
- The applicability of the valuation methods of policy instruments are limited to the environment where they develop and the availability of reliable data (Onofri & Nunes, 2020; Xie et al., 2021).
- Some programs which have been implemented in economic instruments lack a baseline for the ex-ante for comparing the results of interventions. Likewise, secondary information is used because preliminary information is limited or expensive (Xie et al., 2021).
- Usually, economic instruments are implemented in combination with other instruments or environmental policies that make it difficult or sometimes impossible to identify the

impacts of a particular instrument. Additionally, face challenges as design and implementation rigor, investment stability, and scale implementation (Bergek & Berggren, 2014; Bräuninger et al., 2011).

Some knowledge gaps in the environmental policy and instruments include:

- Multi-focus analysis of the effects of sectoral approaches at the local and regional level on land use management and benefits of financial transfers for landscape protection (Schmithüsen & Zimmermann, 2001).
- There are schemes for assessing economic instruments at a general level; however, there is a lack of benchmarks for evaluating the actual effectiveness of different methods currently used, such as payment for ecosystem services (Xie et al., 2021).
- Forests require understanding how to implement adaptation processes to climate change and involve all stakeholders in the forestry sector in these new adaptation measures and the consequences of those decisions (Blanco et al., 2017).
- Studies are required on the best available technology standards and impact assessment of the proposed technologies to improve environmental performance (Bergek & Berggren, 2014).
- The environmental problems tend to be very complex due to human activities require constant extraction or use of natural resources and affect not only the aid but also the ecosystem services associated at the local, regional, and in some cases, international level (Mickwitz, 2003)
- Since the emergence of economic instruments and environmental policies, interest has been aroused among the different actors to evaluate their effects, effectiveness, and efficiency (Vaz & EEA, 2001). Thus, they have arisen standards, methodologies, and proposals for evaluation. However, assessment of policies and instruments are still required since there are still knowledge gaps depending on various factors that affect their operation.

3.2 Adaptation Measures of Forestry Climate Change Policies

Adaptation measures address the impacts of climate change that are already occurring or expected to occur (IPCC, 2022). These actions and strategies are designed to reduce the vulnerability of natural and human systems to the adverse effects of climate change. Depending on the measures implemented and their scale, they can have short-, medium-, and long-term effects (Biesbroek et al., 2013). Often, these measures are local or regional, focusing on a community or ecosystem's specific characteristics and needs. The primary goal is minimizing damage and increasing resilience, ensuring that communities and ecosystems can continue functioning in a changing climate (Fankhauser, 2017; IPCC, 2022; Lindner et al., 2008).

Adaptation measures in climate change policies for the forestry sector are strategies and actions designed to reduce the vulnerability of forests and the communities that depend on them to the impacts of climate change. These measures cover a wide range of options to reduce vulnerability and increase the resilience of forests. For instance, sustainable forest management (SFM) is a comprehensive approach to forest management that seeks to balance present and future environmental, economic, and social needs (Hickey, 2008). SFM ensures that forests maintain their biodiversity, productivity, and regeneration capacity to fulfill essential ecological, financial, and social functions at local, national, and global levels (Castañeda, 2000; Siry et al., 2005). The following practices are exemplified within this measure. However, it is essential to note that these practices are not the only ones, as they continually evolve in response to the challenges presented by the dynamic climate.

- Selecting and planting tree species more resistant to changing climate conditions, diseases, and pests involves conducting thorough research on species' adaptability to projected climate scenarios. Includes assessing factors such as drought tolerance, resistance to pests and diseases, and ability to thrive in different soil types and temperature ranges (Forest Europe, 2020).
- Maintaining a diversity of species to increase the resilience of the forest to disturbances is crucial for promoting ecosystem stability and adaptability. By preserving a wide range of tree species within forest ecosystems, biodiversity is enhanced, reducing the risk of catastrophic impacts from pests, diseases, and environmental stressors (European Commission, 2015).
- Adjusting forest management practices based on continuous monitoring and research on climate change involves regularly assessing the impacts of climate variability and extreme weather events on forest ecosystems. It may include employing remote sensing technologies to monitor forest health and productivity changes (Forest Europe, 2020; Siry et al., 2005).

- Prevention of the spread of invasive species through regular monitoring to detect the presence of invasive species, implementation of cleaning protocols for equipment and vehicles used in the forest, as well as educating the local community about the risks associated with invasive species and promoting practices of gardening and management that prevent its spread (European Commission, 2015; Liu et al., 2018).
- Water management is an alternative to optimize the water cycle within forest ecosystems. Promoting dense and diverse plant cover reduces soil evaporation and maintains moisture. Rehabilitation and protection of riparian areas to maintain water quality and regulate water flows. And promote water infiltration into the soil through watershed management techniques to recharge underground aquifers and maintain groundwater levels (Carpenter et al., 2011; Li et al., 2017).
- Fire prevention through awareness campaigns and implementing strict regulations governing activities such as campfires, logging, and land clearing during periods of high fire risk. Early detection of fires through surveillance systems enables rapid identification of fire outbreaks, allowing for swift response and containment efforts by firefighting teams. Fire suppression involves deploying various firefighting resources, including fire engines, helicopters equipped with water-dropping buckets, and specialized firefighting crews (Eastmond & Faust, 2006; Forest Europe, 2020).
- Forest health monitoring programs to assess the prevalence and impact of pests and diseases on forest ecosystems. These programs involve visual assessments of tree health and collecting and analyzing biological samples to identify pest species and disease pathogens. Early detection allows for timely intervention measures to prevent the spread of infestations and mitigate their negative impacts on forest health and productivity (Forest Europe, 2020; IPCC, 2022).
- Soil erosion prevention strategies involve implementing measures to control water drainage and runoff within forested landscapes. It may include the construction of contour ditches, check dams, and terraces to slow down the water flow and minimize soil erosion on steep slopes. Additionally, promoting riparian buffer zones and vegetative cover along waterways helps stabilize stream banks, filter sediment, and reduce the transport of pollutants downstream (Forest Europe, 2020; Knowler, 2004).

Additionally, combining forest conservation and restoration creates an integrated and holistic approach to forest management, influencing the improvement of ecosystem services and biodiversity, increasing resilience, and generating benefits for dependent communities (Chazdon, 2019; Lindenmayer, 2019). Forest conservation focuses on protecting and preserving existing forest areas to maintain their biodiversity, ecological functions, and environmental services (Ihemezie et al., 2022). At the same time, forest restoration consists of recovering and revitalizing degraded or deforested areas to restore their original structure, composition, and function or to create healthy and resilient forest ecosystems (de Jong et al., 2021). Some of the measures included in this approach are presented below.

- Planting trees to improve the capacity of forests: Reforestation involves the replanting of trees in areas that have been previously deforested or degraded, aiming to restore forest cover and ecosystem function (IPCC, 2018). Afforestation, on the other hand, refers to the establishment of forests on land that has not been forested for a long time or has never been forested (IPCC, 2018). Both practices increase carbon sequestration and storage capacity, as trees absorb carbon dioxide (CO2) from the atmosphere during photosynthesis and store it in their biomass and soil (Forest Europe, 2020).
- Restoration of degraded forests: Forest degradation occurs when forests experience declining health and productivity due to logging, land conversion, and unsustainable land management practices. Restoring degraded forests involves implementing measures to rehabilitate ecosystem structure and function, such as planting native tree species, controlling invasive plants, and restoring soil fertility (Forest Europe, 2020).
- Conservation of primary forests: primary forests are ecosystems that have reached a mature stage of development and have not been significantly disturbed by human activities. These forests harbor a wealth of biodiversity, including rare and endemic species, and provide important ecological functions such as carbon storage, water regulation, and soil protection. Conservation efforts for ancient and virgin forests focus on protecting these valuable ecosystems from further degradation and destruction by establishing protected areas, implementing sustainable management practices, and enforcing strict regulations against illegal logging and land conversion (Forest Europe, 2020; IPCC, 2022).

Furthermore, research and development, policies, and governance are transversal measures that help adapt forests to climate change. On the one hand, research and development refers to monitoring climate change by establishing monitoring systems to evaluate the effects of climate change on forests and the effectiveness of adaptation measures. Promotes research on forest biology, changes in climate patterns, and best adaptive management practices. And the use of climate models to predict future scenarios and plan accordingly (Winkel et al., 2022). At the same time, policy and governance include formulating policies integrating forest management with other agriculture, water, and energy sectors and training forest managers and local communities to adapt and implement sustainable management practices. And the participation of local communities in decision-making (Winkel et al., 2022).

3.3 Industrial Roundwood Consumption

Forests, essential for various ecosystem services, play a pivotal role in carbon sequestration, regulation of the hydrological cycle, maintenance of soil health and climate stability, and providing habitats for diverse flora and fauna (European Commission, 2015; McRae et al., 2016; Millennium Ecosystem Assessment, 2005; Winkel et al., 2022). Moreover, they serve as vital resources for human activities, serving as centers for tourism, recreation, education, and as sources of raw materials such as timber, pulp, resins, and fruits (Atkinson & O'Brien, 2019; Brancalion et al., 2014).

Despite their immense benefits, forests confront various challenges hindering their optimal functioning (FAO, 2022b). Encroachment from agricultural expansion reduces floristic diversity, limiting forests' resilience to climate change and making them susceptible to pests and fungal infections (Barbier, 2022; Barthel et al., 2019; Liu et al., 2018; Quintas-Soriano et al., 2016). Overexploitation, improper harvesting, and overgrazing further degrade these ecosystems (Naughton-Treves, 2004; West et al., 2023).

Global forest area in 2020 reached 4.06 billion hectares, with approximately 1.15 billion hectares designated for forest management and product production, including timber and non-timber resources. Europe leads with 515 million hectares, followed by North and Central America with 231 million hectares, and Asia with 190 million hectares. Notably, Montenegro, Denmark, and Albania allocate the highest proportions of their forests for production (FAO, 2020).

Roundwood, encompassing all woody material from forests, constitutes a significant resource, primarily for industrial purposes. Global roundwood extraction and consumption in 2020 were approximately 3,911,952,000 m^3 and 3,912,012,000 m^3 respectively, with Asia being the largest consumer. The United States, China, India, Brazil, and the Russian

Federation lead in roundwood consumption per country. In the European Union, Sweden, Germany, and Finland are the primary consumers (FAO, 2022a).

Analyzing forest production and wood consumption is imperative due to climate change and international policies like the Paris Agreement and the European Green Deal. Sustainable forest management is crucial to meet wood demand while minimizing environmental impacts (Kayo et al., 2015; Stubenrauch & Garske, 2023). Understanding consumption patterns and forest dynamics is vital for devising strategies that ensure long-term ecological integrity (Keith et al., 2021; Winkel et al., 2022). Furthermore, economic instruments, such as timber taxes or subsidies for sustainable forest management, can impact how wood is consumed (OECD, 2021a). For this reason, instruments and policies are required to promote the responsible use of timber and adopt sustainable management practices to help maintain a balance between the supply and demand of forest products, thus promoting the long-term conservation of forests.

3.4 Landcover Change

Climate change is driven in part by land cover conversion and large-scale deforestation. Activities such as clearing, felling, and burning trees release greenhouse gases (GHG) and other substances, which increase global temperatures (Nobre et al., 1991; Tinker et al., 1996). Land cover, defined as "the physical (bio)cover observed on the Earth's surface" (di Gregorio, 2005), is also described as "the sum of all land surface properties at a given location (e.g., biophysical, morphological, topographic), typically characterized by vegetation and soil properties" (Pongratz et al., 2018). This coverage is classified into broad categories that can be subdivided into more detailed classes (Shukla et al., 2019).

Land use is defined as a "direct link between land cover and human actions in its environment (socioeconomic functions)" (di Gregorio, 2005). Furthermore, it refers to "the purposes or functions that humans assign to a place and how they interact with the land," also classifying into broad and detailed categories (Pongratz et al., 2018). It is important not to confuse these terms, although this is often done (di Gregorio, 2005; Pongratz et al., 2018). Organizations such as the IPCC, FAO, IUFRO, and CIFOR use six broad categories that combine land cover classes and land uses: forest land, cropland, grassland, wetlands, settlements, and other land. This helps standardize national GHG inventories (IPCC, 2003).

Land cover change refers to the transition from one land cover class to another due to changes in land use, natural conditions, or land management over time (Pongratz et al., 2018; Shukla et al., 2019). Monitoring these changes is crucial for obtaining reliable information on terrestrial phenomena, allowing studies on the impacts of climate change, the quantification of carbon sinks, and the management of water resources (Latham et al., 2014).

Various methodologies to classify land cover vary in spatial resolution, scale, and definition of use categories. These differences can affect management decisions based on this information. For this reason, global standardization systems, such as the GLC-SHARE database, have been proposed to facilitate comparison and avoid information biases (Latham et al., 2014). Land cover is an essential climate variable (ECV) for monitoring climate change, which is crucial for quantifying carbon sinks and changes in forest extent and landscape flows (Bojinski et al., 2014).

Since the 1980s, multiple systems have been developed to monitor land cover. These include remotely sensed datasets with different spatial and temporal resolutions, such as MODIS Land Cover and CORINE Land Cover (CLC). These tools are essential for management decisions and policy evaluation (Latham et al., 2014; Martínez-Fernández et al., 2019; Pérez-Hoyos et al., 2012). Furthermore, categories defined by the IPCC, such as AFOLU and LULUCF, are central to national reporting for the Paris Agreement (Shukla et al., 2019).

Since 1985, the European Commission's CORINE program has collected environmental information relevant to member states, with land cover inventories updated in 1990, 2000, 2006, 2012, and 2018, providing accurate data for various investigations (Büttner et al., 2021). Since 1990, numerous investigations have been based on the CLC inventory and the European database, underlining their importance in environmental analysis and policy planning (Bielecka & Jenerowicz, 2019; Cabral et al., 2016; Feranec et al., 2016; Ramankutty & Foley, 1999; Reinhart et al., 2021; Waser & Schwarz, 2006). In the forestry sector, land cover monitoring is applied in studies of phenology, forest fires, pests, diseases, illegal logging, storm damage, drought monitoring, and carbon fluxes. These studies have generated vital concepts for the interpretation of the observed patterns such as afforestation (planting activities on land not classified as forest), reforestation (planting and natural regeneration activities on land classified as forest), and deforestation (activities that remove forest cover to non-forest land use) (Atzberger et al., 2020; Feranec et al., 2010; Rufino et al., 2019).

Land cover change is crucial in studying and implementing economic instruments and forest policies. It directly affects the ecosystem services forests provide, such as climate regulation, water purification, and biodiversity (Cabral et al., 2016). Quantifying these changes allows for designing and evaluating economic instruments like payments for environmental services (PES), which encourage the conservation and sustainable use of forest resources (N. Lin et al., 2019). Additionally, programs like REDD+ depend on accurate monitoring of changes in forest cover to measure emissions reductions and determine financial incentives. Information on land cover changes is also essential for developing adaptive management strategies, identifying priority areas for conservation, and quickly responding to illegal activities such as poaching (IPCC, 2003).

Likewise, land use planning at the national and local levels benefits from a clear understanding of how land cover changes, allowing agricultural and urban development to be balanced with the conservation of natural resources (Shukla et al., 2019). Changes in land cover also directly impact communities that depend on forest resources, affecting their livelihoods and necessitating policies that consider these socioeconomic impacts. Finally, continuous monitoring of land cover ensures compliance with forest laws and regulations, using remote sensing tools and geographic information systems (GIS) for efficient, large-scale surveillance (Atzberger et al., 2020). This data informs decision-making and ensures that forestry policies are practical and beneficial to the environment and local communities.

4. METHODOLOGY

4.1 Study Area

The study is focused on the European Union, comprised of 27 member states. These encompass Austria (AT), Belgium (BE), Bulgaria (BG), Croatia (HR), Cyprus (CY), Czech Republic (CZ), Denmark (DK), Estonia (EE), Finland (FI), France (FR), Germany (DE), Greece (GR), Hungary (HU), Ireland (IE), Italy (IT), Latvia (LV), Lithuania (LT), Luxembourg (LU), Malta (MT), Netherlands (NL), Poland (PL), Portugal (PT), Romania (RO), Slovakia (SK), Slovenia (SI), Spain (ES), and Sweden (SE) (see Figure 1a). Various case studies were conducted for each objective, incorporating different combinations of EU countries due to data availability.

The analysis of forest policies, SWOT analysis, and identification of economic instruments was conducted across the European Union, including Austria and the Czech Republic (see Figure 1a, d, e). Additionally, an assessment of wood consumption and its implications for economic instrument utilization was carried out in the 15 EU countries, collectively representing over 96% of industrial roundwood consumption, according to the Jenks Natural Breaks classification. Specifically, these countries are Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Italy, Netherlands, Poland, Portugal, Romania, Slovakia, Spain, and Sweden (see Figure 1c).

In-depth interviews were conducted in twelve countries where stakeholders responded to invitation emails and chose to participate in interview sessions voluntarily. These countries include Austria, Belgium, Czechia, Germany, Greece, Italy, Luxembourg, Poland, Slovakia, Slovenia, Spain, and Sweden (see Figure 1b). Lastly, an analysis of forest cover change and environmental investment in wastewater treatment plants (WWTPs) was performed in the Czech Republic (see Figure 1d). Brief descriptions of the European Union, Austria, and the Czech Republic are provided below, as these countries were selected for the various case studies on economic instruments.

The European Union (EU) is an economic and political organization made up of 27 European countries to promote cooperation where part of their sovereignty has been delegated to common institutions to democratically make decisions on matters of common interest such as health, environment, climate, foreign relations, security, justice, and migration. The EU has some of the highest environmental standards in the world to protect the environment and biodiversity, minimize risks to human health, and promote the transition to a circular economy (European Commission & Directorate-General for Communication, 2020). For this reason, the EU was selected as an area of study to identify and understand how the use of economic instruments for management, improvement of processes in the forestry sector, and the conservation of forests and their ecosystem functions are applied.

Austria is a Central European country that has been part of the EU since 1995 and has a population of 8,932,664 (European Union, 2018). The country has a national forestry strategy agreed upon with multiple actors to strengthen the forestry sector, increase biodiversity, and conceptualize the forest as a provider of various ecosystem functions of provision, regulation, maintenance, and culture (Federal Ministry for Sustainability and Tourism Austria, 2018). Likewise, it is aligned with other national policy documents that aim to allow the sustainable development of the forestry sector and diversification of forest products, functions, and services it provides for society. Austria had 24,344km2 of protected areas in 2021 and a total roundwood production of 18,903.72 thousand m3 (2019), while the total environmental taxes of agriculture, forestry, and fishing in 2019 are reported at 127.65 million euros (European Union, 2018).

The Czech Republic is a country in Central Europe that joined the EU in 2004 and has 10,701,777 inhabitants (European Union, 2018), is located between latitudes 48° and 51° N and longitudes 12° and 19° E, in the temperate zone of the northern hemisphere with an area of 78,870 km2 and is divided into 14 regions (Český statistický úřad, 2020). The national forestry strategy was updated and launched in 2020. The action plan was established in 2021, meaning its implementation is in the initial stages, and the modifications proposed for managing the forestry sector still need to be observable. Czechia in 2021 reports 17,273 km2 of protected areas, and a total roundwood production of 32,586 thousand m3 (2019), while the total environmental taxes of agriculture, forestry, and fishing in 2019 are reported at 169.66 million euros (European Union, 2018).

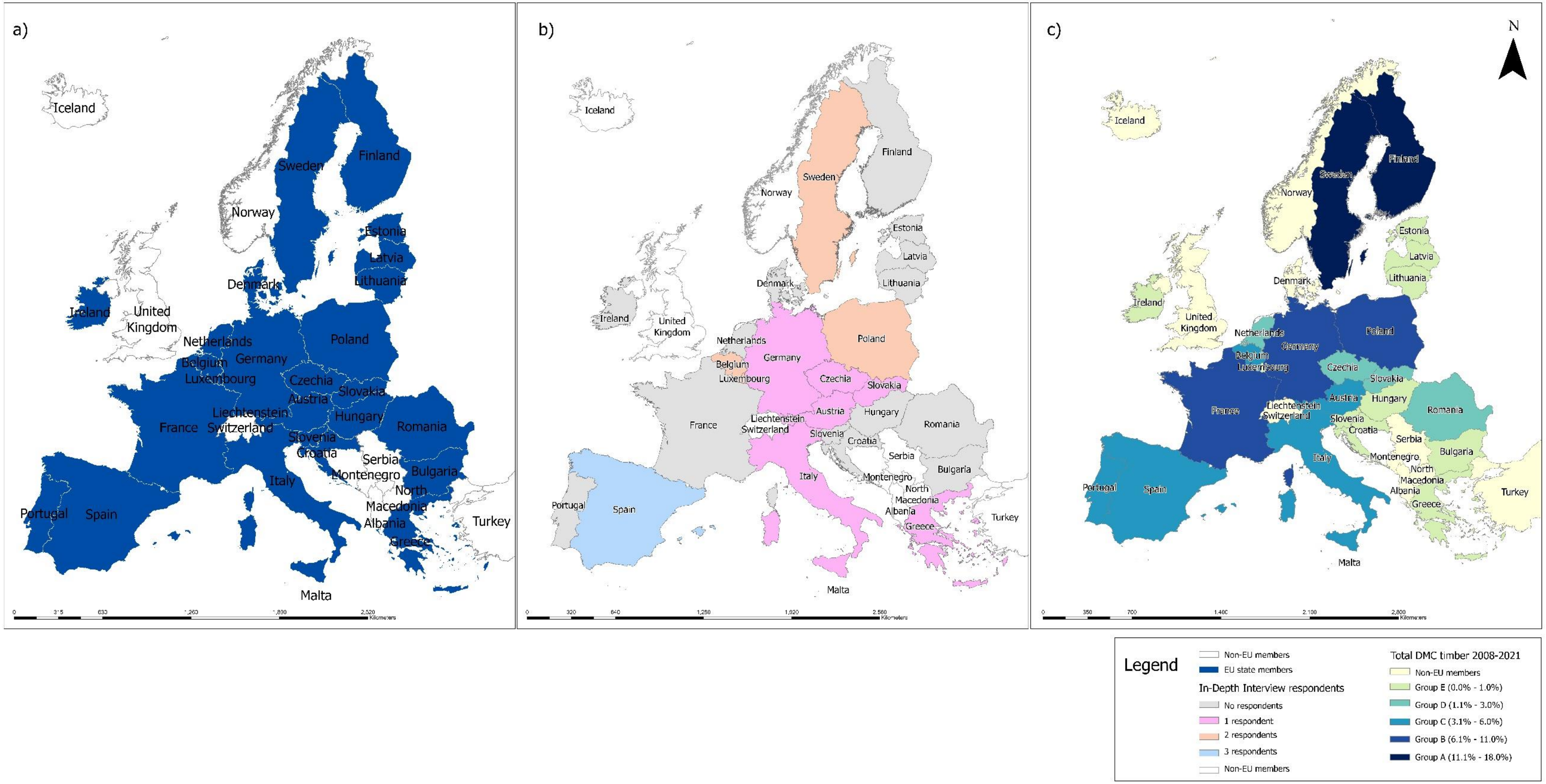


Figure 1. Location of the study area. a) Member countries of the European Union. b) Geographic distribution of the number of participants per country for in-depth interviews. c) Classification of countries according to domestic material consumption of wood.

4.2 Data Selection, Acquisition and Preprocessing

The selection of data and information was guided by their relevance to the study objectives and the accessibility of sources. Various academic and scientific databases, including Scopus, Scielo, ResearchGate, ScienceDirect, and Web of Science, were consulted, alongside governmental and organizational reports. This comprehensive approach facilitated a thorough literature review of economic instruments, associated policies, and implementation programs within the EU context.

Furthermore, primary data were obtained through in-depth interviews and the Czech national survey. These methods provided valuable insights into the practical utilization of economic instruments from the perspective of forestry stakeholders. Additionally, secondary data for the research were sourced from reputable institutions such as Eurostat, the United Nations Economic Commission for Europe (UNECE), FAO, national statistical agencies, and organizations specializing in economic instrument research, such as, OECD, which offer open-access databases.

Based on the chosen methodology, initial analyses and database construction were conducted using Microsoft Office Excel (Microsoft 365 MSO, 2023). Qualitative analysis was undertaken with Atlas.ti (version 24.1.0.30612), while diagrams and figures were crafted using Microsoft Office PowerPoint (Microsoft 365 MSO, 2023). In-depth interviews were facilitated via Microsoft Teams (Version 1.5.00.21668) and subsequently processed with Microsoft Office Word (Microsoft 365 MSO, 2023).

For quantitative analysis, calculations employing the multiple panel regression method were executed using R Studio software (Posit team, 2023), leveraging the 'linear models for panel data' (PLM) package. The statistical analysis of forestry perceptions was performed using IBM SPSS Statistics version 25 (IBM Corp., Armonk, NY, USA). Lastly, the analysis of Czech land cover changes and the visualization of spatial data were conducted using ArcGIS Pro (Esri, 2023).

4.3 Qualitative Analysis

To answer the research question, what specific economic instruments, including policies, incentives, and mechanisms, are effective in stimulating climate change adaptation within the EU forestry sector, and what are the expected results? A review and selection of strategic documents of the forestry sector was carried out to identify the existing economic instruments and financing schemes implemented in the forestry sector of the EU, Austria, and the Czech Republic. The central documents under review were the forestry strategies and financing programs, including the forestry strategy, the forestry law, and financing programs, including the EU's long-term Budget and Next Generation EU, the European Agricultural Fund for Rural Development (EAFRD), LIFE program, Horizon 2020, and European Structural and Investment Funds. For more information about the selected documents and their content, see results section 5.1.1.

4.3.1 SWOT Analysis

The SWOT analysis was selected to assess the strengths, weaknesses, opportunities, and threats of the economic instruments available in the EU forestry sector. Through content analysis of EU, Austrian, and Czech forestry policy documents, a series of questions were established for each SWOT component to extract specific quotes and relevant aspects of the available economic instruments, their use, evaluation, performance, and other elements that were found suitable for analysis. The questions include favorable and unfavorable aspects for achieving the objectives of the identified economic instruments (see Appendix 1).

SWOT analysis is a strategic assessment technique that emerged in the 1960s in the United States (Baudino et al., 2017). It was initially developed by Albert Humphrey at Stanford University during a research project to identify why companies had strategic planning problems. Since then, it has become a popular tool used in various contexts, such as business management, strategic planning, policy formulation, project management, community development, and strategic planning at the government level (Baudino et al., 2017; Helms & Nixon, 2010).

SWOT analysis is used to examine both the internal and external environment of an entity, policy, community, project, etc. By identifying and understanding these key factors, effective strategies can be developed to maximize strengths, address weaknesses, capitalize on opportunities and mitigate threats, to achieve positive and sustainable results (Arsić et al., 2017; Datta, 2020). Consists of:

- Strengths: The internal resources and capabilities that can provide a competitive advantage.
- Weaknesses: Internal limitations and deficiencies that could hinder performance and achieving goals.

- Opportunities: Positive external factors that can be taken advantage of to improve the current situation or to achieve goals.
- Threats: Negative external factors that represent challenges or risks and that could prevent the achievement of objectives.

ADVANTAGES AND LIMITATIONS OF SWOT ANALYSIS

Utilizing the SWOT analysis methodology offers several advantages across various contexts. Firstly, it furnishes a holistic perspective of the entity, policy, community, project, or any subject under scrutiny, thereby aiding in a comprehensive understanding of its current state. Moreover, it serves as a valuable tool for pinpointing key areas for strategic planning, allowing stakeholders to allocate resources efficiently and prioritize objectives. Additionally, by factoring in both internal strengths and weaknesses along with external opportunities and threats, it empowers decision-makers to make well-informed choices that are grounded in a nuanced understanding of the landscape. Lastly, the participatory nature of SWOT analysis fosters collaboration and dialogue among diverse stakeholders, fostering a sense of ownership and collective responsibility towards achieving shared goals.

While SWOT analysis offers valuable insights, it also presents certain limitations to consider. Firstly, its tendency to categorize factors into four dimensions may lead to an oversimplified portrayal of reality, potentially overlooking nuanced complexities within each category. Moreover, the subjective nature of interpreting these factors introduces the risk of bias, as interpretations may vary depending on the perspectives of the individuals conducting the analysis. Additionally, while SWOT analysis identifies strengths, weaknesses, opportunities, and threats, it may fall short in providing explicit guidance on how to translate these findings into actionable strategies, leaving decision-makers grappling with the challenge of operationalizing the insights gleaned from the analysis.

4.3.2 QUALITATIVE CONTENT ANALYSIS

Qualitative content analysis (QAC) serves as a research technique employed to delve into and grasp the essence of various forms of unstructured data, including texts, documents, images, and videos (Elo & Kyngäs, 2008). This method adopts a systematic yet flexible approach, facilitating an in-depth exploration of content nature and context. By meticulously interpreting the content, researchers uncover underlying patterns, themes, meanings, and relationships (Zhang & Wildemuth, 2011). Widely applied across diverse fields such as social sciences, psychology, education, communication, health, and policymaking, qualitative content analysis offers a qualitative lens to dissect complex phenomena.

While over 20 software programs exist for qualitative content analysis, each possessing distinct advantages and limitations in terms of usability and acquisition, our study opted for the ATLAS.ti Windows version. This software systematically organizes, codes, categorizes, and analyzes qualitative data (Zhang & Wildemuth, 2011), offering researchers a robust toolset for conducting rigorous qualitative analyses.

This study's quantitative content analysis process was structured around three pivotal phases: preparation, organization, and presentation (Elo & Kyngäs, 2008). During the preparation phase, the content was carefully selected and prepared, establishing a conceptual framework or delineating analysis categories. The fundamental unit of analysis was defined as any text, regardless of size, encapsulating a topic pertinent to the research questions.

Correspondingly, the organization phase mirrors qualitative content analysis's coding and categorization procedures. Here, analysis units were discerned, and codes or labels representative of salient topics were allocated. During this stage, categories and the coding schema were meticulously crafted based on insights from the literature review, prior knowledge, and collected data. Furthermore, each code was accompanied by a precise definition to forestall misinterpretations during the coding process. For each qualitatively analyzed objective, different codes were used according to the needs of the research. Following the establishment of the coding scheme, rigorous testing ensued, employing a small sample to validate and refine the methodology before its application across the entire dataset.

Finally, the reporting phase includes interpretation and analysis in qualitative content analysis, where emerging patterns, relationships, and meanings within the content are analyzed to present clear and coherent findings. In this phase, data coding was completed, and code diagrams and other graphs were prepared to present the results.

ADVANTAGES AND LIMITATIONS OF QUALITATIVE CONTENT ANALYSIS

Qualitative content analysis offers several significant advantages in the research process. First, it allows for thoroughly exploring the content and addressing topics from a holistic and detailed perspective. Its flexibility and adaptability are notable, as it can be applied to various data sources and research contexts, making it a versatile tool for researchers in various fields. Furthermore, qualitative analysis facilitates the identification of patterns, trends, and underlying meanings in the analyzed content, which contributes to a deeper and more contextualized understanding of the phenomena studied (Elo & Kyngäs, 2008).

However, qualitative content analysis also has some limitations, such as the coding and analysis process can be intensive and laborious, consuming a significant amount of time and resources. Furthermore, the interpretation of the content can be subjective and influenced by the researcher's biases, which could affect the results' objectivity. Finally, the validity and reliability of the analysis may be compromised if clear and consistent coding criteria are not established, which could affect the accuracy and reliability of the findings (Elo & Kyngäs, 2008; Zhang & Wildemuth, 2011).

4.3.3 In-Depth Interviews

To answer the research question, how do different stakeholders in the EU forestry sector perceive the effectiveness and accessibility of economic instruments and financing schemes aimed at facilitating adaptation to climate change in forest management and forestry wood production? The in-depth interview technique was used to obtain detailed information about the economic instruments, as well as the participants' motivations, perceptions, and experiences of use.

In-depth interviews are a widely used qualitative research technique to obtain a detailed and contextualized understanding of various topics. During interviews, researchers interact directly with participants, using open-ended and semi-structured questions to explore in depth their experiences, opinions, and perspectives on a specific topic (Boyce & Neale, 2006). These interviews are used in various research fields, such as sociology, psychology, anthropology, health, and policy formulation, among others. Its main objective is to obtain rich and detailed information on the topics investigated and to delve into the participants' motivations, perceptions, and experiences (Robles, 2011).

For this research, a guided questionnaire was developed, comprising 19 semi-structured open questions addressing aspects related to forest ecosystem services, climate change adaptation measures, and economic instruments (see Appendix 2). These questionnaires, crucial tools for gathering specific information from study subjects (Robles, 2011; Sansoni, 2011), were crafted as a framework for the interviews. Throughout the process, questions were adjusted based on responses and experiences observed during the interviews.

Previously, in July 2022, the guide underwent testing with three doctoral students in forestry, who offered valuable feedback to refine the initial questions and enhance the interview process.

To establish contact with forestry stakeholders in each country of interest, a database was compiled using information from FAO National Focal Points and other forestry institutions. This database provided access to contact information and the expertise of key individuals for the investigation, considering criteria such as years of experience in the forestry sector. Subsequently, 350 individuals were invited to participate in the study via email, outlining the background, objectives, and methodology. While 28 individuals expressed interest, only 18 were available and participated in the in-depth interviews, scheduled in 60-minute intervals after receiving confirmation from interested parties.

Between August 1 and September 30, 2022, a total of 18 online interviews were conducted using Microsoft Teams (Version 1.5.00.21668) (see Table 1). Consent was obtained from participants to record the interviews, ensuring comprehensive capture of information, and preventing loss. Interviews were transcribed using the transcription feature of the Teams application and processed in Microsoft Word. Except for four instances where Spanish was used, all interviews were conducted in English, with the content of Spanish interviews translated into English during transcription. The intelligent textual method was employed for transcriptions, eliminating fillers and redundant comments to produce more concise and readable transcripts without altering the essence of the interviewees' responses (McMullin, 2021). Finally, responses were anonymized to safeguard the confidentiality of participants.

It is essential to highlight that in-depth interviews do not seek to generalize for an entire population but instead focus on an inductive process that depends mainly on the information provided by the interviewees and the aspects they consider relevant and significant within their context and experience (Dworkin, 2012; Robles, 2011). The concept of saturation is the most determining factor when reflecting on the sample size in qualitative research. Although some studies suggest that between 5 and 50 participants are appropriate, there is considerable debate (Mason, 2010). In this study, priority was given to the data quality, the research scope, the topic, the amount of useful information obtained from each participant, and the use of saturated data.

Table 1. Profile of interview participants

#	GENDER	COUNTRY	#	GENDER	COUNTRY
1	Male	Austria	10	Male	Poland
2	Male	Belgium	11	Male	Poland
3	Male	Belgium	12	Male	Slovakia
4	Male	Czech Republic	13	Male	Slovenia
5	Female	Germany	14	Male	Spain
6	Female	Greece	15	Male	Spain
7	Male	Italy	16	Female	Spain
8	Male	Luxembourg	17	Female	Sweden
9	Male	Luxembourg	18	Male	Sweden

ADVANTAGES AND LIMITATIONS OF IN-DEPTH INTERVIEWS

In-Depth interviews allow for fluid and flexible conversation, making it easy for participants to share their ideas freely and in detail. A key advantage of in-depth interviews is their ability to provide an enriched understanding of the topics studied. They allow you to explore the diversity of perspectives and experiences of participants, identify emerging patterns and themes, and establish meaningful relationships between the data collected. Additionally, they promote the active participation of participants in the research process, which can lead to greater trust and cooperation (Boyce & Neale, 2006).

However, in-depth interviews also have some limitations. They can be intensive in terms of time and resources, both in the preparation phase and in conducting and analyzing the interviews. Additionally, interpretation of data may be affected by researcher bias, and generalizability of findings may be limited due to the qualitative and contextualized nature of the interviews (Boyce & Neale, 2006).

4.3.4 COMPUTER-ASSISTED WEB INTERVIEWING

Computer-Assisted Web Interviewing is a survey technique that takes advantage of Internet connectivity to collect data through online interviews. Participants access an online questionnaire through a web browser and answer survey questions using their computer, tablet, or smartphone. It is used in a variety of research studies and opinion surveys to collect data from a wide audience efficiently. It is especially useful when you need to reach a geographically dispersed population or when you want to collect data quickly and inexpensively (Randolph et al., 2006; Sowa et al., 2015; Zijlstra et al., 2017).

Two Computer-Assisted Web Interviews (CAWI) were conducted for this research. The first, in 2020, focused on the perception of ecosystem services, while the second, in 2022, surveyed broader topics related to forests in the Czech Republic and their various uses. The perception of forest ecosystem services (FES) refers to any opinion or thought regarding their characteristics (Millennium Ecosystem Assessment, 2005). This document defines performance as the level at which respondents perceive selected forest products or services based on their knowledge and experiences (Van Ryzin, 2004).

In November 2020, a CAWI was employed in collaboration with the external market research firm Stem/Mark, a.s. Recruitment was done by sending questionnaires to potential respondents on the company's list, selected according to age, gender, education level, region, and village size. This sample included 1509 respondents aged 16 to 65 from the Czech Republic. All returned questionnaires were included in the analysis (100%). The questionnaire was designed as a closed-ended tool, featuring four levels of respondents' expectations regarding Czech forest services related to water supply and regulation, ranging from 1 (strongly disagree) to 4 (strongly agree). An additional category was included for those unable to judge. Five levels of importance were used to rate the perceived performance of Czech forest services related to water supply, where 1 indicated little importance, and 5 indicated high importance. Respondents' educational levels were categorized as secondary education without a final exam (maturita), with a certificate, or higher education (university level).

To collect data on the use of economic instruments by the public in the Czech Republic, a second national survey was carried out in 2022. This survey targeted online respondents aged 18 to 65, distributed proportionally according to the regional population size (NUTS level 3). The survey was conducted in collaboration with the external market research company ppm factum Research Ltd. Respondents completed a structured questionnaire that included sociodemographic details and general questions about using economic instruments. An option labeled "other" option was thoughtfully included to allow participants to contribute supplementary information, which was subsequently categorized and coded for in-depth analysis.

Given the nuanced nature of economic instrument usage, particularly in bridging theory with practical application (Huertas-Bernal & Hájek, 2023), a specific focus was directed toward forest owners or managers. These respondents were presented with three additional queries within the national survey framework. These questions sought to elucidate their perspectives on subsidies, technical support, payment reception, and interest in potential state subsidies contingent upon logging restrictions. Furthermore, participants were prompted to contemplate the funding responsibility for forest ecosystem services beyond timber production across various forest management scenarios. Due to the exploratory nature of the research and the complexity associated with economic instrument concepts and their practical implementation, a minimum sample size was not prescribed. This decision was made to accommodate the intricacies of the subject matter and ensure a thorough investigation of participant insights.

ADVANTAGES AND LIMITATIONS OF COMPUTER-ASSISTED WEB INTERVIEWING

Online surveys offer some significant advantages for data collection. Accessibility is one of the main benefits, as participants can complete the survey from anywhere with an Internet connection, increasing accessibility and convenience. Additionally, the CAWI is highly efficient, allowing data to be collected quickly and effectively, eliminating the need to use paper questionnaires or conduct telephone interviews. This efficiency also carries an economic advantage, as it can be more economical by removing the costs associated with printing and distributing paper questionnaires. Automating the online data collection process makes managing and further analyzing the collected data easier, saving time and resources (Randolph et al., 2006; Sowa et al., 2015).

However, the CAWI also has certain limitations. For example, the availability of Internet access may limit survey participation, excluding certain population groups who may not have technological access or skills. Additionally, the sample obtained through the CAWI may be biased toward individuals with greater technological access and abilities, which could affect the representativeness of the survey results. Additionally, participants may not pay the same attention to online questions as they would in a face-to-face interview, which could influence the quality of the answers (Sowa et al., 2015; Zijlstra et al., 2017).

4.4 Quantitative Analysis

4.4.1 MULTIPLE PANEL REGRESSION MODEL

To answer the research question, what are the multifaceted implications of the utilization of economic instruments, including policies and incentives, on market dynamics, resource utilization, forest management practices, and socioeconomic aspects within the EU timber industry? The multiple panel regression technique was used to examine the relationship between industrial roundwood consumption and imports, exports, and tax payments, considering the variations between the selected EU countries for 14 years.

The Multiple Panel Regression Model (MPRM) is a statistical technique used to analyze panel data, consisting of observations of multiple individual economic units over two or more periods (Arellano & Honoré, 2001; Chamberlain, 1984). These particular units, often called cross-sectional units, can represent various entities, such as individuals, companies, industries, or countries, as in this study. For more than 40 years, panel data sets have been available to examine the relationship between a dependent variable and multiple independent variables, considering variations between individuals and over time (Arellano & Honoré, 2001; Chamberlain, 1984). It is applied when you have longitudinal data that shows changes in variables over time, and you seek to understand how these variables relate to each other and how these relationships evolve (Pesaran, 2015). Using the MPRM involves estimating a series of regression equations, one for each cross-sectional unit, over different periods. These equations capture the relationship between the dependent and independent variables within each data panel. The results of these equations are then combined to provide a comprehensive understanding of the overall relationship between the variables (Pesaran, 2015).

In recent years, this technique has seen advancements and has become increasingly accessible to researchers. It offers the capability to analyze a large volume of data from diverse individual units, and specialized software has been developed to facilitate calculations and ensure replicability across various fields of study (Croissant & Millo, 2018; Pesaran, 2015). Examples include the Panel Study on Income Dynamics and national longitudinal surveys conducted in the United States and Europe, covering various socioeconomic factors such as populations, living conditions, labor markets, and economic growth (Anton & Afloarei Nucu, 2020; Baltagi, 2021; Charfeddine & Mrabet, 2017; Ciarreta & Zarraga, 2010; Çoban & Topcu, 2013; Pesaran, 2015).

POOLED MODEL

The Pooled Ordinary Least Squares (Pooled OLS) model is a regression technique for analyzing panel data. The model assumes that the coefficients of the independent variables are constant over time and between individuals (or entities). This model does not consider possible individual heterogeneities or the specific effects of each period (Pesaran, 2015). The Pooled OLS model uses the following formula:

$$y_{it} = \alpha + \beta x_{it} + \epsilon_{it} \quad (1)$$

Where: y_{it} is the dependent variable for the individual *i* at time *t*. α is the intercept common to all individuals and periods. β is the vector of coefficients applied to the independent variables x_{it}. $X_{it}$is the vector of independent variables for individual *i* at time *t*. ϵ_{it} is the error term, which is assumed to have zero mean and constant variance.

FIXED-EFFECTS (FE) MODEL

The fixed effects model focuses on studying the impact of variables that vary over time, controlling for the specific characteristics of each individual that do not change over time. This control is done by including individual fixed effects in the model, allowing each individual to have their intercept (Pesaran, 2015). The model formula is:

$$y_{it} = \alpha_i + \beta x_{it} + \epsilon_{it} \quad (2)$$

In this equation, y_{it} represents the dependent variable for the individual *i* at time *t*. α_i is the intercept common to all individuals and periods. β is the vector of coefficients applied to the independent variables x_{it}. $X_{it}$is the vector of independent variables for individual *i* at time *t*. ϵ_{it} is the error term.

RANDOM-EFFECTS (RE) MODEL

The random effects model is used in data analysis to model variability between groups or heterogeneous entities (Pesaran, 2015). Unlike the fixed effects model, the random effects model considers the effects as random variables that follow a specific distribution. The basic formula of the random effects model for a linear model is:

$$y_{ij} = X_{ij}\beta + Z_{ij}\, b_i + \epsilon_{ij} \qquad (3)$$

Where y_{ij} is the variable of interest for the ith unit in the jth group. X_{ij} is the vector of covariates for the ith unit in the jth group. β is the vector of fixed coefficients. Z_{ij} is the vector of covariates for the random effects. b_i is the random effects vector for the ith unit, which follows a specific distribution. ϵ_{ij} is the random error associated with the ith unit in the jth group, which follows a normal distribution with mean zero and variance σ^2.

Several transformations seek to eliminate unobservable heterogeneity between individual units in a random effects model, thus converting it into a fixed effects model. Transformations are based on different approaches to remove random effects from observations, either by taking differences between the observed values and the mean values of each unit (Swamy-Arora), adjusting observations using regression models within each unit (Wallace -Hussain and Nerlove), or by decomposing the total variance of the observations into variance components that come from random effects and random errors (Amemiya) (Arellano & Honoré, 2001; Baltagi, 2021). Once the transformation has been performed, the resulting model is more straightforward to interpret, as it eliminates the complexity of random effects and allows for a more precise analysis of the relationships between the explanatory variables and the dependent variable (Pesaran, 2015).

F TEST FOR INDIVIDUAL EFFECTS

The F test for individual effects compares two models, one constrained and one unconstrained, allowing one to determine whether individual effects are significant in a fixed effects regression model. The restricted model does not include personal effects and only contains the coefficients of the explanatory variables' standard to all units. All individual effects are assumed to be equal to zero. At the same time, the unrestricted model includes both the personal effects and the coefficients of the explanatory variables' standard to all units (Baltagi, 2021; Pesaran, 2015).

HAUSMAN TEST

The Hausman test determines which estimator is more efficient in a random versus fixed effects model. It is based on comparing the coefficient estimates obtained using the random effects estimator (which assumes that the random effects are uncorrelated with the explanatory variables) with the estimates obtained using the fixed effects estimator (which allows the individual effects to be correlated with the explanatory variables). The Hausman test compares the differences between these estimates under the null hypothesis that the two estimators are consistent. If the differences between the estimators are systematically different from zero, the null hypothesis is rejected, suggesting that one of the models is more efficient and preferable to the other (Baltagi, 2021; Pesaran, 2015).

The data used in this study is sourced from secondary sources, including Eurostat, the United Nations Economic Commission for Europe (UNECE), and FAO. This dataset spans 14 years, from 2008 to 2021, and includes observations from fifteen European Union member countries. The focus of the study is on the domestic material consumption of timber (DMC) as the response variable, and the predictive variables include exported industrial roundwood (EIR), imported industrial roundwood (IIR), and total environmental taxes (TET). For more detailed information, please refer to Table 2.

Table 2. Overview of variables analyzed in the Multiple Panel Regression Model

VARIABLE	UNIT	DEFINITION	SOURCE
Domestic material consumption of timber (DMC)	Thousand tonnes	DMC represents the total materials directly utilized by an economy, calculated as the annual volume of raw materials extracted plus physical imports minus physical exports per country. It specifically refers to using materials to produce semi-finished wood products, finished goods derived from semi-finished products, and by-products. However, it does not encompass the direct wood consumption of individual consumers within each country.	Material Flow Accounts (Eurostat, 2023b)
Exports of timber (EIR) **Imports of timber (IIR)**	EUR per m3, current prices	Timber exports and imports denote the value of industrial roundwood traded, either exported or imported, measured in annual volume. Initially denominated in USD per square meter at current prices, these values were subsequently converted into EUR using the annual US dollar/Euro exchange rate provided by the European Central Bank (ECB, 2022).	TIMBER database (UNECE & FAO, 2023)

VARIABLE	UNIT	DEFINITION	SOURCE
Total environmental taxes (TET)	EUR current prices	TET refers to income in EUR generated from economic activities (taxpayers) exhibiting a specific and proven damaging environmental impact. It conforms to EU Regulation 691/2011 on European environmental economic accounts. The financial activities considered in this study include the manufacturing of wood and wood and cork products (division 16), the manufacture of paper and paper products (division 17), and the manufacture of furniture (division 31) following the NACE Rev.2 classification of economic activities.	Environmental taxes by economic activity (Eurostat, 2023a)

The regression equation for panel data is formulated as follows:

$$dmc_{it} = \alpha + \beta_1 eir_{it} + \beta_2 iir_{it} + \beta_3 tet_{it} + u_{it} \quad (4)$$

In this equation, dmc_{it} represents the domestic consumption of industrial roundwood material for a given EU Member State during a specific year. eir_{it} denotes the volume of industrial roundwood exported, iir_{it} represents the quantity of industrial roundwood imported, and tet_{it} represents the aggregate of total environmental taxes applied to wood manufacturing.

ADVANTAGES AND LIMITATIONS OF MULTIPLE PANEL REGRESSION MODEL

There are several advantages of the multiple-panel regression model in econometric analysis. A key benefit is its ability to control individual heterogeneity, meaning it can consider differences between individuals, companies, states, or countries. This is crucial because ignoring this heterogeneity in time series or cross-sectional studies can lead to biased results. For example, omitting certain variables can introduce biases when modeling consumption as a function of lagged consumption, price, and income. Panel data can address this problem by controlling for state and time-invariant variables. Additionally, panel data provides more informative and variable-rich data sets than time series or cross-sectional data. This means that more reliable parameter estimates can be obtained, and the adjustment dynamics can be studied more effectively. Furthermore, panel data models allow us to identify and measure effects that may not be detectable in purely cross-sectional or time series data. In addition, panel data offer the advantage of measuring variables more accurately at the micro level, reducing biases resulting from aggregation over companies or individuals (Baltagi, 2021; Pesaran, 2015).

However, panel data also has limitations that should be considered. These include design and data collection issues, such as problems with survey design and measurement errors. Selectivity issues, such as self-selectivity, nonresponse, and attrition, can also affect the reliability of panel data analysis. Furthermore, the short dimension of micro panel time series and the cross-section dependence in macro panels can pose challenges for accurate inference (Baltagi, 2021; Chamberlain, 1984).

4.4.2 Forest Covers Gains and Losses

To answer the research question about the effects of economic instruments on water quality and their implications for forests in the Czech Republic, a multidisciplinary analysis was conducted. Using perception surveys, analyses of changes in forest and water body landcovers, elimination efficiency of water quality parameters, assessments of environmental protection investments, and perceptions of forest ecosystem services related to freshwater provision.

The land cover of the Czech Republic in hectares was extracted from the freely available Corine Land Cover (CLC) database of the Copernicus Land Monitoring Service (European Union et al., 2021) and processed with ArcGIS Desktop version 10.8 (Esri, 2019). The database was developed by interpreting satellite images from Landsat, SPOT, IRS P6 LISS, RapidEye, and Sentinel-2; each inventory and update were developed according to the technology and information available during the preparation period. The CLC database contains an inventory and four updates from 1990, 2000, 2006, 2012, and 2018. It has evolved in response to advances in instruments and image interpretation and processing methods, with a scale of 1:100,000 and a minimum mapping unit (MMU) of 25 hectares. The geometric precision for 1990 is ≤50 m, while for 2000, 2006, and 2012, it is ≤25 m, and for 2018, it is ≤10 m using data from the Sentinel-2 satellite. This freely accessible product allows monitoring of land cover changes over time, providing reliable information about terrestrial phenomena (European Union et al., 2021). For more information on the methodology and usage instructions, see the following link: https://land.copernicus.eu/pan-european/corine-land-cover (accessed May 2024).

The CLC database includes the following categories: (1) artificial surfaces; (2) agricultural areas; (3) forest and semi-natural areas; (4) wetlands; and (5) bodies of water, comprising 44 land cover classes. The CLC in the Czech Republic consists of 29 classes, while Austria has 32 classes. The categories of forest are described in more detail in Table 3. The forest areas analyzed in this paper fall under broadleaf, coniferous, and mixed forests, compared with information collected from the Ministry of Agriculture (MoA) of the Czech Republic (Ministry of Agriculture of the Czech Republic, 1999; Ministry of Agriculture of the Czech Republic (MoA), 2019). Meanwhile, data on water bodies were collected from CLC watercourses and water bodies and compared with national reports from yearbooks of the Czech Statistical Office, specifically Section 3.1, on land use balance every six years from 2000 to 2018 (Czech Statistical Office, n.d.).

Table 3. Summary of the CLC of forests and water bodies in the Czech Republic and Austria utilized in the studio according to the CLC nomenclature (Kosztra et al., 2019).

CLASSIFICATION		DEFINITION
Forest and semi-natural areas	311: Broad-leaved forest	Areas occupied by forests and woodlands with trees higher than 5 m and canopy closure of a minimum of 30%, or young shoots with the minimum cut-off-point of 500 subjects per ha. Vegetation formation predominated by broad-leaved species.
	312: Coniferous forest	Areas occupied by forests and woodlands with trees higher than 5 m and canopy closure of a minimum of 30%, or young shoots with the minimum cut-off-point of 500 subjects per ha. Vegetation formation predominated by coniferous species.
	313: Mixed forest	Areas occupied by forests and woodlands with trees higher than 5 m and canopy closure of a minimum of 30%, or young shoots with the minimum cut-off-point of 500 subjects per ha. Vegetation formation is neither broad-leaved nor coniferous species predominate.
Water Bodies	511: Water courses	Natural or artificial watercourses that function as drainage channels—minimum width for inclusion: 100 m.
	512: Water bodies	Natural or artificial bodies of water characterized by the presence of stagnant bodies of water for most of the year.

Adapted from (Kosztra et al., 2019).

A structured methodology was followed to analyze coverage change and thus identify forest gains and losses. First, the land cover layers corresponding to the different periods of interest (1990, 2000, 2006, 2012, and 2018) were imported. These layers were then clipped using the regional layer for the Czech Republic, downloaded from the Nomenclature of Territorial Units for Statistics (NUTS) 2021.

Subsequently, the "Raster Calculator" tool was used to subtract the coverage layers of each pair of periods, thus allowing the areas of change to be identified. This operation distinguished between loss and gain of land cover: areas where coverage decreased were identified as losses, while areas with increased coverage were identified as gains. The formula behind this calculation is:

$$Percentage\ of\ area\ change = \frac{Area\ (b) - Area\ (a)}{Area\ (b)}\ x\ 100\%, \qquad (5)$$

where $Area\ (b)$ was the forested landscape and water bodies (in hectares) at the earliest reported year, while $Area\ (b)$ referred to the final year.

The attributes resulting from the spatial analysis were exported to Excel for further manipulation and analysis. In addition, thematic maps were created that represented the areas of land cover loss and gain for each period. Finally, to ensure the precision of the results, tests of normality of the distribution of non-categorical data were performed using the Kolmogorov-Smirnov test. Non-parametric statistical tests, such as the Wilcoxon signed rank test, were also applied to compare the changes for the years 1990–2006, 2006–2018, and 1990–2018.

ADVANTAGES AND LIMITATIONS OF LAND COVER CHANGE ANALYSIS

The analysis of changes in vegetation cover provides a historical and up-to-date view of changes in land cover over time. This allows a complete understanding of patterns and change trends in forests and other natural areas. Additionally, specific areas where gains or losses of vegetation cover have occurred can be accurately and efficiently identified, facilitating the targeting of conservation and management efforts (Feranec et al., 2010, 2016).

However, it also has certain limitations. The spatial resolution of satellite data may limit the detection of changes in small or fragmented areas, which could underestimate the magnitude of local changes in vegetation cover. Additionally, the accuracy of the results can be affected by the subjective interpretation of satellite images and errors associated with data processing. Finally, although statistical tests are used to validate results, the precision of change estimates may vary depending on the quality of the input data and the complexity of the landscape analyzed (European Union et al., 2021; Martínez-Fernández et al., 2019).

4.4.3 REMOVAL EFFICIENCY OF WATER QUALITY PARAMETERS

Removal efficiency (RE) or load reduction on water quality refers to the ability of a wastewater treatment system to reduce the number of contaminants present in water. It is an indicator of the effectiveness of the treatment process to eliminate or reduce the concentrations of certain contaminant parameters. The RE is calculated by comparing the concentrations of these parameters in the water before and after treatment. It is generally expressed as a percentage indicating the proportion of contaminants removed by the treatment system (European Commission, 2019b; European Commission et al., 2020).

Raw data on the physicochemical parameters of water quality, including biological oxygen demand (BOD), chemical oxygen demand (COD), suspended solids, total nitrogen (total N), and total phosphorus (total P), as well as characteristics of wastewater treatment plants, were extracted from the annual reports of the Czech Statistical Office on water supply, sewerage, and watercourses for the period 2009-2019 (Czech Statistical Office, n.d.). The units for the measured parameters for both the influent and effluent of wastewater treatment plants are expressed in tons per year. The raw data specify that the biological oxygen demand was analyzed using a standard 5-day incubation period at 20 °C, and the chemical oxygen demand was measured using the dichromate method.

The removal efficiency for each water quality parameter assessed annually in this study was computed utilizing the subsequent formula (2):

$$RE\ or\ Load\ reduction\ (\%) = \frac{Inflow - Outflow}{Influent} x\ 100, \qquad (6)$$

Analyzing the quality of water in a territory can benefit the state of the forests due to the close interrelation between aquatic and terrestrial ecosystems. Forest health is intrinsically linked to water quality, as forests play a fundamental role in regulating hydrological cycles and protecting watersheds. Quality water contributes to maintaining biodiversity and the balance of forest ecosystems, providing healthy habitats for flora and fauna. Additionally, water pollution can have adverse effects on forests, such as soil acidification, vegetation degradation, and decreased forest productivity. Therefore, understanding and monitoring water quality is critical to promoting the health and resilience of forest ecosystems (European Commission, 2015; Gretchen et al., 1997; Millennium Ecosystem Assessment, 2005).

ADVANTAGES AND LIMITATIONS OF WATER REMOVAL EFFICIENCY

The use of water quality parameter removal efficiency provides a quantitative measure of the ability of wastewater treatment systems to reduce the contaminant load, allowing for an accurate assessment of the effectiveness of these infrastructures in protecting and conserving water resources. Additionally, by calculating removal efficiency for specific parameters, you can identify which contaminants are most effectively removed and which treatment areas may need additional improvements to address specific sources of contamination (European Commission, 2019b; European Commission et al., 2020).

Despite these advantages, the removal efficiency methodology also has some important limitations. The calculation of removal efficiency largely depends on the accuracy and reliability of input data on water quality in the influent and effluent of treatment plants. Any error or variability in these data could affect the accuracy of the results and the interpretation of treatment effectiveness. Additionally, removal efficiency can vary depending on treatment plant operating conditions and incoming water quality, making comparing different systems or time periods difficult. Therefore, it is essential to interpret removal efficiency results with caution and consider other environmental and operational factors that may influence the ability of treatment systems to protect water quality and aquatic ecosystems (Baun & Marek, 2013; European Commission, 2019b).

4.4.4 ENVIRONMENTAL PROTECTION EXPENDITURE ACCOUNTS

Environmental protection investment refers to expenses for acquiring assets for environmental protection and expenses related to environmental protection activities. In contrast, environmental noninvestment expenditure refers to operational activities, including wage costs, rent payments, energy and other materials, supplies, and payments for services of the companies that manage the activities. The wastewater management budget includes constructing water treatment plants and sewerage systems to control water quality and other activities and facilities to prevent pollution generation (Czech Statistical Office (CZSO), 2021; European Commission. Eurostat, 2010).

In the Czech Republic, various tools are available to address water pollution. These include taxes on the permitted discharge of wastewater into underground or surface sources, subsidies to manage pond sludge and mitigate flood damage, and voluntary programs such as the eco-labeling system EMAS (European Management and Audit Scheme). This study focused on environmentally motivated subsidies through environmental protection spending accounts. In 2019, more than CZK 10.7 billion was allocated to support water management.

Data on investments in environmental protection and non-investment environmental expenditures for wastewater management in the Czech Republic were obtained from the annual reports of the Czech Statistical Office on environmental accounts from 2005 to 2019 (in CZK thousands of current prices, with inflation, average exchange rate in 2019: EUR 1 = CZK 25.36) (Czech National Bank, 2019; Czech Statistical Office (CZSO), 2021). The correlation between investment in environmental protection and expenditure on environmental non-investment, and water pollution removal efficiency was examined using Spearman's nonparametric correlation for the period spanning 2005 to 2019.

ADVANTAGES AND LIMITATIONS OF ENVIRONMENTAL ACCOUNTS

One advantage of evaluating expenditure and investment in environmental protection is that it provides a clear and systematic structure to distinguish between spending to acquire assets for ecological protection and operational costs related to environmental protection activities. This allows a better understanding of how financial resources are allocated to address pollution and promote environmental sustainability. Furthermore, by analyzing the correlation between investment in environmental protection and efficiency in removing water pollution, possible causal relationships can be identified, and the effectiveness of environmental protection policies and programs in improving water quality can be determined (Herzig et al., 2008).

However, some significant limitations should be considered when interpreting the results. Correlation analysis does not necessarily imply a causal relationship between investment in environmental protection and efficiency in removing water pollution. Other factors, such as climatic conditions, industrial and agricultural practices, and changes in wastewater treatment infrastructure, can also influence water quality and the effectiveness of water management systems. Additionally, the availability and quality of data used in the analysis can affect the accuracy and reliability of the results, requiring careful consideration of potential biases and limitations in the interpretation of the findings (European Commission. Statistical Office of the European Union., 2017; Herzig et al., 2008).

4.4.5 Forests Ecosystem Services' Analysis

To compare the means of respondents' ages (non-categorical and normally distributed data) among regions, ANOVA was employed, while categorical data (such as gender, education level, city size, and frequency of forest visits) were analyzed using a chi-square test. Binary logistic regression was utilized to determine significant predictors of public expectations and the perceived performance level of Czech FES related to freshwater provision (where 1 represents a low score of public expectation/perceived performance level). The variables included in the analysis comprised age, gender (where 1 represents female), education level (where 1 represents maturita and higher), frequency of forest visits (where 1 represents rarely, twice a year, and less), city size, and region. Statistical significance in all analyses was determined with a p-value of less than 0.05.

5. Results

5.1 Application of Economic Instruments in the EU Forestry Sector

5.1.1 Core Documents

The documents chosen to identify the economic instruments available for the European forestry sector, Austria, and the Czech Republic are presented in Table 4. These 18 documents were selected for their significance in outlining the mission, vision, and management strategies concerning forests in the EU, Austria, and the Czech Republic. Additionally, they provide valuable insights into the policy instruments relevant to the forestry sector.

Table 4. Core Documents Selected for Economic Instrument Analysis in EU Forestry

DOCUMENT	KEY ASPECTS
New EU Forest Strategy for 2030	The strategy aims to protect, restore, and sustainably manage forests, in line with the European Green Deal and the 2030 Biodiversity Strategy. Additionally, it advocates for a sustainable forest bioeconomy, financial incentives for forest managers, and close collaboration with Member States and other relevant stakeholders (European Commission, 2021d).
Austrian Forest Strategy 2020+	This strategy serves as a model of good governance as it was collaboratively developed by 85 organizations involved in forest policy, including forest owners and interest representatives. It also incorporates financial incentives for forest owners and managers, aligning existing forest policy tools with national and international policy guidelines (Federal Ministry for Sustainability and Tourism Austria, 2018).
The Concept of State Forestry Policy by 2035	This strategy addresses the critical state of forests due to changing environmental conditions. Despite the pessimistic outlook, the strategy aims not to surrender to unfavorable developments. Instead, it proposes utilizing legislative, financial, and informational instruments to preserve forests for future generations while also sustaining the timber industry (Government of the Czech Republic, 2021).

DOCUMENT	KEY ASPECTS
Sustainable Forestry and the European Union: Initiatives of the European Commission	Member States implement EU forestry policies within a defined framework of property rights based on longstanding national and regional laws and regulations, which prioritize long-term planning. Furthermore, the EU allocates significant funds and employs numerous officials and experts to pursue its forestry objectives, encompassing research, development, project financing, and the monitoring of forest economy and environment (European Commission, 2003).
Federal Law Gazette I No. 1975/440	The Forest Law of 1975 regulates the sustainable management of forests in Austria, emphasizing the preservation of biological diversity, productivity, and the regenerative capacity of forests to fulfill ecological, economic, and social functions at local, national, and global levels. It includes provisions on utilizing subsidies, taxes, and other financial instruments for managing forested areas (Federal Law of July 3, 1975, Which Regulates Forestry (Forest Act 1975), n.d.).
Czech Law N. 289/1995 Coll. Forest Act	Czech law establishes conditions for forest conservation, care, and restoration as an irreplaceable national asset. It focuses on sustainable management to ensure compliance with both the productive and non-productive functions of forests. Additionally, it includes provisions for granting subsidies and other financial aspects (Act No. 289/1995 Coll., on Forests and on the Amendment and Addition of Certain Laws (Forest Act), 1995).
The Eu's 2021-2027 Long-Term Budget and Nextgenerationeu	The 2021-2027 budget allocates more than 50% of its funds to new priorities such as research, innovation, climate and digital transition, preparedness, and resilience. This shift in focus aims to enhance the value of EU action in critical areas for the future, such as the Horizon Europe program and the Just Transition Fund (European Commission & Directorate-General for budget, 2021).
Austrian Forest Fund	The Forest Fund Act aims to compensate forest owners for losses caused by climate change, primarily due to the proliferation of the bark beetle. Its objectives include reducing infestations of these insects, developing climate-friendly forests, and strengthening the use of timber as a raw material for climate protection. It establishes a forest fund administered with a contribution of 350 million euros of federal funds, intended to finance measures such as reforestation, prevention of forest fires, research on

DOCUMENT	KEY ASPECTS
	biofuels, and promoting biodiversity in forests (Federal Ministry of Agriculture, Forestry, Regions and Water Management, n.d.).
Statute Forest and Wood-Processing Fund 2021	The Forestry and Wood Processing Fund was established by the Federation of Forestry and Wood Industry of the Czech Republic to support science, education, research, and development in the forestry and wood industry and promote environmental protection and biodiversity. The Fund aims to enhance the competitiveness of the forestry and wood processing industry, promote the sustainable use of forests and wood as a renewable raw material, and raise public awareness about forest management and wood products (Federation of Forestry and Timber Industry of the Czech Republic - LDK, 2021).
Evaluation of the Regulation (EU) No 1305/2013 on Support for Rural Development by the European Agricultural Fund for Rural Development (EAFRD)	The evaluation noted that forestry projects often take a long time to yield results, making an accurate assessment of their impact challenging. Additionally, key factors influencing the management and adoption of forestry measures include previous successful implementation experience, continuity of established support, financial considerations, and administrative simplicity. The availability of information and technical support is crucial for adopting these measures, especially for the smallest beneficiaries (European Commission, 2019a).
Rural Development Programme for Austria - Factsheet on 2014-2020	Austria's Rural Development Program focuses on investing in sustainable agricultural and forestry practices, promoting innovation, improving natural resource management and cultural landscapes, and fostering balanced local development. The program has six priorities addressing key areas such as agricultural competitiveness, environmental preservation, adaptation to climate change, enhancing resource efficiency, and social inclusion in rural areas. Main measures of the program include payments for agri-environmental and climate practices, payments to areas with natural restrictions, investments in physical assets, essential services, and revitalization of rural towns, and support for organic agriculture (ENRD, 2015b).

DOCUMENT	KEY ASPECTS
Rural Development Programme for the Czech Republic - Factsheet on 2014-2020	Key challenges facing agriculture in the Czech Republic include the dual structure of agricultural holdings, low labor productivity, and the necessity for modernization and competitiveness. Additionally, the importance of sustainable management of natural resources is underscored, especially in areas affected by natural constraints, pressure on agricultural land, and the need to protect and enhance ecosystems related to agriculture and forestry. The Czech Rural Development Program's six priorities include support for the modernization of agricultural holdings, investments in the processing and marketing of farm products, promotion of organic agriculture, and actions to restore and conserve ecosystems related to agriculture and forestry (ENRD, 2015a).
Ready, Steady, Green! LIFE Helps Farming and Forestry Adapt to Climate Change.	LIFE has been a crucial source of support for implementing climate change adaptation actions in the forestry sector. Eighty-six projects have contributed to enhancing the resilience of EU forests, with a total budget of €141.3 million. Of this amount, €74.4 million comes from LIFE co-financing. This financing is vital for implementing measures that strengthen the capacity of European forests to withstand and adapt to the impacts of climate change (European Commission. Directorate General for Environment., 2019).
Life Programme in Austria	Since its inception in 1992, the LIFE Program has funded 129 projects in Austria, with a total cost of €442 million. Of this amount, the EU contributed €188.5 million. This program has played a significant role in addressing environmental and climate challenges in Austria and aligns with the objectives and goals of the European Green Deal. Projects funded by the LIFE Program in Austria have tackled various environmental and climate issues, from biodiversity conservation to promoting the circular economy and transitioning to clean energy (European Commission, 2022a).
Life Programme in Czechia	Since its inception, the LIFE Program has funded 44 projects in the Czech Republic, with a total project cost of €101 million. Of this amount, the EU contributed €61.5 million. This program has been instrumental in addressing environmental and climate challenges in the Czech Republic, aligning with the objectives of the European Green Deal. Projects under the Nature and Biodiversity category in the Czech Republic have focused on conserving habitats and species, such as thermophilic habitats and alluvial forests. Additionally, projects have been implemented to improve the management of natural sites in the Natura 2000 network (European Commission, 2022b).

DOCUMENT	KEY ASPECTS
Special Report 23/2022: Synergies Between Horizon 2020 and European Structural and Investment Funds	Despite efforts to establish synergies between Horizon 2020 and the ESIFs, several challenges hinder their implementation, such as differences in the legal frameworks of the two programs, lack of cooperation between research and innovation stakeholders, absence of an integrated database for ESIF projects interoperable with the Horizon 2020 database, and the absence of a system to monitor synergies (European Court of Auditors, 2022).
Austria Horizon 2020 Country Profile	Austria has demonstrated significant participation in Horizon 2020, with approximately 5,083 participations. The country exhibits strong performance in research and innovation, boasting an R&D intensity index of 3.2%. Moreover, it holds the second position among EU countries in terms of R&D intensity. The total investment in R&D reaches around €2.23 billion, with an EU contribution of €277.8 million (European Commission, n.d.-a).
Czechia Horizon 2020 Country Profile	Czechia's involvement in Horizon 2020 comprises around 1,880 participations, representing approximately 1.06% of the total participation in the program. Similarly, the country demonstrates moderate performance in research and innovation, with an R&D intensity index of 1.8%, slightly below the EU average of 2.1%. Czechia ranks 10th among EU countries in terms of R&D intensity. The total R&D investment amounts to approximately €3.04 billion, with an EU contribution of €2.53 billion (European Commission, n.d.-b).

5.1.2 EU FINANCIAL PROGRAMS

Ten financing programs associated with EIs and linked to the forestry sector have been identified (see Table 5). These initiatives contribute directly and indirectly to promoting sustainable management, competitiveness, and resilience, as well as implementing adaptation and mitigation measures in EU forests (Huertas-Bernal & Hájek, 2023).

Table 5. EU Financing Programs Associated with Economic Instruments

FUNDING PROGRAM	DESCRIPTION AND CONNECTION TO THE FORESTRY SECTOR
Horizon Europe	This funding program aims to enhance research and innovation within the EU. It supports initiatives contributing to the European Green Deal for climate neutrality, resilience, biodiversity, and sustainable growth. It serves as a cross-cutting program for the forestry sector by financing various forest management initiatives, forest improvement projects, ecosystem services,

FUNDING PROGRAM	DESCRIPTION AND CONNECTION TO THE FORESTRY SECTOR
	and even using non-forest products derived from woodlands. Each program period implements enhancements based on management evaluations' findings and recommendations. The program's latest version (2021-2027) includes actions for the forestry sector under the thematic group "Food, Bioeconomy, Natural Resources, Agriculture, and Environment".
Invest EU	This program promotes innovation, job creation, and more robust value chains in Europe through targeted investments. It is implemented through implementing partners, such as the EIB Group. It also serves as a cross-cutting program for the forestry sector. It finances four initiatives: sustainable infrastructures, research, innovation, digitalization, SMEs and skills, and social financing, all aimed at fulfilling the European Green Deal and environmental commitments.
European Regional Development Fund (ERDF)	It is a fund aimed at reducing social, economic, and territorial disparities through national or regional programs executed by the European Commission and national authorities of member countries. The latest version (2021-2027) has five priorities where the forestry sector can access funding under the greener, low-carbon, resilient, sustainable tourism, and local and sustainable development across the EU.
Cohesion Fund (CF)	It is a fund to strengthen EU member countries' social, economic, and territorial cohesion with a per capita gross national income below 90% (15 countries, including the Czech Republic). It is executed through public and regional authorities and the forestry sector. The sector can benefit from environmental investment as one of its priorities.
React-EU	It is a complementary fund to the ERDF and ESF with execution until the end of 2023, which arose to recover from the crisis generated by the COVID-19 pandemic. It has been used to support the forestry sector by injecting capital to promote crisis repair and contribute to the green and resilient recovery of the economy.
European Social Fund+ (ESF+)	It is a fund to address the crisis generated by the coronavirus pandemic. The forestry sector can benefit by encouraging the workforce to train and develop skills for transitioning to the green economy.
Erasmus+	It is a program supporting education and training in the EU. It is implemented through participating organizations (schools, universities, and

FUNDING PROGRAM	DESCRIPTION AND CONNECTION TO THE FORESTRY SECTOR
	organizations) and provides a grant to cover participation costs. It benefits the forestry sector by enabling knowledge and skill development through practice.
European Agricultural Fund for Rural Development (EAFRD)	It is a fund to finance rural development programs (RDPs) formulated at the national or regional level aligned with the EU's rural development objectives. The forestry sector is related as it promotes sustainable management of natural resources and climate action.
Programme for Environment and Climate Action (LIFE)	The program promotes capacity development and governance by financing strategic projects that promote regional, multiregional, or national cooperation. It is directly related to the forestry sector as it focuses on protecting, restoring, and improving environmental quality, halting, and reversing biodiversity loss and ecosystem degradation through four subprograms: Nature and Biodiversity, Circular Economy and Quality of Life, Climate Change Mitigation and Adaptation, and Transition to Clean Energy.
Just Transition Fund (JTF)	It is a fund to support the transition to climate neutrality and reduce regional disparities arising from structural changes in the EU. The forestry sector benefits from this fund as it finances the creation of new businesses, research, innovation, environmental rehabilitation, clean energy, and the transformation of existing carbon-intensive facilities.

Adapted from (Huertas-Bernal & Hájek, 2023).

5.1.3 ECONOMIC INSTRUMENTS IN THE EU FOREST-BASED SECTOR

According to the classification proposed by the OECD mentioned in the literature review, five types of economic instruments within the forestry sector in the European Union, Austria, and the Czech Republic were identified from the study's core documents and databases cataloging available economic tools (European Environment Agency, 2020; Institute for European Environmental Policy & European Commission, 2017; OECD, 2017). The search used keywords related to the economic instruments identified during the literature review. The findings are detailed in Table 6.

Table 6. Overview of Economic Instruments in the Forestry Sector

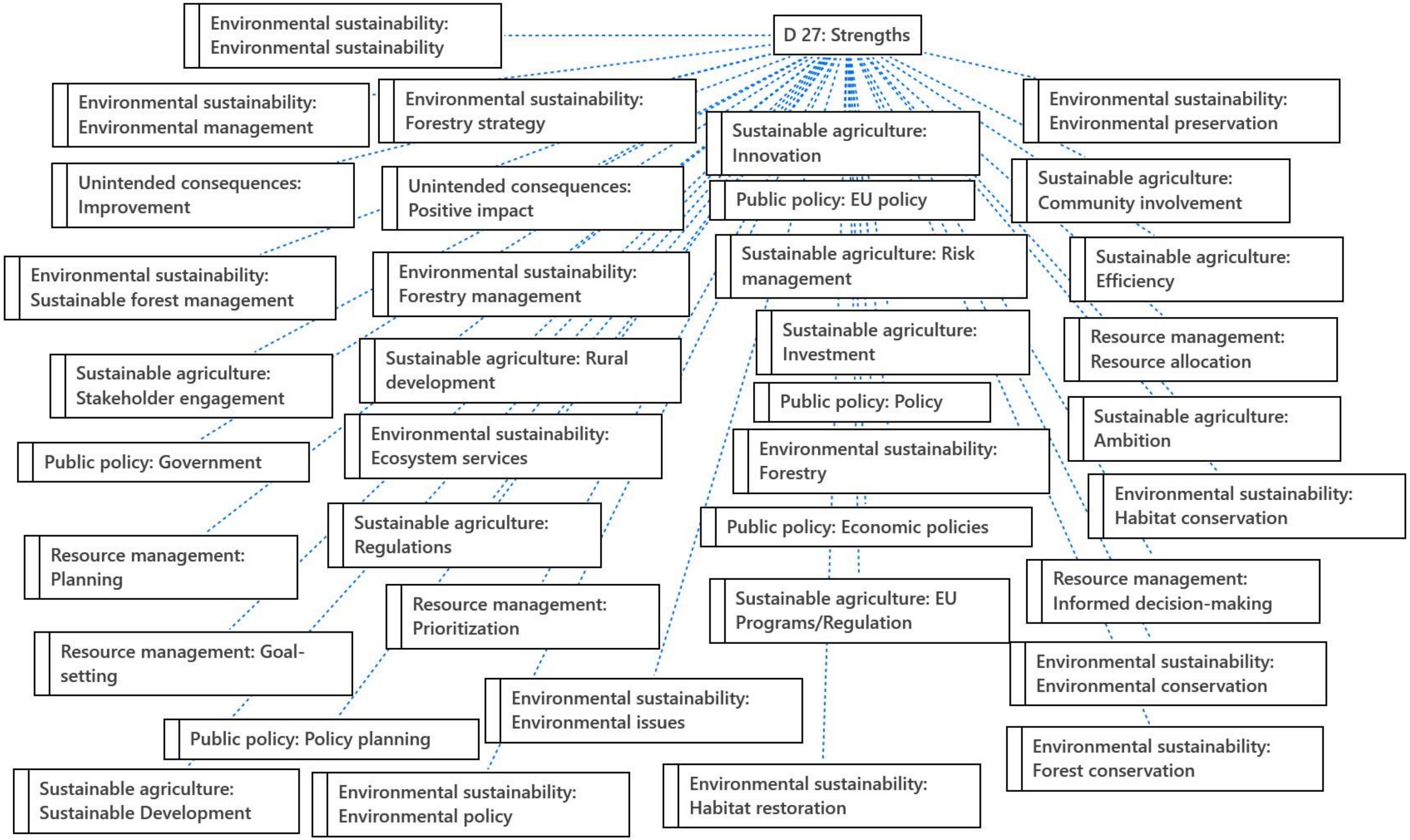
CATEGORY	ECONOMIC INSTRUMENT NAME
Taxes	Aggregates tax
	Fertilizers tax
	Land tax
	Landfill tax
	Natural resource tax
	NOx tax
	Packaging tax
	Pesticides tax
	Pollution Tax (Other)
	Timber/ Forestry tax
	Waste tax (other)
	Waste water tax
	Water abstraction tax
Fees and charges	Stumpage fee
	Wildlife/ Hunting fee
	Land-related levy (other)
	Pay-as-you-throw (PAYT) Scheme
	Various
Marketable permits	Emissions Trading System (EU ETS)
Voluntary approaches	Offset/ Habitat Banking Scheme
	Payment for Ecosystem Services Scheme
Subsidies	Forest management
	Reforestation
	Land conservation
	Organic or environmentally friendly agriculture
	Cultivation without pesticides
	Investment to increase resistance and the ecological value of forests
	Tending of seedling and young stands
	Investments improving the resilience and environmental value of forest ecosystems
	Nature and cultural heritage
	Purchase of new machinery and new equipment for forestry operations
	Public value and protection against natural hazards

Adapted from (European Environment Agency, 2020; Haeler et al., 2023; Institute for European Environmental Policy & European Commission, 2017; OECD, 2017).

5.1.4 SWOT ANALYSIS OF ECONOMIC INSTRUMENTS

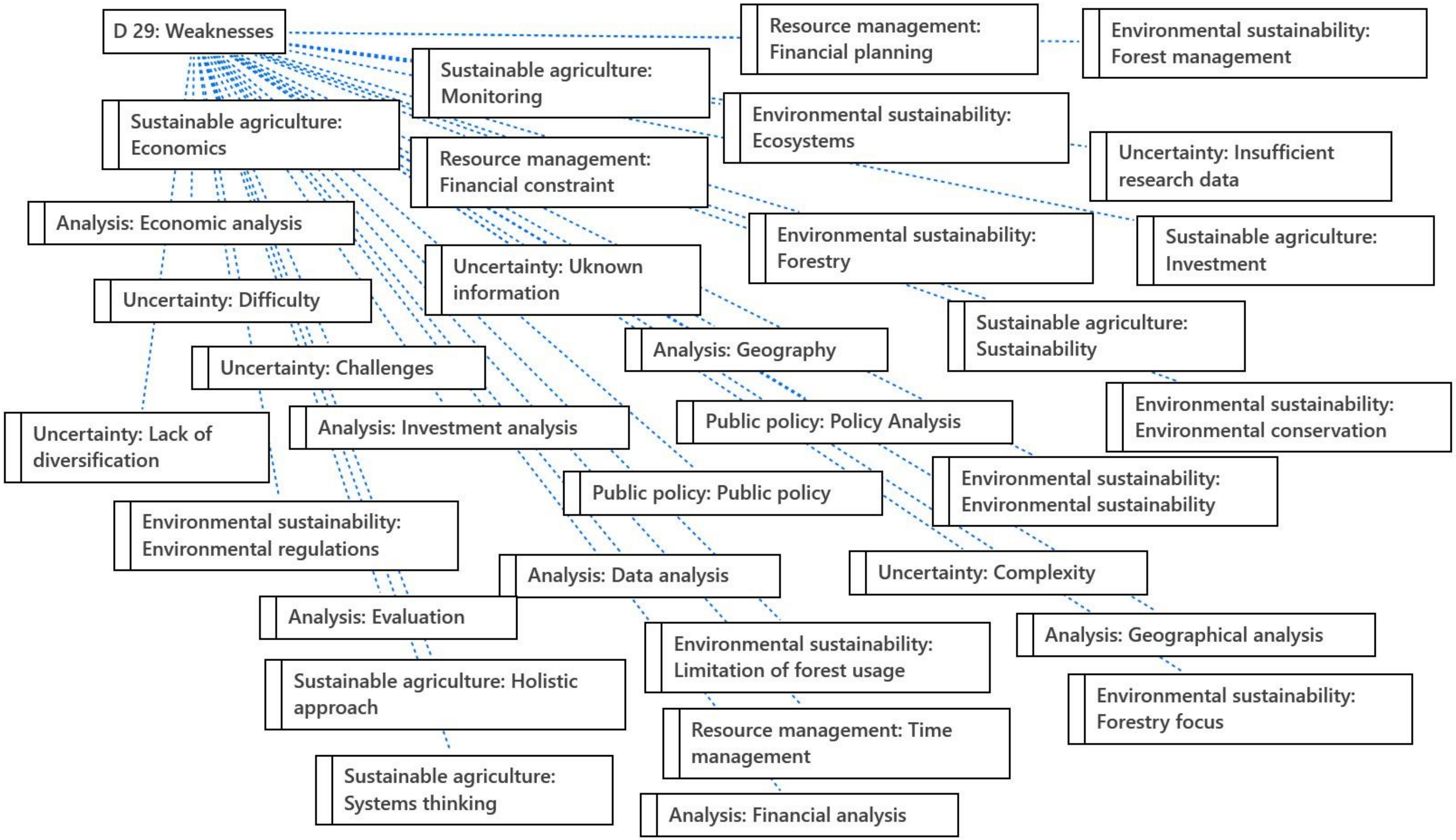
Figure 2 shows the concepts identified during the SWOT analysis to evaluate the forest policy strategies of the European Union, Austria, and the Czech Republic concerning the available economic instruments. Twenty-seven strengths (see Figure 2a), 29 weaknesses (see Figure 2b), 26 opportunities (see Figure 2c) and 28 threats (see Figure 2d) were identified. These SWOT aspects were grouped into 14 fundamental concepts: agroforestry, biodiversity, circular bioeconomy, cross-border cooperation, stakeholder dialogue, budget optimization, forest ecosystem services, informed decision-making, policy monitoring, forest multifunctionality, resilience, forest management sustainability, tourism industry, and compensation planning in implementation. These concepts were interconnected through universal semantic relationships to evaluate their potential use in improving the economic instruments accessible within the EU to finance the forestry sector, establishing a framework that allows analyzing sustainable forest management objectives.

a)



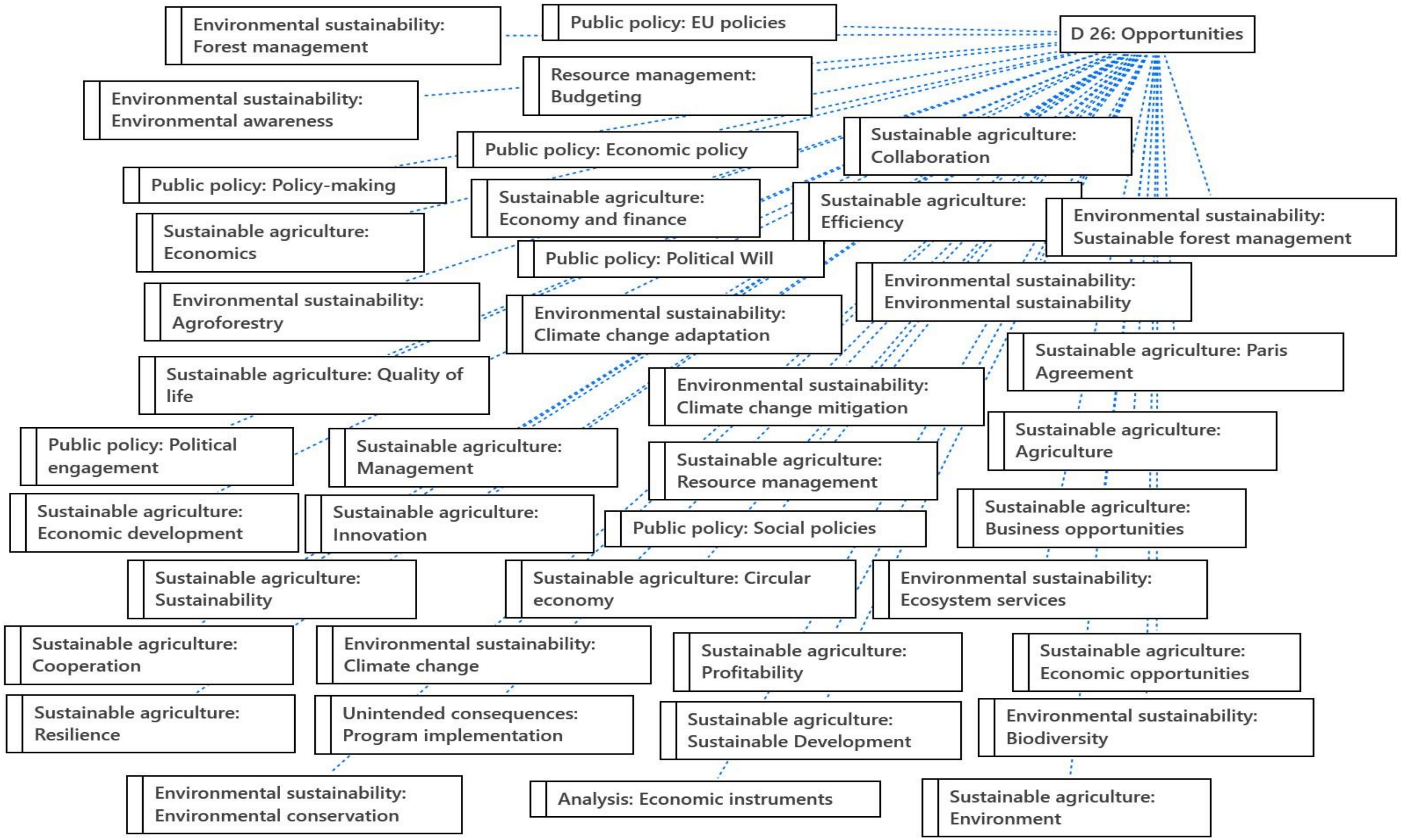
D 27: Strengths
Environmental sustainability: Environmental sustainability
Environmental sustainability: Environmental management
Environmental sustainability: Forestry strategy
Sustainable agriculture: Innovation
Environmental sustainability: Environmental preservation
Unintended consequences: Improvement
Unintended consequences: Positive impact
Public policy: EU policy
Sustainable agriculture: Community involvement
Environmental sustainability: Sustainable forest management
Environmental sustainability: Forestry management
Sustainable agriculture: Risk management
Sustainable agriculture: Efficiency
Sustainable agriculture: Investment
Resource management: Resource allocation
Sustainable agriculture: Stakeholder engagement
Sustainable agriculture: Rural development
Public policy: Policy
Sustainable agriculture: Ambition
Public policy: Government
Environmental sustainability: Ecosystem services
Environmental sustainability: Forestry
Environmental sustainability: Habitat conservation
Public policy: Economic policies
Resource management: Planning
Sustainable agriculture: Regulations
Resource management: Informed decision-making
Resource management: Prioritization
Sustainable agriculture: EU Programs/Regulation
Resource management: Goal-setting
Environmental sustainability: Environmental conservation
Environmental sustainability: Environmental issues
Public policy: Policy planning
Environmental sustainability: Forest conservation
Sustainable agriculture: Sustainable Development
Environmental sustainability: Environmental policy
Environmental sustainability: Habitat restoration

b)



D 29: Weaknesses
Resource management: Financial planning
Environmental sustainability: Forest management
Sustainable agriculture: Monitoring
Sustainable agriculture: Economics
Environmental sustainability: Ecosystems
Uncertainty: Insufficient research data
Resource management: Financial constraint
Analysis: Economic analysis
Environmental sustainability: Forestry
Sustainable agriculture: Investment
Uncertainty: Uknown information
Uncertainty: Difficulty
Sustainable agriculture: Sustainability
Analysis: Geography
Uncertainty: Challenges
Environmental sustainability: Environmental conservation
Public policy: Policy Analysis
Uncertainty: Lack of diversification
Analysis: Investment analysis
Environmental sustainability: Environmental sustainability
Public policy: Public policy
Environmental sustainability: Environmental regulations
Analysis: Data analysis
Uncertainty: Complexity
Analysis: Evaluation
Analysis: Geographical analysis
Environmental sustainability: Limitation of forest usage
Sustainable agriculture: Holistic approach
Environmental sustainability: Forestry focus
Resource management: Time management
Sustainable agriculture: Systems thinking
Analysis: Financial analysis

c)


D 26: Opportunities
Environmental sustainability: Forest management
Public policy: EU policies
Resource management: Budgeting
Environmental sustainability: Environmental awareness
Public policy: Economic policy
Sustainable agriculture: Collaboration
Public policy: Policy-making
Sustainable agriculture: Economy and finance
Sustainable agriculture: Efficiency
Environmental sustainability: Sustainable forest management
Sustainable agriculture: Economics
Public policy: Political Will
Environmental sustainability: Environmental sustainability
Environmental sustainability: Agroforestry
Environmental sustainability: Climate change adaptation
Sustainable agriculture: Paris Agreement
Sustainable agriculture: Quality of life
Environmental sustainability: Climate change mitigation
Sustainable agriculture: Agriculture
Public policy: Political engagement
Sustainable agriculture: Management
Sustainable agriculture: Resource management
Sustainable agriculture: Economic development
Sustainable agriculture: Innovation
Public policy: Social policies
Sustainable agriculture: Business opportunities
Sustainable agriculture: Sustainability
Sustainable agriculture: Circular economy
Environmental sustainability: Ecosystem services
Sustainable agriculture: Cooperation
Environmental sustainability: Climate change
Sustainable agriculture: Profitability
Sustainable agriculture: Economic opportunities
Sustainable agriculture: Resilience
Unintended consequences: Program implementation
Sustainable agriculture: Sustainable Development
Environmental sustainability: Biodiversity
Environmental sustainability: Environmental conservation
Analysis: Economic instruments
Sustainable agriculture: Environment

d)

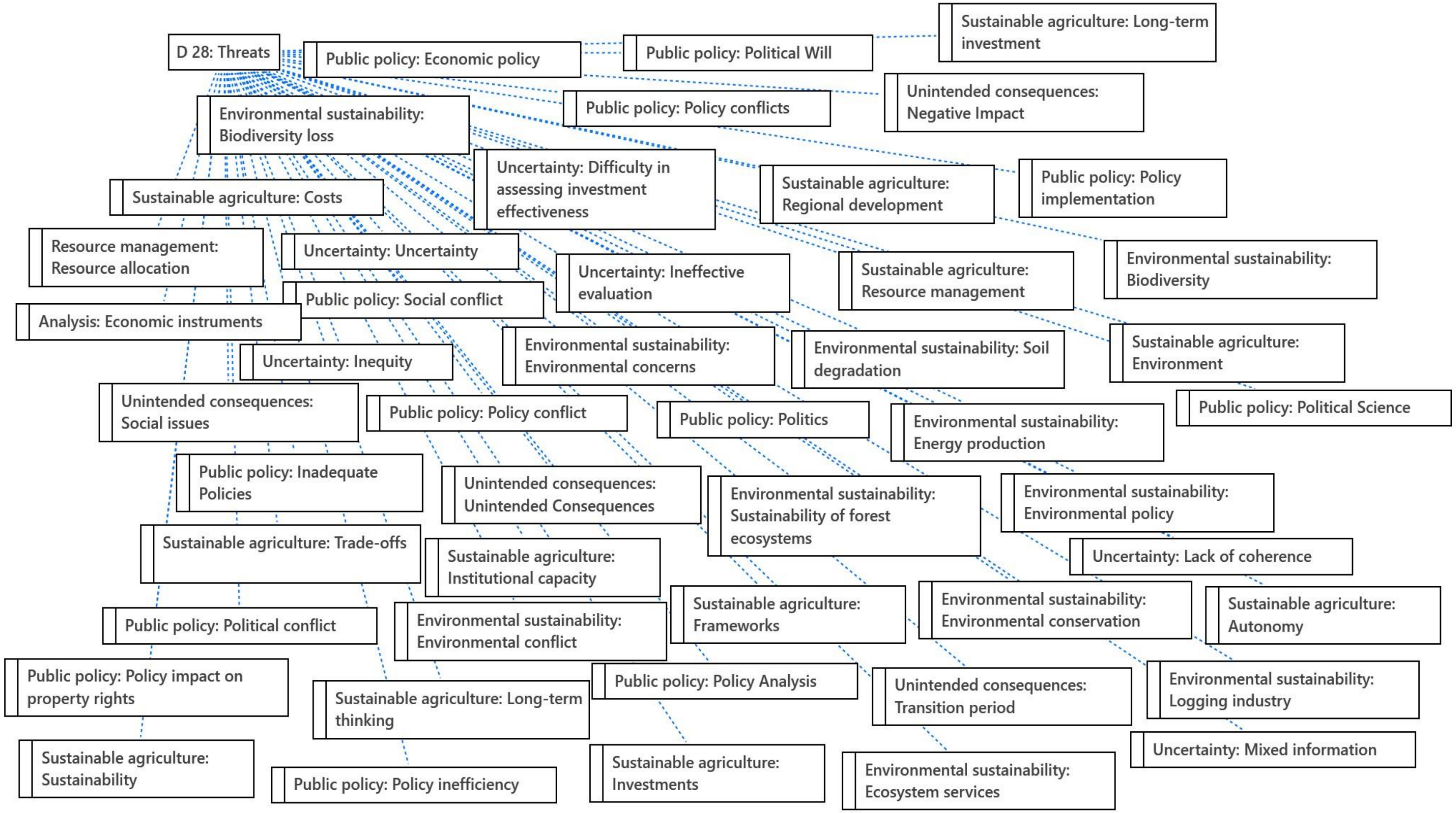


Figure 2. Conceptual Network of a) Strengths, b) Weaknesses, c) Opportunities, and d) Threats Extracted from Core Documents

5.2 Opinions of Foresters on Economic Instruments

The results of the in-depth surveys were divided into three sections for better understanding. The first is generalities and forestry context, the second is forestry instruments and policies, and the third is opinions according to their experience of use and access to the policies and instruments available in their context. The evidence, some specific anonymized quotes, and an analysis of the implications it generates for the European forestry context are presented below.

5.2.1 Generalities and Forestry Context

The forestry experts interviewed have extensive experience in scientific research, practical implementation, and the management of forest policies, with a significant focus on climate change adaptation, mitigation, and biodiversity conservation. The average profile of the interviewees is presented in Table 7, highlighting some aspects of their extensive experience.

Table 7. Profile and Highlights of Interviewees Experience

KEY ASPECT IDENTIFIED	DESCRIPTION
Experience in forest research and management	Many experts have over 20 years of experience in forestry research, particularly in forest ecology, nature dynamics in forest reserves, and nature conservation in Europe (Natura 2000). A specific approach in forestry avoids artificial regeneration, achieving 96% natural regeneration. This approach is crucial for maintaining the health and resilience of forests in the face of climate change.
Knowledge of climate change impacts	Experts have practical experience with the effects of climate change, such as prolonged dry summers, which have led to high tree mortality (10-15% dead, 20-40% diseased). Implementing management techniques such as dense planting to maintain soil moisture has been essential.
Experience in management and conservation	Some experts mention their experience in conserving forest genetic resources, seeds, and nursery plants and improving programs for conserving forest species of interest. They have also worked on national forest inventories and forest management projects, including forest fire management.

KEY ASPECT IDENTIFIED	DESCRIPTION
Recognition of forest ecosystem services	Most experts highlight that forests are crucial for ecosystem, species, and genetic biodiversity. They also provide essential services such as soil protection, water storage, and carbon fixation. In addition to tangible benefits, forests offer important cultural, climate, and erosion regulation services for local communities.
Education and training	Many experts have been involved in forest science education and training, teaching about forest planning, the multifunctionality of forests, and the multiple benefits they provide. They also work with government agencies and international organizations to develop and comply with regulations on forest reproductive materials and forest health.
Innovation and knowledge transfer	Some experts report involvement in transferring innovation to the forestry sector, working closely with public stakeholders, and promoting sustainable forest management. They also research and use GIS and remote sensing technologies for forest management and monitoring.
Roles and responsibilities	The interviewed experts occupy important roles as directors and coordinators in research institutions and forest administrations, leading forest management projects and programs.

On the other hand, the experts' perception of the ecosystem services provided by forests was investigated to understand their interests in the forest and how they value its services. Experts emphasize that forests are vital for the tangible resources they offer and the numerous environmental and cultural services they provide, which are essential for human well-being and the planet's sustainability. As mentioned by those interviewed, the ecosystem services provided by forests are summarized below.

- Wood Production: One of the most apparent and traditionally used services. Wood is used for energy and construction, providing income for forest management.
- Water and Climate Regulation: Experts recognize forests' crucial role in regulating the water cycle and improving water quality. They highlight that forests act as carbon sinks, helping to mitigate climate change and provide cooler temperatures within forested areas.

- Biodiversity: Forests are reservoirs of biodiversity at the ecosystem, species, and genetic levels. They conserve essential species and habitats and maintain natural cycles that benefit biodiversity.
- Cultural and Recreational Services: Forests offer spaces for recreation and human well-being, such as hiking, hunting, and ecological tourism. These cultural services were especially valued during the pandemic as people seek contact with nature.
- Soil Protection: Forests protect the soil from erosion, maintaining its integrity and fertility, which is crucial for agriculture and the stability of terrestrial ecosystems.
- Non-Timber Forest Products: In addition to wood, forests provide other products, such as mushrooms, fruits, and medicinal plants, which are essential for both the local economy and resource diversity.
- Air Quality: Forests contribute to air purification by removing dust particles and producing oxygen, which is essential for human health, especially in urban areas.
- Protection against Natural Disasters: In mountainous regions, forests act as natural barriers against landslides and avalanches, protecting local communities.

Likewise, the effects of climate change on forests and the ecosystem services they provide were investigated. The findings highlight several adverse impacts of climate change on forests, including tree mortality, water stress, increases in pests and diseases, increased frequency of forest fires, and challenges to forest management and conservation (see Table 8).

Table 8. Effects of Climate Change on Forests and Their Ecosystem Services

PERCEIVED EFFECTS OF CLIMATE CHANGE	**DESCRIPTION**
Tree mortality and stress:	There is notable mortality rate in species such as fir, pine, and beech. Although pine is generally drought resistant, there has been an increase in the problems it faces.
	A reduction in the distribution area, the capacity to respond to environmental parameters and the natural regeneration of tree species is reported.
Groundwater level:	Extreme droughts have caused a significant reduction in groundwater levels, affecting the availability of water for the trees that depend on it.

PERCEIVED EFFECTS OF CLIMATE CHANGE	DESCRIPTION
Increase in pests and diseases:	An increase in the population of insects such as the bark beetle (Scolytidae) has been observed in species such as spruce, which has serious economic and biological implications.
	The combination of water stress and extreme temperatures has weakened trees, making them more vulnerable to pathogens and invasive species.
Forest fires:	Forest fires have become more frequent and intense due to heat waves and elevated temperatures. The lack of equipment and adequate preparation in countries such as Spain, Portugal and Italy have been highlighted as a critical problem.
Economic and social impacts:	Diseased forests have difficulty providing all the ecosystem services necessary for society, such as carbon absorption, biodiversity, and recreation.
Phenology and change in species composition:	Changes have been observed in the phenology of plants and bird migration, with imbalances in reproduction time.
	Changes in species distribution are being observed, with species such as oak moving into areas previously dominated by beech due to climatic conditions more suitable for oak.

5.2.2 FORESTRY INSTRUMENTS AND POLICIES

The knowledge of economic instruments varies widely among those interviewed. Still, at a general level, forestry sector actors are not fully informed about financing mechanisms for adaptation and forest management measures related to climate change. Those with more excellent knowledge recognize that there are multiple sources of financing from the European Union, such as the EAFRD, LIFE programs, Horizon 2020, and Interreg funds, which are channeled through the national government and the regions. Funds can be distributed at different administrative levels, including national, regional, and local. For example, in Poland, national and regional funds for environmental protection and water management finance projects related to ecosystem services. While in some countries, there is a combination of private and public financing for forestry initiatives. For example, in

Luxembourg, a climate fund managed by the Ministry of the Environment finances measures related to climate change in forests.

They also mention that state forestry companies receive financing from the government to provide services to society, where wood production is less of a priority than ecosystem services. While private forest owners depend more on timber sales, they also receive subsidies for providing ecosystem services, such as maintaining roads open to the public and planting native species. However, it should be highlighted that regional differences and specific local needs must be considered when applying forestry policies and measures. Legislation and initiatives must be cautiously tailored and based on extensive professional knowledge to be effective.

5.2.3 Experience of Use and Access to the Financing Programs

When investigating the experience of use and access to funding programs, it is identified that European funding programs offer opportunities for sustainable forest management and research. Still, bureaucratic complexity and access challenges can limit their effectiveness and widespread adoption. The main aspects mentioned by the interviewees are listed below:

- European Union financing programs are seen as highly bureaucratic and demanding in dedication and effort. Exhaustive planning, the development of procedure manuals, and detailed justification of each proposed measure are required. This implies a significant effort for researchers and forest owners seeking these funds.
- The complexity of the fund application and management processes often requires the assistance of homeowners' associations or specialized consultants. This is because the successful application of financing programs usually involves preparing a large amount of documentation and compliance with a series of administrative requirements.
- Although financing programs are available, many forest owners, especially smaller ones, do not access them for various reasons, such as language barriers, lack of knowledge, or limited resources to manage administrative requirements.
- The availability of funds for forestry initiatives may depend on political decisions at the state or regional level. Some regions are beginning to take advantage of European Union funds to finance forestry projects, indicating a growing recognition of the importance of sustainable forest management.

- Despite the associated bureaucracy, some have positive experiences with the European Union's financing programs. The importance of careful proposal preparation and collaboration with appropriate partners is highlighted to increase the chances of success in obtaining funding.
- A shift in funding strategy towards more extensive, more complex research projects is noted, which may increase competition and reduce opportunities for smaller, more local projects. It is suggested that a more decentralized and flexible approach could be more beneficial in fostering innovation and participation.
- It is noted that European Union financing can be less restrictive and easier to manage compared to national funding. This may be due to differences in procedures and regulations between the national and European levels.
- The importance of focusing on the evaluation of progress and actual results of projects is highlighted instead of focusing solely on bureaucratic and formal aspects. It is suggested that evaluation processes prioritize project effectiveness and impact.
- The importance of collaboration and coordination between countries and partners in projects funded by the European Union is recognized. The need to establish solid partnerships and work together to maximize the benefits of European funds is highlighted.

Additionally, through the national survey conducted in the Czech Republic the use of subsidies, technical support, and environmental payments across nine different forms of forest management or related aspects were investigated. The results, presented in Figure 3, reveal that different areas receive varying levels of support. Technical support is especially prominent in Natura 2000 (100%), ecological forms of agriculture (40%), and soil and water protection measures (40%). Forest restoration initiatives receive significant subsidies, with 37.50% reporting such support. Landscape protection is the only area reporting payments for ecosystem services (PES), at 8.30%. Other types of support are notably high in several areas, including soil and water protection measures (60%), pesticide-free cultivation (57.10%), and protection against invasive species and pests (55.60%).

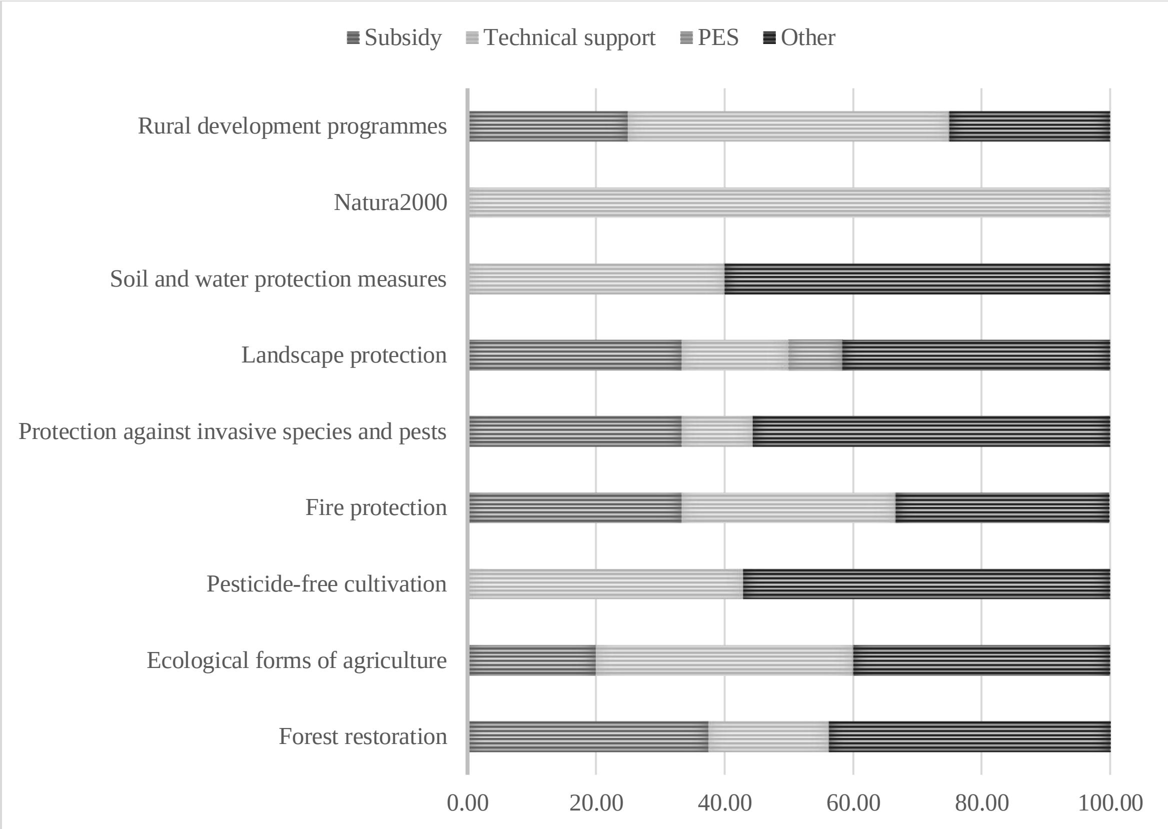


Figure 3. Results of the Survey on the Receipt of Subsidies, Technical Support, and Payments for Ecosystem Services in Different Fields in the Czech Republic

5.3 Impact of Economic Instruments on Roundwood Consumption

Figure 4 presents the variables studied by country in the wood industry. Regarding domestic wood consumption (see Figure 4a), Sweden and Finland exhibit the highest levels, with 564,173.22 and 442,491.36 tons, respectively, followed by Germany, Poland, and France. This variable accounts for using materials to produce semi-finished wood products, finished products derived from semi-finished products, and by-products rather than the direct wood consumption by individual consumers within each country. Regarding wood exports (see Figure 4b), Germany, the Czech Republic, France, Poland, and Belgium are the leading exporters. Conversely, Austria, Germany, Sweden, Finland, and Italy are the largest importers of wood (see Figure 4c). Finally, when analyzing the total environmental taxes related to the manufacturing of wood, paper, and furniture (see Figure 4d), Italy, Germany, France, Spain, and Sweden emerged as the primary taxpayers.

The results of the panel multiple regression models are presented in Table 10 .Additionally, the correlation matrix of variables is given in Table 9, where it is assumed that due to the weak correlation between independent variables, multicollinearity will not affect the estimation of the parameters. On the other hand, it can be interpreted that when using the F test for individual effects, H0 is rejected (the p-value is 2.2e-16 less than 0.05). Therefore, fixed effects are preferable for this case. On the other hand, when using the Hausman Test between the fixed effects model and random effects models 3 to 6, H0 is accepted with p values of 0.221, 0.3311, and 0.6028 in models 3, 4, and 6, respectively. While model 5, H0 is rejected (the p-value is 0.02082 less than 0.05). Therefore, fixed effects are preferable for this case.

Table 9. Correlation Matrix of Variables

	DMC_TON	**EIR_EUR**	**IIR_EUR**	**TET_EUR**
DMC_TON	1			
EIR_EUR	0.100771	1		
IIR_EUR	0.555375	0.104459	1	
TET_EUR	0.242126	0.249874	0.3378234	1

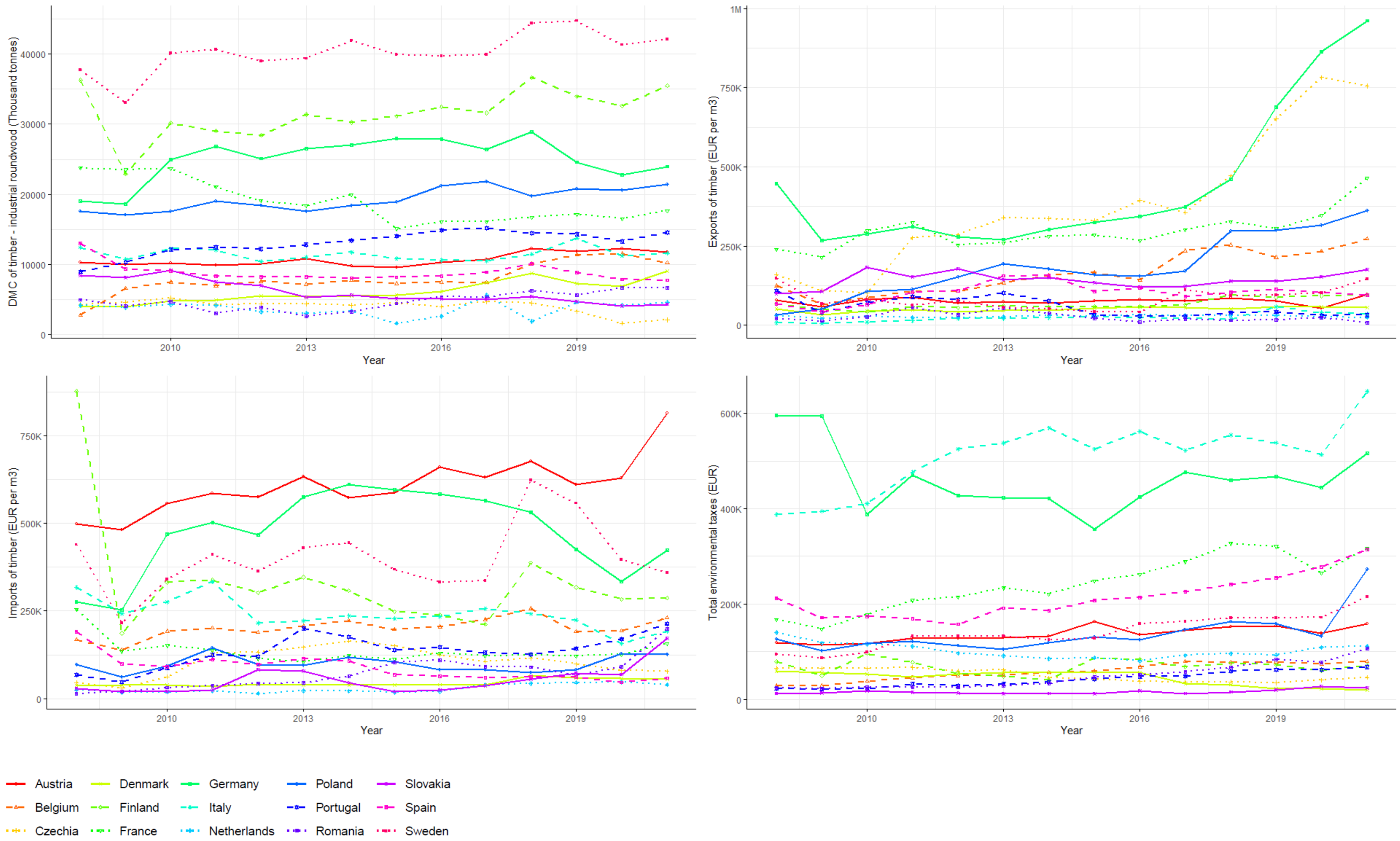


Figure 4. Country-specific variables, a) domestic material consumption, b) exports, and c) imports of timber, d) total environmental taxes of manufacturing of wood, paper, and furniture

Table 10. Estimates of Multiple Regression Models in Panel Data

Independent Variables	**Model 1** **Pooling model**	**Model 2** **Fixed effects**	**Model 3** **Random effects (Swamy-Arora's transformation)**	**Model 4** **Random effects (Wallace-Hussain's transformation)**	**Model 5** **Random effects (Amemiya's transformation)**	**Model 6** **Random effects (Nerlove's transformation)**
EIR_EUR	-6.0902e-07 (5.8030e-07)	**6.0366e-07 ***** **(1.5167e-07)**	**6.0124e-07 ***** **(1.5242e-07)**	**5.8935e-07 ***** **(1.7740e-07)**	**6.0152e-07 ***** **(1.5175e-07)**	**6.0181e-07 ***** **(1.5105e-07)**
IIR_EUR	**3.6980e-06 ***** **(5.0607e-07)**	-1.3093e-07 (1.9639e-07)	-1.0692e-07 (1.9661e-07)	5.6943e-09 (2.2503e-07)	-1.0965e-07 (1.9583e-07)	-1.1250e-07 (1.9501e-07)
TET_EUR	**-3.8559e-03 ***** **(6.3025e-04)**	-3.5827e-04 (3.6830e-04)	-4.0309e-04 (3.6632e-04)	-5.9682e-04 (4.0762e-04)	-3.9806e-04 (3.6513e-04)	-3.9279e-04 (3.6389e-04)
R-Squared	0.26138	0.079691	0.073096	0.054701	0.073783	0.074515
Adj. R-squared	0.25062	-0.0017947	0.059598	0.040935	0.060294	0.061038
F-statistic	24.2996 *** [3, 206 df]	5.54186 * [3, 192 df]				
Chi squared			16.2453 * [3 df]	11.9205 * [3 df]	16.41 * [3 df]	16.5861 * [3 df]
Effects						
Idiosyncratic			0.03544 0.18826 0.018	0.1522 0.3902 0.098	0.0349 0.1868 0.016	0.0324 0.1800 0.014
Individual			1.88141 1.37165 0.982	1.4007 1.1835 0.902	2.0911 1.4461 0.984	2.2431 1.4977 0.986
Theta			0.9633	0.9122	0.9655	0.9679
F test for individual effects	643.57 *** df1 = 14, df2 = 192					
Hausman test			4.4039 [3 df]	3.4212 [3 df]	9.7494 * [3 df]	1.8563 [3 df]

*Significance level of 0.1% ***/ Significance level of 5% * / In parentheses standard error*

5.4 Effects of Economic Instruments on Forest Ecosystem Services

5.4.1 LAND COVER CHANGES

Table 11 shows a significant increase in coniferous forest area and total forest area between 1990 and 2018, with increases from 1,655,719.55 ha to 1,665,902.94 ha and from 2,490,864.05 ha to 2,592,941.12 ha., respectively. These differences are statistically significant ($p < 0.001$). Broadleaf and mixed forests also increased from 249,729.32 ha to 283,338.26 ha and 585,415.17 ha to 643,699.92 ha, although this difference is not statistically significant. Regarding water bodies, both watercourses and water bodies showed an increase, with the total increase in water bodies being notable from 53,835.15 ha to 58,293.84 ha, also with a significant difference ($p < 0.001$). This suggests improvements in forest and water resource management during this period.

Table 11. Land Cover Changes in the Czech Republic in 1990 and 2018 by Type of Forest and Inland Water

TYPE OF COVER	1990		2018	
Broad-leaved forest	249,729.32		283,338.26	
Coniferous forest	1,655,719.55	b*	1,665,902.94	a*
Mixed forest	585,415.17		643,699.92	
Total forest area	2,490,864.05	b	2,592,941.12	a
Water courses	4,542.62		4,685.46	
Water bodies	49,292.53		53,608.38	
Total water bodies	53,835.15	b	58,293.84	a

*a significant difference with the year 1990 / b significant difference with the year 2018 / * $p < 0.001$*

Figure 5 shows in pink scale a reduction in forest cover (coniferous, broadleaved, and mixed forests) in the Liberec and Hradec Králové regions in the north, in the Moravian-Silesian and Olomouc regions in the northeast, and the Pilsen region to West. At the same time, on a blue scale the gain zones, which appear in small spots distributed throughout the territory, specifically in the regions of Karlovy Vary, Ústí nad Labem, Liberec, Vysočina, South Bohemia, and Pilsen.

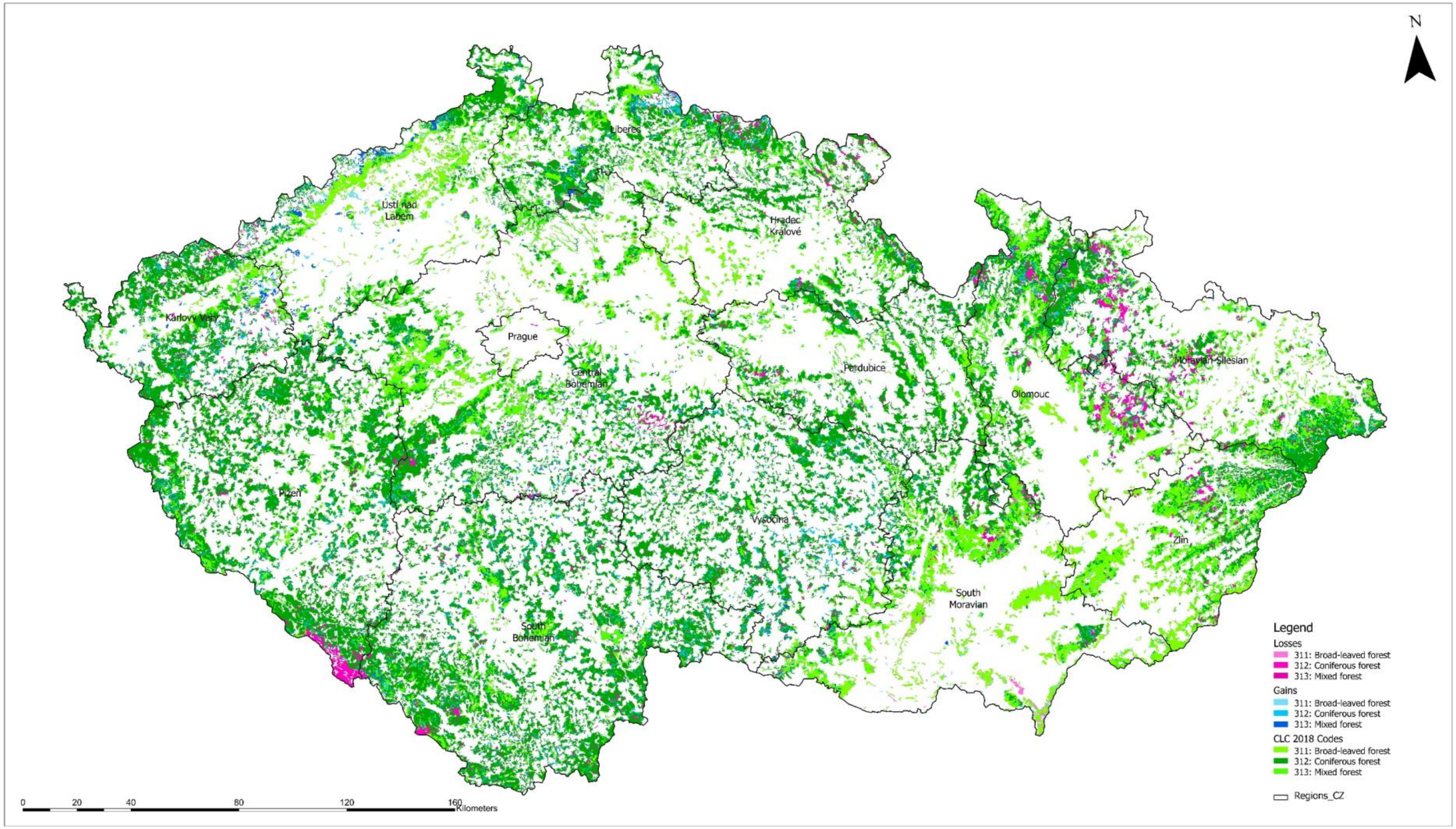


Figure 5. Geospatial Representation of Forest Cover Change in the Czech Republic, 1990–2018

5.4.1 WATER QUALITY

Figure 6 shows the evolution of water quality in the Czech Republic between 2009 and 2019, highlighting stability in the levels of DOC and undissolved substances, and increases in BOD5, total nitrogen and total phosphorus. The BOD5 gradually increased from 97.74 in 2009 to 98.53 in 2019, suggesting more biodegradable organic matter. The COD remained relatively constant, with a slight increase from 94.09 to 95.04 in the same period, indicating stability in contaminants that can be chemically oxidized. Undissolved substances also showed consistency, from 97.04 in 2009 to 97.92 in 2019, reflecting a stable amount of suspended particles. In contrast, total nitrogen increased significantly from 70.92 to 81.29, and total phosphorus from 83.19 to 87.58, pointing to increased contamination potentially attributed to agricultural or industrial sources.

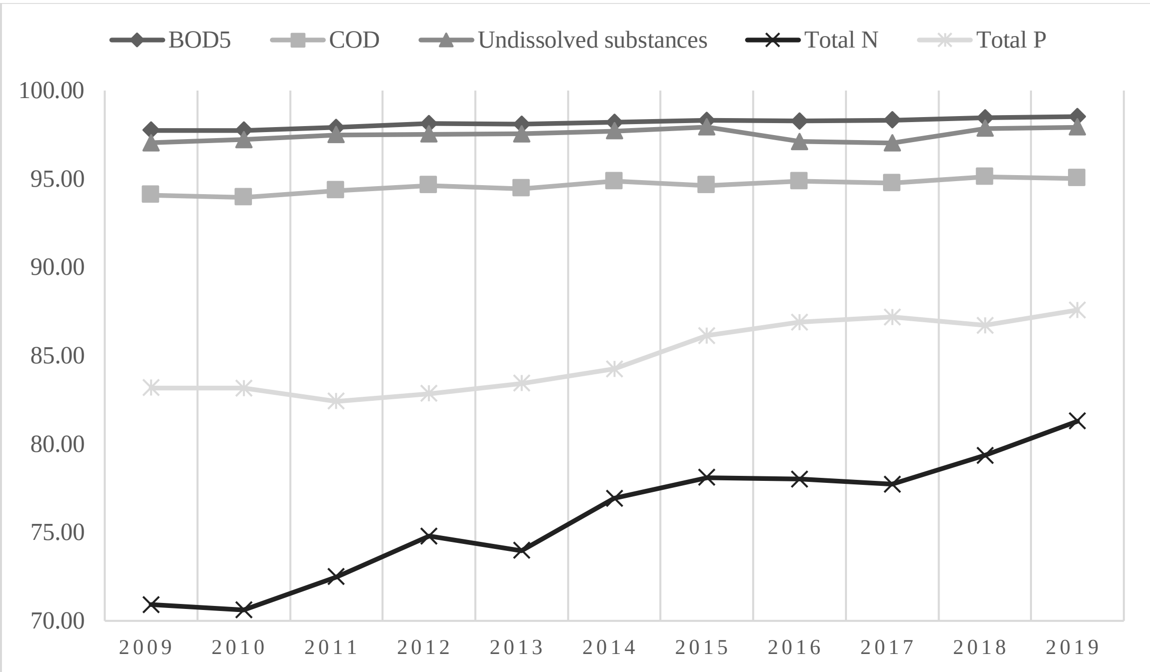


Figure 6. Load of Nutrients and Organic Substances in the Outflow Water of Wastewater Treatment Plants in the Czech Republic Between 2009 and 2019.

The average efficiency of contaminant removal by wastewater treatments has shown a general trend of improvement over the years. In 2009, efficiency was 88.60%, and by 2019 it had increased to 92.07% (see Figure 7). This increase has been observed almost annually, except for a slight decrease in 2010 compared to the previous year. The most notable improvement occurred between 2013 and 2014 when efficiency increased from 89.50% to 90.39%.

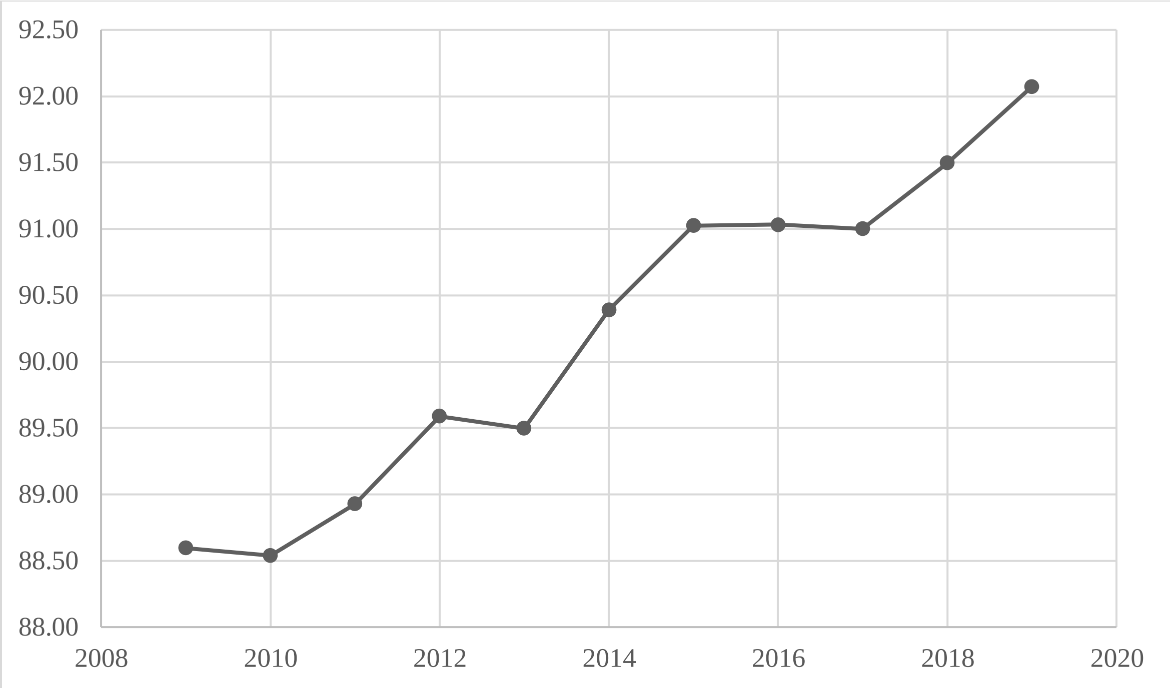


Figure 7. Average of Removal Efficiency of the Wastewater Treatments (%) in the Czech Republic Between 2009 and 2019.

5.4.2 POLICY INSTRUMENTS ON WASTEWATER MANAGEMENT

Figure 8 highlights the variability in resource allocation for wastewater management in the Czech Republic. Investment in environmental protection fluctuated considerably throughout the period, reaching its highest point in 2013 at CZK 15,189,426. In contrast, non-investment spending showed a general downward trend, starting at CZK 14,358,006 in 2009 and decreasing to CZK 8,215,608 in 2019. Significant fluctuations were observed throughout these years, with a notable drop in investment following the peak in 2013. Unlike investment, non-investment spending declined more steadily throughout the period.

Through non-parametric correlations, it was identified that removal efficiency has a positive and significant correlation with non-investment spending on wastewater, with a Spearman correlation coefficient (rho) of 0.358 and a level of significance (Sig. 2- tailed) of 0.041. Likewise, there is a positive and highly significant correlation between investment and non-investment spending on wastewater, with a Spearman correlation coefficient (rho) of 0.516 and a significance level (Sig. 2-tailed) of 0.002. In contrast, no significant correlation between removal efficiency and wastewater investment is observed.

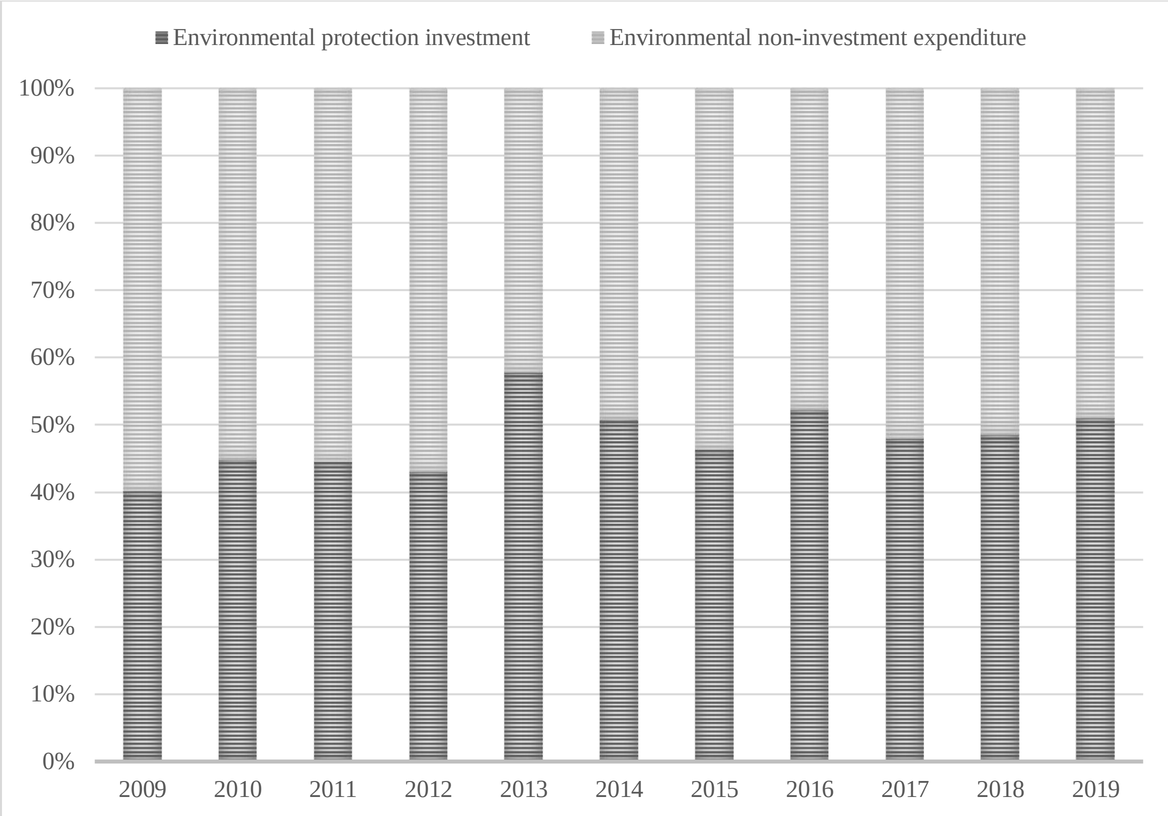


Figure 8. Environmental Protection Investment and Non-Investment Expenditure on Wastewater Management in the Czech Republic During 2009 - 2019

5.4.3 PUBLIC PERCEPTION ON WATER PROVISIONING SERVICES

The typical characteristics of the respondents in the Czech Republic (N=1338) include that 51.2% of the respondents are men, and the average age of the respondents is 42.3 years, with a standard deviation of 13.4 years. 39.5% (528) of the respondents do not have a certificate of completion of secondary studies (maturita). Meanwhile, 60.5% (810) of the respondents have a certificate of completion of secondary studies (maturita) and higher education (see Figure 9). The difference in educational levels is significant, with a p-value < 0.05. 78.0% of the respondents visit the forest more than twice a year. At the same time, 22.0% of the respondents visit the forest twice a year or less or never. The difference in the frequency of visits to the forest is also highly significant, with a p-value < 0.001.

Regarding the expectations and perception of the performance of Czech forests in water provision services, it is observed that the expectations regarding these services are moderately high, with an average rating of 3.4 on a scale of 5. In contrast, the perceived performance is even higher, reaching an average of 4.3 on the same scale (see Figure 10).

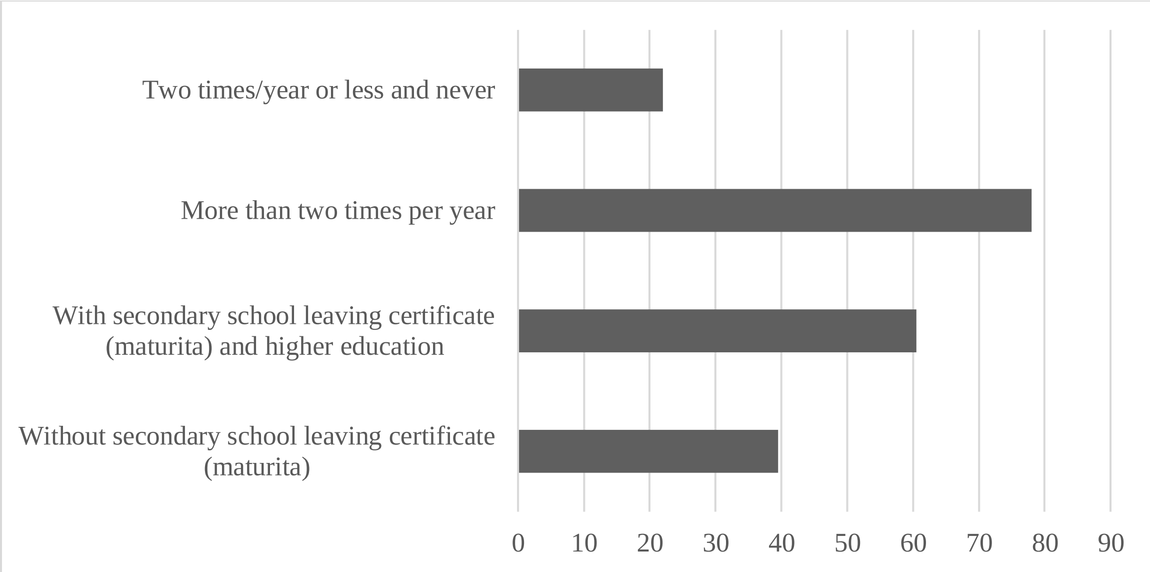


Figure 9. Distribution of Educational Level and Frequency of Visits to the Forest in the National Survey

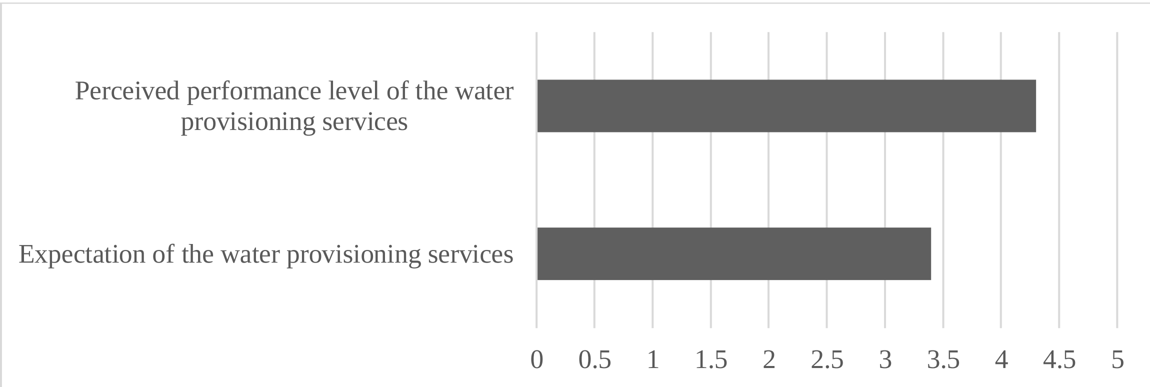


Figure 10. Expectations and Perceived Performance of Czech Forests in Water Provision Services

Regarding the proportion of expectations (see Figure 11) and the level of perceived performance (see Figure 12), it is observed that more than half of the respondents strongly agree that forest water provision services are essential, and a similar proportion considers that the performance of these services is critical.

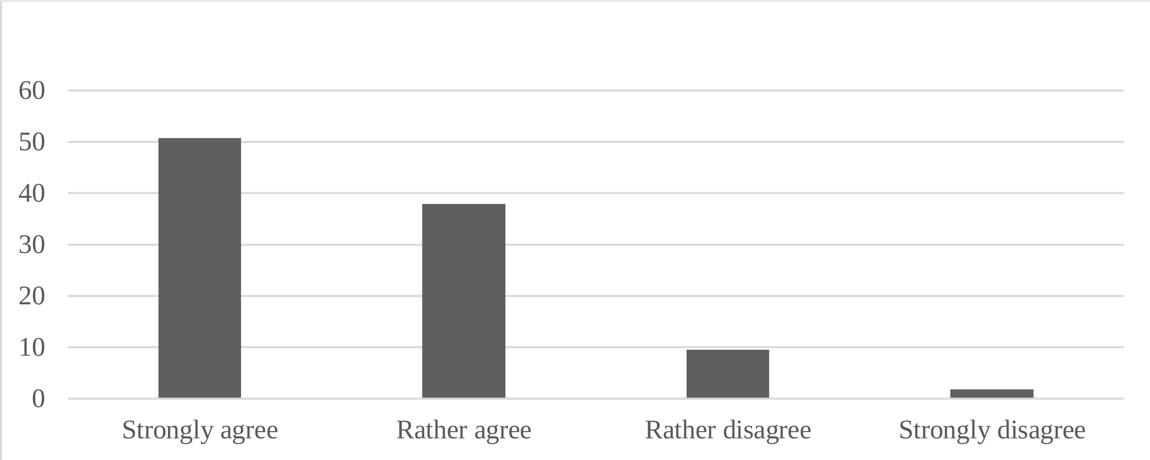


Figure 11. Proportion of expectation of the Czech forests on water provisioning services

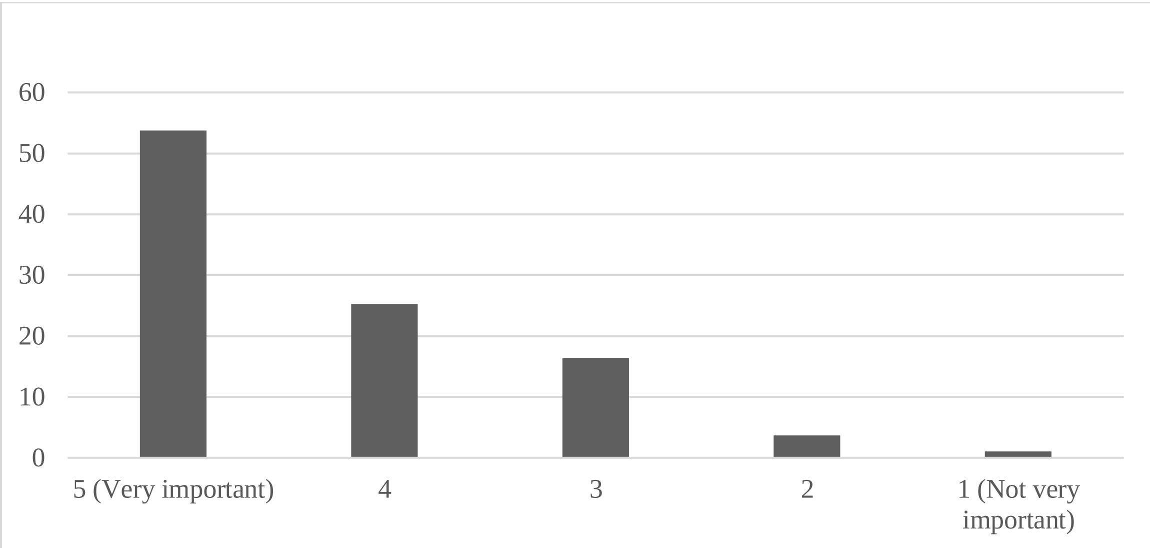


Figure 12. Proportion of perceived performance level of the Czech forests on water provisioning services

Additionally, respondents' age and educational level were identified as significant predictors of low expectations and perceived performance levels in forest water provision. Age is significantly and negatively associated with low expectations and low levels of perceived performance. At the same time, a lower educational level is also significantly associated with a lower evaluation of the performance of these services. Although these associations are statistically significant, the R^2 values indicate that age and educational level explain only a tiny portion of the variability in expectations and perceptions.

6. DISCUSSION

6.1 Application of Economic Instruments in the EU Forestry Sector

6.1.1 CORE DOCUMENTS

The 18 core documents selected (see Table 4.) highlights the evident commitment of the European Union, Austria, and the Czech Republic towards sustainable forest management, as well as their concerted efforts to address environmental and economic challenges. Although variations are observed in the degree of development and implementation of forest policies and initiatives between the two countries of the study and in comparison, with the general panorama of the EU, the commitment to the protection, restoration, and sustainable management of forests is observed, aligned with the European Green Deal and the Biodiversity Strategy for 2030 (European Commission, 2021d; Krutilla, 2011; Mickwitz, 2003).

Austria stands out as a collaboration model between multiple stakeholders, including forest owners, industry representatives, and governmental and non-governmental organizations (Federal Ministry for Sustainability and Tourism Austria, 2018). This effective collaboration strengthens forest strategies by involving diverse actors in their design and implementation (Hallberg-Sramek et al., 2023), which in turn increases the chances of success of the strategies as participants feel part of the process and the proposed decisions (Santos et al., 2023). The Czech Forest strategy instills optimism by updating its vision and proposing a forestry strategy that not only encourages sustainable economic development, but also protects forests and frames the multiple benefits of the forest, in line with European political guidelines (Government of the Czech Republic, 2021). This underscores a dedicated commitment to enhancing forest health, fostering biodiversity to withstand ongoing climate changes, and refining forest management practices to optimize ecosystem services (Hájek et al., 2021).

Likewise, the importance of research and innovation in advancing sustainable forest management is recognized (European Court of Auditors, 2022). Developing effective strategies to transfer the knowledge generated in research to a broader public is essential, contributing to more informed decision-making by the forestry industry and foresters (Directorate-General for Research and Innovation (European Commission), 2021).

Although the value of economic instruments in improving forest management is recognized (OECD, 2021a; OECD, 2021b), improvements must be implemented to ensure that all forestry actors can access information and effectively benefit from available programs and projects (Barde, 1994; Šišák, 2013). It is essential to provide specific support to small forest owners (Blanco et al, 2017). In addition, robust evaluation and monitoring systems for forestry policies and initiatives must be established (Andersen et al., 1997; Krutilla, 2011; Mickwitz, 2003) and supported by European funding (European Commission & Directorate-General for budget, 2021), and administrative simplification and access to technical support for beneficiaries must be ensured (United Nations, 2015).

6.1.2 EU FINANCIAL PROGRAMS

The ten EU financing programs (see Table 5) represent a valuable opportunity for the forestry sector, offering direct financing and support for initiatives that promote sustainability, innovation, and adaptation to climate change (OECD, 2021b). These programs are aligned with the objectives of the European Green Deal and the Biodiversity Strategy for 2030, highlighting their importance in promoting sustainable forestry practices (Huertas-Bernal & Hájek, 2023). Although support for different aspects and coordination between programs is highlighted, it is essential to improve the accessibility of information about these resources (Cortina-Segarra et al., 2021). It would ensure that all relevant actors, especially small forest owners, can access financing opportunities (Blanco et al, 2017). Likewise, integrating more robust sustainability criteria in selecting and evaluating projects financed by these programs would be crucial (Cubbage et al., 2007). This would ensure that investments contribute effectively to the conservation and sustainable management of forests, as well as the mitigation and adaptation of climate change (Henstra, 2016).

6.1.3 ECONOMIC INSTRUMENTS IN THE EU FOREST-BASED SECTOR

Identifying economic instruments within the EU for the forestry sector allows us to reflect on the complexity and breadth of the financial strategies used to address this sector's environmental and economic challenges (OECD, 2021b). Many economic instruments identified, such as natural resource taxes and logging fees, are designed to encourage sustainable forestry practices and environmental conservation (Barde, 1994; Šišák, 2013). Furthermore, economic instruments include approaches such as payment for ecosystem services schemes and habitat banks, which aim to conserve and restore biodiversity and maintain and improve ecosystem services provided by forests (Börner et al, 2017; OECD, 2021b). This recognizes the importance of forest ecosystem services and biodiversity and the willingness to invest in their protection and improvement (Ansell et al., 2016; Millennium Ecosystem Assessment, 2005).

However, having such a wide range of instruments could generate a lack of coordination and coherence between them, resulting in fragmented or duplicate implementation of policies and limiting the effectiveness of efforts (Barde, 1994; Barde, 1999). Likewise, there is a need to improve the accessibility and transparency of these economic instruments to ensure that all relevant actors, including small forest owners, can understand and access the available opportunities (Carattini et al., 2017). Evaluation and monitoring systems must also be strengthened to measure the impact of these economic instruments in the forestry sector, which would allow adjustments to be made to improve their effectiveness and ensure that they meet their planned objectives of conservation, sustainable management, and promotion of biodiversity (Xie et al., 2021).

6.1.4 SWOT Analysis of Economic Instruments

Strengths

The European Union's forestry policies and programs exhibit notable strengths, as a SWOT analysis reveals (see Figure 2a). Firstly, the EU provides substantial financial support to promote sustainable forest management, reforestation efforts, and forest fire prevention initiatives, underlining its commitment to long-term ecological sustainability (European Commission & Directorate-General for budget, 2021). Furthermore, EU forestry policies actively promote sustainable management practices, which contribute significantly to biodiversity conservation, soil protection, and climate change mitigation and adaptation efforts (European Commission, 2021d; Fankhauser, 2017). This holistic approach reflects a deep awareness of the interconnectedness of environmental concerns. Likewise, the EU's emphasis on research and innovation in the forestry sector is evident through its funding of technological development projects and support for innovative practices in forest management (Directorate-General for Research and Innovation (European Commission), 2021; European Court of Auditors, 2022). This forward-thinking approach ensures that forestry practices remain adaptable and responsive to evolving environmental challenges (Cubbage et al., 2007; Henstra, 2016).

Importantly, EU forestry policies balance economic, social, and environmental objectives, advocating multifunctional forest management encompassing timber production, recreational opportunities, and conservation efforts (Ansell et al., 2016; Millennium Ecosystem Assessment, 2005). By facilitating collaboration and knowledge exchange between member states, research institutions, and stakeholders in the forestry sector, the EU fosters cooperation through networks and platforms, thus promoting the dissemination of best practices and advancing collective knowledge (Koziell & Swingland, 2002; OECD, 2021a). Furthermore, the EU has developed robust monitoring tools and systems that provide detailed data on the state of forests, empowering evidence-based decision-making processes and ensuring informed policymaking (Hanewinkel et al., 2022). Additionally, specific initiatives designed to address various aspects of forest management, such as the restoration of degraded forest ecosystems and the conservation of protected species and habitats, further highlight the EU's comprehensive approach to forest governance (Lindner et al., 2010). In particular, EU forestry policies play a crucial role in boosting economic and social development in rural areas, generating employment opportunities, and improving the quality of life of local communities through financial, technical, and logistical support for sustainable forestry activities (Auer & Rauch, 2021; Begemann et al., 2023). Finally, the EU's economic instruments and forest policies are strategically designed to strengthen the resilience of forests to climate change, advocating for adaptation measures and mitigation practices that safeguard the long-term health of forest ecosystems (Nabuurs et al., 2024).

WEAKNESSES

Regarding weaknesses, several aspects of the forestry policies and programs of the European Union concerning the economic instruments were identified (see Figure 2b). First, forest management is primarily in the hands of member states, leading to policy fragmentation and a lack of cohesion in implementation at the EU level (Barde, 1994; Šišák, 2013). Although different funds exist, these are often insufficient to cover the conservation and sustainable management needs of forests and the competitiveness needs of forest managers and owners (Cortina-Segarra et al., 2021; Hrabanski, 2015; Schmithüsen & Zimmermann, 2001). Available programs and funds usually involve complex bureaucratic procedures, which can deter stakeholders from applying for and using them effectively (Soukopová & Struk, 2011). Resources and benefits from economic instruments are not always distributed equitably, leaving some forest areas less supported (Blanco et al, 2017). Integrating climate objectives into forest policies is not always practical, and the capacity of forests to act as carbon sinks is underutilized (Mickwitz, 2003). The lack of robust systems to monitor and evaluate the impact of policies and programs limits the ability to adjust and improve strategies in real-time (Andersen et al., 1997; Krutilla, 2011). The coexistence of economic (logging exploitation) and environmental (biodiversity conservation) objectives can generate conflicts of interest, making implementing sustainable policies difficult (Andersen et al., 1997; Krutilla, 2011; Mickwitz, 2003).

OPPORTUNITIES

Through the SWOT analysis, several opportunities were identified in the forestry policies and programs of the European Union, often related to the implementation and effectiveness of available economic instruments (see Figure 2c). Economic instruments provide financial incentives to promote sustainable forest management practices, such as forest certification, adaptive management, and biodiversity conservation (Hrabanski, 2015; OECD, 2021a). Carbon markets offer opportunities for forest owners to generate income by participating in carbon sequestration projects and selling carbon credits, thus promoting conservation and reforestation (Brink et al., 2016). Economic instruments can support the development of a sustainable forest bioeconomy by promoting forest products such as biomass, wood products, and other renewable biomaterials (Borgström, S, 2018). Research funds and programs can drive technological innovation in the forestry sector, including developing new management techniques, remote forest monitoring, and geographic information systems (Directorate-General for Research and Innovation (European Commission), 2021). Economic instruments can finance projects to restore degraded forest ecosystems and conserve protected areas, thus improving forest health and biodiversity (Ansell et al., 2016). Economic incentives can encourage the development of ecotourism in forest areas and the valorization of the ecosystem services that forests provide, such as recreation, water harvesting, and protection against natural disasters (Hájek et al., 2021; Millennium Ecosystem Assessment, 2005). Public-private financing mechanisms can facilitate collaboration between the public, private, and civil society to implement sustainable forestry projects and manage shared resources (Mickwitz, 2003). Economic instruments can specifically target local communities that depend on forests for their livelihoods, strengthening their management and conservation capacity (Blanco et al, 2017).

THREATS

Finally, the following threats related to economic instruments were identified in the European Union's forestry policies and programs (see Figure 2d): The demand for timber resources and other forest products can generate economic pressure for intensive logging, harming biodiversity and the long-term health of forest ecosystems (Koplow & Steenblik, 2022). Some subsidies and financial aid can distort forest markets, favoring unsustainable practices or creating disincentives for adopting more sustainable forest management practices (Lehmann, 2012; OECD, 2003). Additionally, economic crises can reduce the resources available for forest conservation and management, potentially negatively impacting implementing policies and programs to promote forest sustainability (UNEP, 2004; Watson et al., 2022). Volatility in forest product prices can affect the profitability of sustainable forest management and make long-term planning for forest conservation and management difficult (IPCC, 2022). On the other hand, competition from different economic sectors, such as agriculture or urbanization, can pressure forest areas, threatening their preservation and long-term sustainability (UNEP, 2004). Trade policies and international agreements can influence trade in forest products, affecting forest management and conservation in the EU (Auer & Rauch, 2021; Fürtner et al., 2022). Climate change can also affect the productivity and health of forests, potentially resulting in significant economic consequences for forest owners and related industries (Fankhauser, 2017; IPCC, 2022; Lindner et al., 2008).

6.2 Opinions of Foresters on Economic Instruments

Interviewees reported climate change has imposed significant challenges on forest management, requiring urgent adaptation to new climatic conditions. This coincides with studies that indicate the need to introduce new species and promote diversity in forests to increase their resilience (Fankhauser, 2017; IPCC, 2022; Nabuurs et al., 2024). The concern expressed by those interviewed about the future is notable; they anticipate that if current conditions persist, the problems observed so far could intensify, resulting in even more significant losses of forests and biodiversity (Ansell et al., 2016; IPCC, 2022). These effects underscore the importance of implementing adaptive and proactive forest management strategies to mitigate the adverse impacts of climate change and protect our forest ecosystems for future generations (Fankhauser, 2017; Lindner et al., 2008).

Additionally, there is notable variability in the awareness and use of economic instruments among the different actors in the forestry sector. Some important aspects are briefly described below.

- Large players and those with greater financial interest tend to be more aware and proactive in using these mechanisms. In some countries, forest owners are well organized and supported by organizations or state forest services that inform them about subsidy mechanisms and assist them in practical forest management (Biffi et al., 2021; Garrone et al., 2019). This support is essential to ensure that all landowners, regardless of size, can access the resources necessary for sustainable forest management.
- However, smaller private landowners in other countries may not be as informed due to a lack of interest or language or information access barriers. This disparity in the level of information and proactivity is notable among the different actors in the sector and can significantly influence forest management and access to financial resources (Blanco et al., 2017; Schmithüsen et al., 2010).
- Awareness of economic mechanisms largely depends on the financial interest of the owners. When mechanisms are financially attractive, owners quickly become interested. This economic motivation is a key driver for adopting sustainable practices and taking advantage of subsidies and other financial support (Biffi et al., 2021; Garrone et al., 2019).
- In some places forestry regulation varies between regions, which can confuse (Barbier, 2007; Russi et al., 2016; Xie et al., 2021). However, efforts are being made to unify the policies and make them more understandable (OECD, 2021a; United Nations, 2015).
- Programs such as LIFE are well-known, but only a small percentage of interviewees use them. The complexity of the process can be a barrier for some owners as they are often not well-informed and may not be interested in the financing mechanisms due to the complexity and administrative requirements (European Commission. Directorate General for Environment, 2019; UNEP, 2004; Watson et al., 2022). This lack of information and the perception that processes are complicated can limit their participation in financing programs (Barbier, 2007; Xie et al., 2021).
- In some regions, there is growing awareness of carbon offset and capture mechanisms driven by initiatives from companies outside the forestry sector (Baranzini et al., 2000;

Brink et al., 2016). These initiatives are helping to increase awareness and participation in sustainability financing programs (Baranzini et al., 2000).

6.3 Impact of Economic Instruments on Roundwood Consumption

Analyzing the domestic roundwood consumption, it was identified that Sweden and Finland have a long-standing tradition and well-developed infrastructure in the timber and forestry industry (see Figure 4a). Both nations possess robust industrial capacities for wood processing, supported by vast forest resources and sustainable forest management practices. This combination allows Sweden and Finland to add value to local raw materials and compete in international markets with high-quality products. Additionally, government policies in these countries strongly support the timber industry, promoting its growth and sustainability through incentives, environmental regulations, and research and development programs (Borgström, 2018; Ministry of Enterprise and Innovation Sweden, 2022; Siiskonen, 2007; Villalobos et al., 2018).

Regarding the exportation and importation of roundwood variables, it was identified that Germany's prominence in exporting and importing wood underscores its crucial role in the global industry and its ability to efficiently integrate different aspects of the supply chain, from importing raw materials to exporting high-quality finished products (see Figure 4b,c). Germany is a key trade hub in Europe, importing large volumes of wood for processing and exporting finished or semi-finished products (Auer & Rauch, 2021; Hanewinkel et al., 2022). Other countries also leverage their resources, industrial capabilities, and strategic locations to maintain and expand their participation in the wood market. For instance, Sweden and Finland import wood to diversify their raw material sources and ensure a constant supply (Ministry of Enterprise and Innovation Sweden, 2022; Siiskonen, 2007).

On the other hand, the environmental taxes variable allows us to identify that despite not being a large consumer or importer of wood compared to other countries, Italy pays high environmental taxes (see Figure 4d). This suggests that Italy's timber industry is subject to stringent regulations and environmental policies, resulting in a high tax burden (Lanfredi et al., 2023). In Germany, the significant payment of environmental taxes reflects the extensive industrial activity in wood processing and manufacturing (Gong & Löfgren, 2013). On the other hand, Sweden, one of the largest domestic consumers of wood, pays relatively low environmental taxes compared to the countries analyzed despite its extensive forestry industry (Holmgren et al., 2005).

According to the fixed effects model results (Model 2), the positive and highly significant coefficient for exports (6.0366e-07) suggests a positive relationship between exports and domestic wood consumption. As exports increase, domestic wood consumption also tends to rise (Kastner et al., 2011; Luppold & Bumgardner, 2016; Tian et al., 2017). This may indicate that countries exporting more wood products also use more wood domestically, likely due to a more robust and active wood industry (Holmgren et al., 2005; Siiskonen, 2007; Wang & Haller, 2024). Conversely, the negative and non-significant coefficients for imports and total environmental taxes suggest no clear evidence that these factors significantly impact domestic wood consumption. The amount of imported wood does not substantially affect domestic consumption, and while environmental taxes are a financial burden, they are not high enough to significantly influence wood consumption behavior (Gregory, 1966; Kastner et al., 2011).

On the other hand, the results from the random effects models (Models 3, 4, and 6) consistently indicate that exports have a positive and significant impact on domestic wood consumption. Imports and environmental taxes, however, do not show significant effects. This suggests that countries with higher wood exports tend to consume more wood domestically, possibly due to a more developed wood industry and greater processing capacity (Ministry of Enterprise and Innovation Sweden, 2022; Siiskonen, 2007; Wang & Haller, 2024). Current policies and regulations, including environmental taxes, appear to have no significant direct impact on domestic wood consumption. This may imply that environmental regulations are not stringent enough to influence wood consumption or that the current level of taxes does not significantly affect consumption decisions (Kastner et al., 2011; Siiskonen, 2007; Tian et al., 2017; Wang & Haller, 2024).

6.4 Effects of Economic Instruments on Forest Ecosystem Services

6.4.1 Land Cover Changes

Reducing forest cover (coniferous, broadleaf, and mixed forests) in the Liberec and Hradec Králové regions in the north, in the Moravian-Silesian and Olomouc regions in the northeast, and the Pilsen region in the west (see Figure 5) is consistent with the results of the 2018 study, where at a 20 m scale resolution, land cover analysis identified a reduction in coniferous forests due to disturbance by bark beetles and the Kyrill windstorm in 2007 (Janík & Romportl, 2018). On the other hand, the gain zones, which appear in small spots distributed throughout the territory, specifically in the regions of Karlovy Vary, Ústí nad Labem, Liberec, Vysočina, South Bohemia, and Pilsen are consistent with the results of some studies that analyze the change in cover at different scales of interpretation. Still, they reflect forest management trends and the slight increase in forest cover in other areas of the Czech Republic (Boucníková & Kucera, 2005; Dvořáková et al., 2022; Feranec et al., 2010; Kupková et al, 2013).

6.4.1 Water Quality

Figure 6 illustrates the evolution of pollution levels by BOD5, COD, undissolved substances, total nitrogen, and total phosphorus in Czechia between 2009 and 2019. This data reveals a worrying trend of increasing water pollution during this period. Despite this national trend, significant variations are observed between regions of the country. South Moravia stands out for consistently presenting the highest BOD5 and COD loads. This situation could be attributable to the region's high population density and intense industrial activity. On the other hand, Zlínský shows a notable increase in the loading of undissolved substances, possibly related to the rise in the population connected to the sewage system in that area (Český statistický úřad, 2020; Irfan et al., 2017).

The performance of the Wastewater Treatment Plants (WWTP) in Zlínský in reducing COD is notable, which suggests the effective implementation of physical treatments. However, challenges persist in removing total nitrogen and phosphorus, with South Moravia being the region that best manages this problem, while Central Bohemia faces more significant difficulties (Giokas et al., 2002). Data indicates widespread growth in water pollution over the years in Czechia despite meeting the minimum load reduction requirements established by European Union Directives (Baun & Marek, 2013; European Commission, 2019b; Janosova et al., 2006).

The average efficiency of contaminant removal by wastewater treatments reflects continued advancements in wastewater treatment technologies and practices in the country (Český statistický úřad, 2020; Janosova et al., 2006) (see Figure 7). Although WWTPs have improved their efficiency, increasing water pollution, measured by parameters such as BOD5, COD, undissolved substances, total nitrogen, and total phosphorus, indicates that current efforts are insufficient to eliminate additional pollution sources (Baun & Marek, 2013; Giokas et al., 2002).

6.4.1 POLICY INSTRUMENTS ON WASTEWATER MANAGEMENT

The variability in resource allocation for wastewater management in the Czech Republic (see Figure 8) suggests the need for more consistent financing strategies to address environmental protection effectively (Šantrůčková et al., 2017). Regarding non-parametric correlations, by identifying that removal efficiency has a positive and significant correlation with non-investment expenditure in wastewater and a positive and highly significant correlation between investment and non-investment expenditure in wastewater, it can be interpreted that, although investment in infrastructure is essential, operation and maintenance expenses (not investment) have a more direct impact on improving the efficiency of contaminant removal in wastewater treatment. This underlines the importance of investing in infrastructure and ensuring adequate financing for the operation and ongoing maintenance of wastewater treatment plants (Baun & Marek, 2013; Janosova et al., 2006; Šantrůčková et al., 2017).

6.4.1 PUBLIC PERCEPTION ON WATER PROVISIONING SERVICES

Regarding expectations and perception of the performance of Czech forests in water supply, there is evidence that the public's perception of the forests in this aspect exceeds their expectations. However, these differences are not statistically significant. This is contrasted with the results of some studies that explore the value that forest visitors attribute to the different services that forests provide (Doria et al., 2009; Francis et al., 2015; Gebrehiwot et al., 2014). For example, the 2009 study suggests that the perception of water quality is mainly influenced by satisfaction with organoleptic properties, risk perception, contextual cues, and perception of chemicals in water. These findings highlight the complexity of public perceptions of water and the need to understand these factors to improve confidence in water supply (Doria et al., 2009). It is highlighted that understanding public perceptions and comparing them with studies in other regions can help design more effective and socially accepted policies. Implementing adaptive and proactive forest management strategies, such as reforestation and watershed protection, can be more successful if they align with public expectations and perceptions (Carattini et al., 2017; Russi et al., 2016; Xie et al., 2021).

7. CONCLUSION AND RECOMMENDATIONS

7.1 Conclusions

The study's conclusions are presented below according to the objectives and research questions posed at the beginning of the research.

7.1.1 IDENTIFICATION OF ECONOMIC INSTRUMENTS

Concerning identifying economic instruments that stimulate climate change adaptation in the EU forestry sector, five main types of available instruments have been recognized: taxes, fees and charges, tradable permits, voluntary approaches, and subsidies. The implementation of each type of economic instrument varies within member countries, depending on the sociopolitical context and sectoral interests associated with forestry policies.

For example, in countries such as Sweden and Finland, where the forestry sector plays a crucial role in the national economy, strong forestry policies have been implemented that promote both the forestry industry and the conservation of natural resources (Ministry of Enterprise and Innovation Sweden, 2022; Siiskonen, 2007). These policies include measures to promote sustainable forest management and the efficient use of forest resources. On the other hand, in countries like the Czech Republic, forestry policies have historically focused on forest exploitation and wood production. However, recently, there has been a shift towards more modern policies aligned with international standards for sustainable forest management (Šišák, 2013). Although this transition is ongoing, full implementation of these policies may require time and a continued commitment to sustainable forest management. On the other hand, in Austria, the presence of political will, interest, and the active participation of multiple forestry stakeholders has enabled the implementation of forestry actions aligned with the sector's objectives and vision (Federal Ministry for Sustainability and Tourism Austria, 2018). Additionally, the plans devised to execute the forestry strategy have a higher likelihood of success and better monitoring of policy tool implementation.

Notably, the wide range of economic instruments available can lead to a lack of coordination and coherence between them, resulting in fragmented or duplicated implementation of policies. This lack of coherence may limit the effectiveness of efforts to promote climate change adaptation in the EU forestry sector. Therefore, working towards better coordination and alignment of economic instruments is crucial to maximize their impact on forest adaptation to climate change.

7.1.2 Perceptions on the Use of Economic Instruments

Regarding the interpretation of forestry actors on the use of economic instruments to facilitate the adaptation of the EU forestry sector to climate change, a variety of levels of knowledge and perceptions are observed, influenced by factors such as the size of the property, the financial interest, and the bureaucratic complexity of European financing programs (Huertas-Bernal & Hájek, 2023).

At an average level, it is found that forest sector actors are not fully informed about the financing mechanisms available for forest management and adaptation measures related to climate change. It has been identified that those with greater knowledge recognize the existence of multiple sources of financing from the European Union. However, small forest owners tend to have a more limited understanding of these financing mechanisms and often require intermediaries to access information or apply for this type of financing for their forests.

Furthermore, it has been observed that the financial interest of the owners strongly influences the level of knowledge of economic mechanisms. When mechanisms are perceived as financially attractive, owners show greater interest in them. However, forestry actors have also pointed out that European financing programs often present a high bureaucratic complexity, limiting their accessibility and effectiveness. This administrative complexity can hinder widespread access to these instruments. On the other hand, it has been highlighted that regional cooperation can play an essential role in improving access to these instruments and increasing their effectiveness throughout the EU since it allows taking advantage of the different capacities and resources available in the other member countries.

7.1.3 Impact of Economic Instruments on Wood Consumption

Concerning the impacts of economic instruments on wood consumption in the EU, it is concluded that exports exert a positive and significant influence on domestic wood consumption. At the same time, imports and environmental taxes do not show discernible effects. This suggests that countries with high wood exports tend to engage in higher levels of domestic wood consumption, possibly due to a more advanced wood industry and outstanding processing capabilities (Auer & Rauch, 2021; European Commission, 2003).

However, current policies and regulations, including environmental taxes, appear to lack a significant direct impact on domestic wood consumption. This may indicate that environmental regulations are not rigorous enough to influence wood consumption or that current tax levels do not substantially affect consumption decisions.

7.1.4 EFFECTS OF ECONOMIC INSTRUMENTS ON CZECH FOREST ECOSYSTEM SERVICES

Finally, several significant conclusions can be drawn regarding the implications of using economic instruments in water treatment and their effects on forest ecosystems in the Czech Republic. Firstly, it is noted that the public's perception of the role of forests in water supply exceeds their expectations, with more than half of respondents strongly agreeing that forest water supply services are essential (Huertas Bernal et al., 2021). Furthermore, a significant increase in coniferous forests and the total Czech forest area between 1990 and 2018 is highlighted, as well as the reduction of forest cover due to disturbances such as bark beetles and the Kyrill storm in 2007 (Janík & Romportl, 2018).

Regarding water quality and policy instruments for wastewater management, it is concluded that investment in infrastructure is crucial. It is observed that operation and maintenance expenses have a more direct impact on improving contaminant removal efficiency in wastewater treatment. This underlines the importance of investing in infrastructure and ensuring adequate financing for the operation and ongoing maintenance of wastewater treatment plants (Huertas Bernal et al., 2021).

7.1.1 ALLOCATION OF FINANCIAL RESOURCES TO ADAPT THE EUROPEAN FORESTRY SECTOR

The research has made it possible to identify five main economic instruments available to the forestry sector: taxes, charges, tradable permits, payments for ecosystem services, and subsidies. However, the diversity and complexity of these instruments and the differences in terminology and regulations between countries and regions have posed a significant challenge in international comparisons and evaluating their performance uniformly.

Through the SWOT analysis and the study of forestry actors' perceptions of these instruments, crucial qualitative aspects have been identified that can be used to improve the implementation of financial instruments and optimize their effectiveness. Coordination and coherence between economic instruments are essential to maximize their impact.

Furthermore, the standardization and improvement of the available information would allow for better comparisons before and after implementing these instruments.

The diversity of forestry approaches and policies among EU countries underlines the importance of specific socio-political contexts for adopting and managing financing mechanisms. Forest sector actors have varied perceptions of economic instruments influenced by property size and bureaucratic complexity. The lack of information and the need for intermediaries highlight the importance of improving accessibility and simplifying financing mechanisms. Better coordination of economic instruments and simplification of administrative processes are essential to strengthen the adaptation of the European forestry sector to climate change, promoting sustainable and efficient forest management throughout the EU.

7.2 Recommendations

Based on the research findings, policy recommendations have been formulated to enhance economic instruments for forest resource management.

- Implement standards and regulations to regularly update databases on economic instruments. This ensures the accessibility, quality, and consistency of information, facilitating the evaluation and monitoring of economic instruments for more effective forest management.
- Continue investing in research and development of methods to value economic instruments in the forestry sector. This will enable a more accurate and comprehensive assessment of their impact on forest management and environmental sustainability.
- Formulate and implement policies encouraging multidisciplinary cooperation in evaluating and managing economic instruments. This approach fosters a better understanding of socioeconomic issues. It allows for a comprehensive analysis of economic instrument implications on the environment and society, promoting efficient resource utilization for sustainable forest management.
- Improve public participation in environmental policy formulation and implementation by providing precise and accurate information, conducting public consultations, and actively engaging civil society in decision-making processes. Training local forestry agents can also facilitate more sustainable and participatory forest management practices.

- Conduct awareness and training campaigns targeting forestry actors to enhance their understanding of the benefits and applications of economic instruments in forest management. This would contribute to increased acceptance, adoption, and effectiveness of these instruments in climate change adaptation.
- Conduct periodic evaluations of the impact of economic instruments on wood consumption to identify areas for improvement. This data can inform adjustments to existing policies or the development of new instruments promoting sustainable forest resource utilization.
- Strengthen policies and regulations related to environmental components to safeguard forest ecosystems. This could involve periodic assessments of the state of forest ecosystems and existing policies to identify areas for improvement, as well as developing environmental education programs for the general public to raise awareness about the importance of forest ecosystem services.
- Regularly update and make available to the public information on forest cover to monitor changes in forest area and effectively detect possible threats or pressures on forest ecosystems. This ensures timely interventions and conservation efforts to protect forest resources.

7.3 Key Takeaways

The need for a more forest-focused approach is highlighted in the research context, given their crucial importance in mitigating, and adapting to climate change and conserving biodiversity. The holistic analysis of the economic instruments available in the EU, conducted using a mixed methodology, has provided a significant understanding of these instruments, with particular attention to their impact on forest management.

It is essential to highlight that the effectiveness of economic instruments is directly affected by other policies that may promote less sustainability and more significant income for users. In this sense, evaluating efficiency is crucial to identify which instruments have reported significant improvements in environmental quality and limit those that only provide economic benefits at the expense of environmental degradation.

Likewise, the importance of multisectoral and public participation in developing and implementing these instruments is highlighted. Cooperation between different economic sectors and the involvement of all interested parties are essential elements to guarantee more significant results at the national level.

During the research, significant limitations were found in the databases on economic instruments. The variability and lack of standardization in the terminology of these instruments, together with the lack of updating and accessibility of databases, pose significant challenges. It is essential to address these issues to ensure an accurate and comprehensive evaluation of economic instruments.

On the other hand, it is crucial to recognize the importance of the adaptability of economic instruments to specific local contexts. There is no single or universally practical approach; a flexible approach is required to adapt to local needs and realities.

This research contributes to developing more effective and sustainable environmental policies, providing a solid basis for informed decision-making in the forestry and environmental field. A deep understanding of economic instruments and their impact on forest management is essential to ensure a sustainable future for our forests and the environment.

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List of Abbreviations

AFOLU	Agriculture, Forestry, and Other Land Use
BOD	Biological Oxygen Demand
CF	Cohesion Fund
CIFOR	Centre for International Forestry Research
CLC	Corine Land Cover
CO2	Carbon dioxide
COD	Chemical Oxygen Demand
EAFRD	European Agricultural Fund for Rural Development
EC	European Commission
ECV	Essential Climate Variable
EEA	European Environment Agency
EIs	Economic instruments
EMAS	European Management and Audit Scheme
ERDF	European Regional Development Fund
ESF+	European Social Fund+
EU	European Union
FAO	Food and Agriculture Organization
FE Model	Fixed-Effects Model
GHG	Greenhouse Gases
IPCC	Intergovernmental Panel on Climate Change
IUFRO	International Union of Forestry Research Organizations
JTF	Just Transition Fund
LIFE	Programme for Environment and Climate Action
LULUCF	Land Use, Land Use Change and Forestry

MMU	Minimum Mapping Unit
MOA	Ministry of Agriculture of the Czech Republic
MPRM	Multiple Panel Regression Model
OECD	Organization for Economic Cooperation and Development
PES	Payment for Ecosystem Services
QCA	Qualitative Content Analysis
RDPs	Rural Development Programs
RE	Removal Efficiency
RE Model	Random Effect Model
SFM	Sustainable Forest Management
UN	United Nations
UNECE	United Nations Economic Commission for Europe
WWRP	Wastewater Treatment Plants

APPENDIX

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Strengths

- What is being done well?
- What resources can be used?
- What are the strong points for financing?
- What is reportedly being done correctly?

Weaknesses

- What could be improved?
- Where do you have fewer resources than others?
- What are others likely to see as weaknesses?
- What do the reports mention as areas for improvement?

Opportunities

- What opportunities are opening for the financing of forestry initiatives?
- What trends could be taken advantage of?
- How could strengths be turned into opportunities?
- Which planned measures have not yet been implemented but could help finance forestry initiatives?

Threats

- What threats could harm the proposed financing?
- How are other sectors being financed?
- What threats expose weaknesses?

Appendix 2. In-Depth Interview Guideline

Consent Agreement:

Thank you for taking the time to participate in our research. My name is Diana Carolina Huertas Bernal, and I would like to interview you about your experience in the forestry sector, specifically about funding mechanisms for initiatives to adapt to climate change in the context of forest ecosystem services.

The expected length of the interview is about 60 minutes. I will be recording the session because I do not want to miss any of your comments. Although I will take some notes during the session, I may not be able to write fast enough to write it all down. Because we are recording, please be sure to speak loud and clear, so we do not miss your comments.

All responses are confidential. Your interview responses will only be shared with members of the research team. We will ensure that any information we include in our publications does not identify you as the respondent. Personal data will be handled following General Data Protection Regulation and APA regulations. There are no known risks associated with the study, but if you have any follow-up questions, you will always have the opportunity to contact our team. Remember, you do not have to talk about anything you do not want to, and you can end the interview at any time. Do you agree to the terms and are you willing to participate in this interview?

Questionnaire

1. Could you mention the relevant aspects of your experience in the forestry sector?
2. Which forest ecosystem services do you consider forest provide?
3. What consequences of climate change have you observed in the forest ecosystems of your country?
4. What are climate change adaptation measures being taken against these effects at the national and regional levels?
5. Do you know of any payment or compensation program for ecosystem services in your country?
6. How is forest ownership in your country?
7. What mechanisms do you use to involve stakeholders in climate change adaptation initiatives for forest ecosystem services?

8. Do you know where the economic resources to finance forestry initiatives come from?
9. Do you think that stakeholders in the forestry sector are aware of the financing mechanisms for the adaptation and management of forests in the face of climate change?
10. How does forest ownership influence the management of forest ecosystem services and access to finance for adaptation to climate change?
11. How does the forest management plan contribute to the forest policy in your country?
12. What do you think about the European Union programs to finance forestry initiatives?

(LIFE, Common agricultural policy, Rural Development Program, Horizon Europe, European Structural and Investment Funds)

13. Do you know the action plan for the financing of sustainable growth of the European Union? What is your opinion about it?
14. What do you think about raising funds from activities that threaten ecosystem services and then investing that money in initiatives to manage and improve the state of natural resources?
15. Have you had any experience obtaining financing to manage or develop initiatives related to forest ecosystems and adaptation to climate change?
16. What challenges you have faced when implementing management measures in the forestry sector? How have you solved them?
17. Do you think financial resources are used efficiently for climate change adaptation of forest ecosystems in your country?
18. How can your country's financing mechanism for adapting forest ecosystems to climate change be improved?
19. Any additional comments that you want to share with us?

Appendix 3. Code in r for Multiple Regression Panel

```
# load packages
library(readxl)      # Read excel files
library(plm)         # Linear models for panel data
library(gplots)      # Various R programming tools for plotting data
# loading the data
file.choose()
data_excel <-"C:\\ Multiple panel regression EU\\panel_data.xlsx"
db <- read_excel(data_excel,
              sheet = '15') # 15 countries 96.2% dmc
# Descriptive statistics panel data
summary(db)
# creating data frame with all countries
df <- pdata.frame(db, index = c("country", "year"))
#------------------------ REGRESSION MODEL WITH PANEL DATA ---------------------
# Multiple linear regression: The Pooling Model -------------------------------
Model_pool <- plm(dmc_ton ~ exp_eur + imp_eur + tet_eur,
               data = df,
               model = "pooling")
summary(Model_pool)
# Regression with fixed effects (FE) ------------------------------------------
Model_fe_within <- plm(dmc_ton ~ exp_eur + imp_eur + tet_eur,
                  data = df,
                  model = "within")
summary(Model_fe_within)
# individual effects of each country
```

```
fixef(Model_fe_within)

# Comparing fixed effects and pool -------------------------------------------

# H0: pooled model (OLS) vs H1: fixed effects

pFtest(Model_fe_within, Model_pool)

# H0 is rejected (p-value less than 0.05),

# therefore fixed effects are preferable for this case

# Regression with random effects (re) ----------------------------------------

# Swamy-Arora's transformation

Model_random = plm(dmc_ton ~ exp_eur + imp_eur + tet_eur,

              data = df,

              model="random")

summary(Model_random)

# Wallace-Hussain (1969)

Model_re_walhus <- plm(dmc_ton ~ exp_eur + imp_eur + tet_eur,

            data = df,

            model = "random",

            random.method = "walhus")

summary(Model_re_walhus)

# Amemiya (1971)

Model_re_amemiya <- plm(dmc_ton ~ exp_eur + imp_eur + tet_eur,

             data = df,

             model = "random",

             random.method = "amemiya")

summary(Model_re_amemiya)

# Nerlove (1971)

Model_re_nerlove <- plm(dmc_ton ~ exp_eur + imp_eur + tet_eur,
```

```
              data = df,
              model = "random",
              random.method = "nerlove")
summary(Model_re_nerlove)
# Model selection ------------------------------------------------------------
# H0: random effects vs H1: fixed effects
# Hausman test
# H0: The random effects model is consistent
# H1: The fixed effects model is consistent
phtest(Model_random, Model_fe_within)
phtest(Model_re_walhus, Model_fe_within)
phtest(Model_re_amemiya, Model_fe_within)
phtest(Model_re_nerlove, Model_fe_within)
# End ------------------------------------------------------------
```

Appendix 4. First Publication

Title: Societal Implications of Forest and Water Body Area Evolution in Czechia and Selected Regions

Type: Article

Authors: Diana Carolina Huertas Bernal, Ratna Chrismiari Purwestri, Mayang Christy Perdana, Miroslav Hájek, Meryem Tahri, Petra Palátová and Miroslava Hochmalová

Journal: Remote sensing

Year: 2021

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CERTIFICATE OF PUBLICATION

The certificate of publication for the article titled:

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Appendix 5. Second Publication

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Authors: Diana Carolina Huertas Bernal and Miroslav Hájek

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Dr. Shu-Kun Lin
Publisher & President

Appendix 6. Dissemination of Results

CONFERENCES

- The 29th annual conference International Sustainable Development Research Society (ISDRS). "Half-way through Agenda 2030: Assessing the 5Ps of SDGs (people, planet, prosperity, peace and partnership)" 11-13th July 2023. Biodiversity and economic instruments: implications on biodiversity due to using harmful financial tools. [Book of abstracts - Conference]
- The 16th International Scientific Conference WoodEMA 2023. Current Trends and Challenges for Forest-Based Sector: Carbon Neutrality and Bioeconomy. June 14th - 16th 2023. EU funding for bioeconomy transition: Perception of forest actors. ISBN: 978-953-8446-01-6 [Book of abstracts - Conference]
- The 27th Conference of the Environmental and Sustainability Management Accounting Network (EMAN Europe). May 31st -June 2nd, 2023. Bioeconomy: an opportunity for biodiversity? [Conference]
- The 24th Annual Conference. Environmental Economics, Policy and International Environmental Relations. Prague University of Economics and Business. 24-25 November 2022. Perception of economic instruments in the forest-based sector of the EU. ISBN 978-80-7490-287-1 [Book of abstracts - Conference]
- Meeting of economics departments 2022. Science and Research at Economic Departments and Institutes of Forestry and Timber Faculties. 21-22 September 2022. Perception of Economic Instruments in the Forestry Sector as a Mechanism for Adapting to Climate Change in the Context of the EU. [Conference]
- Fourth International Forest Policy Meeting - IFPM4. European Forest Institute's Governance Programme. 27-29 April 2022. Economic instruments in forest cultural services: a comparison study between the Czech Republic and Austria. [Conference]
- The 23rd Annual Conference. Environmental Economics, Policy and International Environmental Relations. Prague University of Economics and Business. 25-26 November 2021. Water quality and policy instruments interaction in the Czech Republic. ISBN 978-80-7490-230-7 [Book of abstracts - Conference]

- XVII International Conference Sustainability Accounting and Reporting. Ministry of the Environment, Czech Business Council for Sustainable Development and Czech Ecological Management Center. 6-7 October 2021. Policy Instruments and Water Quality Interaction in the Czech Republic. [Conference]

POSTERS

- 26th IUFRO World Congress 2024. Forest and society towards 2050. 23-29 June 2024. Optimizing the Forest Bioeconomy: Balancing Biological Limits and Empowering Local Communities and Exploring Forest Stakeholders' Perspectives on Payment for Ecosystem Services in the European Union. [Posters]
- Green for Good VI conference. European Federation of Biotechnology. 12-15 September 2022. Perspectives and challenges of financing mechanisms for forest bioeconomy transition. [Poster]
- ELLS Summer School on Bioeconomy 2021: Euroleague for Life Sciences. University of Natural Resources and Life Sciences, Vienna (BOKU). Comparison of Bioeconomy Strategies case study Belgium and Czech Republic. [Poster]

WORKSHOPS

- European Bioeconomy Scientific Forum 2023. Moving towards the transformation. 6th-8th September 2023. Vienna, Austria. European Bioeconomy University Alliance (EBU). [Participant]
- Meeting of Bioeconomy Youth Ambassadors. 4th-5th September 2023. Vienna, Austria. European Commission. [Participant]
- Workshop on perceptions of bioeconomy in the CEE region. Czech University of Life Sciences Prague. Team for forest bioeconomy. May 16, 2023. [Participant]