CICLO: XXXVI

THE ECOSYSTEM SERVICES OF THE FOREST: ANALYSIS OF POLITICAL AND SOCIO-ECONOMIC ASPECTS

Stefano Bruzzese

Supervisor:
Prof. Filippo Brun

PhD Cycle Coordinator:
Prof. Domenico Bosco

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Il dubbio è l'inizio della conoscenza.
- Cartesio -

Summary

List of acronyms

ARIES: ARtificial Intelligence for Environment & Sustainability
ADM: Avoided Damages Method
AKIS: Agricultural Knowledge and Innovation Systems
BTM: Benefit Transfer Method
CAC: Command-And-Control
CART: Classification and Regression Tree
CMM: Choice Modelling Method
CVM: Contingent Valuation Method
ES: Ecosystem Services
FES: Forest Ecosystem Services
InVEST: Integrated Valuation of Ecosystem Services and Tradeoffs
IUCN: International Union for the Conservation of Nature
LULUCF: Land Use, Land Use Change and Forestry
MBI: Market-Based Instruments
MES: Markets for Ecosystem Services
MSE: Mean Squared Error
PES: Payments for Ecosystem Services
PICO: Population, Intervention, Comparison, Outcome
PRISMA: Preferred Reporting Items for Systematic reviews and Meta-Analyses
RCM: Replacement Cost Method
SEEA: System of Environmental-Economic Accounting
SMOTE: Synthetic Minority Oversampling TEchnique
SolVES: Social Values for Ecosystem Services
SP: Stated Preferences
TEV: Total Economic Value
WOS: Web Of Science
WTA: Willingness To Accept
WTP: Willingness To Pay

1. Introduction

1.1 Research background

Forests, with their products and services, can play a vital role in addressing the global triple crisis - biodiversity loss, climate change, and pollution (Harrison et al., 2022; European Commission, 2021). They can also support the three key sustainability pillars: environmental protection, social equity, and economic viability (Aguayo Lopes da Silva, 2023; IRP, 2019). However, this positive role depends on proper planning and management. Recent years have seen international, European, and national environmental policies like the 2015 Paris Agreement, the Sustainable Development Goals of Agenda 2030, the European Green Deal, the EU 2030 Biodiversity Strategy, and the new EU Forest Strategy for 2030 strongly advocate for the importance of forests.

Simultaneously, human overexploitation of these services and ecosystems (i.e., natural capital) is putting their future at risk (Dasgupta, 2021). In this context, economics, as the driving force behind policy decisions, plays a crucial role in making informed choices about managing ecosystems and land use changes. It involves evaluating the benefits of their presence and the costs associated with their loss. In 1997, the estimated global value of ecosystem services (ESs) ranged from $15 to $42 trillion annually (Costanza et al., 1997). A decade later, this value more than tripled to $125-145 trillion per year, with annual estimated losses of $4-20 trillion due to land use changes (Costanza et al., 2014). Over the past 30 years, environmental economics has made significant strides. This progress includes the development of monetary economic valuation methods to quantify ecosystem products and services and the creation of Market-Based Instruments (MBIs) to internalise the value of these resources in the market (Engel et al., 2008; Stern, 2006; Wunder, 2005; Daily, 1997; Coase, 1960). Today, economic evaluation of ESs serves various purposes, such as providing information and raising awareness, supporting green accounting, analysing specific policies, and helping territorial planning at different scales (Costanza et al., 2017). However, there is still much work to be done to provide increasingly precise evaluations that consider not only the instrumental value of these services but also their intrinsic and relational value in an integrated and participatory manner (van Noordwijk et al., 2023). In other words, that there is a shift in paradigm from an anthropocentric approach to an ecocentric one that considers nature also for its own sake rather than solely in utilitarian terms.

1.2 Research gap

In light of the findings from the scientific literature, the following research gaps were identified:

- lack of critical analysis of MBIs currently applied or potentially applicable internationally for Forest Ecosystem Services (FES).

- Absence of studies assessing ex-post the design, implementation, and impact of payment for forest ecosystem services schemes in developed economies.
- Lack of support for selecting the most suitable monetary economic method to evaluate the protective service provided by forests.

1.3 Research questions and key objectives

The primary objective of this thesis is to emphasise the importance of FES in the contemporary economy and society. In a broader perspective, the aim is to demonstrate how the economic evaluation of these services contributes to: creating greater awareness of the significance of natural ecosystems; conserving and enhancing biodiversity; assisting institutions in making informed decisions regarding the environment; better management of natural resources; and as stated by economist Pavan Sukhdev, who led one of the most significant global assessments of ecosystem and biodiversity economic evaluation projects (TEEB, 2009), making the "invisibility of nature" visible.
Based on these considerations, the thesis identifies the following specific objectives:

- develop a systematic review of MBIs already applied or potentially applicable for international FES.
- Establish a methodological framework for the ex-post evaluation of Payments for Ecosystem Services (PES) schemes and apply it to a case study.
- Explore the criteria for selecting economic evaluation methods for a specific ES, creating a methodological framework for related decision-making processes.

With the intent of addressing the following questions:

- RQ1) Which MBIs are most widely used today for the valuation of FES, and how are they structured?
- RQ2) What elements can determine the success or failure of a PES scheme in developed economies?
- RQ3) Which monetary economic method is best suited, in terms of risk analysis and decision support, to evaluate forest protection service?

1.4 Theoretical framework

The thesis builds its constructs and analyses on the theories of neoliberal and environmental economics. In these theories, the term "ecosystem service" takes on an anthropocentric meaning, rooted in the philosophical doctrine of utilitarianism (Bentham, 1907; Mill, 1998), and, as a result, in the pursuit of individual pleasure. In support of this view, one of the best known and accepted definitions of ESs

characterises them as "the multiple benefits that an ecosystem can provide to humans" (Millennium Ecosystem Assessment, 2005). This perspective regards ESs as environmental goods, hence as pure public goods (Samuelson, 1948) or impure goods that can also become externalities; in other words, unintended effects, positive or negative, that impact the well-being of other individuals (Pigou, 1920). As is well known, pure public goods are defined as goods for which individuals cannot be excluded if they haven't paid for them and are non-rivalrous in consumption or use, while impure or, more precisely, *common* goods lack the characteristic of non-excludability (Hardin, 1968). However, according to neoliberal economics, these ESs are not allocated efficiently in the market, due to their characterisation as externalities and/or public goods, which are often associated with information asymmetry between contracting parties (i.e., demand and supply). Consequently, they are subject to market failure because they fail to reach the Pareto optimum, that is the point at which no individual in the market can improve his or her well-being without harming that of others.
To this should be added that the physical nature of natural resources often hinders the assignment of clear property rights, i.e. who has the right to do what. Property rights, as outlined by Schlager & Ostrom (1992) can pertain to:

- Access: for entry onto the property.
- Withdrawal: for harvesting natural products or receiving a service from the property.
- Management: for managing and adopting practices that directly or indirectly alter the property.
- Exclusion: for deciding who can access the property.
- Alienation: for transferring, renting, or selling some or all property rights.

In order to achieve a second-best solution, environmental economics has developed monetary evaluation methods to economically quantify these services and internalise them as costs or benefits depending on the context, through market-based policy instruments. Unlike command-and-control instruments, which are highly coercive, and informational corrections, of broader scope, these corrections occupy a middle ground in terms of individual coercion but foster greater trust and virtuous behaviours (Paletto et al., 2020).

1.5 Thesis structure

The rest of the thesis is structured as follows: Section 2 illustrates the methodology employed in the PhD research project and how the data was collected; this is followed by the results (Sections 3-5) presented in the three articles:

- a Systematic Review of Markets for Forest Ecosystem Services at an International Level.
- A Framework Proposal for the Ex-Post Evaluation of a Solution-Driven PES Scheme: The Case of Medvednica Nature Park.

- The Decision Trees Method to Support the Choice of Economic Evaluation Procedure: The Case of Protection Forests.

Finally, Section 6 discusses and comments on the results obtained, highlighting take-home messages, and concluding with the implications of this project, its limitations, and possible future developments.

2. Methodology

To address the research questions of the project, a tailored approach was developed to align with the specific research requirements; thus, a uniform methodology replicated across the three studies was not employed. In the first study, a critical review was conducted to understand the state of the art of FES markets. This review followed a systematic protocol widely recognised and adopted in various fields, including meta-analyses, known as the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analysis) protocol. This protocol provides a checklist of elements guiding the review process (Page et al., 2021). Simultaneously, the PICO (Population, Intervention, Comparison, Outcome) framework was employed to define the systematic research strategy and its respective string (Salazar-Sepúlveda et al., 2022).

The research questions and hypotheses for the second study related to PES schemes were derived from the systematic review. In this context, a sequential mixed-methods approach (qualitative and quantitative) was employed to address these questions (Creswell, 2009). Specifically, a logic model or "*theory of change*" was developed and applied to a case study in Croatia, drawing from document reviews, web scraping of reviews from a site (i.e., TripAdvisor), and semi-structured interviews with stakeholders and citizens. In the latter case, the willingness to pay approach was used.

Finally, in the last study on monetary economic methods, a mixed-methods approach (qualitative and quantitative) was adopted to create a decision support tool applied to the case study of forest protection services against rockfall. An initial qualitative exploratory analysis of choice criteria for selecting one economic method over another was conducted. Subsequently, predictive models were developed for each identified method, using a well-established machine learning algorithm, the *decision tree* technique (Gocheva-Ilieva, Kulina, and Ivanov, 2021). This algorithm facilitated the classification of guiding criteria in method selection and prediction of under which circumstances its use would be suitable and superior or inferior to other methods.

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1st Article

3. A systematic review of markets for forest ecosystem services at an international level

Stefano Bruzzese[1], Simone Blanc[1,]*, Alessandro Paletto[2], and Filippo Brun[1]

[1] Department of Agricultural, Forest and Food Sciences (DISAFA), University of Torino, Largo Paolo Braccini 2, Grugliasco, 10095, Italy

[2] Consiglio per la ricerca in agricoltura e l'analisi dell'economia agraria (CREA), Forestry and Wood Research Centre, Trento, 38123, Italy

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Abstract: Markets for ecosystem services (MES) can play a key role in the protection of natural capital and the remuneration of sustainable management practices. This study aims to present the state of the art on forestry MES at the international level through a systematic review. The main objectives are (i) to analyse the distribution of actual or potential markets for forest ecosystem services (FES) that exist internationally today, (ii) to identify the spatial scale at which market-based instruments (MBIs) are applied and the respective measures of economic value used to assess FES, and (iii) to identify the actors and their involvement in the implementation of forestry MES. The study collected 304 peer-reviewed publications using the Scopus and Web of Science databases. The PRISMA (Preferred Reporting Items for Systematic reviews and Meta-Analyses) protocol was used to guide the systematic process and select the 52 articles analysed in the review. The results show that Europe is the most representative continent in terms of geographical areas involved (n=8) by forestry MES, followed by America (n=6), Asia (n=5), and Africa (n=1). The main scale of application of MBIs for forestry MES is local, i.e., at the level of forest stand, municipality, or province (n=31), followed by subnational (n=10), national (n=9), and international (n=2). The main pattern of social composition in forestry MES is buyers, sellers, and intermediaries (n=25), followed by buyers and sellers only (n=12), buyers, sellers, intermediaries, and knowledge providers (n=5), and buyers, sellers, and knowledge providers (n=3). In terms of the measure of economic value, most studies use willingness to accept (n=30), as opposed to willingness to pay (n=17), and only 5 studies used both. Future research on forestry MES should be directed towards a better understanding of the process leading to their creation, implementation, effectiveness, governance, and level of satisfaction in economic terms of the actors involved.

Keywords: market for ecosystem services (MES), payments for ecosystem services (PES), market-based instruments (MBIs), PRISMA protocol, PICO framework.

3.1. Introduction

3.1.1. Natural capital accounting

In recent years, natural capital - defined as a stock of non-renewable and renewable resources including the production of ecosystem services and life-support functions (De Groot 1992) - has received strong recognition in its role as a mitigating agent of climate and environmental crisis, such that it is considered in decision-making processes at different spatial scales (Dasgupta 2021; Farrell et al. 2021). However, natural capital is frequently underestimated in decision-making processes and subject to continuous threats and pressures (European Environment Agency 2019; Souliotis and Voulvoulis 2021). Natural capital accounting allows tracking the contribution of nature, understood as ecosystems, to human well-being and development, and the positive interactions between society, economy, and environment (Bagstad et al. 2021; Bruzzese et al. 2022; Li et al. 2022). The results obtained from accounting can then be used individually or in an integrated way in complex decision-making processes (Bateman and Mace 2020; Vysna et al. 2021): in economic impact and cost–benefit analyses of planning choices and policy programmes, and to inform governments, institutions, and society about the use of natural resources.

3.1.2. Policy framework

Among the various ecosystems that make up natural capital, forests play a key role, as they account for 31% of the Earth's land surface (FAO and UNEP 2020) and host around 80% of its biodiversity (IPBES 2019). Today, there are several agreements, strategies, and policies adopted at various spatial scales that take forests into account. At the international level, there are Sustainable Development Goals promoted by the UN 2030 Agenda (United Nations 2015), specifically Goal 15: "*Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss*" and the UN Strategic Plan for Forests 2017–2030 with six global forestry goals and 26 associated targets also to be achieved by 2030 (United Nations 2017). At the continental level, the new European Union (EU) Forestry Strategy 2030 has as primary objective to improve the quantity and quality of multifunctional forests, by reversing negative trends and increasing their resilience against the high uncertainty brought about by climate change. The EU Forestry Strategy 2030 has several points in common with both the EU Biodiversity Strategy and the EU Bioeconomy Strategy. All these documents can be considered

an integral part of the wider European Green Deal (European Commission 2021). In the United States, there is the USDA Forest Service Strategic Plan: FY 2015–2020 (USDA Forest Service 2015) and the USDA Strategic Plan: FY 2018– 2002 with goal 6: "*Ensure Productive and Sustainable Use of Our National Forest System Lands*" focusing on forests (USDA 2018). At country level, according to the FAO's FRA report (FAO 2020), almost all countries have a forestry policy, accounting for 99% of the total forest area. The same report then highlights the presence of more than 230 forestry programme projects in 82 countries with a project budget of USD 246 million (2020).

3.1.3. Policy instruments

Governments can use different environmental policy instruments to meet previously mentioned commitments, agreements, and targets. According to Liao (2018), there are three main categories of instruments available to policy makers:

- **Command-and-control instruments (CACs)** in which the government sets, for example, a standard on the maximum emission limit of companies, and then is responsible for monitoring the performance and compliance with the requirements demanded by the standard (Liu et al. 2020). These are policy instruments such as directives, standards, regulations, laws, bans, and permits, which, although inflexible and coercive, are often used by governments, especially in conditions of market failure (Solà et al. 2020).
- **Market-based instruments (MBIs)** where an attempt is made to encourage or discourage certain behaviours through incentives (Murphy et al. 2021). They are flexible, cost-effective, and more effective instruments, compared to CACs, for environmental progress. MBIs are useful in preventing biodiversity loss and promoting the provision of ecosystem services (Pirard 2012). Several authors have also tried to propose a classification of MBIs, such as Pirard and Lapeyre (2014). In this work, they were subdivided according to the type of transaction, including *price-based instruments* that internalize the environmental cost within an existing market, such as taxes and subsidies, or promote the creation of new markets that remunerate the provision of ecosystem services, such as auctions and Payments for Ecosystem Services (PES) (Gao et al. 2020; Yu et al. 2021; Benra et al. 2022); *quantity-based instruments* that regulate the quantity and quality of an environmental resource, good, or service by creating a market, such as cap- and-trade systems, carbon offset schemes, and emissions trading schemes (Ellerman 2002; Alhassan et al. 2019; Frey et al. 2021); and *market friction instruments* that remove or reduce barriers in existing markets to improve their functioning; examples include ecolabels (Soria et al. 2021; Takahashi et al. 2021).

- **Information-based instruments** through which attempts are made to influence people's behaviour by leveraging their knowledge, beliefs, and values through communication and knowledge transfer (Howlett 2019; Walker et al. 2020). These are the least coercive policy instruments, which are not mandatory and do not require additional incentives or sanctions, such as advertising campaigns, information dissemination, and stakeholder engagement processes (Moore et al. 2020; Dalby et al. 2021).

This review analysed MBIs, as they are the tools that most stimulate attentive and virtuous behaviour towards the environment, creating trust between the actors involved and promoting forms of cooperation (Paletto et al. 2020). Starting from this consideration, we developed the following hypothesis:

- The presence of Markets for Ecosystem Services (MES) can play a role in rewarding climate and environmentally friendly practices implemented by landowners and managers.

3.1.4. Reviews

Several literature reviews have looked at MBIs, analysing particular instruments such as incentives (Nikolakis and Innes 2017; Mitani and Lindhjem 2021) or PES (Ojea et al. 2016; Sarvašová et al. 2019; Vuletić et al. 2020), focusing on a precise spatial scale: continental (Baumber et al. 2019; Maier et al. 2021), multinational (Loft 2011), or local (Seehusen 2009). In some cases, studies have used economic methods to assess ecosystem services rather than MBIs (Quillérou and Thomas 2012; Garcia et al. 2018). The only work found in the scientific literature that makes an analysis of different MBIs internationally is from the early 2000s (Landell-Mills and Porras 2002). Therefore, our intention is to fill this gap in the scientific literature by updating the current situation and investigating the following questions:

- RQ1) What is the distribution of forest ecosystem service (FES) markets at an international level?
- RQ2) What is the spatial scale of application of MBIs for forestry MES?
- RQ3) Who are the actors involved in the implementation of forestry MES and what are their relationships?
- RQ4) Which measures of economic value are used to assess forestry MES?

These four research questions were considered in the present study because they include the most important aspects related to the implementation and replicability of PES schemes in other contexts. The first two research questions investigate countries with a more consolidated experience on the FES markets and on the peculiarities in their implementation (e.g., socio-economic context, scale of application, category of ecosystem services). The other two research questions focus on two key aspects of the PES scheme implementation cycle (Vuletić et al.

2021; Valatin et al. 2022): identification of the key actors to be involved in the design and implementation of a PES scheme and the economic value to assign as a starting point to an ecosystem service without a market.

Table 1. Search strategy.

Main categories	Keywords
Forest ecosystem services	TITLE-ABS-KEY ("forest environmental service$" OR "forest ecosystem service$" OR FES OR "cultural * service$" OR "provision** service$" OR "regulati** service$" OR "supportin** service$")
MBIs	AND TITLE-ABS-KEY ("market * ecosystem service$" OR MES OR "MBI$" OR "market-based instrument$" OR "incentive$" OR "incentive$ program*" OR "incentive-based program$" OR "regulatory-based market incentive$" OR "cap-and-trade polic*" OR "payment* for ecosystem service$" OR PES OR "additionality" OR "payment* mechanism$" OR "provision point mechanism$" OR "crowdfunding" OR "auction$" OR "subsid* system$" OR "market$ tool*")
Forest	AND ALL ("forest$" OR "woodland$")

Operationally, a systematic review process was set up following the guidelines proposed by the "PRISMA" (Preferred Reporting Items for Systematic reviews and Meta-Analyses) reporting protocol, with the specific aim of answering research questions.

3.1.5. Sections

The rest of the article is structured as follows: Section 2 describes the process that led to conducting the systematic review, the PICO (Population, Intervention, Comparison, Outcome) framework, and the PRISMA protocol. Sections 3 and 4 show and comment on the results obtained from the systematic review, while the last section concludes with the limitations of this study and its possible developments.

3.2. Materials and methods

3.2.1. Search strategy

This review was designed following the guidelines proposed by the PRISMA protocol (Page et al. 2021). The search was conducted between May and October 2021, using Scopus and Web of Science (WOS) databases. The search strategy was developed from three main categories: "forest ecosystem services", "market instruments", and "forest". Then, related keywords and synonyms were identified and manipulated with Boolean operators (AND and OR) and wildcards, obtaining

the search string shown in Table 1. The search of the first two categories was restricted to the fields “title, abstract, and keywords”, while the last one was extended to “all fields” to give more emphasis to the research field, that is forestry.

3.2.2. Eligibility criteria

The PICO framework was used to formulate the research hypothesis in a structured way and to determine the eligibility criteria (Speckman and Friedly 2019; Schiavenato and Chu 2021; Alayan et al. 2022; Salazar-Sepúlveda et al. 2022). Such criteria are Population (P): forest ecosystem services; Intervention (I): the presence of market instruments; Comparison (C): the presence of other policy instruments; Outcome (O): the ability to reward climate and environmentally friendly practices implemented by landowners and managers. Studies that did not meet the PICO criteria were excluded, while those in which some criteria were doubtful or difficult to assess were analysed in full text before making an inclusion/exclusion decision. Subsequently, other inclusion criteria were added such as (i) only primary research articles, (ii) written in English, and (iii) published since 2003, referring to the previous international review done on MES and published in 2002.

3.2.3. Data extraction

Suitable articles were reviewed manually and independently by two researchers. Files were exported in .csv (CSV) format for initial analysis, containing the following information: authors, title, year of publication, source, and document type for those analysed by Scopus, and authors, title, and source for articles analysed by WOS. Data extraction was done using an Excel® spreadsheet and collecting the following information from the full-text articles: ID, database in which the article is present, title, author(s), year of publication, ecosystem service category (provisioning, regulating, supporting, and cultural services) using the Millennium Ecosystem Assessment classification system (Millennium Ecosystem Assessment 2005) Land Use, Land-Use Change and Forestry (LULUCF) activities, MBIs, spatial scale, geographical area, current market status (already implemented or only potential), presence or absence of an estimated Willingness to Pay (WTP), Willingness to Accept (WTA) compensation in the analysed paper, type of stakeholder involved, decision-making process adopted, and additional notes (Table 2, Appendix A).
To simplify the data extraction process, some variables were classified according to classification criteria already available in the literature.
Regarding the spatial scale, reference was made to the classification proposed by Krishan and Singh (2019). At the “local” level, studies with reference to forest stands, municipalities, districts, and provinces are included. At the “subnational”

level, studies on the geographical basis of counties, regions, and federated states are included. At the "national" level, countries are included, while at the "international" level, studies that include more than one country are included.

Table 2. Description of variables considered in the data extraction phase (in brackets whether the variable refers to MBIs or MES).

Variable	Variable options
ID, database in which the article is present, title, author(s), year of publication, geographical area, and additional notes	N/A
ES categories (MES)	"Supporting", "Provisioning", "Regulating", and/or "Cultural"
LULUCF activities (MES)	"Afforestation", "Reforestation", and/or "Forest management"
MBIs	"Auction", "Contract", "Financial instrument", "Incentive", and/or "Negotiable certificate"
Spatial scale (MBI)	"Local", "Subnational", "National", and/or "International"
Market status (MES)	"Potential" and/or "Actual"
WTP (MES)	"Yes" or "No"
WTA (MES)	"Yes" or "No"
Type of stakeholder (MES)	"Buyer", "Seller", "Intermediary", and/or "Knowledge provider"
MES implementation decision-making process	"Top-down approach" and/or "Bottom-up approach"

About the category of stakeholders, the classification proposed by Nisbert *et al.* (2020) and Paletto *et al.* (2021) was used. "Sellers" are those who manage natural capital and are responsible for its conservation, protection, and improvement through good management practices. "Buyers" are those who purchase the service provided by natural capital and provide seed capital to start implementing the PES scheme. "Intermediaries" are those who manage the market, regulate it at different scales or facilitate its development, and protection. Finally, "knowledge providers" are those involved in providing technical and scientific advice, promoting the market, and evaluating and monitoring its effectiveness.

MBIs have been grouped into five main options based on the intrinsic properties of the instrument. *Contracts* include the following options: Payments for Environmental Services (Wunder 2005) - also known as PES - watershed management contracts, reforestation contracts, and biodiversity management

contracts. *Financial instruments* include the following options: shares, bonds, CALL and PUT options (i.e., the rights to buy in the first case and to sell in the second to the holder who holds them, a given stock), crowdfunding. *Incentives* include subsidies, government payments, green payments, private payments, and property tax incentives. *Tradable certificates* include offset/carbon credits, certified emission reductions, and transferable development rights. There are no options in the *Auctions*.

3.3. Results

3.3.1. Search results

The flow chart, illustrated in Fig. 1, shows the operational steps taken in the review process for selecting studies. A total of 304 records were found in the period analysed. Scopus returned 171 studies and WOS returned 133. Of these studies, 116 were removed because they were duplicates, 51 because they did not meet the inclusion criteria, 3 because their full texts were not available, and 1 because WOS provided a double result of the same record. Of the 138 potentially eligible articles, after reading the titles and abstracts, only 79 met the PICO eligibility criteria and, of this, only 52 were selected for qualitative analysis after reading the full text.

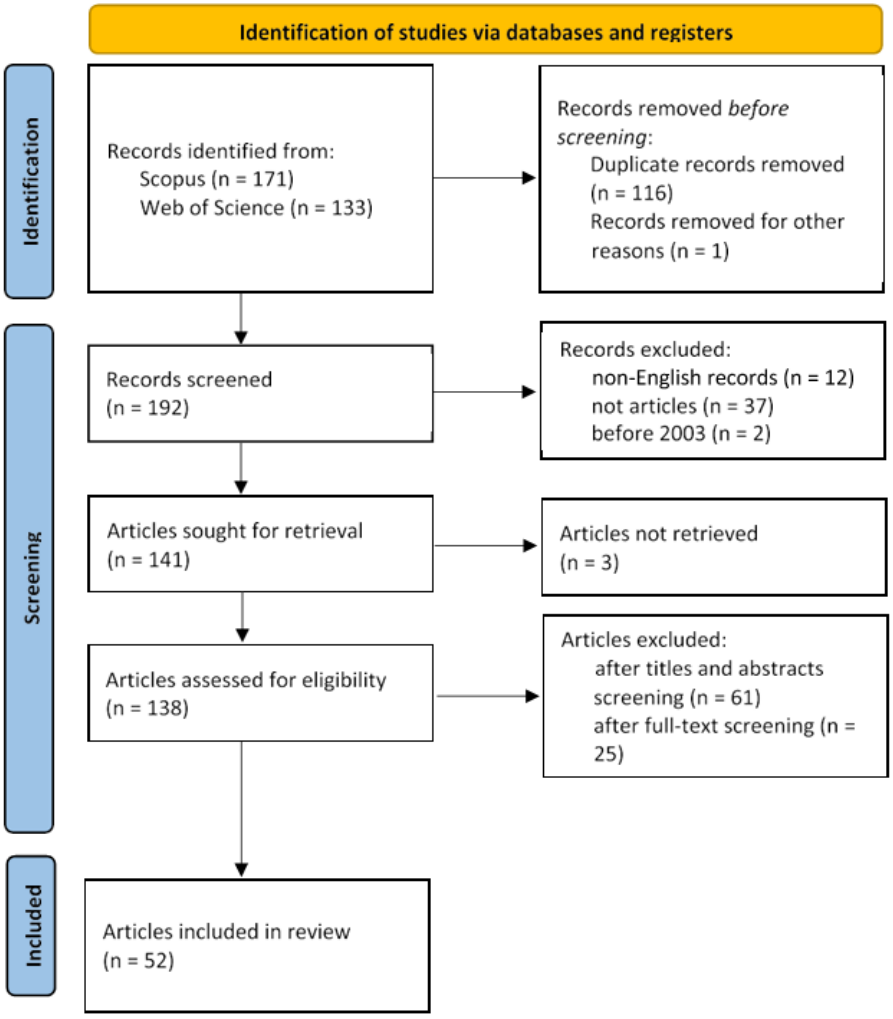
3.3.2. Geographical distribution of the forestry MES, ecosystem service categories, and types of MBIs

Table 3 shows the geographical distribution of forestry MES studies by type of MBI used and ecosystem services category. In terms of distribution of studies, Europe is the most represented continent, since 8 geographical areas are involved, followed by America with 6, Asia with 5, and Africa with 1. No studies were found in Oceania. In terms of number of publications, Asia, with 22 studies, is the most represented continent, followed by America with 15, Europe with 13, and Africa with 2 studies both in Madagascar. In absolute terms, the countries with the highest number of studies are Vietnam (n=17), followed by United States of America (n=7), and Italy (n=5). There are also two countries exclusively focused on one category of ecosystem services, respectively “cultural” for Croatia (n=1) and “regulating” for Poland (n=1).

Regarding the FES assessed, almost all studies (n=49) deal with regulating services and just over half deal with cultural services (n=29) and provisioning services (n=27), while only one study deals with supporting services. Many of these studies assess more than one category of services at a time; indeed, of the 52 studies analysed, only 11 focus exclusively on regulatory services and 1 on cultural services. However, there are no studies that have analysed supporting services and provisioning services individually. In addition, it is interesting to highlight that 16

papers focused on three different FES (provisioning, regulating, and cultural), 11 on two (provisioning and cultural), and 11 on only one (regulating).

Fig. 1. PRISMA flow diagram for the study selection process.



Regarding MBIs (Fig. 2), America is the most versatile continent, as it uses all the types of instruments presented. Europe and Asia follow with 3 and 2 types of instruments, respectively. Finally, Africa only has contracts.

3.3.3. Types of MBIs applied per spatial scale and LULUCF activities

Contract, in the form of PES or PES-like, is the most applied typology (*n*=40), followed by incentives (e.g., subsidies and green payments) and tradable certificates (*n*=4 each); auctions (*n*=3) and financial instruments are less frequent (*n*=2). Almost all studies (*n*=44) analysed MBIs applied to FES when there was active forest management, only 4 studies focused exclusively on reforestation, and 2 considered both conditions. No study analysed cases of afforestation.
The spatial scale at which MBIs are applied is shown in Table 4 and Fig. 3.
About the spatial scale, MBIs adopted in active forest management are the most numerous. The data show that, out of the 44 articles considered, more than half are reported at the local scale (*n*=25), namely at the level of forest stand, municipality, city, or province; 9 studies are focused at subnational level; 8 at national level; and only 2 at the international level. Regarding studies on reforestation/afforestation practices or combined with active forest management, 4 studies were applied at the local scale and only 1 at the subnational and national scale. The results show that some MBIs tend to be more commonly researched at a certain scale and other MBIs at a different one. For example, contracts and auctions are more widely used on smaller spatial scales, while financial instruments, public incentives, and tradable certificates, such as carbon credits, have larger markets on a national and international scale.

3.3.4. Categories of stakeholders and decision-making process

Table 5 shows the categories of actors involved in the decision-making process and the approach adopted. The most used approach is the top-down one (*n*=30), followed by the bottom-up approach (*n*=14). However, it was not possible to identify the approach adopted for 8 studies. Regarding the different categories of stakeholders, in the bottom-up approach, many studies involved only sellers and buyers (*n*=8 out of 14), whereas in the top-down approach, the most representative pattern was the presence of sellers, buyers, and intermediaries (*n*=22 out of 30). These results highlight how often the intermediary is the State or other public bodies, which may play the role of mere sellers or buyers, but often are also market regulators, or private bodies acting as brokers as in the case of the carbon market or as lenders in the case of funds.

Table 3. Geographical distribution of the forestry MES by ecosystem service category and type of MBI adopted (articles are listed in Appendix A using the number within squared brackets).

	Ecosystem services categories														
	Supporting	Provisioning				Regulating					Cultural				N/A
	Market-based instruments														
Geographical area	CO	AU	CO	IN	NC	AU	CO	FI	IN	NC	CO	FI	IN	N/A	CO
Bangladesh			[40]				[40]								
Brazil							[30]	[2]		[2]					
Caribbean Region			[28]				[28]				[28]				
Chile				[27]					[27]						
Costa Rica			[33,50]				[33,50,52]				[33,50,52]				
Croatia											[46]				
Eastern Europe and the Mediterranean Basin	[24]		[24]				[24]				[24]				
Finland							[32]			[35]					
France			[16]				[16]								
Great Britain				[39]					[39]				[39]		
Indonesia			[4]				[4,18]				[4]				
Italy			[34,42]				[3,21,34,42,43]				[21,34,42]				
Madagascar							[5,41]								
Mexico					[13]					[13]					
Poland							[45]								
South Korea			[19]				[19]				[19]				
Spain			[10]				[10]								
Thailand										[17]				[17]	[17]
USA		[6,14,15]	[44]	[12]		[6,14,15]	[44]	[36]	[12,49]		[44]	[36]	[49]		
Vietnam			[1,8,20, 22,25,31, 37,39]				[1,7–9,11,20, 22,23,25,29,31, 37,39,47,51]				[1,7–9, 11,20,22, 25,29,31, 37,47,51]				[26,48]

Note: Abbreviations: AU, Auction; CO, Contract; FI, Financial Instrument; IN, Incentive; NC, Negotiable Certificate; N/A, Not Available

Fig. 2. Number of MBIs by continent and type.

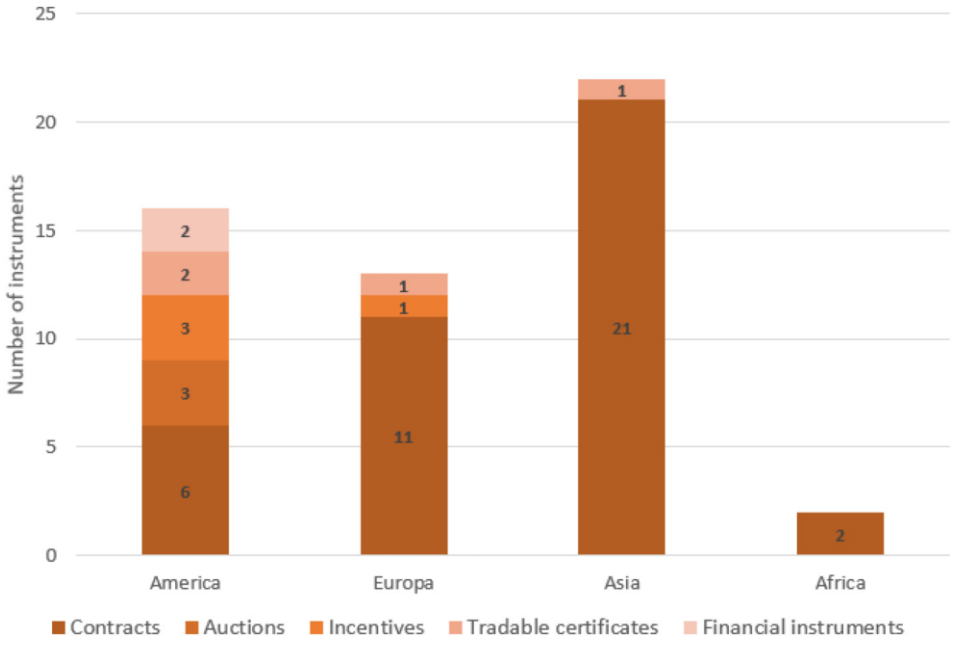


Table 4. Types of MBIs applied per spatial scale and LULUCF activities (papers are listed in Appendix A).

	LULUCF activities								
	Forest management				Reforestation		Forest management and reforestation		N/A
	Spatial scale								
Market-based instruments	Local	Subnational	National	International	Local	National	Local	Subnational	Local
Auction	[14,15]	[6]							
Contract	[1,3,4,7,11,18–20,25,26,28,29,32,37,39–43,46–48,51]	[5,8,10,16,21,44]	[24,31,34,45,50,52]		[9,30]		[23]	[33]	[22]
Financial instrument		[2]	[36]						
Incentive		[27]		[38,49]		[12]			
Negotiable certificate		[2]	[34]		[17]				[13]
N/A					[17]				

With regard to the decision-making process, the most used forms of forestry MES implementation are the top-down approach with buyers, sellers, and intermediaries (*n*=22), the bottom-up approach with only sellers and buyers (*n*=8), and the top-down approach with all four categories of stakeholders (*n*=5).

3.3.5. Measures of the economic value and market status

The different measures used in the studies for economic value and market status are shown in Table 6. The data show that most studies use WTA (n=30) as a measure of economic value, compared to WTP (n=17). Only 5 studies use both, while 10 studies do not report any economic value.
Regarding market status, 27 studies refer to potential markets, 24 studies to actual markets, and only 1 study refers to both types.

Fig. 2. Number of MBIs per LULUCF activities and spatial scale.

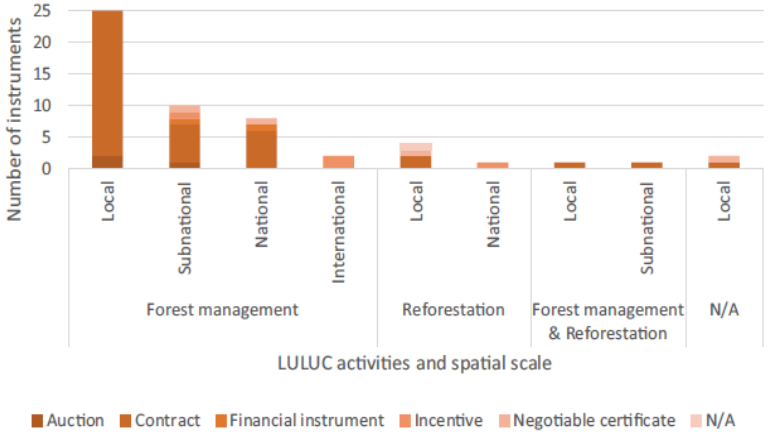


Table 5. Categories of stakeholder and decision-making process adopted per spatial scale (papers are listed in Appendix A).

Decision-making approach and type of stakeholders	Spatial scale			
	Local	Subnational	National	International
Bottom-up				
Buyers and sellers	[3,17,19,32,43]	[5,10]	[36]	
Buyers, sellers, and intermediaries	[41]	[16]		
Buyers, sellers, and knowledge providers	[14,15]	[6]		
N/A			[35]	
Top-down				
Buyers and sellers	[13]	[2]	[12]	
Buyers, sellers, and intermediaries	[1,4,7,9,11,18,20,22, 23,25,26,28,29,37, 39,40, 47,48,51]	[8]	[31,45]	
Buyers, sellers, intermediaries, and knowledge providers		[33]	[24,34,50,52]	
N/A				
Buyers and sellers				[49]
Buyers, sellers, and intermediaries	[42]			
N/A	[30,46]	[21,27,44]		[38]

In real markets, WTA is the main measure of economic value (n=20), while in potential markets WTP (n=15) is the most widely used. These results suggest that WTP is used for initiating a potential market, while WTA is mainly applied in real markets. WTA is best suited to real markets because many PES programmes involve the implementation of nature conservation measures that have the potential to reduce the income of landowners and farmers. Therefore, landowners' participation in PES programmes is conditioned by the opportunity cost (direct and indirect) for them. For this reason, WTA payment for a change of agricultural or forestry practices is more appropriate and easier to understand by landowners and farmers. Conversely, in the potential markets the supply of an ecosystem service has not yet been defined and for this reason WTP is more suitable for understanding how much buyers are willing to pay sellers for a desired and requested service.

3.4. Discussion

Forests and their ecosystem services can play an important role in addressing ongoing climate change and biodiversity loss, as argued by several authors (Cachinero-Vivar et al. 2021; Kim et al. 2021; Rontard and Hernandez 2022).

Table 6. Measures of economic value used by market status (papers are listed in Appendix A).

Measures of economic value	Market status		
	Actual	Potential	Actual and potential
Willingness to accept			
Yes	[1,7,9,11,13,16,20,22,23,25,26,29–31,37,39,47,48,50,51]	[2,3,10,12,15, 27,32,35,38,43]	
No	[8,18,33,40]	[4–6,14,17,19,21,24,28,34,36,41,44–46,49,52]	[42]
Willingness to pay			
Yes	[18,37]	[3,5,6,12,14,17,19,21,28,32,36,41,43,44,52]	
No	[1,7–9,11,13,16,20,22,23,25,26,29–31,33,39,40,47,48,50,51]	[2,4,10,15,24,27,34,35,38,45,46,49]	[42]

The adoption of environmental policy instruments (e.g., MBIs) can help manage these natural resources and at the same time reward those who own or manage them for adopting sustainable management practices.

First of all, it is important to highlight how the present study has contributed to an advance compared to the previous study by Paletto *et al.* (2020). Those authors investigated a more general issue than the present study (PES scheme in general rather than MES in particular) and adopted a different methodology (Bibliometric

network analysis rather than Systematic review). In other words, this study can be considered an in-depth analysis on the key issue of MES to fill the most important knowledge gap in the international literature. Four key findings emerge from our analysis that answer the research questions, specifically:

1. Regarding the RQ1, Europe is the continent with the largest number of countries with one or more forestry MES, but in terms of publications, Asia ranks first. What stands out as a common factor, however, is that most of the countries with an MES, excluding Europe, are characterized by emerging economies. As reported by Razzaque (2017) and Paudyal *et al.* (2018), such instruments may have been implemented to address rural poverty, help indigenous communities, improve livelihoods and the local economy. The fact that Vietnam has the most studies may therefore depend on its emerging economic potential (Doan et al. 2021), as well as on its strong subsidy policy that led to the adoption of a forest PES program at national level. This programme started on only two pilot cases in 2008 but was then extended nationwide in 2011, as emphasized by several authors (Duong and De Groot 2020; Pham et al. 2021). Acharya *et al.* (2019) reported that regulating services ranked first, followed by provisioning and cultural services in the global trend in FES evaluation. Our results agree on the importance of regulatory services but see the other two reversed. This may be attributed to the growing interest shown in cultural services in recent years and driven even more by the current health pandemic, as argued by Bamwesigye *et al.* (2021) and Weinbrenner *et al.* (2021) or to the raise in green care issues, as reported by Mammadova *et al.* (2021) and Vivona *et al.* (2021). The importance attached to regulating services is attributed as reported by Mengist *et al.* (2020) to their ability to maintain the world we live in, regulate ecosystem processes, and reduce disasters and diseases. At the same time, it is important to emphasize that provisioning services are often not labelled as such in the literature, but as products (e.g., timber and non-wood forest products) and that the adoption of MBIs is unnecessary because there is already a traditional market in which these products are priced and marketed (Agundez et al. 2022; Andrade et al. 2022; Saritaş and Turker 2022).
2. Regarding the RQ2, the local scale is the most adopted spatial scale by MBIs, followed by subnational, national, and international scales. This result is justified by the characteristics of the applied MBIs, as many studies have analysed PES, and these are mainly applied at the local level. However, this result could also suggest that governance of ecosystem services at the local level can lead to better cost-effectiveness, positive environmental outcomes, greater consensus in decisions, and better support from local communities, as also reported by Bork and Hirokawa (2021). The most widely used MBI is the contract, followed by incentives, tradable certificates, auctions, and financial

instruments. This result shows a reversal of the trend. A decade ago, as reported by Rademaekers *et al.* (2011), it was financial instruments, specifically taxes that were mainly used globally as MBIs for the environment. However, most applications of MBIs were related to waste and emissions and not for the protection of the natural resource. They were attached to the approach of the "polluter pays" and not the "provider gets". Nowadays, however, there has been a change of trend. The only form of contract that emerged from the studies analysed was PES. This can probably be attributed to the strong interest shown in the last decade by the market for this type of MBIs, as stated by several authors (Salzman et al. 2018; Parajuli et al. 2020) and also to the fact that the term PES might have been inconsistently used across the different studies due to multiple PES definitions and to the fact that sometimes it has been used ambiguously. Moreover, this typology is very adaptable, as it can be applied at different spatial scales, involves different types of stakeholders, is cost-effective and produces socio-ecological benefits for local communities, as also reported by Osborne and Shapiro-Garza (2018).

3. Regarding the RQ3, buyers, sellers, and intermediaries are the main stakeholders involved in forest MES adopting a top-down approach. The finding points to a key role of intermediaries, as also reported in the case studies presented in the Department for Environment, Food and Rural Affairs (Smith et al. 2013) report on guidelines for designing and implementing a PES scheme. This finding can be supported by the high frequency of case studies in Vietnam, where state policy, using a top-down approach, involves public institutions as market regulators for FES. Further research is needed to understand whether the role of intermediaries, as in the case of the Vietnamese government, can also be a factor leading to the success and continuity of PES schemes beyond their implementation. However, Paletto *et al.* (2021) argue that the public authority should have a dual role, as a market regulator and as a buyer or seller of ecosystem services. Gallo *et al.* (2018) and Van Putten *et al.* (2022) confirm how the public authority is important in ensuring the protection of natural capital, but that this depends especially on the level of trust in it. Good levels of trust lead to better conflict resolution between different groups of stakeholders and acceptance of environmental policies, whereas low levels reduce the collaboration.
4. Regarding the RQ4, slightly more than half of the analysed markets are potential, while the other half are real markets. There is also a close relationship between the measure of economic value adopted and the market status. Indeed, in potential markets the main measure is WTP, while in real markets it is WTA. The rationale for most markets being potential lies in the fact that marketing of ecosystem services still remains at the stage of a hypothetical/academic exercise rather than having developed to real world practices and for which efforts are being made to identify acceptable prices for

ecosystem services with the WTP of potential participants, as argued by Nielsen-Pincus *et al.* (2017). On the other hand, since ecosystem services are public or common goods, for which it is impossible to assign property rights, it is unlikely to achieve adequate supply in such markets, as reported by Gao *et al.* (2020).

3.5. Conclusions

The intention of this review was to determine the state of the art of potential and actual markets for FES at an international level. Over the years, academia has increased its interest in this topic, as evidenced by the growing number of studies published during the period under review. The literature has found emerging evidence that forest MES can play a rewarding role for landowners and land managers who adopt climate and environmentally sound practices. Our results helped identify the current distribution of actual and potential forestry MES, the MBIs adopted and their level of spatial application, the stakeholders involved in implementing these markets, and the measures of economic value used to assess MES.

3.5.1. Limitations and implication for research

There are five potential limitations to this review. Firstly, the screening of the articles was done by two authors with the same basic training and belonging to the same institution. However, the third author, with the impartial role of resolving any doubts and conflicts, had different research interests and came from another institution. The second limitation is that the selection of articles was limited to only two databases and without considering the grey literature. The third limitation concerns the selection of articles only in English, which may have affected the distribution of forest MES. This may have affected South America, where the main languages are Spanish and Portuguese, and West Africa, where the first language is French. The fourth limitation is due to the poor identification of MBIs for provisioning services, which probably being largely “traditional” services in forestry, are often called by different names, such as timber harvesting and mushroom picking, and were therefore not identified with the search string. There is therefore a need for future developments of this research to expand the lexicon of terms used in the search string. The last limitation relates to the difficulty of some studies in attributing a precise spatial scale, due to the promiscuity of the spatial entities.
The gaps on the social component of forestry MES implementation indicate the need for further research, as it was difficult to obtain information on the types of stakeholders involved and the approach taken to involvement, especially in European cases. Further research must then be carried out on the African continent

to understand whether the knowledge gap in this review is only attributable to the limitation of the selected language or whether there is a real lack of such tools on the ground.
In conclusion, future research should be directed towards a better understanding of the process leading to the creation, implementation, effectiveness, and governance of an MES, and the level of satisfaction in economic terms of the actors involved, but we think that our study has contributed to increasing the knowledge in this interesting and promising field.

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Data availability
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Author contributions
Conceptualization: SteB, SB Data curation: SteB, SB, AP, FB Formal analysis: SteB, SB Investigation: SteB Methodology: SteB, SB Resources: FB Software: SteB Supervision: AP, FB Validation: AP, FB Visualization: SteB Writing – original draft: SteB, SB, AP, FB Writing – review & editing: SteB, SB, AP, FB.

Competing interests
The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Appendix A

Table A1. Full reference of articles selected in the systematic review process.

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1.	Phan, T.-H.D., Brouwer, R., Hoang, L.P., and Davidson, M.D. (2017). A comparative study of transaction costs of payments for forest ecosystem services in Vietnam. *Forest Policy and Economics*, *80*, 141–149. https://doi.org/10.1016/j.forpol.2017.03.017.
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2nd Article

4. A Framework Proposal for the Ex-Post Evaluation of a Solution-Driven PES Scheme: The Case of Medvednica Nature Park

Stefano Bruzzese[1,*], Iva Tolić Mandić[2], Sanja Tišma[2], Simone Blanc[1], Filippo Brun[1] and Dijana Vuletić[3]

[1] Department of Agricultural, Forest and Food Sciences, University of Turin, 10095 Grugliasco, Italy

[2] Institute for Development and International Relations—IRMO, 10000 Zagreb, Croatia

[3] Department for Scientific International Cooperation in Southeast Europe—EFISEE, Croatian Forest Research Institute, 10450 Jastrebarsko, Croatia

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Abstract: Payments for ecosystem services are a voluntary market-based instrument to remunerate provider(s) of ecosystem services by those who benefit from them. Our research aimed to create an ex-post evaluation framework to identify bottlenecks and elements hindering the success of a solution-driven PES scheme. The framework was applied to a case study to assess its feasibility and concerns the provision of health and recreational services in the Medvednica Nature Park (Zagreb, Croatia). The framework was set up through three main sources: the study of PES implementation project documentation, semi-structured interviews with visitors and key stakeholders, and web-scraping of TripAdvisor reviews of the park. The main findings confirm society's interest in the park, but the lack of mapping, quantification, and accounting of the services analysed, the little or no demand from society to pay for their provision, and confused knowledge of the property rights of some ecosystem service providers in the area limit the success of the PES scheme. The framework was useful to describe the chosen PES scheme and to identify bottlenecks and fragilities of the system in place, allowing it to correct its application flaws and, on the other hand, to demonstrate its replicability in other contexts.

Keywords: forest ecosystem services; tourism; recreational activities; health; methodological
framework; nature park; protected area.

4.1. Introduction

In recent decades, there has been ample evidence that using market-based instruments (MBIs), as alternative policy instruments to command-and-control, can help improve the provision of ecosystem services and ensure sustainable local development. These include payments for ecosystem services (PES), or payments for environmental services, schemes defined by Wunder (Wunder, 2015) as: "voluntary transactions between service users and service providers that are conditional on agreed rules of natural resource management for generating offsite services". The main benefits of ecosystem services internalised by PES include regulating services, such as biodiversity protection (Lomeu et al., 2022), hydrogeological protection , and carbon storage (Soltani et al., 2019). In recent times, cultural services, such as tourism–recreational activities and health are also gaining recognition (Tyrväinen et al., 2017; Hassan et al., 2022).

However in order to be defined as PES schemes in the strict sense, they must meet certain preconditions, which Wunder (Wunder, 2005) identifies as a transaction voluntarily; a clear definition of the ecosystem service provided or the resource that provides it; the presence of at least one buyer/user of the service and one seller/provider of the service; and conditionality, namely, if the provision of the service ceases or diminishes, payment for it is stopped or reduced. Other preconditions are added to the previous ones, according to Smith et al. (Smith et al., 2013): additionality, namely, payment is made for improvement or maintenance interventions that the provider makes on the resource and that would not otherwise be there; prevention of leakage, in other words, an undesirable negative impact on the provision of other ecosystem services or another natural resource to the detriment of the guarantee of the service or the resource protected by the PES scheme; the permanence of the service, in the sense that the interventions made by the provider should not have reduced effectiveness and rapid reversibility.

A PES scheme to be defined as such must fulfil all the previous preconditions. If only some of them are met it is defined as PES-like and in a broad sense it becomes an economic incentive or MBI (AA.VV., 2019). Several definitions of PES schemes exist in the literature (Wunder, 2005; Porras et al., 2008; Muradian et al., 2010; Tacconi, 2012; Engel, 2016; Huber-Stearns et al., 2017; Liu et al., 2018), which allow for the inclusion of a large part of the world's PES programmes that do not meet the restrictive criteria proposed by Wunder. However, at the same time, they lead to a lack of harmonisation of results and replication and transfer of experiences from one site to another, due to a non-unique definition (Wells et al., 2020; Li et al., 2023). For the development of this study, the narrowest meaning of the term was considered. PES schemes originated mainly in countries with developing economies to reduce poverty, environmental degradation (e.g., REDD+ programme), and the economic divide, but today they are also widely applied in developed economies, as witnessed by programmes in Costa Rica (Blackman and Woodward, 2010), Brazil (Saad et al., 2021), Mexico (Selfa et al., 2022), Vietnam

(Pham et al., 2021), the United States (Del Rossi et al., 2021), Poland (Bartczak and Metelska-Szaniawska, 2015), and Finland (Tikkanen et al., 2017). Nevertheless, the geographical areas most targeted are China and the American continent (Snilsveit et al., 2019; Wunder et al., 2020). It is also important to point out that many PES programmes only exist in the grey literature and that some organisations have tried to collect data from them but have produced reports that are difficult to understand (Li et al., 2023).

At the same time, it should be noted that for the adequate protection and enhancement of natural resources, it is not enough just to use MBIs, such as PES, but there is a need to adopt other instruments, methods, and approaches beyond the market alone. This is because the limitations associated with such instruments are widely discussed in the literature and range from biophysical, institutional, ethical issues to rights-based aspects (Gómez-Baggethun and Muradian, 2015).

4.1.1. Review of the Literature

There are several reports in the grey literature that provided guidelines or best practices on the design and implementation of PES schemes (Dunn, 2011; Smith et al., 2013; Viszlai et al., 2016), while others collected the different PES currently in place (Cavelier and Munro Gay, 2012), while others demonstrated both (Mayrand and Paquin, 2004; Rankine et al., 2009; Herbert et al., 2010; FAO, 2011; Fripp, 2014; United Nations Economic Commission for Europe, 2018). The problem with these reports is that - apart from not having received a peer-review process - they are often long and complex to read or focus exclusively on PES in countries with developing economies. At the same time, in the scientific literature, several authors hypothesised methodological frameworks related to PES schemes with more emphasis on some aspects than others; indeed some focused on the development of early PES schemes for poor and developing economies (Jack et al., 2008; Pagiola et al., 2008); on the institutional and political economy framework (Muradian et al., 2010); on the environmental component with life-cycle assessment (LCA) (Page et al., 2015); on the creation of a PES case study dataset (Wunder et al., 2018); on socio-economic outcomes (Wu et al., 2019, 2021); on behavioural economics and social psychology for the motivation to conserve and manage a natural resource behind a reward (Ezzine-de-Blas et al., 2019); on choosing between different alternatives of PES schemes (Kurttila et al., 2020); on the improvement of already existing methodological frameworks (Wunder et al., 2020); and on the integration of a framework containing biodiversity and carbon sequestration (Kangas and Ollikainen, 2022).

Most of the frameworks listed above, however, serve for implementing PES schemes and not for their ex-post evaluation. Impact evaluation studies do exist in the literature, but they have been carried out for PES schemes implemented in threatened and degraded areas, for conservation and protection or poverty

alleviation (Adhikari and Boag, 2013; Samii et al., 2014; Börner et al., 2016; Ezzine-de-Blas et al., 2016). For PES schemes that are instead implemented at the suggestions of external organisations, for example by scientific projects (i.e., solution-driven PES scheme; see Section 2.1.1), and that do not originate to address a threat, but rather to increase the welfare of the local communities, some have identified the successful elements for their implementation (Gios and Rizio, 2013) or have performed an ex ante evaluation (Tikkanen et al., 2017), but an ex post evaluation framework is lacking.

This is the context for our research, the aim of which is to investigate the bottlenecks and elements that might hinder the success of a solution-driven PES scheme. In this study, a methodological framework for the ex-post evaluation of the design, implementation, and impacts of a PES scheme was created to respond to our research question. Document analysis, web scraping, and semi-structured interviews were the methods used to answer the different blocks of the framework.

4.2. Materials and Methods

4.2.1. A Solution-Driven PES Framework Proposal: Design, Implementation, and Impacts

Figure 1 shows the methodological framework for the ex-post evaluation of the design, implementation, and impacts of a solution-driven PES scheme. Specifically, the proposed methodological framework is the contribution of the authors, while some of the elements that make up the various boxes refer to the literature, as extensively documented in the following Sections 2.1.1–2.1.7. In this section, an attempt is made to answer the following questions: How is the area that the PES scheme is to be implemented in identified (Section 2.1.1)? What are the governance elements required to initiate a PES scheme (Section 2.1.2)? How is ecosystem service provision assessed (Section 2.1.3)? What are the conditions that create the market (Section 2.1.4)? Who are the actors involved (Section 2.1.5)? What elements constitute a PES scheme (Section 2.1.6)? How are the impacts of its implementation evaluated (Section 2.1.7)?

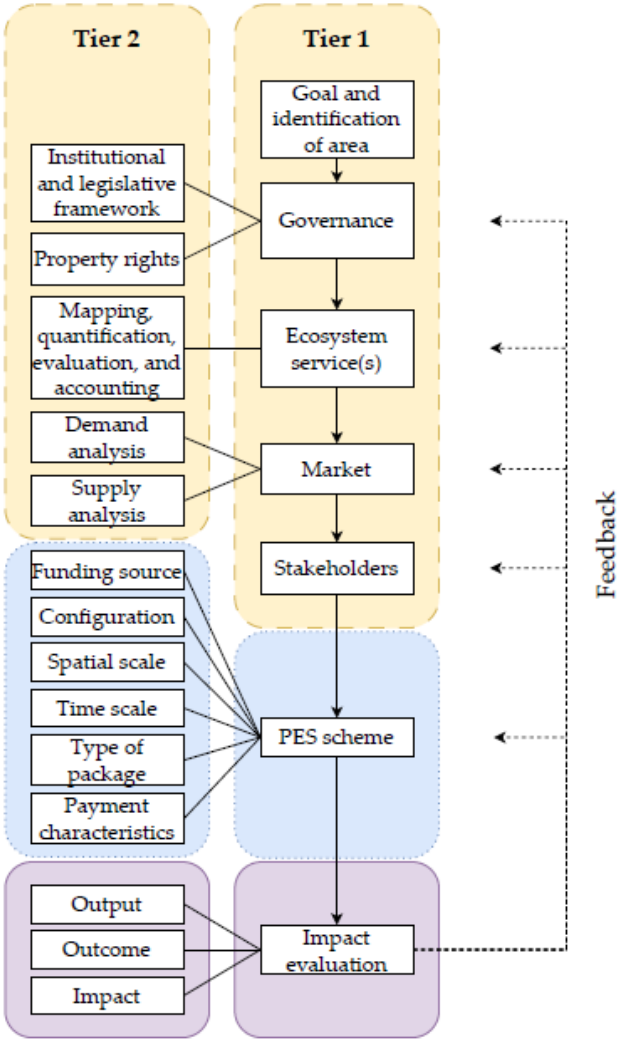


Figure 1. Framework for the ex-post evaluation of a solution-driven PES scheme. Dashed orange boxes are the inputs, pointed blue boxes are the treatment, and solid violet boxes are the results.

4.2.1.1. Goal and Identification Area

The levers that create the initial interest in setting up a PES scheme are various. An International Union for Conservation of Nature (IUCN) report (Greiber, 2009) divides them into three main categories:

1. demand-driven: this is the case when service users encounter a problem in its provision and are willing to pay for its maintenance or improved provision - for example, improving the quality and quantity of drinking water (off-site). In this case, service providers are incentivised to produce it;
2. supply-driven: this is found when there is a problem on-site, related to the conservation and management of the ecosystem. In this case, the economic contribution by the service users helps the provider to maintain or improve the management of the natural resource for the benefit of both the ecosystem and the users;
3. solution-driven: this occurs when a third-party organisation identifies cases where the creation of a PES scheme would be feasible and beneficial.

In the case of a solution-driven PES, the area can be identified by analysing its social interest, usage, and frequentation. In this respect, the use of sociometric methods such as site and social content analysis or social network analysis (Bruzzese et al., 2022) can help identify the potential area (Barbierato et al., 2021; Sergiacomi et al., 2022).

4.2.1.2. Governance

For a PES scheme to be successful, it must have effective governance upstream, capable of considering the legal, institutional, and property rights framework in the territory in which it operates. The legal framework helps to define the role of institutions, and the characteristics of the PES mechanism, with its limitations and massive diffusion as legally recognised. Legal references can refer to different spatial scales, from the international scale, for example with agreements, to the local scale with regulations, to the supranational, national, and regional scales with guidelines, regulations, constitutions, and laws.

The institutional framework is useful to define the role and respective "arenas of power" of the social, economic, and political actors involved in a PES scheme. The institutional framework can be purely public, private, or mixed. Institutions remove different barriers; they can, for example, help reduce transaction costs and risks, manage possible conservation or ecosystem use conflicts, provide economic support, and coordinate different mechanisms and policies (Forest Europe, 2019).

Property rights regulate land tenure, namely, the relationship between a good or resource and the individual or group of people concerned. Starting with ownership as the most exclusive right, FAO (FAO, 2002) identifies three different sub-categories of rights:

1. access and use: the possibility of choosing who can have access to and whom to exclude from the land for use;
2. control: the possibility of choosing what land is to be used for;

3. transfer: the possibility of transferring the right of access, use, and control to other persons, by selling, mortgaging, or bequeathing the land tenure.

To identify the elements of governance, diagnostic analytics of documents can be useful.

4.2.1.3. Ecosystem Services

The spatial identification of ecosystem services and their quantification, evaluation, and accounting (necessary to understand their trade-offs) is crucial for the successful design and implementation of a PES scheme. Regarding spatial targeting, Wunder *et al.* (2018) emphasise the importance of identifying both areas where the density of ecosystem services (i.e., supply) is highest, and areas threatened by unsustainable management practices where the adoption of a PES scheme could make a difference and bring added value. For the quantification and evaluation of ecosystem services in the literature, there are several valuation methods, including biophysical, economic, and socio-cultural methods (Santos-Martin et al., 2018), and decision support systems and models, such as ARIES, InVEST, ORVal, and MESH that allow mapping, quantifying, and valuing ecosystem services in one go (Bruzzese et al., 2023).

For accounting purposes, a framework called system of environmental economic accounting (SEEA) (United Nations, 2021) was developed at the international level that is capable of monitoring and integrating the biophysical component of ecosystem stocks and ecosystem service flows with the related economic component in monetary terms. This framework allows for harmonised and comparable statistics across countries.

4.2.1.4. Market

The analysis of supply and demand is essential in the development of a PES scheme. In demand, there is a distinction to be made between payments made to obtain the provision of a service and funding for the creation of the PES scheme. Payments can be made by a public or a private component. To assess the demand, there are various monetary economic valuation methods (Bruzzese et al., 2023), such as those based on stated or revealed preferences, which can estimate the willingness-to-pay (WTP) on the part of users/buyers for the provision of the service. For there to be demand, it is important that there is the precondition of additionality and, thus, that the service provider produces benefits for the users/buyers of the service. Such benefits, according to Porras *et al.* (2008), may relate to the restoration of destroyed or degraded land; the reforestation or afforestation of an area; the conservation and protection of the managed resource; and the management and improvement of land practices.

Similar to demand, the same preference-based methods can be used for supply to estimate the willingness-to-accept (WTA) compensation from providers. This WTA is the leverage that moves the provider to maximise the provision of other ecosystem services at the expense of productive activity alone (e.g., agricultural harvest or forest cutting) and, thus, the private return. Indeed, if the WTA does not cover the private return that would have been obtained from the productive activity alone, the PES scheme fails. Conversely, if the provision of the service(s) increases the private return beyond that derived from mere production, the provider has a greater incentive to participate in the scheme.

The service provider/seller and the service user/buyer are stakeholders in a PES scheme and are discussed in more detail in the following subsection.

4.2.1.5. Stakeholders

Knowing who the stakeholders are involved in a PES scheme allows one to understand their roles and relationships and the respective powers with which they can influence its design and implementation. The broader the participation in the scheme, the more transparent and socially accepted the process is (Forest Europe, 2019). To date, several classifications of stakeholder groups exist (Porras et al., 2008; Matzdorf et al., 2013; Smith et al., 2013); here, we propose that from Paletto *et al.* (2021), modified as follows:

1. service producers/sellers: the public or private land and forest owners who conserve and manage the natural resource;
2. service users/buyers: who are willing to pay for the provision of the service and may also be public or private;
3. intermediaries**:** who connect producers and users and who support the creation of the PES scheme, for example, trade associations, public institutions, and NGOs. This category also includes donors, regulators who influence, control, and facilitate the start-up and effectiveness of PES and funding agencies that support the start-up and operation of the scheme with for example feasibility studies;
4. knowledge providers: those who provide advice, knowledge, and assistance for the development of the PES scheme, such as experts, planners, universities, and research institutes and consultants.

The use of participatory methods, such as focus groups, the Delphi method, semi-structured interviews, deliberative workshops, and meetings can support the decision-making process related to the design and implementation of the PES scheme by analysing the different interests, values, opinions, and behaviours of the stakeholders. The identification and selection of stakeholders at the beginning of the design of a PES scheme are of paramount importance for its success. In this

context, the use of stakeholder analysis can help to identify who needs to be involved, kept informed, and satisfied and the role they play in the scheme.

4.2.1.6. PES Scheme

Several key design aspects need to be considered when developing a PES scheme. The funding source of the PES scheme can be public, private, or mixed depending on whether the payer is a governmental body, a private party or both. The role of stakeholders in the scheme may be different (see Section 2.1.5) and be configured in different ways depending on the number of service users and service providers (Smith et al., 2013). It can be:

1. a single service provider and service user (one-to-one): such as the case of the government or a company that comes into direct contact with an individual forest or landowner (Smith et al., 2013);
2. many service providers and a single service user (many-to-one)**:** such as the case of Vittel with farmers in France (Perrot-Maître, 2006);
3. a single service provider and many service users (one-to-many): such as the case of the UK Ministry of Defence and retail companies and the North Pennines AONB with the UK Woodland Carbon Code in Cumbria (AA.VV., 2022);
4. many service providers and service users (many-to-many): such as the case of water certificates issued by the Bonneville Environmental Foundation between private sector businesses and landowners in the USA (Bonneville Environmental Foundation, 2013).

The spatial scale of application of the scheme can vary from local/neighbourhood, through catchment areas and valleys, to national and international depending on market needs and ecological processes. At the same time, the time scale may also vary from short- to long-term depending on the typology of the ecosystem service provided, the conservation status of the ecosystem; the duration of the project, programme, and environmental policy; and the ongoing provision of financing by service users (FAO, 2011).

Ecosystem services can be sold and packaged in different ways (Smith et al., 2013) depending on whether a service user or a consortium of service users buys all the ecosystem services produced in that PES-scheme area in one solution (bundling); several service users buy several ecosystem services provided by the area (layering or stacking); and whether a service user buys a single or a few ecosystem services, but also receives the provision of other services from the area for free (piggy-backing, “free-riding” phenomenon).

There are also several payment characteristics to consider (United Nations Economic Commission for Europe, 2018):

1. arrangement: whether it is based on improved management practices (action-based), on the actual provision of the ecosystem service (result-based), or mixed (hybrid-based);
2. type: whether it is cash, in-kind, or mixed;
3. time: whether it occurs as a one-off, or whether it is periodic, or mixed;
4. frequency: whether it occurs upfront, after practice improvement, or after service delivery.

4.2.1.7. Impact Evaluation

Once the PES scheme has been implemented, it is important to verify the results both to trigger the feedback process, should it be necessary, to modify or implement parts of the scheme or integrate its prerequisites (learning), and to make stakeholders more aware of and accountable for the PES scheme they have implemented (accountability) (Lippi, 2007). The impact evaluation is based on the cause–effect theory and the adoption of a logic model or theory of change makes it possible to explain the causal link between the resources/inputs and treatment employed and the outputs, results, and impacts achieved (Weiss, 1997). Outputs are the short-term products obtained from the resources used, outcomes are the medium-term effects of the problem to be solved, and impacts are the long-term outcomes. The impact evaluation can consider several criteria such as the efficiency of the scheme (output/input), its effectiveness in solving the problem for which it was implemented (output/outcome), its cost-effectiveness and availability of the inputs used, and equity, namely, the right balance between benefits and costs distributed among the various stakeholders. Monitoring and enforcement can be used in the evaluation of outputs, whereas the evaluation of outcomes and impacts requires the counterfactual approach and, thus, measuring the difference between a scenario with the treatment adopted and one without it.

4.2.2. Case Study

The Medvednica Nature Park (IUCN category V) is one of 12 Croatian nature parks and is located near the capital Zagreb (Tisma et al., 2020). The total area of the park (17,938 ha) is a Natura 2000 site, of which approximately 81% is covered by forests. It has an extension ranging from 120 to 1035 m, culminating in a peak named Sljeme. More than a quarter of the Croatian population lives in its surroundings. The park provides various forest ecosystem services depending on the season; for example, in summer it mitigates high temperatures and in winter it provides recreational activities such as skiing. In this respect, the park has various accommodations, sports, and cultural facilities as well as more than 70 hiking and biking trails. Ownership of the forests is split between the state (50%, Ministry of Agriculture of the Republic of Croatia), private individuals (47%), and the Faculty

of Forestry and Wood Technology, University of Zagreb (3%). Almost all private individuals, however, own less than 5 ha of land, and more than 80% of them have only 1 ha (Bakarić et al., 2021).

The park was selected by the Spurring INnovations for forest eCosystem sERvices in Europe (SINCERE) project of the Horizon2020 programme (https://sincereforests.eu/) to raise the awareness of civil society on forest ecosystem services, and design and implement a PES scheme on the health and recreational services offered by the park. The payment mechanisms selected for the PES scheme are donation boxes placed at the beginning of two trails and available to any visitor, and one-time concession permits, i.e., a fee for sports organisations and other entities carrying out activities in the park.

4.2.3. Data Collection

To identify bottlenecks and elements hindering the success of a solution-driven PES scheme, a diagnostic analytics was conducted on the Medvednica Nature Park and PES scheme developed in the SINCERE project. Data collection ranged from data mining to document review and semi-structured interviews.

4.2.3.1. Data Mining

A data-mining technique called web scraping was used to collect society's interest in the case study. This technique enables the extraction of data from websites using *ad hoc* software programmes (Zhao, 2017). Data were collected in December 2022 and January 2023 from the TripAdvisor review platform for the "Medvednica mountain" page (https://www.tripadvisor.com/Attraction_Review-g294454-d549693-Reviews-Medvednica_mountain_Sljeme-Zagreb_Central_Croatia.html, accessed on 15 January 2023).

4.2.3.2. Document Review

To identify the institutional and legal framework of PES in Croatia, as well as to identify the stakeholders involved in the PES of the Medvednica Nature Park, its characteristics and the results obtained from the project, several documents were collected and subsequently analysed, which are shown in Table 1.

Table 1. Review documents.

Document Category	Document Name
Institutional and legal framework	Constitution of the Republic of Croatia [73] Forest Act and its regulations (OG 68/18)[74] Environment Protection Act (OG 80/13, 153/13, 78/15, 12/18, 118/18) [75]
Stakeholders	Three multi-actor group (MAG) meeting [76]
Characteristics of PES and project results	Report D4.1 —Assessing the upscaling potential of SINCERE IAs using a theory of change structure [77] Report D4.2 —Synthesis report of the experiences and lessons learnt, situating them in the global experiences and knowledge [78]

4.2.3.3. Semi-Structured Interviews

To analyse demand, namely, the willingness of park visitors to pay for the forest ecosystem services, and to analyse stakeholders' opinions on the success factors and bottlenecks encountered during the implementation of the PES scheme, interviews were conducted. The participants of the survey were selected among the

visitors of the Nature Park. Employees of the Medvednica nature park approached the visitors of the park and if they were willing to take a part in the research, they were interviewed. The research for demand was conducted in two rounds - the first part in the second half of 2018 with 155 participants, and the second part in the second half of 2020 with 148 participants of different ages and origins. The interviews consisted of 11 questions with a first part related to socio-demographics and a second part related to FES and the WTP stated by visitors (Appendix A).

The stakeholder opinion interviews were conducted at the end of the SINCERE project between May and June 2022 on a sample of 10 respondents. The interviews consisted of six questions with a first warm-up part and a second part aimed at identifying the stakeholders' opinions on the elements they consider successful for a PES scheme, the main difficulties encountered in the development of the scheme, and the added value of being involved in the project (Appendix B).

4.2.4. Data Analysis

The visual software WebHarvy was used for web scraping (Laksono et al., 2019). This paid software allows the automatic identification of data patterns on web pages without the need to write scripts or code for data extraction. The items collected from the TripAdvisor page on "Medvednica Mountain" concern the reviewer (name, origin, and the number of reviews made on the site) and the reviews (month and year, travel objective, and title and text of the review). We identified 247 reviewers, of whom 197 left a review in addition to the evaluation alone between 2008 and 2022. To collect and analyse the data, we simply entered the URL of the page of interest into the software and visually selected the categories of items. The methodology used by Sergiacomi *et al.* (2022) was adopted for the analyses.

MAXQDA Analytics Pro 2022 software was then used to analyse the transcripts of the semi-structured interviews on stakeholders' opinions. Stakeholders were grouped into three broad categories (users, managers, and consultants) according to their role in the PES scheme. For coding, the code–category analytical approach was used for qualitative data analysis (Saldaña, 2009) on textual data that ranged from single words to whole sentences. The naming of codes and categories (merged codes) were identified through a review of the literature, which allowed the interview questions to be structured. Coding was performed using a bottom-up approach; therefore, codes and categories were identified from the text without having previously identified them. Various coding methods were used for coding (Saldaña, 2009), both first-cycle methods such as elemental methods (structural coding, in vivo coding, and initial coding) and affective methods (emotion coding), and second-cycle methods such as focused coding. For the first review of the transcripts, initial coding was used, an open-ended method without specific guidelines incorporating in vivo coding, which allowed parts of the transcripts to be

coded using the same words and language as the respondents. Subsequently, content-based structural coding was used to further segment the transcripts and emotion coding to intercept emotions expressed by the respondents or inferred by the researcher. Ultimately, focused coding was used to categorise similar codes. The frequencies of the codes are not shown in the results because we wanted to focus exclusively on their variety and not on their quantity. The analysis performed allowed for an ex-post understanding of what worked, what did not, and what could be improved in projects related to the implementation of PES schemes.

4.3. Results

Figure 2 shows the results from the application of the ex-post evaluation framework. A general description of the individual boxes follows.

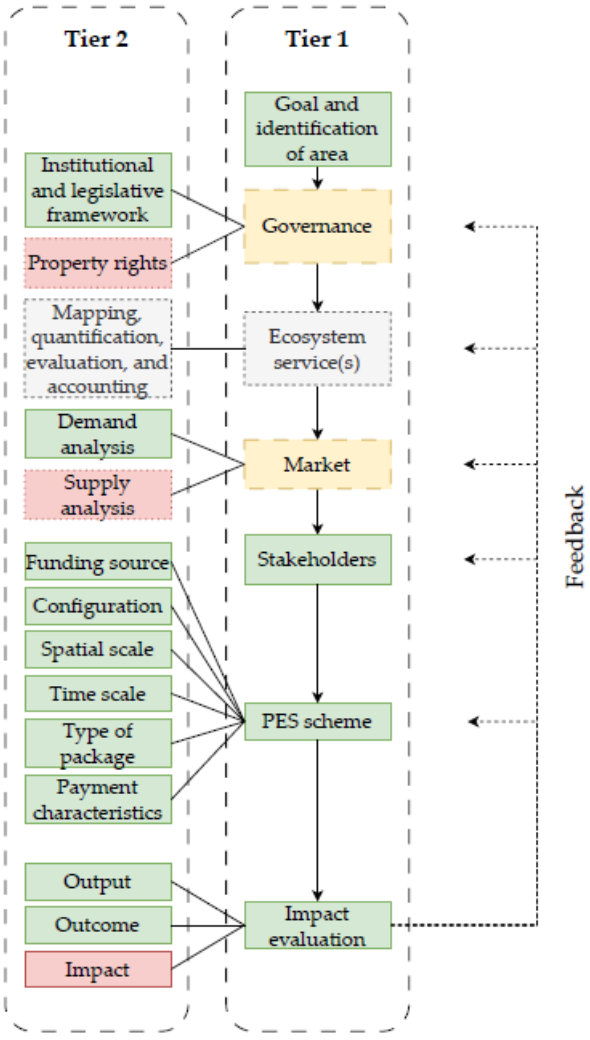


Figure 2. Application of the ex-post evaluation framework for solution-driven PES schemes. In solid green are the positive boxes, in dashed yellow are the incomplete ones, in dotted red are the negative ones, and in dotted grey are those not found.

The initial interest in the development of a PES scheme in the Medvednica Nature Park was solution-driven because it was chosen as part of a research project (the SINCERE project). The choice of the area as a case study can be supported by the analysis conducted on TripAdvisor. Figure 3 shows the time trend of the collected reviews both as frequency (Figure 3a) and growth rate (Figure 3b). The results suggest a bimodal distribution of reviews with peaks in 2013 and 2015,

possibly due to specific sports and/or recreational events in the mountains. There is also a sharp decline in reviews in 2020 (a drop of −80%), probably due to the COVID-19 health emergency and a slow recovery from the following year.

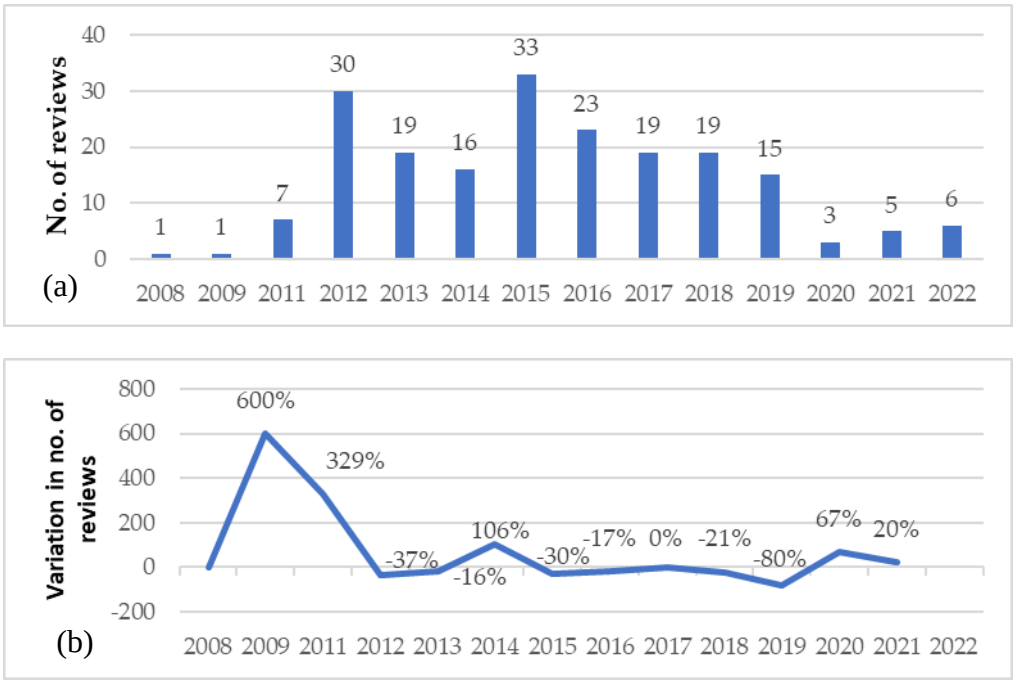


Figure 3. Time trend of Medvednica Mountain reviews on TripAdvisor. (**a**) Annual frequencies, (**b**) annual growth rate.

Figure 4 shows the reviews by seasonal (Figure 4a) and monthly (Figure 4b) trends. A constant interest emerges in the different seasons, with a strong peak in the summer period, specifically in August and June, and in the winter season, probably due to both recreational events (e.g., fairs and events) and sports competitions (such as skiing and orienteering).

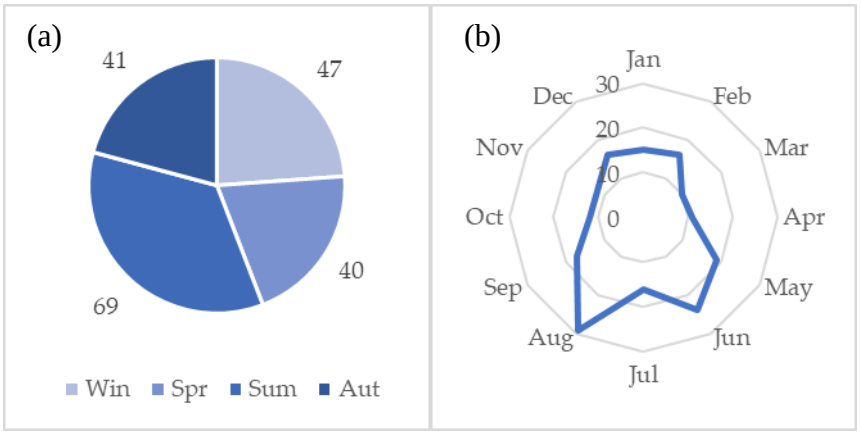
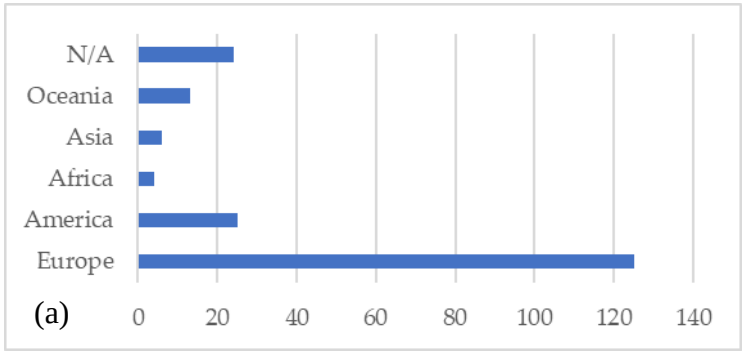


Figure 4. The number of Medvednica mountain reviews per month (**a**) and per season (**b**).

The continents and European countries of the provenance of the reviewers/tourists are shown in Figure 5. Europe ranks first as the continent of origin (*n* = 125), followed by America (*n* = 25). In Europe, Croatia is the country with the most reviewers (*n* = 71) due to its proximity to the study area, followed by the United Kingdom (*n* = 22) and Germany (*n* = 5).



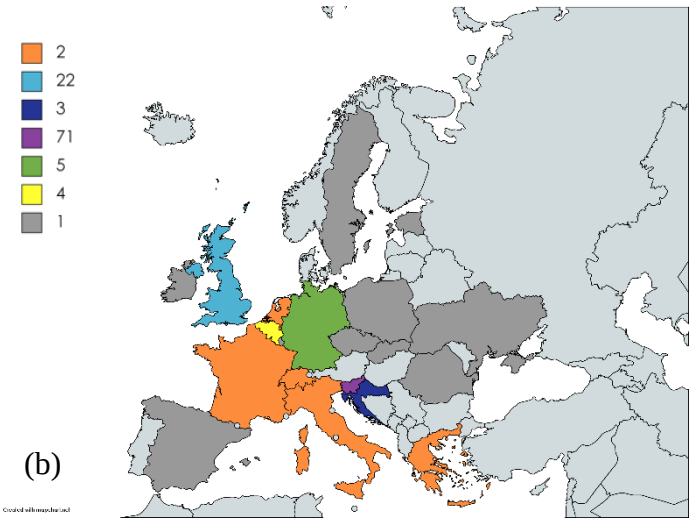


Figure 5. Provenance by continent (**a**) and by European country (**b**) of reviewers/tourists. Source: created with mapchart.net. Note: only countries where at least one review was made are shown on the map.

In general, it can be inferred that the study area is frequented by a good number of tourists and society living in neighbouring areas continuously throughout the year. The decision to develop a PES scheme for tourism and health aspects is, therefore, cohesive.

In terms of governance, Croatia has a well-defined legal and institutional framework. It recognises the importance of forests and natural resources in its constitution and, since 1990, has developed ad hoc legislation (Amendments to the Forest Act OG 41/90) for the first Croatian PES forestry, which was a green tax that has now been merged into Articles 65 and 68 of the latest Croatian Forest Act OG 68/18. Regarding institutions, forests are a state competence, as the Ministry of Agriculture with the company Croatian Forests Ltd. oversees forest management, while the Ministry of Environment Protection and Energy deals with environmental protection, which includes forests and natural resources in general (see the various Environmental Protection Acts).

Property rights, however, are only clear for the state park manager, but for the PES scheme to work, the entire Medvednica area must be studied for the provision of its forest ecosystem services. In this area, there are several conflicts of ownership between private individuals and little knowledge of their rights, as also revealed in the stakeholder interviews (Table 2).

The stakeholders who participated in the semi-structured interviews used various attributes to express their opinions on PES schemes and the SINCERE project (Table 2). These attributes are subsequently grouped into four main

categories (“emotions”, “elements for the success of a PES”, “difficulties for the implementation of a PES”, and “value added by the project”). Managers were the stakeholders who most contributed to the identification of the attributes (n = 15), followed by users (n = 13) and consultants (n = 9). Concerning the categories, all roles perceived positive emotions in being involved in such a project.

These emotions, as reported during the interviews, changed negatively during the development of the project because of various conflicts and the general perception that nothing would change. Regarding the elements considered most important for the success of a PES scheme, the social component was prioritised, namely, good cooperation and mentality of those involved in the implementation of such schemes and increased awareness and education of users and visitors about the role and importance of forest ecosystem services provided by ecosystems. The main difficulties perceived during the development of the PES scheme are related to the misunderstanding among the stakeholders involved and the users’ and visitors’ conception that nature is free, and, thus, the lack of demand to trigger the PES mechanism. Finally, according to stakeholders, the SINCERE project has brought added value in terms of its ability to create collaborations and potential new opportunities between stakeholders and in raising stakeholders’ awareness of the importance of forest ecosystem services. However, negative aspects also emerged from the interviews, such as the perception that the project remained only at a theoretical level and that nothing had changed.

Table 2. Stakeholder opinions are broken down by attribute, category, and type of stakeholder.

Category	Attribute	Role		
		User	Manager	Advisor
Emotions	Positive	x	x	x
	Negative	x	x	
	Neutral	x		
Elements for PES success	"Paying a tax for transit"	x		x
	"Mindset"		x	x
	"Showing the difference between Business-As-Usual and PES scenario"			x
	"Charge for the facilities/things that are used in the PES area"	x		
	"Raising the awareness and education of users"		x	x
	"Good cooperation with all stakeholders"	x		x
	"Understanding the willingness to pay for forest ecosystem services"			
	"Transparency"		x	
	"Legislation"	x		
	"Better communication to the public"			x
Difficulties for PES implementation	"Different point of views"	x		
	"Misunderstanding"	x	x	
	"Ownership conflicts"		x	
	"Nature is free"	x	x	
	"Do not consider different scenarios"			x
Project added value	"Cooperation with different stakeholders"		x	x
	"Implications only in theory and not in practice"	x	x	
	"Good foundation for the future"		x	
	"Raising the awareness about the benefits of forest ecosystem services to society"	x	x	
	"Implementation and replication of a PES mechanism"		x	
	"Nothing is changed"	x	x	
	"Fostering new innovative approaches to the monetary valuation of ecosystem service"		x	

No mapping, biophysical quantification, or accounting of forest ecosystem services was found, probably because it was not the aim of the project and because biophysical quantification and accounting of cultural ecosystem services is difficult.

Regarding the market, participants were asked if they knew what forest ecosystem services were, and most of them answered that they did not know - 106 (68.8%) of them in 2018 and 104 (80%) in 2020. In 2018, 48 visitors stated that they were aware of forest ecosystem services, and the most frequently mentioned services were oxygen production (14 visitors), provision of natural recreational space (10 visitors), protection from soil erosion and fresh air (7 visitors), water treatment, impact on psychophysical health and animal habitat (5 visitors), provision of a natural resting place, health services, and air purification (4 visitors). Other forest ecosystem services mentioned were CO2 sequestration, biodiversity, climate change mitigation, tourism, balance management, and many others.

In the survey conducted in 2020, 26 visitors responded to knowing what forest ecosystem services are, and the most frequently mentioned were providing a natural recreational place (11 visitors), oxygen production (7 visitors), water purification (6 visitors), health services and air purification (5 visitors each), and food and timber (4 visitors each). Visitors also mentioned tourism, soil protection from erosion, animal habitat, offering a natural resting place, offering a natural educational site, biodiversity, CO2 sequestration, and many others.

Participants were also asked to compare the impact of the experience of visiting the Medvednica Nature Park on health and well-being with commercial products and services (Figure 6). In a survey conducted in 2018, most respondents (33.3%) compared this impact to a visit to the gym (HRK 35—about 5 EUR-per hour), 20.1% to that of a day at a wellness centre (HRK 150—about 20 EUR-per day), and 15.7% to that of going to the cinema. The lowest number of visitors, 4.4%, compared a visit to the park to a concert worth HRK 200 (about EUR 25).

Similar results were shown in the research conducted in 2020—33.8% of visitors compared the effect of a visit to Medvednica to a visit to the gym (HRK 35 per hour), followed by 14.4% who compared it to a day at the spa (HRK 150 per day), and the same percentage who compared it to local trips (HRK 350—about EUR 50). The smallest number of visitors, 2.9 per cent, compared a visit to Medvednica with an international trip worth HRK 2100 (about EUR 280).

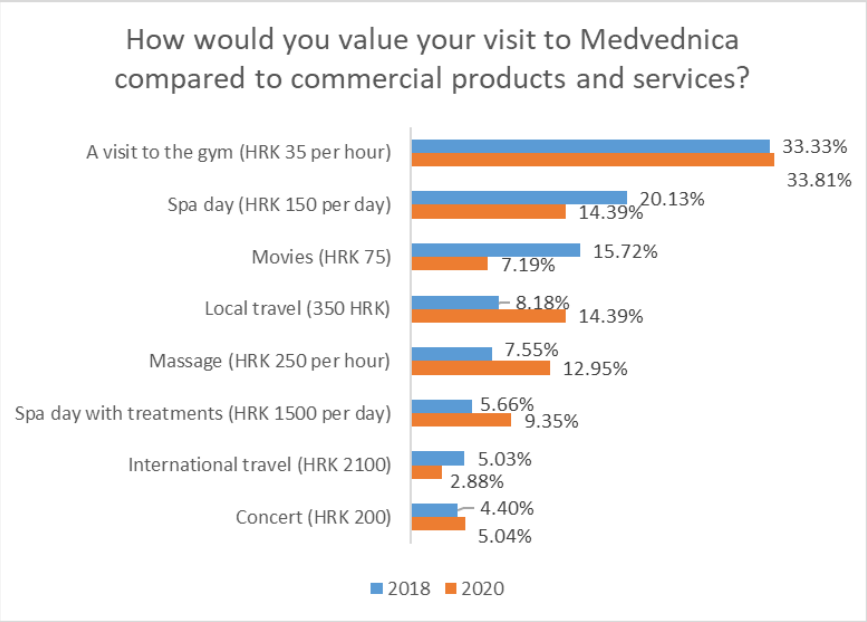


Figure 6. Visit to Medvednica compared to commercial products and services.

Regarding the question of the WTP stated to visit the Medvednica Nature Park (Figure 7), of the 102 visitors who answered the question in the survey conducted in 2018, 54 respondents (35.3%) answered no, while 99 (64.7%) answered yes. Out of 99 respondents who said yes, 48.5% are willing to pay HRK 10 (about EUR 1.50), 26.3% HRK 15 (about EUR 2), and 25.3% of respondents are willing to pay HRK 5 (about EUR 0.60).

The research conducted in 2020 showed slightly different results than that conducted in 2018. Although most of the visitors stated that they are willing to pay to visit Medvednica (54.7%), their share is lower than in the research conducted two years earlier. On the other hand, the share is lower, but the amount they are willing to pay is higher - 44.4% of visitors who are willing to pay for staying in Medvednica Nature Park are willing to pay HRK 15, 38.3% HRK 10, and 17.3% HRK 5.

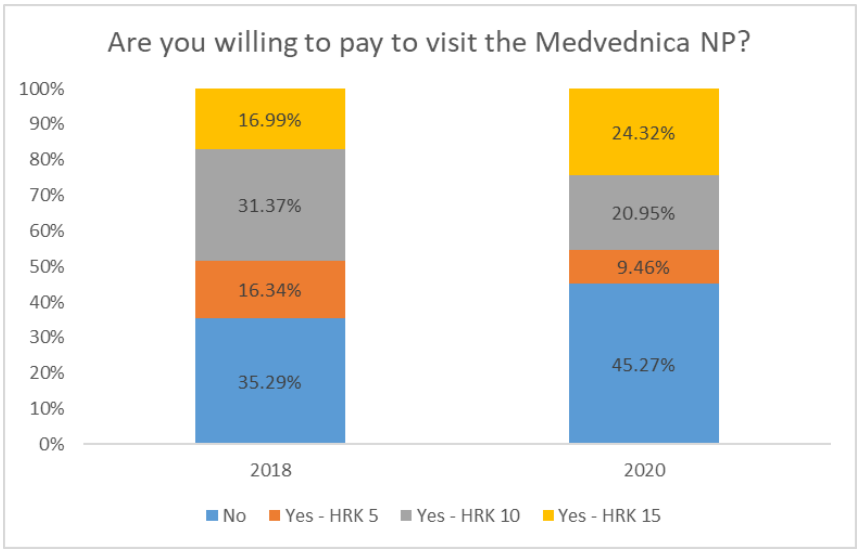


Figure 7. WTP to visit the Medvednica Nature Park.

The WTA has not been estimated to compensate landowners and foresters for continuing with their forest management practices in the area for the benefit of the community and at the expense of their private return from productive activity alone (i.e., forest logging). This is probably because, for the publicly managed portion of forests, it would not make sense to estimate the WTA, while for the privately managed portion, little or no knowledge of forest owners or conflicting property rights undermine the success of its estimation.

Intermediaries and knowledge providers were also involved in the development of the PES scheme. The providers were the private owners and the public administration of the Medvednica Nature Park. The service users were visitors to the donation boxes and organisations and entities organising events in the park for one-time concession permits (e.g., Croatian Mountain rescue service and triathlon club). The intermediaries were civil society and business activities (e.g., web service providers). The knowledge providers were research institutions (e.g., Faculty of Forestry, University of Zagreb). During the project, three meetings were held between 2018 and 2019 to involve stakeholders from the area. The first meeting involved only five stakeholders, but in the other meetings, their participation increased.

The PES scheme designed with the two mechanisms has private funding, with a many-to-many configuration due to the different service providers and users, is applied locally, and has a validity period equal to the duration of the research project (short-term). Recreational and health services are sold and packaged in the form of piggy-backing as users who buy these services also benefit from others free

of charge. In terms of payment characteristics, the arrangement is result-based, namely, based on the actual delivery of the services, with cash, one-off payment for the one-time concession permits, and periodically for the donation boxes, and takes place after the delivery of services.

Regarding the evaluation of impacts, it was not possible to assess the mechanism of the donation boxes, because they were vandalised and destroyed. About the one-time concession permits mechanism, reports from the SINCERE project show that the involvement of different stakeholders in the meetings creates a greater awareness of forest ecosystem services and the importance to pay for such services. Another result of the project shows that the mechanism allows for a re-direction of conflicts between the users of the area, because it assigned each group a different area and the funds collected from the permits could be used for investments in recreational infrastructures. Furthermore, there was a monitoring of fauna, flora, and soil damage. However, there was no impact assessment because there was no comparison with the counterfactual scenario, but it is likely that there will be an improvement in the recreational experience in the park with a consequent increase in demand for recreational services. However, the experience gained from this mechanism did not trigger the feedback or verification process to improve or implement parts of the PES scheme and its duration.

4.4. Discussion

PES schemes can contribute to the conservation of threatened areas and ecosystems and improve the well-being of local communities, as reported by several authors (Banerjee et al., 2013; Ezzine-de-Blas et al., 2016; Börner et al., 2017). For PES schemes to be successfully implemented, however, their effectiveness and efficiency, as well as the results obtained, must be analysed. Otherwise, they remain a mere theoretical exercise and lose credibility, as argued by Wunder *et al.* (2018). The framework proposed here aimed to evaluate ex post a solution-driven PES scheme, independently of the ecosystem service analysed. This was performed by attempting to consider both the political/institutional and social, economic, and environmental components. Our attempt differs from those found in the literature, such as the one proposed by Page *et al.* (2015) about the evaluation of local PES proposals by monitoring their environmental impact with LCA, or the one proposed by Schomers *et al.* (2015) about assessing the potential of intermediaries to improve the effectiveness of PES schemes, or the one proposed by Tikkanen *et al.* (2017) for the ex-ante evaluation of schemes applied to nature-based tourism.

The application of the framework allowed us to answer our research question and identify bottlenecks that potentially limited the success of the PES scheme implemented in the Medvednica Nature Park. For a successful implementation of a PES scheme, it is important to have a suitable background, as argued by Brand (2002). In this regard, the results reveal a strong societal interest in the study area,

as also reported by Bakarić *et al.* (2021) and Tisma *et al.* (2020), and, thus, the potential for implementing a PES scheme. At the same time, as reported in the study conducted by Vuletić *et al.* (2020) on water-related PES schemes in south-eastern European countries, Croatia has more than 30 years of experience with the legal and institutional and, thus, theoretical framework of PES schemes. The absence of such a factor would likely have led to the failure of the scheme, as argued by the review conducted by Yan *et al.* (2022) on PES as an essential instrument for improving ecosystem services. However, although a large part of the forests in the park are in public ownership, the remaining private part faces a lack of clear ownership rights among the landowners, as argued by some managers involved in stakeholder interviews, which not only limits the success of up-scaling the scheme, and of the SINCERE project, but also risks undermining its success and generating leakage situations. In a review conducted by Adhikari and Agrawal (2013) on the ecological and social outcomes of PES projects, the importance of property rights and tenure security for a project's success emerged, as also reported by Yan *et al.* (2022).

The methodological framework also highlights the lack of spatial identification and quantification of forest ecosystem services and the areas with their greatest hotspot within the study area. According to Wunder *et al.* (2020) and Ezzine-de-Blas *et al.* (2016), who analysed past experiences of PES schemes, these factors are one of the main factors for environmental additionality along with payment differentiation and conditionality. However, the case study analysed cultural ecosystem services that, due to their intrinsic characteristics, are difficult to biophysically quantify and account for. The results indicate a lack of knowledge of forest ecosystem services, which probably led to reduced or no willingness on the part of society to pay for them. During the course of the project, however, as reported by Tisma *et al.* (2020), society's perception and knowledge of such services increased, and this will certainly influence their stated WTP in future research projects. In this regard, Poudyal *et al.* (2021) highlight society's knowledge of ecosystem services and PES as one of the socio-economic factors affecting the implementation of PES schemes.

In general, the methodological framework reveals potential bottlenecks, especially in the preparatory context for a PES scheme, but the design and implementation are successful in the study area. A final element to be reported is the evaluation of the impacts that was partially carried out, but the conditionality for the continuous provision of recreational and health-related services by private landowners was not verified. This may be due both to the fact that monitoring the effects of the scheme would increase transaction costs by not making the instrument as cost-effective compared to other economic/political instruments, and to the short duration of this scheme, which had the same validity as the SINCERE research project. There is, however, a need to emphasise the importance of monitoring, verifying conditionality, and sanctioning non-compliance, as reported by several authors (Ezzine-de-Blas et al., 2016; Wunder et al., 2018; Puspitasari et al., 2021)

so that PES schemes are stable over time and do not become mere economic additions to "business as usual" conditions where the service is either not provided or poorly provided.

4.5. Conclusions

Recently in the field of environmental economics, there has been a shift from a "polluter pays" approach typical of political and command-and-control-based instruments to a "provider gets" approach, such as that of market-based instruments, capable of creating virtuous and cooperative behaviour among the actors involved. Among MBIs, PES schemes have attracted increasing interest over the past three decades, first as a tool for protecting threatened ecosystems in developing and emerging economies, and then as a tool for enhancing ecosystems in developed economies. In this context, there is a need for evaluation frameworks, guidelines, and supports that can monitor and evaluate the effectiveness and success of such schemes.

This study attempted to establish an ex-post evaluation framework to identify bottlenecks and obstacles to the success of solution-driven PES schemes by integrating the four main spheres of sustainability, namely, environmental/ecological, social, economic, and political, into one proposal.

The results express a clear societal interest in the area subjected to the PES scheme - given its year-round attendance - but at the same time, reveal potential obstructive elements for the successful implementation of such a scheme. The mechanism based on donation boxes for visitors to the park fail due to vandalism. In contrast, the mechanism based on one-time concession permits, which mainly involve organisations and entities organising events and recreative activities in the park, although moderately successful and interesting, encounter obstacles in the unclear property rights of landowners, the absence of mapping, quantification, and accounting of the forest ecosystem services under study, little or no WTP on the part of the demand side for such services, and the absence of application of the feedback process of the functioning of the scheme for its improvement or integration. Regarding the WTP from the demand side, this is probably one of the main weaknesses of solution-driven schemes, where a third party dreams up a scheme without a particular need from the market/society. There is also a need to add that both mechanisms proposed in the project fail in the proposed PES schemes defined by Wunder, as no spatial externalities are produced, but ecosystem services are consumed locally. Therefore, it would be more correct to talk about innovative mechanisms, yes, but related to MBIs and not to PES schemes.

In a general sense, the proposed assessment framework lends itself to replication in other geographical contexts with an even greater spatial extent than the local context, depending on the application of the PES scheme. The framework is versatile and can be modified and integrated with other boxes depending on the context, such as the need to integrate local communities' knowledge of ecosystem

services and their uses. The main limitations of the framework relate to technical capacity, data availability, and a clear view of the political-institutional complexity of the case study in which it is applied. With reference to technical capacity, there is a need to have trained figures with some level of knowledge of the topic or several figures that may be involved, each specializing in a particular part of the framework. Regarding data availability, this is a problem that plagues all research, although the digitization of information, the presence of digital data collection platforms, and the era of big and smart data are improving this situation. Regarding the institutional complexity and the possible different stakeholders in it, at the European level there is the presence of agricultural knowledge and information systems (AKIS) diagrams that map the relational and institutional framework of a country's agricultural and forestry sector. However, there is a present need to investigate for potential similar diagrams internationally. Our future developments in the research may concern both the creation of guidelines for the proper use of the framework and its application to other case studies, as well as to begin to create a kind of portfolio of analysed case studies and validate the goodness and adaptability of the methodological framework in other contexts.

Regarding the possible implications for decision-makers and those involved in the development of PES schemes, it can be a valuable support in initially identifying the elements that hinder their success, however, there is a need for different technical skills to be able to analyse the different boxes of the framework and there is a need to identify strategies to cope with the possible phenomenon of individual free-riding of scheme participants. In such a case, solutions such as those proposed by Naime *et al.* (2022), namely, monitoring by public detection of individual actions or monetary sanctions by an external central government agency or internally by the community of stakeholders related to the scheme, can be proposed. For researchers, such a framework can be a first step for the ex-post evaluation of PES schemes at the academic level and an element on which further research can be developed to overcome the limitation of its application only for solution-driven cases. Such cases are in the minority compared to PES schemes created to protect an ecosystem or to support landowners and foresters in their management practices.

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Data Availability Statement: Restrictions apply to the availability of these data. Data were obtained from TripAdvisor and are available from the authors with the permission of TripAdvisor.

Author Contributions: Conceptualization, S.B. (Stefano Bruzzese) and S.B. (Simone Blanc); methodology, S.B. (Stefano Bruzzese) and S.B. (Simone Blanc); validation, S.B. (Stefano Bruzzese), S.B. (Simone Blanc), and D.V.; formal analysis, S.B. (Stefano Bruzzese) and I.T.M.; investigation, S.B. (Stefano Bruzzese), I.T.M., and S.T.; resources, S.B. (Stefano Bruzzese) and D.V.; data curation, S.B. (Stefano Bruzzese); writing—original draft preparation, S.B. (Stefano Bruzzese), I.T.M., and S.B. (Simone Blanc); writing—review and editing, S.B. (Stefano Bruzzese), S.B. (Simone Blanc), F.B., and D.V.; visualization, S.B. (Stefano Bruzzese); supervision, D.V. and F.B. All authors have read and agreed to the published version of the manuscript.

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Appendix A

Survey for visitors to the Medvednica Nature Park.

1. Gender:

- Male;
- Female.

2. Age:

- 6–17;
- 18–30;
- 31–45;
- 46–60;
- >60.

3. Level of education:

- Completed primary education;
- Skilled worker;
- Completed secondary education;
- Bachelor/master's degree;
- PhD degree.

4. Where do you come from?
5. Do you know what ecosystem services are?

- Yes;
- No;
- If yes, can you mention some of them?

6. How often do you visit Medvednica?

- First time;
- Once a year;
- Several times a year;
- Once a month;
- Several times a month;
- Once a week;
- Several times a week.

7. Did you go up and down walking?

- Yes;
- No;
- If no, how long are you walking?

8. How often and how intensively do you exercise?

- Once a month -Light activity;
- Several times a month -Moderate activity;
- Once a week -Intense activity;

- Several times a week.

9. How much does the visit of Medvednica impact the following areas? (1—completely disagree, 2—partially disagree, 3—neither agree or disagree, 4—partially agree, 5—completely agree).

- Improvement in social well-being
- 1 → 2 → 3 → 4 → 5
- Improvement in psychological well-being
- 1 → 2 → 3 → 4 → 5
- Improvement in physical well-being
- 1 → 2 → 3 → 4 → 5

10. How would you value your visit to Medvednica compared to commercial products and services?

- A visit to the gym (HRK 35 per hour);
- Movies (HRK 75);
- Spa day (HRK 150 per day);
- Massage (HRK 250 per hour);
- Spa day with treatments (HRK 1500 per day);
- Concert (HRK 200);
- Local travel (HRK 350);
- International travel (HRK 2100).

11. Are you willing to pay to visit the Medvednica Nature Park?

- Yes;
- No;
- If yes, how much?
- HRK 5;
- HRK 10;
- HRK 15.

Appendix B

Semi-structured interview script for stakeholders' opinions.

1. About the project

- What was your role in developing research project and carrying it forward?
- Are there any other PES projects that have helped you in co-designing the project? Which are these and why?

2. About the co-design process

- What was your main emotion during the co-design (enthusiasm, sense of participation, conflictual, affliction, etc.)?

3. About PES

- What element(s) do you think are necessary for the successful implementation of a PES?
- What are the main difficulties/obstacles you found in the implementation of a PES?

4. Future recommendations

- What is your perception of the added value/impact of the project implementation?

3rd Article

5. The Decision Trees Method to Support the Choice of Economic Evaluation Procedure: The Case of Protection Forests

Stefano Bruzzese[1], Simone Blanc[1,*], and Filippo Brun[1]

[1] Department of Agricultural, Forest and Food Sciences (DISAFA), University of Torino, Largo Paolo Braccini 2, Grugliasco, 10095, Italy

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Abstract: The adoption of nature-based solutions, such as forests, is playing an increasingly important role in risk analysis and related decision-making. However, decision-makers struggle to put a value on the services provided by these solutions, as there is no reference market, and are thus faced with several challenges, which relate to the choice of the best forest management program or the interventions needed to make a forest resistant and resilient to the expected negative impacts of ongoing climate change. In this article, we started with an exploratory analysis to identify the key factors in the choice of an economic method to build predictive models to support the choice in an evaluation of the forest protection service against natural hazards. The exploratory analysis showed that non-demand-based methods have a good degree of replicability and reliability and are cheaper, whereas stated preference methods can estimate the intangible component. Concerning predictive models, almost all methods showed a high level of correct classification (95%), apart from the avoided damages method (90%) and, more generally, there is no method that is valid for all operational contexts but rather the choice changes depend on the demands made by the stakeholders and their availability in economic, human, and technological terms. In conclusion, it should be remembered that the methodological framework chosen should not be seen as a substitute for the human ability to analyse complex situations but rather as an aid to this process.

Study Implications: The adoption of decision support systems and methodological frameworks and guidelines can help decision-makers to make the most effective and efficient choices, in terms of time needed, resources used, and intervention costs. The combination of this decision support system with other tools, such as frameworks and guidelines, provides a flexible support system aimed at improving

the design and implementation of future ecosystem service assessments and management as well as related decision-making.

Keywords: decision-making, decision trees, risk analysis, natural hazards, protection forests, ecosystem services evaluation.

5.1. Introduction

In recent years, natural hazards, such as avalanches, surface landslides and rock falls - triggered by ongoing climate change in mountain areas - have increased in both magnitude and frequency (Howard and Sterner 2017, Lupp et al. 2021). Accompanied by growing demographic pressure and profound socioeconomic and land use changes, these hazards have instigated a greater need for human protection (Accastello et al. 2019, Thaler et al. 2018). This demand can be met with artificial structures, such as rock fall nets and avalanche barriers, or with ecosystem-based disaster risk reduction if properly managed (Poratelli et al. 2020). Forests and their ecosystem services can help in the protection against natural hazards (Bruzzese, Blanc and Brun 2022), but they need to be evaluated to be considered in decision-making processes related to risk management. The use of economic evaluation to estimate the value of ecosystem services is often complicated by ethical issues (Accastello et al. 2019, Davidson 2013); however, the failure to consider these values is often more hazardous than the damage caused by their incorrect evaluation (Spangenberg and Settele 2010). Some of the main advantages of economic evaluation are the facilitation of choice when allocating resources and, as identified by de Meo et al. (2018), the greater communicability of the results to people having different experiences and knowledge. Economic evaluation can be of two types: monetary, such as the one proposed in this article, and nonmonetary, such as the economic quality of forests method (Brun 2002), Q-methodology, participatory rural appraisal, and participatory action research (Christie et al. 2012), in which an ecosystem service is evaluated based on technical parameters and judgements. Several monetary evaluation methods can be used to evaluate the protection service offered by a forest. According to ELD Initiative (2019), they can be divided into:

- non-demand-based methods: using current market data, they reflect people's actual preferences. We include in this category the replacement cost method (RCM), in which the forest protection service is worth at least as much as the amount of costs incurred to make artificial structures with the same role (Dvarskas et al. 2020) and the avoided damages method (ADM), in which the forest protection service is worth at least as much as the amount of expected damage to assets at risk in its absence (Bianchi et al. 2018); and
- stated preference (SP) methods: people are directly asked their willingness to pay (WTP) or willingness to accept (WTA)

compensation for maintaining or giving up a given good and service, within a hypothetical market. These include the contingent valuation method (CVM), wherein the forest protection service is worth at least as much as people's WTP or WTA for maintaining or giving up that service (Kim et al. 2021, Mitchell and Carson 2013); and the choice modelling method (CMM), which is similar to the previous method, but instead of asking people directly for their WTP or WTA, they are asked to make a choice between several alternatives (Burnier et al. 2021).

Finally, there is an indirect method known as benefit transfer method (BTM), which consists of transferring data, functions, models or results obtained from "primary" sites, through studies in literature, for the evaluation of ecosystem services belonging to the case study of the so called "secondary" site of our interest (Johnston, Rolfe and Zawojska 2018).

The choice of these five economic valuation methods as the object of study was made based on a previous review conducted by Bianchi *et al.* (2018), in which these methods are listed among those used for the evaluation of the protection service of forest against gravitational natural hazards. In this context, there are several authors who have used these methods, such as Getzner *et al.* (2017), who used the RCM to evaluate the protective function of alpine forests; Kennel (2004), who used the ADM for preventive protection in Bavarian forests; Löwenstein (1995), who used a method based on stated preferences for protective forests against landslides and avalanches, also in Bavaria; and De Marchi *et al.* (2012), who used the BTM in a nature park in northern Italy.

The technical and economic evaluation of the protection offered by forests is becoming more and more central to land planning and resource management in a multifunctional perspective that guarantees the usability of mountain environments for residents and tourists. Therefore, these assessment tools are becoming part of integrated systems to support local managers and administrators in making decisions on a broad scale.

For this purpose, the adoption of decision support systems (DSS) and tools or methodological frameworks and guidelines can help decision-makers to make the most effective and efficient choices in terms of time needed, resources used, and intervention costs (Bruzzese et al. 2020). Currently, several of them exist (Acosta and Corral 2017, Bettinger and Boston 2017, Yamada and Yamaura 2017) and given the uncertainties of environmental conditions and the increasing demands of society, their importance is growing. Such DSS - being qualitative, quantitative or mixed - use different types of evaluation, such as biophysical, monetary, and socio-cultural, and they manage uncertainty, returning a set of choices rather than a single output, as in the case when a single method is adopted. Well-known DSS include integrated valuation of ecosystem services and trade-offs (InVEST), artificial intelligence for ecosystem services (ARIES) and social values for ecosystem

services (SolVES) (Bagstad et al. 2013), however, none of them focus on the protective services offered by forests; InVEST explores how changes in ecosystems can lead to changes in the flows of many different benefits to people, ARIES evaluates how nature provides benefits to people, and SolVES focuses mainly on cultural services. Moreover, they are often not used because they are difficult to implement and do not meet the demands of the various stakeholders, such as decision-makers and managers (Fanok et al. 2022, Walling and Vaneeckhaute, 2020).
Within this context, our research aims to (1) provide an exploratory analysis and a predictive model to evaluate the most widely used economic methods for the evaluation of the protective service provided by forests and (2) provide a simple and readable methodological framework for choosing the most suitable economic method, depending on the operational context and available economic, human, and technological resources.

5.2. Methods

To achieve the research objectives, the analysis of methodologies identified followed a two-step pathway to assess the suitability of use of the methods to evaluate the protection service provided by forests. These methods allow the integration of exploratory analysis and quantitative evaluation. An initial exploratory analysis made it possible to identify in the literature the criteria considered important by stakeholders to evaluate the protection service offered by forest by applying various monetary economic methods. Such criteria were then used in a quantitative analysis based on a machine learning algorithm capable of providing a predictive model for the choice of the most suitable monetary economic method for the decision-maker.

5.2.1. Exploratory Analysis of Monetary Methods

This analysis was used to assess the key factors of each cited method and was carried out on the basis of the criteria identified by Markantonis, Meyer, and Schwarze (2012) (Table 1). For each key factor, a scale was defined that refers to the ability to assess a certain criterion in-depth. This scale starts from the lowest level, indicated by "+", and moves on to the intermediate level "++", and then to the highest level "+++". The levels identified will be used for the quantitative evaluation of methods through the creation of predictive models. The "field of application" identifies the level of detail to which the method has been used to evaluate the regulation service, based on research carried out by Bianchi *et al.* (2018). "Spatial scale" expresses the maximum spatial extent in which the applied method is still valid and "time scale" refers to the duration of the evaluation period. "Cheapness" represents the affordability in terms of time, resources, and money spent to apply the method and "simplicity" shows the availability and amount of

data required to use the method. Finally, the "total economic value" (TEV) criteria identifies which components of the value can evaluate the applied method. The TEV is composed of a use value that can be direct, when there is actual or potential consumption of the ecosystem good, or indirect, when there is no consumption, and a non-use value (or passive use) resulting from the benefits associated with the knowledge of maintaining a particular ecosystem (Nitanan et al. 2020).

Table 1. Criteria used for the evaluation of monetary methods and their respective levels.

Criteria	Qualitative scale		
	+	++	+++
Field of application	protection service	protection service against a natural hazard	protection service against a gravitational natural hazard
Spatial scale	forest stand	local	regional
Time scale	<3 years	3–50 years	>50 years
Cheapness	Low	medium	high
Simplicity	Low	medium	high
Total economic value	direct or indirect use value	direct and indirect use value	use and nonuse value

There are two other categories: the option value, attributed to the availability of an environmental resource by people for hypothetical future use such as bioprospecting (Morse-Jones et al. 2011, Purida and Patria 2019) and finally, the quasi-option value, very similar to the previous one but associated with the

expectation of better information about the resource, so as not to stop maintaining it for possible future use.

5.2.2. Predictive Classification Models of Monetary Methods

An algorithm that is well-suited for determining a classification model is classification and regression trees (CART) (Gocheva-Ilieva, Kulina, and Ivanov 2021), which is represented by decision trees.

Decision trees are a predictive technique belonging to the subbranch of machine learning (Wang et al. 2021), which is used for both regression (quantitative variables) and classification (qualitative variables) problems. The aim is to build a model capable of capturing the mechanisms that give rise to the data (Vanfretti and Arava 2020). The learning method used by decision trees is supervised learning, in which model inputs and outputs are already provided to the computing machine, which in turn learns and elaborates a model that best predicts the desired output.

A decision tree, to give an analogy, is like a natural tree, as far as the structure is concerned, as it is composed of nodes (the variables) and branches (the decisions or rules) (Figure 1). The former, depending on where they are in the structure, take different names: the root node is the primary one, from which the tree develops; the internal nodes are the intermediate ones connected by branches; and the leaf nodes represent the end of the tree. The nodes are, in turn, divided into parent nodes and child nodes, depending on their hierarchical level. Importantly, root nodes can never be child nodes, just as leaf nodes can never be parent nodes.

The decision tree, then, is characterized by a level of depth starting at level 0 for the root node and increasing for each row of internal nodes, until reaching the leaf nodes. For example, the tree in Figure 1 is second level. This feature is important for the evaluation of the analysis, as an excessive number of levels would correspond to an overlapping of data and thus a model that is difficult to interpret, as it is excessively accurate and unable to predict the desired output.

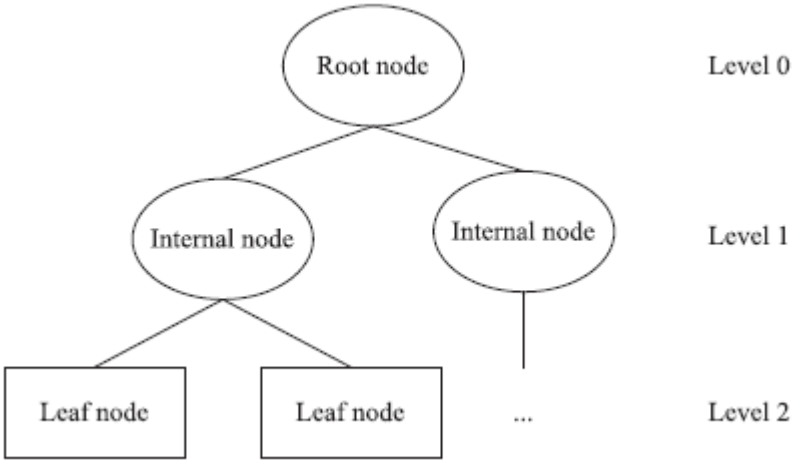

Figure 1. Framework with the elements of a generic decision tree.

A solution for this problem is pruning, which analyses whether or not a node is relevant to the classification of all instances, thus reducing the complexity of the tree and improving its prediction accuracy. Pruning can be done from below (bottom-up), namely from leaf nodes, or from above (top-down) starting from the root node.

Another important feature of the decision tree is its binary structure; that is, each parent node is followed by only two child nodes identified by a recursive binary splitting technique (Wu et al. 2008). This technique allows us to consider all input variables and, through a loss function, to experiment with different splitting points, identifying the one that minimizes the loss. Depending on whether it is a regression or a classification problem, the loss function is different (Wolfson and Venkatasubramaniam 2018). In the former case, the mean square error (MSE) is used, whereas the latter uses the entropy or Gini coefficient. The latter is an index used in univariate descriptive statistics for qualitative variables, with the intention of measuring the heterogeneity of a statistical distribution (Lipinski, Brzychczy, and Zimroz 2020). It can have a range of values from 0 to 1, where 0 means maximum equality (purity) and 1 means maximum inequality (Eq. 1).

$$G(x) = \sum_i p_i(1 - p_i)$$

Here, *G* represents the Gini coefficient for that variable, *i-th* represents a rule of that variable, and p_i is the ratio of training instances with the *i-th* rule in the region of interest.

The datasets (Appendix A) for each economic evaluation method were created using Excel® spreadsheets, taking as input variables the criteria explained above (e.g., field of application, time scale, and spatial scale) and as rules the different options of each criterion (e.g., general protection, protection against natural hazards, and protection against gravitational natural hazards). To understand how many possible combinations there may be between input variables and rules, we relied on combinatorial calculations using arrangements with repetition (Eq. 2).

$$D'_{n,k} = n^k$$

Here, *D'* is the arrangement with repetition, *n* is the number of distinct elements, and *k* is the number of positions. In our case, the arrangement with repetition allowed us to obtain a dataset for each economic evaluation method, with 36 = 729 possible configurations, considering three distinct repeated elements and six positions.

Each dataset was then imported into the SPSS statistical software for processing and divided into two subsets according to a 70/30 ratio, a subdivision value commonly used with machine learning algorithms (Al-Abadi 2018, Rahmati, Pourghasemi and Melesse 2016, Tien Bui et al. 2018). The subset with 70% of the data, referred to as the training subset, was used to train the predictive model, and the subset with 30% of the data, referred to as the test subset, was used to evaluate the performance of the model built.

5.3. Results

5.3.1. Exploratory Analysis of Monetary Methods

From the analysis of the methods, it was determined that the non-demand-based methods (RCM, ADM) have the advantage of referring to real data; therefore, the difficulty of obtaining input data is limited, as an already existing market is present. This feature thus implies a degree of cost-effectiveness in applying these methods, as the effort required - both in terms of financial and human resources, as well as in terms of time - is reduced from that of SP methods (Table 2). The presence of a market implies a certain degree of reliability and replicability in the application of these methods. However, they have a major shortcoming in that they cannot evaluate the non-use value of a good or service, thus making the estimation of TEV incomplete.

By contrast, SP methods (CVM, CMM) can estimate intangible costs, for example, of a natural hazard, and thus estimate TEV. However, these approaches present several difficulties, such as being uneconomical and involving a large commitment of time and resources (survey design, validation, administration, etc.) along with the need for technical expertise, which results in greater complexity in their implementation and understanding by stakeholders. Moreover, as these methods refer to a hypothetical market, their reliability and replicability are diminished, as their application involves many assumptions that may become even more inaccurate as the level of knowledge and skills of those involved in the evaluation become more limited.

As far as the time scale is concerned, non-demand-based methods lend themselves to short- and medium-term evaluations thanks to the presence of a real reference market, whereas SP methods can also be used to evaluate future scenarios with long-term impacts; however, their reliability remains doubtful.

The BTM, on the other hand, is treated separately, as it can be applied to all the methods explained above. It has the advantage of being quick, lending itself to time-limited evaluations with a lack of data or input resources and to those where the required evaluation accuracy is low. For these reasons, it is well suited to preliminary feasibility studies, as, during the cost-benefit assessment of a project, program, or policy, it gives an understanding of whether a more in-depth analysis is required and therefore, whether a primary evaluation study is needed. At the same time, the method may be open to several errors of application, such as those related to the original measurements at the site with the value or those resulting from the transfer of value between the two investigated sites. These errors, which affect the robustness of the results obtained, determine the context in which the estimated value can be applied.

5.3.2. Predictive Classification Models of Monetary Methods

The first check that was carried out concerned the validity of the predictive models obtained in terms of how well they work. In fact, the predictive risk tables reveal an estimated misclassification rate of less than 5% for three out of four models (Figures 2c, 4c, and 5c) and 10% for the ADM (Figure 3c). Similarly, the classification tables, which show an overall percentage of correctly classified cases higher than 95% for the RCM, CVM, and CMM (Figures 2c, 4c, and 5c) and about 90% for the ADM (Figure 3c), allowed us to identify the reason for this difference with the latter method. Specifically, the model trained for the ADM fails to predict positive cases correctly; that is, when the method can be used, as the number of positive cases observed in the training subset is small. The model, therefore, partially suffers from underfitting as it fails to detect a pattern in the data;

Table 2. Explorative evaluation of the monetary methods investigated. Source: Markantonis *et al.* (2012), modified.

Method	Acronym	Field of application	Spatial scale	Time scale	Cheapness	Simplicity	TEV
Non-demand-based methods							
Replacement cost method	RCM	+++	+++	++	+++	+++	++
Avoided damages method	ADM	+++	+	++	++	++	++
Stated preference methods							
Contingent valuation method	CVM	++	+++	+++	+	+	+++
Choice modelling method	CMM	++	+++	+++	+	+	+++
Other							
Benefit transfer method	BTM	++	-	-	+++	+++	++

one resolution for this problem would be to include more observed cases within the training subset. This issue could be solved by using the synthetic minority oversampling technique (SMOTE) algorithm, which uses oversampling to manage the imbalance of classes within a dataset.

At the same time, the decision tree technique usually leans towards the opposite condition of overfitting; in other words, the model overfits the training subset, failing to generalize and therefore making incorrect predictions on the test subset. This occurs because, in the training phase, the model also considers irrelevant information in the subset; hence, the importance of reducing the amount of data with techniques such as pruning, which in our case was applied a priori.
With reference to the a priori probability table (applied only on the training subset), it emerged that the different methods (Figures 3c, 4c, and 5c), except for RCM (Figure 2c), have a reduced probability of being used in the operational context chosen by the stakeholder, although it is a probability applied a priori. This can be attributed to several aspects, such as the need for technical expertise and the high costs in terms of time and resources required for their application, which often discourage their use.
Finally, with regard to the input variables considered by the models (Figures 2a, 3a, 4a, and 5a), we note that the predictive models obtained do not contain them all, as, in the process of division from parent node to child nodes, the Gini loss function ceases when it can no longer find the input variable that minimizes this loss. This is the case when all remaining input variables present the same loss; therefore, the model can be considered concluded and the last nodes become the leaf nodes.

5.3.2.1. Replacement Cost Method

Figure 2 shows several results: the model produced by the training subset, the model produced by the validation subset, and the tables used to evaluate the correct fit of the models. A detailed analysis of Figure 2b shows that 205 observations (root node) were used, as the complete dataset was divided with a 70/30 ratio. From these observations, it appears that the feasibility of the method is about one in two (feasibility of about 42.9%, n = 117); therefore, it is well suited to the different requirements and operational contexts chosen by the stakeholders. Continuing with the analysis of the model obtained, the CART algorithm chose the time scale as the first breakdown variable (Gini coefficient = 0.198). This is because, out of all the variables considered, it is the one with the lowest loss function and therefore the highest level of purity.

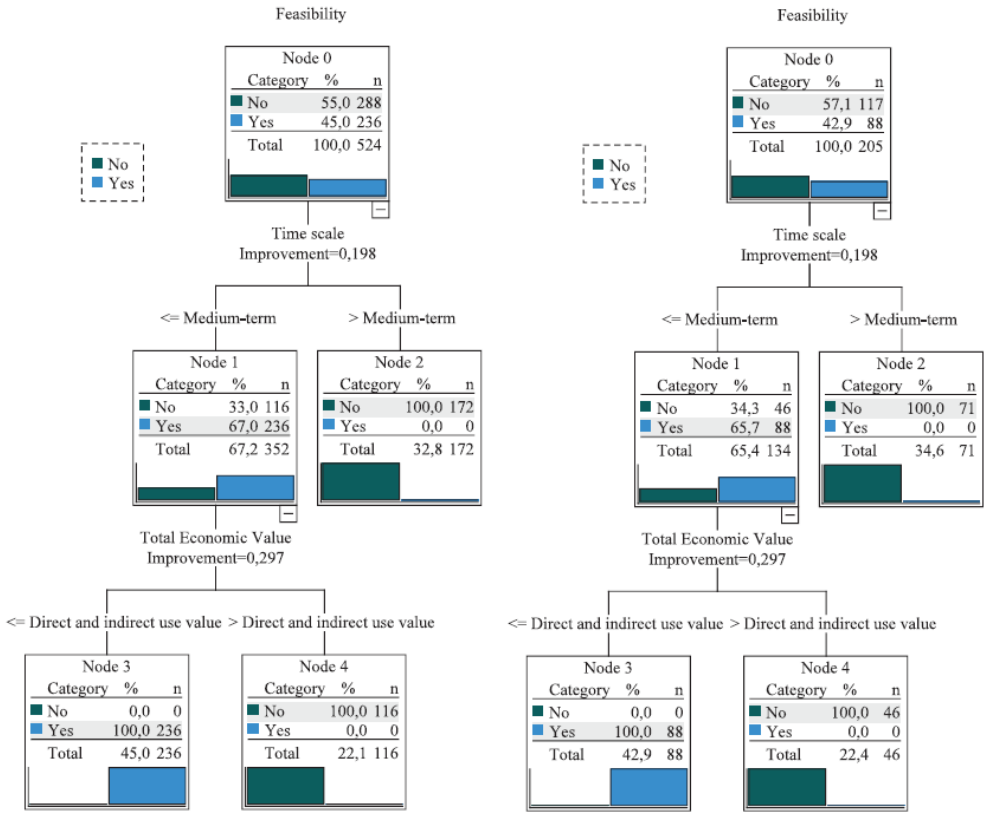

Figure 2. Decision tree of the RCM: 2a) model obtained from the training subset; 2b) model obtained from the test subset; 2c) model statistics.

In the first level, on the other hand, there are two boxes highlighting the different rules used by the time scale variable, from which it can be seen that the method is not used for long time scales (100% no, n = 71), but that about two times out of three it is applied for short and medium time scales (65.7% yes, n = 88). Finally, in the second level, we note that TEV was chosen as the variable (Gini coefficient = 0.297) and that with regard to its rules, the method is not used to estimate the value of nonuse (100% no, n = 46) but only for that of both direct and indirect use (100% yes, n = 88). Therefore, the RCM has good versatility of application, capable of fulfilling the demands of the various stakeholders involved in risk assessment and risk management. This is also shown by the fact that the method is not only suitable for being applied in economic evaluation at long-term time scales and for estimating TEV.

5.3.2.2. Avoided Damages Method

The results of the predictive model obtained from the test subset show that the ADM (Figure 3b) is applicable in few contexts (feasibility of about 7.5%). This is also demonstrated by the fact that the method is not replicable at spatial scales beyond those of the forest stand as it is site-specific and not capable of estimating TEV. However, the lack of versatility of this method should not be confused with the quality of the results obtained. In fact, although the method can only be applied to precise operational contexts, the results are reliable as they refer to input data taken from an existing market.

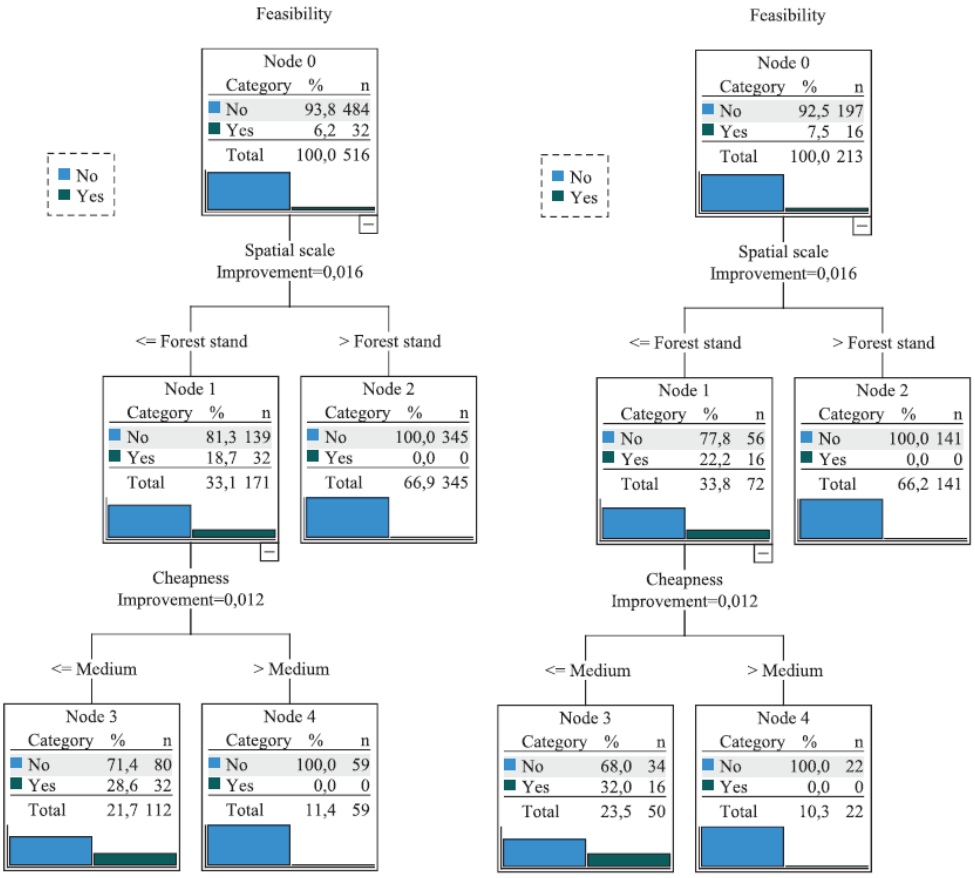

Figure 3. Decision tree of the ADM: 3a) model obtained from the training subset; 3b) model obtained from the test subset; 3c) model statistics.

5.3.2.3. Contingent Valuation Method

The results of the predictive model obtained from the test subset show that the CVM (Figure 4b) is applicable in few contexts (feasibility of about 5%). The results confirm what was reported in the explorative analysis; that is, that the constraints mainly consist of the costs of applying this method and the technical expertise required, which often discourage its use in favour of cheaper and simpler methods. However, this method can be applied at large spatial scales and for long-term estimates and is capable of estimating TEV.

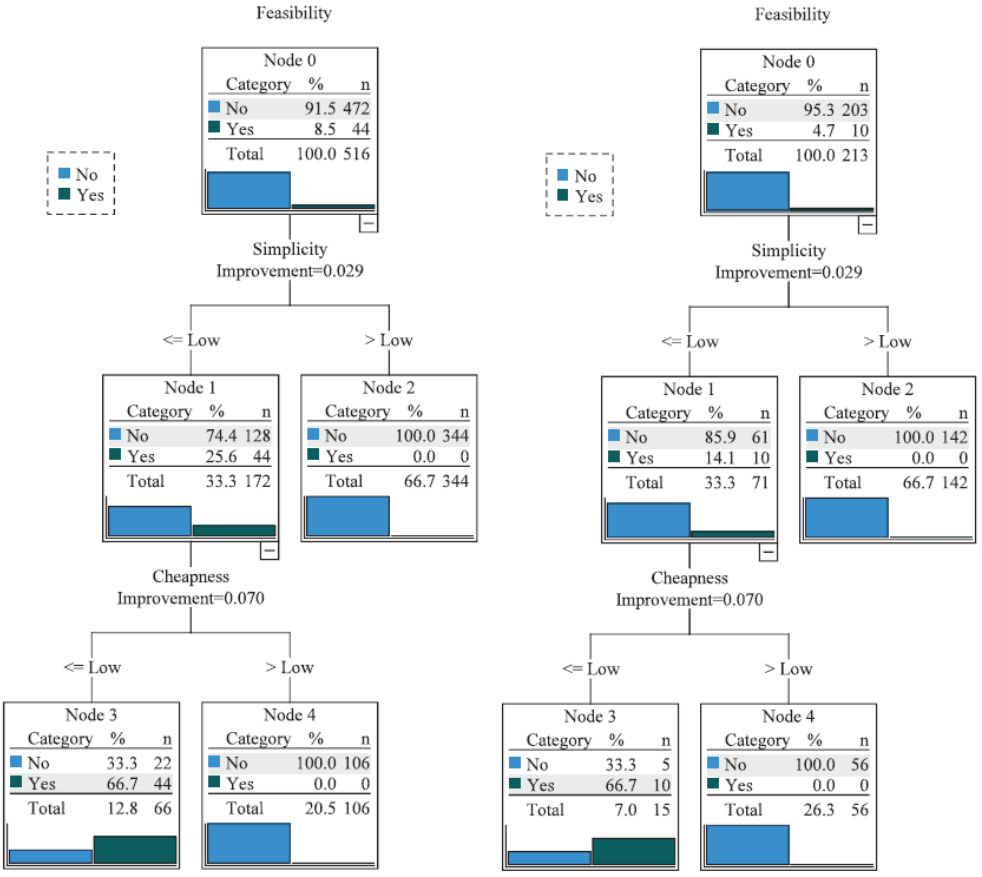

Figure 4. Decision tree of the CVM: 4a) model obtained from the training subset; 4b) model obtained from the test subset; 4c) model statistics.

5.3.2.4. Choice Modelling Method

The results of the predictive model obtained from the test subset show that the CMM (Figure 5b) is applicable in few contexts (feasibility of about 6%). The model resembles the previous one (same input variables considered and same results) as the two methods have similar characteristics. Although this method produces more significant results, as it does not require the respondents to express their WTP directly and it provides sets of choices of already preconfigured scenarios, thus reducing their misunderstandings and strategic behaviour.

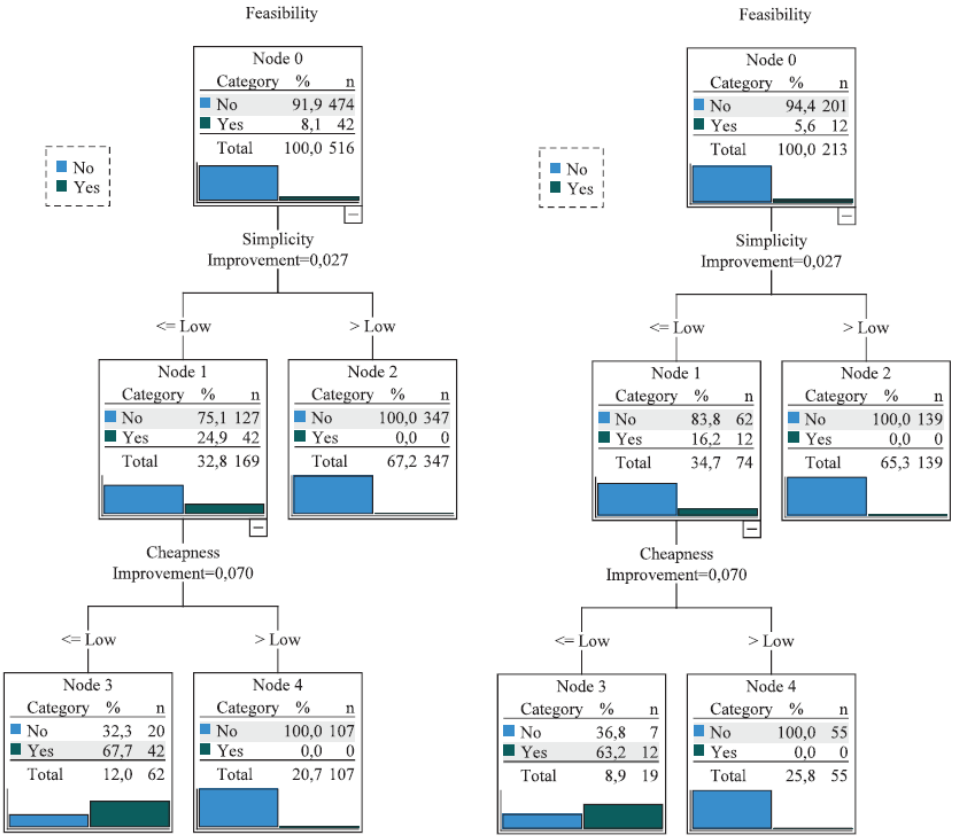

Figure 5. Decision tree of the CMM: 5a) model obtained from the training subset; 5b) model obtained from the test subset; 5c) model statistics.

5.4. Discussion

As highlighted in this article, there are several useful methods for the evaluation of those noncommodifiable ecosystem services, such as biophysical methods (e.g.,

GIS mapping and matrix approach) and socio-cultural methods (e.g., deliberative valuation and narrative analysis), but as Harrison et al. (2018) report, the choice of monetary methods is mainly due to the comparability of the results and the fact that they are established methods. These aspects support our choice to provide a methodological approach for evaluating the protection service provided by a forest using and comparing different monetary methods. Harrison *et al.* (2018) also suggest that an uncertainty factor should be considered whenever an evaluation is made, which, in monetary methods, lies in the reliability and accuracy of the results. This is a factor that is of some importance, for example, in primary evaluation studies where a cost-benefit analysis of public investments is required. In the different methods that we have analysed in this work, we can report some of the factors that contribute to the above-mentioned uncertainty:

- the RCM, as reported by Teich and Bebi (2009), does not consider several elements in the evaluation, such as forest cover, soil characteristics, or spatial scale variations of potential damage, resulting in possible underestimation or overestimation of the value of the forest protection service, also depending on the extent of the damage;
- the ADM, as Teich and Bebi (2009) also state, being based on a risk assessment, compares the costs and effects of different defence alternatives, providing useful information for the correct allocation of public funds; however, its spatial scale of application is very limited and is difficult to replicate because one would have to have the same starting conditions, as this method relies heavily on the values of the anthropic elements (houses, roads, and buildings) to be protected;
- methods based on SP suffer from considerable bias on the part of those involved in the evaluation, as their degree of knowledge about the analysed good or ecosystem service affects the results. However, Liski, Koetse, and Metzger (2019) report that the adoption of an integrated evaluation with deliberative approaches (i.e., small groups of people provided with basic information about the analysed element) would reduce this uncertainty, as the subjects, being exposed to more information, experiences, and attitudes, would have a better understanding of the examined element;
- the BTM, as reported by Khan *et al.* (2020), is susceptible to a high percentage of error in the transfer of value, determining its degree of acceptability depending on the purpose of the study. To reduce this uncertainty, it is therefore advisable to apply value transfer only to sites with similar characteristics.

In this work, an exploratory and quantitative evaluation was then carried out. This allowed us to obtain benefits from both types of evaluation and fill any gaps between them. Not least because, as Huge *et al.* (2020) report, the quality of information that quantitative environmental evaluations add to widespread decision-

making is dubious compared with the time and cost required to develop and apply them. On the other hand, qualitative evaluation of ecosystem services provides an overview, indicates trends, and facilitates policy preparation and strategic planning; however, these should be considered as proxy indicators because, as Busch *et al.* (2012) argue, only a more in-depth analysis, such as a quantitative analysis, provides reliable and explicit information.

The choice of using the decision tree technique in the methodological approaches was connected to the better communicability of the results obtained from the monetary evaluation. Indeed, this technique, according to some authors (Harrison et al. 2018, Quinlan 1990), is easy to understand, as it behaves like a "white box" in which each node and its ramification are transparent and do not have hidden assumptions, providing a clear and concise classification. However, the application of the decision tree technique has demonstrated some limitations, also highlighted by other authors:

- the difficulty in representing complexity, as trees with too high hierarchies become inefficient (Pham, Khosravi, and Prakash 2017);
- the difficulty in generalizing fixed paths, which result in the forced choice of certain decision paths, even if the user prefers other paths to reach the same final decision (Gret-Regamey et al. 2017);
- the binary choice to be made at each decision node, which often hinders the consideration of the various facets of an issue (Nayab and Scheid 2015).

Despite these limitations, which can be improved, for example, by introducing multimodal choice, choosing another technique such as Bayesian neural networks that differentiates different types of decision trees according to the object of analysis and thus reducing complexity, their use facilitates:

- systemic thinking about the elements that influence the choice of one method over another;
- rationalization of the choice of method in retrospect, thus shaping the final aim to the means;
- contextual awareness and the dependence of the results of ecosystem service evaluation on the decision-making path.

This methodological approach as a decision support tool is, however, ineffective without the involvement of the correct public and private sector players involved in decision-making processes, as confirmed by several authors (Barton et al. 2018, Kumar et al. 2013). Such players, however, require clarity on how, when, and why to apply these tools in planning, operations, and governance, as well as the resources needed and the costs of implementing them (Kaspar et al. 2018, Waage 2014).

The study by Martin-Lopez *et al.* (2019) reports that there is often a correlation between the spatial scale at which ecosystem services are evaluated and the players involved in the decision-making process, as the scale determines who will benefit. In this regard, Gret-Regamey *et al.* (2017) state that the players involved at different

spatial scales place a different value on ecosystem services depending on what impact these services will have on their income and living conditions as well as on their cultural background, which often translates into different views on planning and managing an area. A general rule of thumb, as stated by the Millennium Ecosystem Assessment (2005), to limit this variability is to carry out decision-making at as large a spatial scale as possible to ensure that the main benefits offered by the ecosystem are considered. Gregory and Wellmann (2001), meanwhile, claim that the perspectives of players involved in decision-making on environmental issues often depend on their human values and beliefs. This factor could therefore be an additional element to consider in the most appropriate choice of an ecosystem service evaluation tool, compared to others. In general, however, the evaluation methods we have considered, as well as the methodological approach, can be used for different ecosystem service evaluation needs and if combined with each other or even with biophysical, socio-cultural, and integrative methods (e.g., MCDA), could capture the plural values attributed to ecosystem services, which would otherwise be excluded if valued with a single method. In this respect, there are numerous manuals, as proposed by several studies (Dunford et al. 2018, Gret-Regamey et al. 2017, Hirons, Comberti, and Dunford 2016), which guide the choice and design of context-specific evaluation methods.

In today's world, characterized by strong dynamism and very labile environmental logics, the combination of different methods and tools, as well as the creation of new ones, will be necessary to meet future challenges and thus provide more accurate ecosystem service evaluations suitable for decision-making processes. We must also consider, as argued by Martin-Lopez *et al.* (2019), the needs of the potential player involved in the evaluation and the context of its application. Moreover, several authors (Baskent 2020, Baskent et al. 2020, 2021, Díez and McIntosh 2009) advise against a purely scientific focus, as this would result in a misconception of real land management with little acceptance and adoption of the results obtained from these evaluations. Hence, the importance of collaboration between professionals, policymakers, researchers, and scientists in physical and social sciences, with a view to grasping the complex relationship between ecosystem services, the environment, and the society and its economy.

5.5. Conclusions

The aim of our study was to identify the most widely used methods for the economic evaluation of forest protection services today and to analyse the merits and shortcomings of each. At the same time, we wanted to provide a methodological approach for choosing the most suitable method, depending on the operational context, for the stakeholders involved in the risk management and assessment processes.

What emerged from our results is that there is no single method that is valid for all operational contexts; each has its inherent limitations and, depending on the

resources, skills, and time available, one method may be preferable to another. Non-demand-based methods rely on an existing market and are therefore more reliable, require less effort in terms of resources, time, and costs, and can be replicated. However, they are not capable of evaluating TEV and their evaluation period is valid for short and medium time scales. In contrast, SP methods can estimate the TEV of an ecosystem good or service for evaluations even in long time scales, but they are very complex to apply, their results are difficult to understand by stakeholders, and they rely on a hypothetical market and are therefore more prone to errors.

The choice of decision trees as a predictive model fell both on the grounds of their simplicity of implementation and ability to evaluate even categorical variables and their ease of interpretation by those not having a scientific or statistical-mathematical background. The decision trees have shown how the RCM can be well adapted to most stakeholder requirements involved in risk management and assessment, considering, however, the limitations that have emerged in its application.

In conclusion, it is worth mentioning that the approach used for the analysis of different economic evaluation methods should not and cannot replace the human ability to analyse complex situations, but the proposed approach can be valid to structure and communicate the information needed to choose one method over the other. The combination of this approach with others, such as guidelines and frameworks, should provide a flexible support system to improve the design and implementation of future ecosystem service evaluations and related decision-making.

Supplementary Materials

Supplementary material is available at Forest Science online.

Conflicts of Interest

The authors declare no conflicts of interest.

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Appendix A

Link to view training and test datasets for each method: Bruzzese *et al.* 2023.

6. Discussion and Conclusions

Forests, with their products and services, offer various benefits to humankind (Millennium Ecosystem Assessment, 2005). The benefit derived from an ES, however, can only be perceived through interaction with people, their artifacts, and, more broadly, the community. In other words, as stated by Costanza (2020), the relative contribution of natural capital to human well-being occurs exclusively through interaction with the economy (i.e., human and built capital) and society (i.e., social capital). If either of these elements is absent, no benefit can be claimed. Consider, for instance, the protective role of a forest against a natural disturbance such as rockfall. If this forest is located upstream of a settlement, its benefit and role in the liveability of the area become evident, termed as protection against a natural risk. Conversely, in the absence of the human component, the benefit remains imperceptible, defining the disturbance as a natural hazard.

To quantify the relative contribution of natural capital to human well-being, its assessment is crucial and can be done in various ways, using different units of reference (e.g., currency, area, time). Whenever decisions involving choices must be made, as argued by Farber *et al.* (2002), an evaluation, explicit or implicit, is inevitable. Consider again, for example, the forest protecting the settlement and the local administration's decision to retain or remove it for a public project. In this case, the decision involving a trade-off concerning the ecosystem and its services is already inherently assigning a value to it. The problem lies in the fact that this valuation is often implicit in the decision-making process and not visible to the outside world. Therefore, as highlighted by Costanza *et al.* (2014), enhancing transparency in the evaluation process is crucial, making it explicit and providing tools, models, and guidelines to make informed and high-quality decisions.

In this context, economic evaluation is well-suited as it is comparable to the anthropic capital, which is built (also expressed in monetary terms) and more easily understood by society. Among the tools that policymakers can use to safeguard natural capital and promote the supply of ESs are MBIs. As reported by Sattler *et al.* (2013), MBIs have been developed as complements or even substitutes for traditional Command And Control instruments, which are more intrusive into the personal sphere and imposed with a top-down approach, when inappropriate and infeasible.

In light of these considerations, below are the main findings of the three articles that make up this thesis, which answer the initial research questions, namely:

1. RQ1) Which MBIs are most widely used today for the valuation of FES, and how are they structured?

PES or PES-like schemes appear to be the most widespread forest MBIs, followed by incentives (e.g., green payments and subsidies), and tradable certificates. Several factors contribute to this prevalence, including the growing market interest in this

instrument in recent decades, as advocated by Parajuli *et al.* (2020). The emphasis on forest conservation and deforestation reduction, as reported by Alston *et al.* (2013), along with its cost-effectiveness and versatility compared to other instruments, supported by various authors including Wunder (2005) and Pagiola & Platais (2002), contributes to its popularity. Additionally, its initial implementation within national subsidy programs, as seen in Costa Rica, the United States, and Vietnam, where mass diffusion ensued, further explains its widespread adoption. The ambiguous use of its definition, which includes other forms of economic incentives, also contributes to its popularity.

Geographically, Europe emerges as the most represented continent, with several countries engaging in PES followed by America. However, in terms of quantitative measures, specifically scientific publications, Asia, notably Vietnam, surpasses others, followed by America. These findings, mainly centred on PES schemes, appear partially contradictory to Wunder *et al.* (2020) report, which identifies America and China as the primary areas of diffusion. This disparity may be due to the thesis's focus on forest MBIs, specifically PES, as opposed to a broader interpretation used by other authors. Additionally, the restriction to English-language articles during the selection process may exclude relevant literature in Chinese (China) and Spanish (South America).

The widespread distribution in Europe, as suggested by Winckel *et al.* (2022), could be a crucial step towards a continental PES system contributing to a potential integrated approach in the future governance and forest policy of the EU. Most PES or PES-like schemes analysed in the thesis are implemented on local spatial scales. This could be attributed to factors such as the involvement of local actors and communities with better knowledge of the implementation area, potentially reducing informational asymmetry and transaction costs (contact, contract, and control) compared to larger spatial scales. This aligns with Coase's seminal work (1960) and subsequent contributions, including that of Bork & Hirokawa (2021).

At the same time, the most common configuration of stakeholder involves the buyer, the supplier, and the intermediary. The intermediary may be a fund financing the PES scheme, as seen in former subsidy-based programs (e.g., Fondo Nacional de Financiamiento Forestal in Costa Rica), a regulator (e.g., the State) ensuring the proper functioning of the scheme, tradable certificate, or a financial instrument. This is particularly relevant for PES schemes underlying ESs with effects extending beyond the production area (e.g., carbon sequestration, water regulation), potentially involving broader societal concerns about property rights.

The Pigouvian PES scheme, involving the State, as advocated by Thompson (2021), is the most adopted compared to the Coasean approach. This choice facilitates the expansion of the spatial scale of adoption. Finally, it is noteworthy that most of the PES schemes analysed were designed only at the theoretical level, with implementation challenges, as highlighted by Chan *et al.* (2017).

2. RQ2) What elements can determine the success or failure of a PES scheme in developed economies?

One of the key elements contributing to the success of a PES scheme is additionality, meaning the improvement of ES provision compared to the baseline situation following its implementation. In order to achieve this, Martin Persson & Alpízar (2013) developed a classification to assess the level of pre-additionality of an area, determining its potential to be part of a PES scheme. This helps mitigate opportunistic behaviours, such as adverse selection, where a landowner already meets the required conditions for ESs provision (i.e., no additionality and zero opportunity costs) but still requires payment, or moral hazard, where the conditions are not met, there is no intention to do so, but payment is still demanded (i.e., free-riding), as reported by Gómez-Limón *et al.* (2019).
One of the factors that contribute significantly to pre-additionality is spatial targeting, as highlighted by Wunder *et al.* (2020), particularly in the case of PES schemes intended for European implementation, as reported by Winkel *et al.* (2022). Spatial targeting implies the selection of areas with a high supply of ESs and/or biodiversity, areas under significant threat and/or degradation (e.g., deforested areas) or, ideally, areas experiencing both situations, as greater additionality can be achieved. In the Croatian case study analysed, the chosen area for PES implementation is a natural park, characterized by high conservation value and a strong societal demand for ES. Another crucial element for the success of a PES scheme is the accurate definition, quantification, assessment, and accounting of its underlying ES. As emphasized by Naeem *et al.* (2015), many PES schemes present poorly defined ESs or rarely verified additionality conditions. Cultural services, for instance, as in the Croatian case, are difficult to quantify due to their intangible nature, variable perception among individuals and changing values over time, as reported by several authors (Tew et al., 2019; Gould et al., 2018; Willcock et al., 2017). In this context, the importance of post-implementation monitoring of the actual provision of ES and potential sanctions for non-compliance becomes evident, as reported by Kerr *et al.* (2014). Clear property rights among involved stakeholders are also fundamental for the success of a PES scheme, particularly in the case of Coasean PES schemes, as emerged in the case study of this thesis. Some authors, such as Kaiser *et al.* (2023), Kaczan *et al.* (2017), and Engel (2016), argue that collective PES, involving communities or groups instead of individual landowners, can enhance the performance of schemes and address conflicts over property rights, as benefits are distributed more equally within the group. However, collective schemes may introduce other challenges, such as free-riding. Segerson (2022) and Naime *et al.* (2022) propose various solutions, each with different transaction costs, including public monitoring, external sanctions (e.g., governmental), or internal mechanisms such as peer sanctions or rewards and, in extreme cases, the threat of exclusion from the scheme. Diversifying payments

based on environmental, social, and economic characteristics contributes to a fairer distribution of benefits, better budget management, and increased participation in the scheme, as advocated by Engel (2016). This approach helps to reduce informational asymmetry issues, such as adverse selection and moral hazard, especially in areas with varying costs of ES provision. Incentives for spatial coordination aim to enhance the efficiency, success, and participation rates of programmes. Some examples, as reported by Nguyen *et al.* (2022), include agglomeration bonuses if an individual chooses an adjacent area already included in the scheme, threshold bonuses if a predetermined threshold is reached by the group, and threshold payments, in which payment is conditional on reaching specific requirements. The awareness of society regarding ES and their role is also crucial for the success of the scheme. Workshops and similar initiatives have been undertaken in this regard. If society perceives ESs as free and is unwilling to pay for their optimal provision, the PES scheme is likely to fail. A frequently overlooked aspect, that is difficult to evaluate in the short term, is the assessment of the long-term environmental and economic performance effects of participants' practices, termed eco-efficiency by some authors (Ait Sidhoum et al., 2023; Grovermann et al., 2019; Urdiales et al., 2016). In the Croatian case study, this assessment was not possible due to the absence of a counterfactual. However, evaluating impacts poses challenges, as issues of permanence may arise, as reported by Rasch *et al.* (2021) where the cessation of program payments may lead to the discontinuation of certain sustainable management practices, casting uncertainty on whether program effects will persist post-program. At the same time, as reported by different authors (Garrett et al. 2022; Wunder et al. 2020; Pfaff & Robalino, 2017) during the impact evaluation, spillover effects may occur, such as in the case of leakage, where the impacts of the PES scheme can extend beyond its implementation area, or effects due to income variations like the rebound effect, where an increase in the net income of scheme participants leads to increased expenses and consumption, and the magnet effect that can attract immigration due to the increase in social well-being. In the latter two cases, this occurs mainly with the construction of assets, as reported by Wunder *et al.* (2020), such as in the case of new plantations and/or reforestation, and not with the adoption of conservative practices, as in the Croatian case, which may be more prone to leakage issues.

3. RQ3) Which monetary economic method is best suited, in terms of risk analysis and decision support, to evaluate forest protection service?

Schild *et al.* (2018) argue that the choice of the monetary economic evaluation method primarily depends on the analysed ecosystem and the selected service. In the case study of the thesis, methods identified from the literature review by Bianchi *et al.* (2018) were employed for mountain forests and the service of protection against gravitational natural hazards. The results indicate that there is no

one-size-fits-all method, but this depends on the decision-maker's needs and budget, as well as the site conditions, as noted in the Forest Europe (2019) report. Additionally, considerations by Costanza *et al.* (2017) highlight the importance of the evaluation purpose, which ranges from simple information and awareness creation, as in the thesis, to the formulation of tailored policies, green accounting plans, and economic or financial instruments such as PES and common asset trusts.
Another crucial aspect involves marginality, as discussed by Bartkovski & Massenberg (2023), emphasising that economic valuation makes sense for small variations in the quality and quantity of the evaluated ES. In the thesis, the choice of the protection service stems from the increasing role of forests in safeguarding mountainous territories, especially in light of the climate crisis and the heightened occurrence and intensity of natural disturbances, as highlighted by Summers *et al.* (2022). The economic valuation of ESs requires caution against double counting, as indicated by various authors (Enríquez-de-Salamanca, 2023; Wang and Hayashi, 2023), since some services may preclude the provision of others, introducing uncertainty and low reliability in aggregated values.
It is also important consider the spatial scale at which the ES is produced and used and its impact on the interests of stakeholders at different scales, as argued by Wang *et al.* (2022) and Hein *et al.* (2006). Temporal scale plays a crucial role in the evaluation, as emphasised by Hein *et al.* (2016), given that ecosystem impacts resulting from a choice can extend over the long term. Therefore, selecting an appropriate discount rate becomes paramount for comparing all costs and benefits to present value with other choices.
As the purpose of the case study was to provide information and support to decision-makers, an attempt was made to develop a simple and easily communicable methodological framework. A transparent predictive model was therefor used in the processing from input to output, i.e., a white-box model, in line with Harrison *et al.* (2018).

Turning now to the final notes, the main general limitations of this thesis concern the consideration of only the *instrumental* value of the forest ecosystem, that is, the value to achieve a desired objective. This approach neglects the relational value arising from human-nature interaction and the intrinsic value inherent in the ecosystem itself, which is independent of human evaluation. Secondly, the thesis only considers a set of values based on economic efficiency and individualistic preferences (i.e., *homo economicus*) and the determination of willingness to pay, overlooking values related to fairness involving the entire community (i.e., *homo communicus*), using methods like the veil of ignorance, and sustainability that encompasses the entire ecological system (i.e., *homo naturalis*) using modelling systems. In both limitations, a future development could be integrated and participatory evaluation involving various stakeholders, sets of values, and investigation techniques.

Other future developments specific for the presented articles include, in the first study, extending the systematic review to include other economic incentives for FES, such as corporate social responsibility, insurance risk premiums, value chain labels, and liability fees, as proposed in a work by Wunder *et al.* (2023) on wildfire risk reduction. In the second study, applying the methodological framework in other contexts to create a comparative database and provide guidelines and reports on lessons learnt. In addition, conducting longitudinal studies on specific case studies to monitor the status of the scheme over time and potentially take corrective actions to promote its success. In the third study, extending the methodological framework to other economic evaluation methods, as proposed in the systematic review by Selivanov & Hlaváčková (2021), and subsequently replicating the methodology for other ESs.

In conclusion, the thesis has contributed to advancing knowledge on the economic evaluation of FES and the use of MBIs for the valorisation and conservation of forest ecosystems. It aimed to demonstrate the importance of FES for the, as coined by Elkington, triple bottom line – profit, people, and the planet – and the significance of internalising their value in the market and decision-making processes for proper consideration. Ultimately, the thesis sought to provide tools, insights, and approaches for decision-makers, technicians, and researchers interested in designing, implementing, and evaluating MBIs, specifically PES, for forest ecosystem services.

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