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Designing a Sustainability Assessment approach for the provision of Forest Ecosystem Services

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Ang mga batang ngayon lang isinilang
May hangin pa kayang matitikman?
May mga puno pa kaya silang aakyatin?
May mga ilog pa kayang lalanguyan?
Bakit ‘di natin pag-isipan
Ang mangyayari sa ating kapaligiran?
Hindi nga masama ang pag-unlad
Kung hindi nakakasira ng kalikasan

(Asin, 1994, stanza 2)

The newly born children
Will they still have air to breathe?
Will they still have trees to climb?
Will they have rivers to swim?
Why don’t we think about
What will happen to our surroundings?
There is nothing wrong with progress
As long as it doesn’t destroy the environment

Translation by Gino Garcia

Abstract

Forests offer a wide range of goods and services that are essential to human well-being and society. Given that forests are degrading at an alarming rate worldwide, its sustainable management remains a subject of ongoing debate. Meanwhile, sustainability assessments are meant to support decision-makers in making sustainable choices. However, few studies have been done in integrating the ecosystem services concept as a means to communicate the importance of forests in sustainability assessments. This dissertation successively develops a sustainability assessment approach for forests in four articles. The first article is a conflict analysis that investigates stakeholders' competing interests for forest resources. The second article is a literature review that looks into the extent to which the ecosystem services concept has been used for sustainability assessments applied to forest ecosystems in peer-reviewed scientific articles. The third article explores how market-based instruments, particularly payments-for-ecosystem services (PES), are utilized in the European Green Deal as a means to address market failure. The last article is a literature review that assesses how the transdisciplinary approach is used in Biosphere Reserves, as model regions for sustainable development, in the Global South. The findings are then synthesized into a sustainability assessment methodology for forest ecosystems. This methodology follows a nested systems approach and recommends prioritizing forest health and functioning to improve the delivery of ecosystem services, employing participatory and transdisciplinary approaches in forest management, and utilizing payments-for-ecosystem services to address market failure towards regulating and cultural ecosystem services.

Graphical abstract

Category	Focus	Article 1	2	3	4
Sustainability dimension	Environmental	🌳	🌳		
	Social	🌳	🌳		🌳
	Economic	🌳	🌳	🌳	
Approach	Conflict analysis	🌳			
	Literature review		🌳		🌳
	Policy analysis			🌳	
Scale	National	🌳			
	Regional			🌳	
	Global		🌳		🌳
Target	Forests	🌳	🌳		
	Ecosystems			🌳	
	Biosphere reserves				🌳

1 A conflict analysis on Forest Ecosystem Services supply in Germany - the case of biofuel production
2 A Systematic Literature Review on Sustainability Assessments for Forestry
3 Market-based instruments, ecosystems, and the European Green Deal: a cross-sector policy analysis
4 Transnational networks and transdisciplinary education in Biosphere Reserves in the Global South

Template: Simplified Science Publishing

Icon: Freepik

Structure

1. Introduction

Forests cover over 30% of the Earth's landmass (FAO, 2020) and offer a wide range of ecosystem goods and services that are essential for the well-being of society (Daily, 1997). Continued deforestation and forest degradation worldwide is a pressing concern, which has been largely attributed to human activities such as agriculture (Hosonuma et al., 2012) and timber harvesting (C. L. C. Liu et al., 2018), among others. Meanwhile, sustainable development, which is anchored on the balance between the social, economic, and environmental dimensions, has been increasingly institutionalized worldwide since the 1992 Earth Summit in Rio (Purvis et al., 2019). With the Paris Agreement, forests continue to be in the forefront of sustainability due to their natural potential to contribute to climate mitigation (Griscom et al., 2017). However, as it is, the concept of sustainability remains open to interpretation and therefore renders it vulnerable to misuse (Ove Tøllefsen, 2021). This has been observed in forestry as various forest users have differentiated perspectives on what sustainability is and what it implies (Rosenkranz et al., 2017). This is also apparent with the Sustainable Development Goals (SDGs). Since 2015, the SDGs have been at the forefront of promoting sustainable development globally. However, their implementation has continued to lead to economic growth at the expense of the environment (Hametner, 2022), which demonstrates a continued lack of prioritization for the environmental dimension.

Sustainable development requires the participation of various sectors of society in order to reach its objective of transforming our world ("Engaging Stakeholders for Sustainable Development," 2016, pp. 335–342). As the concept continues to be mainstreamed, various tools have been developed in order to guide stakeholders in gauging whether their respective activities are, in fact, sustainable. Examples include the life cycle assessment, environmental impact assessment, vulnerability analysis, and ecological footprint, among others. However, these tools or methodologies can be categorized under the umbrella term "sustainability assessment". A sustainability assessment can be any process that guides decision-makers to make more sustainable decisions (Bond & Morrison-Saunders, 2011). These processes encompass a wide range of methodologies from environmental impact assessments to multi-criteria analysis (Ness et al., 2007; Singh et al., 2009). Many of these methods have been in use in a wide range of industries for a number of decades already and it has been suggested by Geneletti et al. (2015, pp. 215-232) that including an ecosystem services lens to sustainability assessments could render them more useful. Doing so would make the contribution of ecosystems to human well-being more apparent, though the mainstreaming of such an innovation will likely take time.

In this dissertation, a sustainability assessment is proposed specifically designed for the provision of ecosystem services offered by forests. There is an emphasis on the wide range of forest ecosystem services (FES), that is to say that this design goes beyond wood provision and the associated timber industry. Importance is given to other ecosystem services that have the character of public goods in recognition of their significance for human well-being and society. These include regulating services, e.g. water and air regulation, cultural services, e.g. landscape aesthetics, and supporting services, e.g. nutrient cycling. Furthermore, each dimension of sustainability is addressed thoroughly and is synthesized resulting in a more systemic or holistic approach.

The objective of this dissertation to design a forest-specific sustainability assessment approach is tackled through the accumulation of four research articles. The first article uses the ecosystem services concept and is an ex-ante investigation on the potential conflicts that could arise between distinct forest users/stakeholders given a theoretical increase in forest biomass extraction in Germany. The second article is a systematic literature review that shows how the ecosystem services concept is used in peer-reviewed articles on forest sustainability assessments. The third article looks into the extent that Market-based instruments (MBIs) and Payments for Ecosystem Services (PES) are used in the European Green Deal. Finally, the fourth article is a systematic literature review that focuses on Biosphere Reserves (BRs) as model regions for sustainable development in the global south on using a transdisciplinary approach to education.

In the synthesis part of this framework paper, the results shall be presented as a novel design for a forest sustainability assessment with the main objective of improving the long-term provision of the wide range of forest ecosystem services to society. The four research questions addressed are as follows:

1. What type of conflicts between actor groups can be identified in Germany regarding the provision of forest ecosystem services?
2. What is the current state for implementing a Sustainability Assessment in forestry?
3. How can Payment for Ecosystem Services (PES) innovations contribute to the sustainable supply of (non-timber) forest ecosystem services?
4. To what extent are transdisciplinary approaches being used in Biosphere Reserves (BRs), as model regions for sustainable development, in the Global South?

1.1. What is sustainability anyway?

The concept of sustainability emerged in the field of forestry in Germany in the 18th century, referring at the time to the assurance of timber availability for future generations (Hölzl, 2010). Today, the term is commonly used in the context of sustainable development, which is a concept that gained popularity with the Brundtland Commission Report in 1987 and continued with the Rio

Earth Summit in 1992 (Mensah, 2019). There is a plethora of definitions offered by various sources with the most prominent being that of the aforementioned Brundtland Report, which defines sustainable development as “development that meets the needs of the present without compromising the ability of future generations to meet their own needs” (1987, p. 41).

It has also become commonplace to define sustainability as having three dimensions - social, economic and environmental (Purvis et al., 2019). Though there are varying interpretations regarding the relationship of each dimension to each other, the general idea is that finding a balance between all three will result in sustainability (Pryn et al., 2015). This line of thinking is subscribed by institutions worldwide, for example, the European Union as it acknowledges that it aims to balance all three in all its policies (European Union, 2025). There is, however, much criticism regarding the lack of clarity as to how to operationalize this type of definition as it is open to interpretation (Pryn et al., 2015; Purvis et al., 2019). Even the Brundtland Report acknowledges that the interpretation of this definition will largely depend on the background of each country (Brundtland, 1987, p.124).

An argument can be made for the prioritization of the environmental dimension in sustainability discourse. Sustainable development is inherently dependent upon ecosystems to deliver goods and services, and the limitations of these ecosystems must be recognized and be taken into account in planning (Daly, 1990; Folke et al., 2002). This concept of ecological limitations or carrying capacity was quantified by Rockström et al. (2009) in their seminal work about Planetary Boundaries, where they delineate “a safe operating space for humanity” within which the Earth’s condition can still support society as we know it. Among the nine factors defined by Rockström et al. (2009), Earth is already operating beyond the limits of six of them (Richardson et al., 2023).

The openness to interpretation of sustainability and the lack of prioritization of the environmental dimension signify a slew of challenges in implementing sustainable development that must be acknowledged. One issue is conflict between sustainability dimensions. Sustainability goals can best be achieved through the participation of all nations and sectors of society. Projects aiming for sustainable development typically involve various stakeholders who have their respective interests, which possibly conflict with one another, and managing these conflicts is key to achieving sustainability goals (Bahadorestani et al., 2020). Conflicts that are left unaddressed can lead to disenfranchisement and a lack of buy-in from disadvantaged parties, and therefore have the potential to derail sustainable development. Another issue that requires attention is governance. The nuanced implementation of sustainability across multiple policy sectors and administrative levels brings its own complex challenges that require innovation (London International Development Centre (LIDC) et al., 2015, p. 86). Many sectoral goals often conflict with one another, for example economic growth and nature conservation, and their resolution key to bringing sustainable development forward. Then there is the topic of inequality, which can be illustrated on a global scale through the economic disparity between the global North and South, as an example. The global North has appropriated billions in raw material equivalents for several decades from the global South, signifying a gross unequal exchange, even when accounting for foreign aid, that has led to environmental degradation and uneven development (Hickel et al., 2022) This inequality is detrimental to sustainable development in the global South. Sustainable development relies on the maintenance of natural resources for future generations (Costanza & Daly, 1992). These topics show the complexity of the topic of sustainability or sustainable development, which this dissertation attempts to articulate for forest ecosystems.

This dissertation frames forest ecosystems as social-ecological systems (SES). SES analysis acknowledges that the interaction between ecosystems and human society is riddled with complexity and requires critical analysis and dynamic problem solving that adapts to the situation at hand, i.e. non-static (Ostrom, 2007). That said, another foundation of this work is the nested dimensions approach to sustainable development as illustrated by figure 1. This illustrates the three sustainability dimensions as a nested system wherein ecosystems, through its delivery of ecosystem goods and services, make it possible for society to exist, and the economy being a subset of society (Ibisch et al., 2018). Building on these two central concepts, I have designed a sustainability assessment that prioritizes ecosystems, but does not ignore socio-economic factors in sustainable development. I use the ecosystem services concept to communicate that ecosystems are the foundation to sustainability, which benefits society and the economy in the long-term.

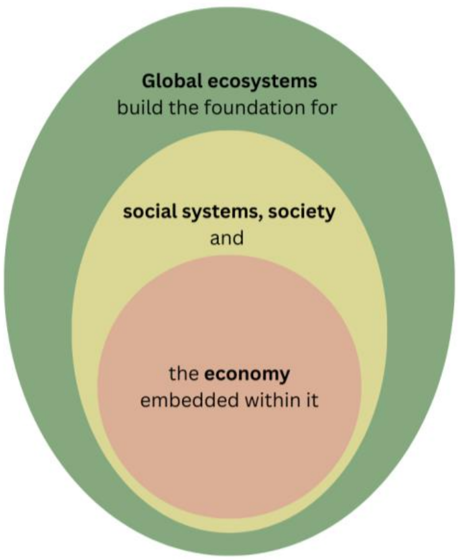

Figure 1. Three dimensions of sustainable development presented as a nested system from Ibisch et al. (2018)

More recently, sustainable development has been further elaborated through the SDGs. The SDGs consist of 17 goals that address a wide range of topics, and give a comprehensive view of what each nation needs focus on by 2030 in order to achieve sustainable development (United Nations, 2015). They range from quality education, gender equality, economic growth, life on land, among others. The implementation of the SDGs calls for a holistic approach, promoting the 17 goals as an interconnected bundle, but countries are allowed to set priorities according to their respective national context. This means that nations have a free hand in deciding which issues they would focus on, which could mean economic development over the environmental protection for certain countries. It is for this reason that the SDGs do not fit into this dissertation. I argue that regardless of national context, a prioritization of the environmental dimension, specifically ecosystems, as a foundation for sustainable development would best serve local and global populations in the long run. Nonetheless, the proposed sustainability assessment approach is holistic in the sense that it acknowledges the complex facets of forests and society's dependence on them.

1.2. Forests and their ecosystem goods and services

Forests offer a wide range of (forest) ecosystem services (FES) that are essential for human well-being (Millennium Ecosystem Assessment (Program), 2005). Three prominent ES classification systems exist, Millennium Ecosystem Assessment (MA), the Economics of Ecosystems and Biodiversity (TEEB), and the Common International Classification of Ecosystem Services (CICES) system. They commonly categorize FES as provisioning, regulating, or cultural. Provisioning FES are material outputs from forest ecosystems such as fuelwood, water, or raw materials. Regulating FES are the benefits from forests regulating natural processes such as water regulation, air purification or climate regulation through carbon stocks. Cultural FES are non-material benefits from forests such as spiritual experience, recreation, or aesthetic values. Figure 2 shows examples of FES from each of these three categories. A fourth category exists in the MA system - supporting FES. These refer to processes that make other FES possible namely nutrient cycling and primary production. The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) has its own system called Nature's Contributions to People (NCP). It is rooted in the MA system but envisioned be adaptable to include indigenous peoples' perspectives and includes not only the positive but also the negative contributions of ecosystems to society (IPBES, 2017).

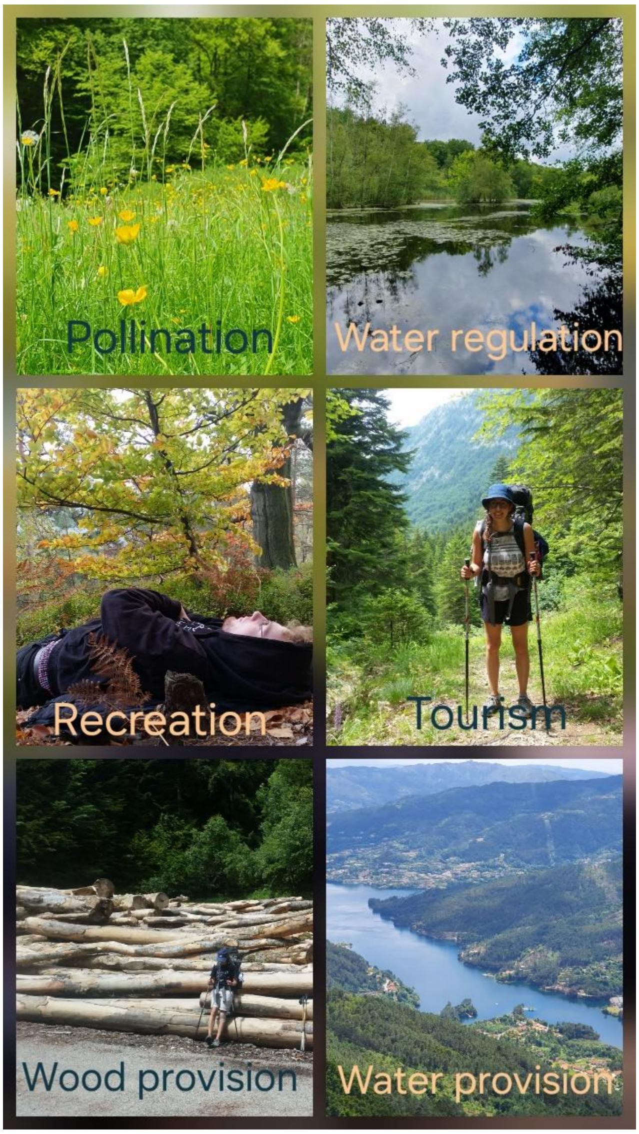

Figure 2. Examples of Forest Ecosystem Services. Photos by Gino Garcia.

The sustainable management of forests will influence the provision of forest goods and services to society and will therefore have a role in how forests are able to meet global demand for resources in the future (Payn et al., 2015). However, the provision of the wide range of FES comes with several challenges, one of note being market failure. Many FES have the character of public goods (Nichiforel et al., 2018), which means that access cannot be controlled, no property rights assigned and hence no economic values determined. This leads to market failure and, as a result, to resource overuse and degradation. This lack of economic incentive for certain services contributes to difficulties in forest management and leads to deforestation (Bulte & Engel, 2007). One prominent example of this is cultural FES. Societal demands for cultural FES are often inadequately addressed in forest management decisions (Torralba et al., 2020).

There is empirical evidence, however, that shows how impactful non-marketable FES are to human well-being. For example, on the topic of climate change, the concentration of CO_2 in the atmosphere continues to increase (Friedlingstein et al., 2023). Forests, with their natural ability to store carbon through photosynthesis, are in the forefront of public debate and are seen as a solution as global temperatures continue to increase. Biodiversity also contributes to this as it enhances overall ecosystem functioning including carbon storage (Poorter et al., 2015). Water regulation, meanwhile, is also coming into focus. Climate change has led to increased precipitation in certain areas in the world (Donat et al., 2016). Forests, through regulation of water flows, offer protection that would lessen the risks of flooding and therefore will contribute to human well-being (Bradshaw et al., 2007).

Designing policies that focus on the provision of the wide range of ecosystem services, i.e. beyond wood provisioning such as carbon sequestration, recreation, and biodiversity, could lead to more benefits for land managers and society (Bateman et al., 2013). In line with this, this dissertation aims to foster a more holistic perspective to forest management by focusing on the provision of the wider range of ES provided by forest ecosystems, with a focus on regulating and cultural FES.

1.3. Sustainability Assessments

There are a number of scholars that have brought forth their respective definitions for sustainability assessment. Devuyst (2001, p.176) define it as “a formal process of identifying, predicting, and evaluating the potential impacts of a wide range of relevant initiatives (such as legislation, regulations, policies, plans, programs, and specific projects) and their alternatives on the sustainable development of society”. This definition already implies the complexity that such an assessment entails. Sala, et al. (2015) more directly state that sustainability assessment is one of the most intricate methods of appraisal, encompassing the three dimensions of sustainability as well as other elements, but notably, it should involve stakeholder participation. Shortall, et al. (2015), meanwhile state that sustainability assessments inform which strategies or actions are to be taken for sustainable development while taking into account social, economic, and ecological factors. As it is, the lack of a standardized definition leaves things quite open to interpretation and opens a wide range of possibilities for implementation. Ness et al. (2007) show that there is a plethora of methodologies that can be considered sustainability assessments. A few examples include ecological footprint, life cycle assessment, risk analysis, and environmental impact assessment to name a few.

Embracing the lack consensus, for this dissertation, I have decided to use the definition proposed by Bond & Morrison-Saunders as it is the most suitable for the purpose of this dissertation. They state that any process that guides decision-makers to make sustainable decisions can be considered a sustainability assessment (Bond & Morrison-Saunders, 2011). Though no standard procedure currently exists, Morrison-Saunders & Pope (2013) have outlined the fundamental steps that appear in most sustainability assessments. The eight generic steps are illustrated in figure 3. The first step is simply deciding to do a sustainability assessment. The second step pertains to the definition of which level of management the assessment will apply. Third, the sustainability goals and criteria for decision-making should be established. Fourth, the development options need to be identified. Fifth, there needs to be a predictive evaluation of the impact of each development option. Sixth, a decision is to be made as to which option will be implemented, which should then be enhanced. Seventh, the decision should be formally approved and announced to all parties concerned. Finally, the development can start and should be monitored.

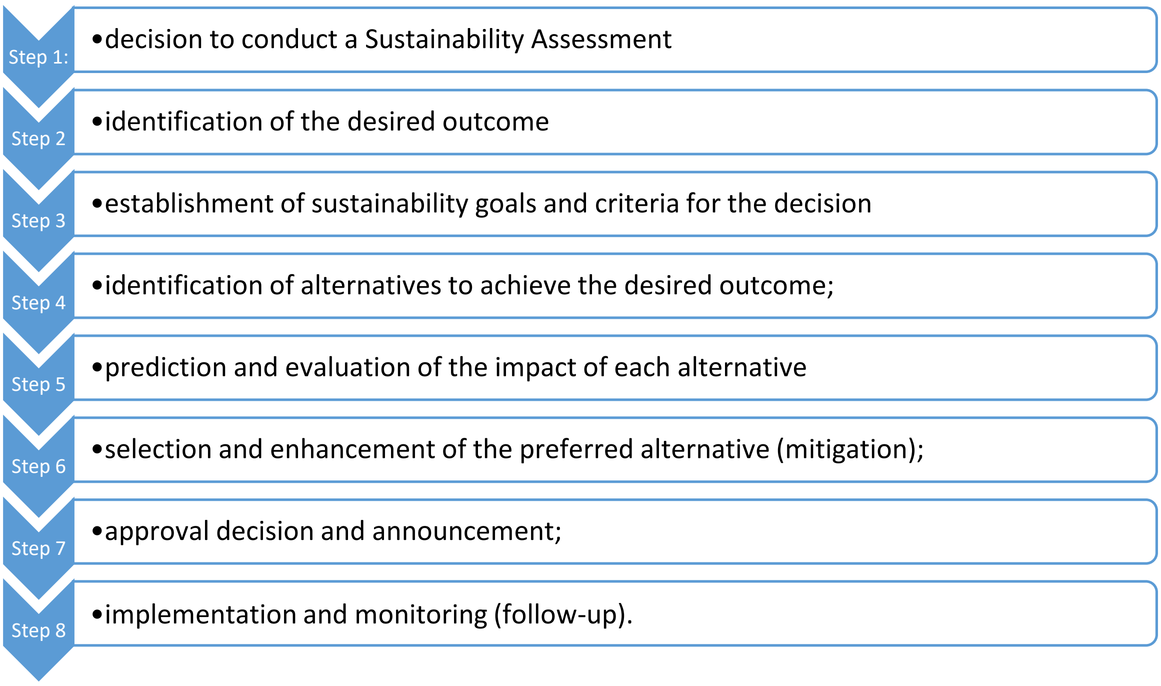

Figure 3. Basic steps for a sustainability assessment (Morrison-Saunders & Pope, 2013)

The outlined steps are generic in nature, with each step being open to interpretation. In practical application, the nuances of each step would depend on the framework conditions under which decision-makers operate, for example the availability of resources to even conduct an assessment. For forestry, there are numerous assessment methodologies that could be applied depending on the sustainability goals and outcomes desired (Ness et al., 2007; Singh et al., 2009). However, the deliberate focus on the provision of ecosystem services as a fundamental objective for natural resources management, including forests, could be transformative as it allows decision-makers to perceive the implications and trade-offs of proposed management plans (Geneletti et al., 2015, p. 228).

1.4. Research design of the dissertation

This dissertation aims to design a sustainability assessment for the provision of the wide range of ecosystem services from forests. Four scientific articles were written, with each one focusing on one dimension of sustainability, albeit non-exclusively. The recognition of the interconnectedness of each dimension to each other is integral part of the design.

The first article is a proposed design for a conflict analysis approach developed within the context of using forest biomass for biofuel in Germany**.** It scans the forest stakeholder landscape, focusing on various demands for various FES. A scenario methodology was used in order to provoke workshop participants and induce innovative discussions among them. The primary focus of this article is the social dimension of sustainability as it deals mostly with the challenges between stakeholder cooperation, but also the opportunities for cooperation. It further delves into the topic of FES provision the foundation for stakeholder demand recognizing that ecosystem functioning as crucial. Businesses dependent on FES provisioning were also involved in the paper. Thus, the economic dimension was also brought to the forefront most notably on discussions regarding PES.

The second article is a systematic literature review of peer-reviewed scientific publications on sustainability assessments applied to forests worldwide. It shows which forest ecosystem services are addressed, but also takes into account other indicators deemed as essential in their respective sustainability contexts. The environmental dimension of sustainability is focused upon in this article, as the indicator analysis revealed that FES and other biophysical factors accounted for more than half of all indicators in the review. However, economic indicators pertaining to multiple forest-related industries, such as tourism and timber, were included. The social dimension includes societal demand for FES and stakeholder collaboration.

The third article is a policy analysis of the European Green Deal investigating which market-based instruments (MBI) have a tangible connection to ecosystems**.** It identifies cross-sectoral policies that fall under the definition of MBIs and then focuses in on the state of Payments for Ecosystem Services (PES) in the Green Deal. The primary focus here is the economic dimension with the topic of PES. The analysis of sectoral policy documents brought into light the environmental dimension as the extent to which ecosystems are being directly targeted in Green Deal policies is shown.

Finally, the fourth article is an investigation on BRs in the Global South. It is a systematic literature review where we sought to determine transnational networking between and the extent to which transdisciplinary approaches are used in BRs. BRs are meant to be model regions for sustainable development, thus all three dimensions here are relevant. The analysis of how much awareness about BRs through education in BRs is tackled. Furthermore, the extent to which a transdisciplinary approach is done.

2. Scientific articles

2.1. Article 1

An integrated conflict analysis approach for the sustainable supply

of Forest Ecosystem Services in Germany –

the case of forest-based biofuel production

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An integrated conflict analysis approach for the sustainable supply of Forest Ecosystem Services in Germany - the case of forest-based biofuel production

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ABSTRACT

The increased harvesting of forest biomass for biofuel production in Germany could lead to trade-offs in the provision of forest ecosystem services (FES). The potential conflicts between already existing forest users and proponents of biofuels from forest biomass are insufficiently investigated. In this paper, we propose an innovative step-wise methodology for analysing the conflicts that could arise due to a foreseen increase in scarcity of various forest goods and services, as well as formulating sustainable conflict management strategies. Based on a mixed study design for triangulation, we carried out twelve expert interviews, two workshops and three focus group discussions in order to assess potential conflicts and to deepen strategies to deal with them. We found that most of our participants were against the prospect of using forest biomass for biofuel production partially due to possible negative consequences for biodiversity, climate regulation, and other FES. Study participants also asserted that there is a lack of information regarding the claimed benefits from biofuels from forest biomass. Participative processes, market-based instruments, and policy harmonization are strategies proposed to alleviate conflicts among forest users. Our insights could help the forest policy decision-making process by increasing transparency regarding possible trade-offs and strategies, which could improve sustainability in forest management.

1. Introduction

Forests provide a range of (forest) ecosystem services (FES) that are essential for human well-being (Millennium Ecosystem Assessment (Program), 2005). They regulate the climate, water and air, while also acting as a biodiversity repository. In addition to providing a plethora of raw materials such as wood, food and fodder, they also offer a range of cultural services such as spaces for spiritual and cultural interaction with nature, recreation and sports. The provision of these forest functions and associated goods and services have become so essential in forest policy and management that harnessing forests is seen as a modern solution for tackling climate change (Sedjo and Sohngen, 2012), biodiversity loss (Lippe et al., 2021), and fostering cultural development (Agnoletti and Santoro, 2015; Marini Govigli and Bruzzese, 2023).

Germany has a total national area of 35.7 million hectares of which 11.4 million, or 32 %, are officially recognized as forested areas (BMEL, 2016). These forests offer a wide range of FES. For example, they contribute significantly to regulating the climate through carbon storage. About 2.6 billion tons of carbon are being stored in German forests as living biomass, dead wood or within the ground (BMEL, 2021). Each year it is estimated that the living biomass carbon stocks in Germany's forests increase about 1.0 t C ha^{-1} yr^{-1} (Wellbrock et al., 2017), which forms an integral part of the country's federal climate change mitigation strategy (Federal Climate Change Act, 2019). Forests in Germany are also recognized as the most important ecosystem for biodiversity conservation. One can find 76 tree species, over 100 shrub species, around 1000 herbaceous plant species (BMEL, 2017), with an estimated 7000 species of fauna residing in local deciduous forests alone (NABU, 2023). Over 40 % of all protected water areas in Germany are found in forests (BMEL, 2021).

Forests in Germany also offer several social benefits. For example, they significantly contribute to the economy of the country. About 39,000 people are directly employed in the forestry sector, which added € 1.2 billion in gross value to the Germany economy in 2020 (Eurostat, 2022). In 2022, the wood industry accounted for the employment of around 135,000 people which generated € 8.25 billion in gross value to the German economy (Statista, 2023). Forests further offer recreational opportunities for locals and vacationers as a place for leisure activities,

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such as mountain biking (Wilkes-Allemann et al., 2020), or to relax after work or for social gatherings (Bösch et al., 2018). It is estimated that 70 % of the German population visit a forest at least once a year for recreational purposes (BMEL, 2021). The importance of forests was highlighted during the covid-19 pandemic as visitor numbers increased for forest recreation in the country (Derks et al., 2020). Elsasser and Weller (2013) estimate the German public is willing to pay around 36.06 €/P/yr. to visit forests, which gives an aggregated value of around 1.9 bill. €/yr. for the whole population of Germany.

In the past decades, however, forest degradation has severely accelerated, affecting the sustainable provision of forest ecosystem services at a global scale (IPBES, 2019), as well as in Germany (BMEL, 2021; UBA, 2021). According to Germany's latest forest health survey ("Bundeswaldinventur"), several indicators show a rapid decline of forest health across the country, e.g. only 21 % of all trees show no crown thinning and the death rate of trees above 60 years of age has drastically increased (BMEL, 2022). The report highlights increased occurrences of drought, storms and pests as the main reasons behind this decline (BMEL, 2022). In line with this, it was found that more than 1200 forest fires occurred between 2018 and 2020 throughout the country (European Commission. Joint Research Centre, 2022), and bark beetle damage currently accounts for 81.4 % of all felling (Statistisches Bundesamt, 2022).

At the same time, Germany has been promoting a bioeconomy transition, i.e. using biological resources to provide products, processes, and services across diverse sectors of its economy. That forests have a vital role in the national bioeconomy strategy through its provision of biomass is readily acknowledged (The Federal Government, 2020). Partly as a reaction to the energy crisis, one of the emerging fields in Germany's bioeconomy strategy is the use of forest biomass for biofuel production for the transport sector. The argument has been made that biofuels generated from forest biomass could emit less greenhouse gases in comparison to fossil fuels, and would therefore be a viable fossil fuel substitute for the country's energy transition (Cowie et al., 2021). There are, however, established streams of forest goods and services uses with a range of interdependent stakeholders in Germany's forests. The assessment of the relationship between established and newly emerging demands for forest goods and services, in this case for biofuel production, might help forest policy and management to become aware of potential conflicts and trade-offs between FES uses and users (Gutsch et al., 2018a; Simons et al., 2021; Tiemann and Ring, 2018; Wang and Fu, 2013).

The number of conflict analysis approaches for forest resource uses is still limited. Typical conflicts that are found in forestry are between timber production and other ecosystem services (Blattert et al., 2023; Gamfeldt et al., 2013; Pohjanmies et al., 2017), in particular with biodiversity conservation (Edwards and Kleinschmit, 2013; Winkel and Sotirov, 2016), or timber production and recreation (e.g. Gundersen et al., 2019; Wilkes-Allemann et al., 2015). Moreover, few studies have examined the occurrence of conflicts among non-timber benefits from managed forests (Pohjanmies et al., 2017). In line with the concept of multi-functional forestry, we position three conflict lines between the ecological, economic and social forest functions at the outset of this research for further investigation: production vs. conservation, production vs. recreation, and conflict between different kinds of production.

First, the production function of forests can conflict with forest conservation efforts (Krumm et al., 2020). Services like timber production and harvesting eventually lead to a certain extent of forest degradation, which compromise forest conservation efforts. At the same time, society is dependent on forest provision services as the industries that need them provide significant economic gains and employment.

Second, the conflict between forest production and forest recreation stems from the significant increase in popularity of recreational use of forests in Germany (Mann and Absher, 2008). This encompasses activities such as hiking, mountain biking, dog walking and horse riding in the forest, among others. Recreational users of forests depend on the atmosphere that trees provide and so certain forest production activities that somewhat compromise the forest aesthetic, e.g. felling, the use of chainsaws, heavy machinery and infrastructural damages, are seen critically by recreational users (Nousiainen and Mola-Yudego, 2022). At the same time, forest managers may also see the drawbacks in allowing certain recreational uses in their areas for safety concerns as forestry activities can be hazardous (Bayne et al., 2022).

Third, there are various conflicts between different types of goods that emerge from forest production. Several industries within the forest production umbrella depend on the provision of raw materials from forests. Forest-based industries and the energy production sector, for example, have certain parallels but are also competing with each other for raw materials (Cazzaniga et al., 2019). Meanwhile, the conflict between forestry and the wood processing industry, in certain contexts, could be dictated by a mismatch between demand and supply of timber assortments and varying prices, among others (Marić et al., 2012). Further, wood pellets and wood chips are in competition with certain wood-based products e.g., wood panels and paper, the intensity of which is dependent upon market conditions (Jonsson and Rinaldi, 2017).

It remains largely unknown how the introduction of forest biomass harvesting for biofuel production might affect stakeholders dependent on pre-existing forest functions or derived ecosystem goods and services. This paper seeks to address this knowledge gap by developing a stepwise methodology for conflict analysis in relation to FES provision and then applying it to the case of forest biomass for biofuel production. We designed and tested our methodology in the framework of the BIO-KRAFT[1] project, which investigated the possible effects of increasing extraction of biomass from forests for biofuel production in Germany. We specifically aim to analyze:

1. What conflicts, synergies and potential innovations arising from stakeholder competition caused by changes in forest management and/or forest biomass use can be identified?
2. How can the potential, limits and challenges of a possible change in forest biomass use for biofuel production be assessed?
3. What strategies can be developed in order to alleviate competing demands for forest biomass?

This paper is structured as follows: after this introduction, the theoretical orientation, which is comprised of natural resource conflict theory and the concept of forest multi-functionality, is discussed as a starting point for our analysis in chapter 2. Methodologically, this study builds on an integrated study design, which is detailed in methods chapter 3. Our study design consists of expert interviews, workshops and focus group discussions to elaborate on potential conflicts and respective management strategies. Potential conflicts between stakeholder groups, the evaluation of how the topic of biofuels could affect forest ecosystems, management and policy, and strategies proposed by stakeholders for dealing with the identified potential conflicts are detailed in chapter 4. The chances and challenges of our proposed methodology for the analysis of potential conflicts are then discussed (chapter 5) and conclusions are drawn for its further refinement and use in the final chapter.

2. Theoretical orientation

We build our theoretical orientation on two concepts that guide our analyses. First, we refer to Buckles and International Development Research Centre, & World Bank, 1999 in order to understand how conflicts for natural resources manifest between stakeholders. Second, we refer to the concept of forest multi-functionality, acknowledging the

[1] The project "Woody biomass availability for biofuel production in DE and EU until 2040" ran from 2021 until the 1st quarter of 2023. It was financed by the German Federal Ministry for Digital and Transport (BMDV)

various societal demands for different forest uses that help us in determining where conflicts occur.

Natural resource conflicts largely emerge due to the multiple and competing demands on natural resources. According to Matiru et al. (2000), they can arise if user groups are excluded from participating in natural resource management decisions. They also occur due to contradictions between local users and new institutions and management systems or lack of information about policy and management objectives. Contradictions or a lack of clarity in laws and policies also functions as a source of conflict, similar to a real or perceived inequity in resource distribution or poor policy implementation. For a structured conflict analysis, the work of Buckles and International Development Research Centre, & World Bank, 1999 outlines four main reasons why conflicts for natural resources arise between stakeholders. First, they describe how the interconnectedness of stakeholders' actions could have far-reaching repercussions for others. Forest stakeholders are competing for a limited supply of FES. As such, the manner in which forest each stakeholder utilizes resources could affect the supply for others, which could cause competition over scarce resource supply, for example, conflicts between timber production and the provision of other FES. In addition, behind competition over varying uses, conflicts can also be due to fundamentally different actor perceptions, values or worldviews regarding forests and forest management and hence may be difficult (or even impossible) to resolve (Winkel and Sotirov 2016). This underlines the need for transparent decision-making over tradeoffs as well as working towards integrated solutions. Second, the complex and unequal relationships and power imbalances between stakeholders could lead to conflicts. Research suggests that not all stakeholders receive equal political support, which therefore hinders each one's capacity to influence forest management. For example, stakeholder demands for cultural FES and particular infrastructures are often less well considered in forest management decisions (Torralba et al., 2020). This leads to their under-provision and/or under-valuation in forest management regimes (e.g. Dwyer et al., 2015). Third, the scarcity of natural resources due to environmental change, increasing demand and unequal distribution is also a significant source of conflict. For example, the intensified climate change mitigation needs (Gutsch et al., 2018b; Naumov et al., 2018), or market and policy trends related to advancing the bioeconomy might further exacerbate scarcity and require decisions over trade-offs with biodiversity conservation and cultural FES (Bauhus et al., 2017; Tyräinen et al., 2017). This is supported by Maxwell and Reuveny (2000) and is closely related to the aforementioned interconnectedness perspective. Finally, stakeholders' identities could also be a source of conflict as they are symbolically defined by their use of natural resources (e.g., as forest owner or forest worker). When traditional stakeholder practices that lead to negative consequences for others (again, interconnectedness) are threatened with change, such as new stakeholder demands and requests for change in forest management, this can lead to conflict. As most forest owners and managers still rely on biomass production for profit generation (Lindahl et al., 2017), this may reinforce the identity of foresters to traditionally provide timber as the main product, even though forest management objectives have evolved integrating new objectives and forestry approaches, such as for biodiversity conservation or carbon sequestration (Bauhus et al., 2017).

As a complement to Buckles and International Development Research Centre, & World Bank, 1999 work, the authors use the concept of forest multi-functionality, namely the idea that forests that fulfill the various ecological, social and economic functions ensure the provision of multiple ecosystem services (Mina et al., 2018). The concept of (forest) ecosystem services (FES) (e.g. Costanza et al., 1996), meanwhile, helped to establish the idea of multi-functional forestry, and the identification of trade-off relationships among conflicting management objectives (Lexer and Brooks, 2005). In Germany, multi-functional forest management became institutionalized in forest planning about half a century ago Gesetz zur Erhaltung des Waldes und zur Förderung der Forstwirtschaft, 1975, but it was criticized for tending to neglect the potential conflicts between different forest functions (Winkel et al., 2011), e.g., production (economic), ecological (protection) and social (Bončina et al., 2019; Führer, 2000). These conflicts stem from user competition for forest functions and services or perceptions of ambiguity for their use and provision in policy and management (Maxwell and Reuveny, 2000; Primmer et al., 2021; Ranacher et al., 2020; Schramm and Litschel, 2017). The tendency to increase provisioning services can reduce regulating and cultural FES, which might lead to conflicts over forest uses, in particular between production and conservation functions, goods and services (Angelstam et al., 2018; Kleinschmit et al., 2017).

With these two main concepts together, we seek to understand how stakeholders who are dependent on various FES could be affected by the possible onset of biofuels from forest biomass, and why conflicts arise.

3. Methodological proceeding for conflict analysis

Study results were cross-validated using various qualitative methods in a triangulation design. In order to generate insights about the potential conflicts an increase in demand for forest biomass for biofuel production could induce for other forest stakeholders, as well as to elaborate about possible conflict management strategies, various qualitative methods have been employed and combined. First, a literature research was undertaken to establish the state of the art of conflicts in forestry in Germany. From there, a stakeholder analysis was carried out with the objective of identifying relevant actors who have an interest or are involved in particular forest uses. Subsequently, expert interviews were conducted with representatives of each stakeholder group. Then, two workshops were carried out for this study. The first workshop focused on the prioritization of the conflicts identified during the expert interviews and the formulation of initial strategies to manage them. The second workshop further elaborated on the types of strategies formulated and the conditions for their implementation. As a final step, three Focus Group Discussions were carried out to further elaborate on particular, contrasting conflict management strategies and the possibilities of their implementation in Germany. Each methodological step incrementally contributed to elaborating the findings and triangulation of the generated results. Fig. 1 shows an overview of the proceedings.

3.1. Stakeholder analysis

The grouping of stakeholders was done using an inclusive (Agnoletti and Santoro, 2015; Torralba et al., 2020), top-down categorization approach, which means that the stakeholder categories were set by the authors (Reed et al., 2009). Three criteria determined a stakeholder group's inclusion into the study: (1) the functioning/existence of their practice is dependent on one type or bundles of provisioning, regulatory, or cultural forest ecosystem services, (2) they have some influence on forest policies, and (3) they are affected by changes in the forest socio-economic landscape.

Based on these criteria, we identify seven major stakeholder groups within the forestry arena in Germany (Table 1). Actors in the group "Forestry" are stakeholders who are directly responsible for the administrative management of forests, including the setting of forest management objectives. Nature conservationists are those groups that prioritize the protection of forests and aim to preserve the ecosystem for future generations. The group "Politics" includes stakeholders who work in public policy or administration. "Industry" are stakeholders who process forest biomass for the production of a wide range of timber-based goods and services, such as the timber processing or biofuel industry. "Science/academia" includes stakeholders affiliated with research organizations. The "Tourism" group refers to stakeholders who are proponents of forest-based outdoor recreation or leisure activities. Finally, the "Health and recreation" group refers to actors who promote the use of forests for health and therapeutic purposes.

Fig. 1. Methodology overview. (Template provided by powerpointschool.com).

Table 1
Identified stakeholder groups with various interests in the forestry arena in Germany.

Stakeholder Group	Description
1. Forestry	• Groups that are responsible for the administration and management of forests • This includes private and public sectors
2. Nature Conservation	• Groups that seek to protect forests and biodiversity and by extension the ecosystem services that they provide • This is generally through the promotion of decreased anthropogenic activities in forests
3. Politics	• Political actors who have an influence on public policy or its implementation that directly or indirectly affect the management of forests
4. Industry	• Covers all groups that receive and process forest biomass for the production of a wide range of products
5. Science/Academia	• Includes scientists, researchers, groups that are affiliated with education and research institutions
6. Tourism	• Encompasses groups that use forests for leisure activities, e.g. biking, hiking, yoga. • These can be profit or non-profit oriented
7. Health and Recreation	• Are using the forest for health purposes or for enjoyment and pastime, spiritual uses

Table 2
List of interviewed experts representing one of the seven stakeholder groups.

Code	Position	Stakeholder Group
TM	Manager at a State Forest	Forestry
LR	Manager at a State Forestry Institution	Forestry
OZ	Coordinator at a Non-Government Organization on Environment	Nature Conservation
ZR	Adviser on Forestry at a Non-Government Organization	Nature Conservation
NM	Adviser on Forest Protection at a National Institution	Politics
NE	Adviser on Sustainable Forest Management at a National Institution	Politics
LH	Director at a Private Biorefinery	Industry
RD	Forest Scientist at a University	Science/Academia
ER	Manager at a National Park	Tourism and Recreation
EH	State Advisor on Forest Politics and Nature Conservation	Tourism and Recreation
EE	Chief Executive at a Health Association	Health
EN	Chief Executive at a Learning Institution for Forest Bathing	Health

3.2. *Identifying potential conflicts through expert interviews*

Problem-centered, semi-structured interviews (Atteslander et al., 2008; Gläser and Laudel, 2010) were conducted with a total of twelve experts to identify potential conflicts related to increased forest biomass uses for biofuel production. The interviewees represent each of the seven stakeholder groups at least once. The aim of the interviews was to identify: (1) each interviewee's fundamental position on the prospect of increasing forest biomass harvesting for biofuel production in Germany, (2) potential conflicts that could arise between the various stakeholder groups, and (3) potential innovations and synergies between stakeholders regarding prospects for change in forest management.

Table 2 shows the anonymized list of experts, their position in their respective organizations and primary stakeholder group association. Due to the corona pandemic, all interviews were conducted online. The interviews lasted between 45 and 75 min.

Experts were first asked to state their opinion concerning forest biomass harvesting for biofuel production and describe previous experiences with the topic. Next they were asked to assess whether conflicts could arise if harvesting forest biomass for biofuels were to increase, decrease, or remain constant in Germany, specifically with regard to the provision of other FES. This was done in order to establish a connection between societal demand for limited forest goods and services (including FES) and conflict between stakeholders.

They were then asked if any positive developments could arise in connection to an increase in forest biomass use, and whether any strategies and innovations could mitigate potential conflicts. Finally, the experts were asked to assess future demands for forest biomass, specifically whether societal demand would increase or decrease in the coming years. This resulted in the formulation of the nine conflict lines as perceived by the interviewed stakeholders (see Appendix A).

3.3. *Workshops for in-depth conflict analysis and strategy development*

As a next methodological step, two workshops were organized. The workshops aimed at identifying the conflicts that could arise from potential changes in forest management focusing on the harvesting of forest biomass for biofuels, the limits and challenges of a change in forest biomass use, and to develop strategies for managing competing demands for forest biomass. Both workshops were held online due to corona pandemic, lasting 3 and 3.5 h respectively.

3.3.1. *First workshop: Understanding conflicts*

The first workshop took place in July 2021. It was attended by 23 participants with each of the seven stakeholder groups represented. The workshop was divided into two phases (see Fig. 2): First, the prioritization of identified conflicts between stakeholder groups, which were based on the findings of the expert interviews, and second the initial formulation of potential strategies for alleviating these conflicts. In the first phase of the workshop, the participants formed four homogenous groups, i.e. each group was comprised of participants who shared

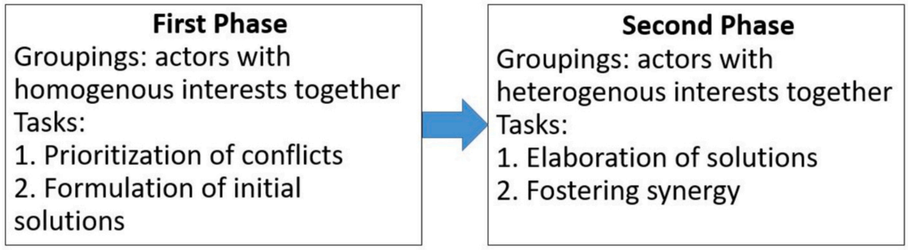

Fig. 2. Overview of Proceeding for the First Workshop.

common views and interests. As an example, the views that cultural FES are crucial for society was shared by members of the "Tourism, Recreation & Health" group members. The additional three groups were: Forestry & Industry, Forestry & Nature Conservation, and Politics & Science/Academia. The groups were asked to rank the conflicts according to which ones, in their opinion, are most pressing and should be prioritized. This was done by presenting the nine conflict lines to each group and the participants ranking each conflict from one to nine (1 being the most crucial and 9 being the least). After this prioritization, participants were asked to formulate initial strategies as to how these conflicts could be tackled, including the identification of the main actors that should be involved in the process.

The top ranked conflicts were as follows: "Wood use vs. Carbon Storage", "Wood Utilization vs. Biodiversity", "New Products (including biofuels) vs. Already Established Products", "Cultural FES vs. Conservation vs. Wood Industry". They were used as a basis for the discussions in the second phase of the workshop.

In the second phase, the participants were re-grouped into heterogeneous groups. Each group was now comprised of stakeholders that had varying, and at times directly conflicting, views on forest management and politics. The groups were asked to comment on the top ranked conflicts from the previous session and to suggest a path forward as to how these could be implemented. Each group presented their strategies to the plenary at the end of the workshop. The workshop was recorded by video for the sole purpose of easing the documentation process. The documentation of the proceedings and results were then shared with participants for validation.

3.3.2. Second workshop: Debating conflict management strategies

The second workshop was conducted online in November 2021 and was attended by 14 participants. Similar to the first workshop, each of the seven stakeholder groups was represented. The aim of the second workshop was to concretize the possible strategies to conflicts arising from biofuel production among stakeholders that were suggested in the first workshop. In order to do this, scenario narratives were used as a communication tool to invoke out-of-the-box thinking and to orchestrate a constructive debate (Aukes, 2021).

Three scenario narratives were formulated with each expressing a unique, overstated vision of the future of forest management in Germany. Each of the narratives demonstrates alternating future developments regarding the use of forest biomass from playing a minimal role in society only (i.e. no use) to being a priority in forest policy. Together with this, all identified stakeholder groups also have varying roles, positions, and levels of influence on the development of forest management in the future. Embedded within the scenarios are the strategies and results from the first workshop integrated as best practices for future forest management and dealing with biofuel production. These strategies include (1) payment schemes for ecosystem services, (2) strong public political and financial support for the development of wood products, and (3) a broad implementation of participatory processes in forest decision-making. As such, each of the three scenarios represents a dominating perspective of stakeholders for a particular forest function (ecological, economic and social). Attached to the functions emerge previously identified conflict lines together with particular strategies as a basis for further debate. As a result, there was one scenario focusing on forest conservation, which was named Nature Conservation Scenario, and one scenario that is timber production centric (Economic Scenario). A third scenario, the Society Scenario emphasizes the multi-functionality of forests and its particular role for society. Table 3 summarizes the three scenarios, including the conflicts addressed and strategies promoted to stimulate debate (see Appendix B for the full display of scenarios).

During the workshop, three heterogeneous groups of participants were formed and assigned one scenario each. The group had three tasks. First, they had to assess the opportunities and limitations of the forest management strategies outlined in each scenario for FES provision. Next, the participants had to gauge the strategies' chances of being implemented in real-world situations. For this, potential barriers were discussed. Finally, required context conditions to the strategies were formulated, which would give each the best chance of success. The workshop was recorded by video. The documentation of the proceedings and results were shared with participants for validation and correction.

3.4. Focus group discussions for deepening conflict management strategies

As a final methodological step, a series of three focus group discussions (FGDs) was organized between April and May 2022 (see e.g. Morgan, 1996; Nyumba et al., 2018; Slovák et al., 2023). In contrast to the workshops, the objective of FGDs was to focus on particular aspects of strategies based on a small set of experts, to elaborate on various aspects of one particular strategy. The FGDs also had less participants (maximum of four), each of whom were experts on the particular strategy of discussion. Finally, the FGDs provided a means to triangulate the findings of the authors about each strategy up to this point. This was done by giving the FGD experts an overview of the preliminary findings for discussion.

Each FGD focused on one of the three strategies identified in the workshops: (1) "Strengthening participatory processes in forest management through the formation of forest committees", (2) "More systematic use of market-based instruments and compensation systems", and (3) "Harmonization of government regulation for the provision of FES". The groups were a mix of two to four representatives of civil service, academia, NGO and private practice each of them being an expert in the FGD topic they were assigned to such as in participatory governance or the design of payments for ecosystem services.

Each FGD had a duration of 90 min. Due to the corona pandemic, all of them took place online. The FGDs were recorded for the sole purpose of easing the documentation process. The documentation of the proceedings and results were then sent to all the participants for validation and feedback.

4. Results

The following section presents the outcomes and results of each methodological step employed. We highlight the potential of the research design to generate insights on conflict lines, stakeholder

Table 3
The three scenarios used for the second workshop.

Scenario	Description	Conflicts Addressed	Strategies
Nature Conservation Scenario	Aspects of nature conservation take precedence over all other forms of forest use	• Forest Production vs. Conservation	• Payment for Forest Ecosystem Services • No bioeconomy • Use of only local timber • Use of only native trees
Economic Scenario	Timber utilization is prioritized and other types of forest use must be subordinated to it	• Forest Production vs. Conservation • Competition on forest biomass between different kinds of production	• Support for bioeconomy • Subsidy program for carbon storage in wood products • Wood and wood products gain political support as being sustainable • Research into innovative wood use
Society Scenario	Future forest use is decisively shaped by participatory processes and thus by a broad public	• Forest Production vs. Recreation • Forest Production vs. Conservation • Competition on forest biomass between different kinds of production.	• Emphasis on multi-functionality of forests • Participative processes integrated in decision-making • Support for bioeconomy • Use of non-native tree species better adapted to climate change

Table 3
Prioritized list of identified stakeholder conflicts from the expert interviews.

Conflict	Description
Energetic vs. Material Use	This refers to the choice that needs to be made between using wood for energy as a substitute for fossil fuels and storing carbon in material use, where carbon is stored for longer and a higher overall economic value is created.
New Products (including biofuels) vs. Already Established Products	Numerous wood products compete for shared sources of raw materials. Biofuels, for example, would be a new product, increasing the demand for forest biomass that is already highly demanded.
Wood Use vs. Biodiversity	An increasing demand for forest biomass is associated with an incentive to harvest more biomass in the forest. This can result in a reduction of the proportion of deadwood in the forest or in the stock of older, larger-sized trees.
Forest Biomass Use vs. Recreation	Increased harvesting of forest biomass could affect the recreational value of forests by limiting access to forest areas or by a decrease of forest area in general.

interests, and possible strategies to deal with conflicting demands. Although the focus is on the case of forest biomass for biofuel production, our investigation also brought to light a wide range of conflicts between several forest uses.

4.1. The identified conflicts from forest biomass use for biofuel production

The expert interviews showed that majority of the interviewees (10 out of 12) were against a potential increase of harvesting volumes of forest biomass for biofuel production. These experts were from forestry, nature conservation, politics, industry, and science/academia. They foresaw that such an increase would lead to increased conflicts and competition with stakeholders using forest biomass for engineered wood products, pulp and paper production or energy production, among others. Furthermore, restricting use to wood residues in order to minimize the aforementioned conflict raised doubts whether a sufficient amount of biofuels could be produced. The experts posit that increasing negative effects of climate change, such as forest fires and bark beetle infestations in recent years, have led and will lead to (further) instabilities in terms of forest biomass availability, which would then also affect an incoming biofuel industry.

During the interviews, the experts provided further background information on the conflicts at stake, which allowed for gaining a deeper understanding of the different stakeholders' perceptions. One example is the idea of using forest biomass for biofuel production being closely connected to general concerns regarding supply chains. Here, the potential effect of utilizing wood for energy production on material supply for wood products, or on biodiversity conservation, should be considered, especially on regional level. Multi-faceted layers of conflict identified through interviews were used as input for the workshops to deepen conflict understanding. Table 3 shows the prioritized list of identified conflict lines.

4.2. Delving deeper into Conflicts from Forest biomass for biofuel and management strategies

The design of the workshop and the composition of participants allowed a deeper understanding of the conflicts at stake, especially regarding their perception of urgency to handle them. For example, the Forestry & Nature Conservation group prioritized the conflict “Wood Use vs. Biodiversity” noting that the demand for forest biomass would lead to unfavorable conditions for Germany's forest biodiversity such as less dead wood or old growth/older trees. In contrast, the Politics & Science/Academia group assigned the topic of “Wood Use vs. Carbon Storage” as their conflict priority. Here, competing interests of carbon storage via the use of forest biomass for timber production, versus storage within intact forests, were addressed. The Forestry & Industry group decided that “New Products (including biofuels) vs. Already Established Products” should be prioritized as various wood products compete for the same raw material source (forest biomass) and an increase in demand due to biofuel production would lead to increased conflicts. Finally, the Tourism, Recreation & Health group defined a new conflict line “Cultural FES vs. Conservation vs. Wood industry”, which describes how some conservation measures, through its restrictions regarding access to forests, and how the wood industry's harvesting of forest biomass both can limit the provision of cultural FES. Table 4 shows an overview of the four prioritized conflicts and the respective groups that named them.

The second part of the workshop was dedicated to formulating and elaborating on potential strategies for the identified and prioritized

Table 4
Conflict prioritization by the homogeneous groups during the first workshop.

Stakeholder Group	Prioritized Conflict
Politics & Science/ Academia	Wood Use vs. Carbon Storage
Forestry & Nature Conservation	Wood Use vs. Biodiversity
Forestry & Industry	New Products (including biofuels) vs. Already Established Products
Tourism, Recreation & Health	Cultural FES vs. Conservation vs. Wood Industry

conflicts from the now heterogeneous groups. Here, the need to debate trade-offs and to work towards compromises is higher than within homogenous groups. For example, regarding the conflict "Wood Use vs. Carbon Storage", the groups recognized the need for a common standard for the establishment of nature reserves, which would support carbon sequestration by forests. A policy to set aside 10 % of the forest area for nature conservation is seen as helpful. In addition, the establishment of a cascade policy for the use of forest product is needed to maximize resource use efficiency. This comes along with the decision whether carbon storage in wood materials should be prioritized over using forest biomass for energy use. Further, discussions regarding the conflict "Cultural FES vs. Conservation vs. Wood Industry", it was stated that communication with stakeholders is key, specifically the mediation between them. In addition, the regional context must first be understood in defining which conflicts for FES are relevant. Table 5 shows two of the prioritized conflicts and a selection of the initial strategies developed by the groups.

The prioritized forest conflicts and the initial strategies formulated from the first workshop were integrated into the three theoretical scenario narratives for the second workshop for further debate. For example, in acknowledgement of the various societal demands for FES, a call for strengthening participatory processes in forest management is particular helpful on communal level. A promising idea that emerged is the formation of forest committees, which shall comprise of the local stakeholders who are depending on the supply of FES. It is envisioned that strategies for alleviating conflicts, including those foreseen by harvesting forest biomass for biofuel production, can be found through dialogue, negotiation and mediation. Another strategy pathway targets Germany's forest policies, including those that indirectly influence forest management, that are found to be conflicting one another when it comes to the provision of FES. Thus, it is recommended that a harmonized or integrated strategy for the provision of FES should be established, which could contribute to a clearer cascade use policy. This would then bring clarity as to how biofuels are prioritized, if at all, in light of other demands for various FES. Finally, establishing compensation systems for regulating or even cultural FES, is seen as a way to address the market failure for their lack of provision compared to timber production. This would offer alternative income streams for forest owners, which in turn could lead to an enlarged set of forestry products and service portfolio. Table 6 shows the three strategies and their descriptions.

4.3. Future strategies for conflict management

Focus Group Discussions (FGD) were carried out to elaborate on previously identified strategies from the workshops and to expound on their effects and the required conditions for implementation. At this point in the study, it became apparent that conflict arising from biofuels

Table 5
Examples for initial strategies from the heterogeneous groups during the first workshop.

Prioritized Conflict	Selection of Initial Strategies
Wood Use vs. Carbon Storage	• Development of indicator set for establishing nature reserves • 10 % set-aside of forest area • Further research on how much energy can be provided by biofuels from forest biomass • Establishment of a cascade use for forest products
Cultural FES vs. Conservation vs. Wood Industry	• More communication and mediation between user groups. • Consideration of regional context when defining existing conflicts • Determination which FES are in demand (where do biofuels stand) • Move away from classic economic perspective/ do not let economic pressure solely dictate forest management

Table 6
Strategies for managing conflicts and the provision of FES derived from the second workshop.

Strategy	Description
1. Strengthening participatory processes in forest management through the formation of forest committees	The forest committee acts mainly through participatory processes and decides how to manage the forest in a particular area with the inclusion of heterogeneous interests and in consultation with all stakeholders
2. More systematic use of market-based instruments and compensation systems	Alternative approaches for generating income from FES beyond timber provision should be supported. This calls for accounting for and valuing natural capital and is especially important for small private forest owners to show management alternatives.
3. Harmonizing government regulation for the provision of FES	A strategy for FES provision is needed. This could begin with identifying which forest policies conflict with each other and addressing them through prioritization or innovation. This could mean the designation of more protected areas with less forest production area being made available in total, which should be managed more intensively.

from forest biomass is only one of many issues that need to be addressed in terms of competing FES demand. Accordingly, the strategies were developed to contextualize the issue of using forest biomass for biofuel production as being a part of a broader spectrum of FES needs that should be accounted for in forest governance.

One future pathway that crystallized as a promising strategy was the formation of forest committees, which is further explained here in order to demonstrate the potential of the designed FGD. As it was elaborated, a forest committee can serve as an exchange platform for citizens, forest owners and managers who are dependent upon the FES provided by, for example, a communal forest. It offers its members the opportunity to co-design forest management strategies and planning approaches. Such structures already exist e.g., in Italy where forest management is done by a "Waldkomitee" or forest committee (Gemeinde, 2023). According to the FGD participants, this strategy offers the opportunity to embed a debate on biofuel production from forest biomass into the context of stakeholder consultation on a local level. Here, societal demands can be raised and trade-offs identified which can be considered in forest management decision-making. One of the experts highlighted that there is dissatisfaction in how little societal concerns are taken into account into public decision-making. In particular, there are general communication problems when it comes to the inclusion of alternative knowledge sources for forest management. Experts felt there is a need to further develop science communication by breaking the barrier between "information bubbles", where scientific information is unable to reach society.

In terms of chances, the establishment of forest committees would mean involving a wider range of stakeholders, which would ideally lead to the inclusion of more diversified opinions on which FES (including biofuels) should be prioritized and ultimately, on how forest management is done. This could result in management decisions that offer more opportunities to account for the conflicts between competing stakeholder interests. Digitalization also offers the chance to reach more stakeholders and facilitates their inclusion into forest management processes. As a prerequisite for forest committees to succeed, the experts expressed the need to work towards a culture of participation that has to be established first in existing governance structures. This would entail forest managers to redefine their roles and to act as mediators that manage the various societal demands for FES. Apart from that, the legitimacy of the forest committee needs to be ensured by its institutionalization. Ideally, this would also entail that the forest management process is transparent and that outcomes of participatory processes are made to be binding. Table 7 shows a summary of the expert findings focusing on that pathway.

5. Discussion

For this study on potential conflicts that could arise from harvesting forest biomass for biofuel production, a methodology that consists of four interlinked steps was developed and tested. By synergizing the findings of each methodological step and its iterative proceeding, the identification of already existing as well as potential future conflicts between forest stakeholders was possible. The analytical capability of the methodology and its potential chances and limitations are discussed.

5.1. Increasing competition requires transparent decisions over trade-offs

As a foundation for conflict analysis, expert interviews were utilized as a means to identify which conflicts exist between the aforementioned stakeholders. The interviewed stakeholders commonly highlighted that the competition for limited forest biomass and forest ecosystem services in Germany's forest arena is high and that new demand for the production of biofuels would exacerbate already existing conflicts. This perception was also largely confirmed during the workshops. It supports Buckles and International Development Research Centre, & World Bank, 1999 theory on conflict due to interconnectedness as the decisions of each forest stakeholder affect the others and thus leads to increased conflict. It also became apparent that resource scarcity (here forest biomass and other FES) leads to additional conflict among stakeholders (Maxwell and Reuveny (2000). Increasing the use of forest biomass for biofuel production, especially the forest-based industries and the energy sector to which biofuels belong, would increase competition for the same resources, accelerating the perception of scarcity (Cazzaniga et al., 2019). This atmosphere (and fear) of scarcity and competition was observed throughout the duration of this study especially in light of the various other societal demands on FES, such as to mitigate the climate change effects in Germany. The interactions with the study participants echo the findings of the latest forest health survey (BMEL, 2022) and the climate risk prognosis of the UBA (2021), that Germany's forests are degrading at an alarming rate and are further at risk due to the effects of climate change. The participants of this study recognize that their respective industries or sectors are very much at risk as well.

Stakeholder selection is crucial to ensure a representative picture of the forestry arena in Germany. Considering the wide variety of opinions and perspectives not only across but also within each stakeholder group (Rosenkranz et al., 2017), the nuances of perception heterogeneity are likely not completely captured in this study. The same can be said regarding the potential conflicts identified. However, the methodology for conflict analysis allowed us to confirm the diversity of interests and perceptions between heterogeneous stakeholders, and underline the need to make trade-offs transparent in the debate regarding biofuels production from forest biomass in light of further FES provision. The need for such a debate was observed specifically during the prioritization of conflicts during the workshops. The homogeneous groups identified their most pressing conflicts, while the formation of the heterogeneous groups initiated more debate between the participants - mostly regarding which FES should be prioritized. Cowie et al. (2021) have argued for the climate benefits of using biofuels from forest biomass as a substitute for fossil fuels. It was found during the first workshop, however, that stakeholders were calling for further quantification of the climate benefits of using this technology in order to have a clearer understanding, which would improve their decision-making. Furthermore, the environmental cost, e.g., the loss of FES such as provisioning of construction timber, water regulation or cultural services, could lead to social conflicts between forest stakeholders if this policy route is taken in Germany.

The designed methodology also demonstrated the diversity of interests between heterogeneous stakeholders. The prospect of using biofuels from forest biomass was not outright dismissed. During the expert interviews, two experts from the stakeholder groups "tourism" and "health & recreation" saw the potential to provide enough forest biomass for biofuel production if done in a regional context, acknowledging how this would benefit the further development of the bioeconomy. Following the development of this stakeholder group further, during the first workshop they defined a conflict, "Cultural FES vs. Conservation vs. Wood industry", which depicts how cultural FES stakeholders often need to negotiate both with conservation efforts, due to restrictive access, and wood industry activities, due to safety concerns in forest management and impacts on landscape picture. Studies have demonstrated that cultural FES are less prioritized in most circumstances in forest management (Agnoletti and Santoro, 2015; Torralba et al., 2020). This likely describes a characteristic within cultural FES stakeholders that supports negotiation and mediation as being standard strategies for pushing for their forest use goals, as they usually have less political influence in forest management (Torralba et al., 2020). This complex and unequal relationship between cultural FES stakeholders and others are described by Buckles and International Development Research Centre, & World Bank, 1999 as a source of conflict. Further investigation on the topic of influence among stakeholders e.g., Marques et al. (2020), is recommended for a better understanding of this relationship and to develop more profound approaches to minimize such conflicts.

5.2. Scenario-workshops as means to debate alternative futures

In contrast to the work of Pérez-Soba et al. (2015), who have shown how scenarios can be used to capture ideal visions of the future for land use planning (including forestry), scenarios in this study were used as a mean for communication. Their intention was to provoke workshop participants by framing forest management in overstated situations in which the role of utilization of forest biomass for the production of

Table 7
FGD results on strengthening participatory processes in forest management through the formation of forest committees.

Barriers	Chances	Framework Conditions
Hardly any participation processes available in public structures (internal as well as external)	Great project-related diversity of opinion	Creation of a general culture of participation in existing governance structures
Concerns/concerns from the population regarding forestry measures are often not taken seriously	Digitization of participation processes	New understanding of the roles of decision-makers; they must allow themselves to be questioned
"Information bubbles" (forestry/science vs. Internet)	Integration into participation processes that have already been successfully conducted	Legitimacy/binding nature of decisions must be ensured

biofuels varies, leading to differing conflicts and pledging for various strategies. The use of scenarios in this study is in line with the methodology outlined by Aukes (2021), which states that one can also use extreme scenarios to induce out-of-the-box thinking among participants. Specifically, the Economic Scenario and the Nature Conservation Scenario which maximize either timber production or biodiversity conservation in forest management, helped participants to reflect on the possible implications of each strategy, the trade-offs these incorporate, and on their particular role. This methodological step resulted in the identification of the three potential strategies for the future.

The strategies were then deepened with help of the focus groups, as a complement to the second workshop, to ground them in reality by identifying the chances, barriers and conditions so they can have an effective chance to minimize the conflicts identified. Though the FGDs were effective in gathering information, the results are however, as Slovák et al. (2023) have pointed out, rooted in and therefore limited to each expert's knowledge and experience. In practical terms, the results from the FGDs are non-exhaustive and should be considered a starting point for more in-depth research on each of the three strategies and their applicability. As an example, the establishment of forest committees aims for the inclusion of a broader range of stakeholders into forest management decisions. In terms of barriers, the FGD showed that the practices and traditions associated with forestry are very much intertwined with the identities of the forest practitioners and that conflicts arise when these identities are being threatened. Krumm et al. (2020) note that this can be observed not just in forestry but in hunting as well. As such, obtaining political support for establishing a Forest Committee would be a significant challenge. This phenomenon is also described by Buckles and International Development Research Centre, & World Bank, 1999 where they state that stakeholders' identities are at times defined by their use of natural resources and are indeed a source of natural resource conflict. Overcoming this barrier by establishing a general culture of participation is then identified as a crucial framework condition for this strategy's success. This supports the work of Beckley et al. (2006) who stated that participatory processes can be designed to enhance forest management by providing a platform for sharing information, expressing one's interests and possibly influence the forest management process. Other.

5.3. Limitations of the study

Overall, the design proposed in this study relies heavily on the variety of stakeholders included in each methodological step. From the expert interviews, workshops and FGDs, the represented perspectives are crucial in ascertaining which FES are to be prioritized, and for identification of potential use conflicts and mitigation strategies. That said, the relatively small participant sample size for the interviews, workshops, and FGDs is therefore a limitation as it is prone to bias. Workshops and FGDs are methodologies that are vulnerable to groupthink and this was observed in more than one occasion where stronger personalities tend to dominate discussions. Furthermore, the workshops and FGDs were moderated by the authors and moderator bias comes into play.

In order to improve the methodology outlined in this study, it is important to increase the range of experts involved in the study, add more perspectives, change group compositions and triangulate results even further. One possibility could be to include the hunting community, wildlife conservationists, and economists among others. The inclusion of new views and the findings would better reflect the more heterogeneous perceptions present in society and would then have marked implications on the overall sustainability of the management of particular forests. Further multi-sectoral investigations into the possible forest user conflicts with biofuels from forest biomass should be undertaken particularly on a local and communal scale. In addition, although there were study participants who support the idea of utilizing forest biomass for biofuel production, no explicit biofuel experts took part in the study. As such, the discussions on its advantages (and disadvantages) for the economy and even the environment were limited. Furthermore, an external moderator could be employed in order to improve the objectivity of the discussions.

The authors encountered significant hurdles during this study due to the corona pandemic as the data gathering was done from June 2021 until May 2022. Most of the activities were originally planned to be in-person events, which had to be adapted online. The authors therefore decided to plan for the workshops to last no longer than three hours each, in order to alleviate as much strain as possible from the participants. This time limit, however, restricted the overall amount of exchange that was possible between the participants during the two workshops. At the same time, shifting to an online format eased the logistical burdens for all parties involved, for example by eliminating travel time and costs for participants.

6. Conclusion

Utilizing forest biomass for the production of biofuels in Germany is a highly debated topic, as many stakeholders are dependent upon the country's forests to provide an array of ecosystem services, which could be affected. This study contributes to the debate as an innovative ex-ante conflict assessment methodology that outlines how the utilization of forest biomass for the production of biofuels could affect already existing types of utilization and related stakeholders, as well as how to co-create management strategies to aid in conflict resolution and inform decision-making. Beyond biofuels, forests are recognized as a key sector to the general progress of the bioeconomy, the development of which could lead to more diversified demand for forest ecosystem services with new stakeholders becoming more active in time. Considering the already crowded forest arena and the current demands for forests, it would also follow that the potential for conflict could also increase. Considering this, further research involving a more heterogeneous range of forest stakeholders would enrich this methodology. This approach could be used as part of a sustainability assessment that engages in critical debate on the provision of forest ecosystem services with concerned stakeholders as part of a participatory process.

CRediT authorship contribution statement

Gino Garcia: Writing – review & editing, Writing – original draft, Visualization, Validation, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Carsten Mann:** Writing – review & editing, Validation, Supervision, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Conceptualization. **Tobias Cremer:** Writing – review & editing, Validation, Supervision, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Conceptualization.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

Gino Garcia, Carsten Mann, and Tobias Cremer report that financial support was provided by the German Federal Ministry of Transport and Digital Infrastructure (BMDV). Gino Garcia reports financial support was provided by Ministry of Science, Research and Culture of the federal state of Brandenburg, Germany. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Appendix A

The nine identified stakeholder conflicts from the expert interviews.

Conflict	Description
Energetic vs. Material Use	This refers to the choice that needs to be made between using wood for energy as a substitute for fossil fuels and storing carbon in material use, where carbon is stored for longer and a higher overall economic value is created.
Wood Use vs. Carbon Storage	The conflict asks: which is the better strategy against climate change – storing carbon in wood products or in trees?
Reforestation vs. Agricultural Use	A growing demand for wood can increase the demand for additional areas for afforestation. These areas are often used for agriculture.
New Products vs. Already Established Products	Many wood products are made from similar ranges, so they compete with each other for a common raw material base. Biofuels, for example, would be a new product, increasing the demand for forest biomass that is already highly demanded.
Wood Use vs. Biodiversity	An increasing demand for forest biomass is associated with an incentive to harvest more biomass in the forest. This can result in a reduction of the proportion of deadwood in the forest or in the stock of older, larger-sized trees.
Forest Biomass Use vs. Recreation	Increased harvesting of forest biomass could affect the recreational value of forests by limiting access to forest areas or by a decrease of forest area in general.
Use of Wood vs. Remuneration for Public Services	Remuneration for public services (e.g. regulatory and cultural FES) could reduce the willingness of forest owners to use wood. This could result in a wood shortage.
Rising Commodity Prices vs. Other Types of Forest Use	If commodity prices rise, other types of forest use could be deprioritized.
Value Creation vs. Non-Utilization	Different targets are being set for the proportion of forests being set aside for non-utilization or conservation. These would further promote the scarcity of raw materials.

Appendix B

The three scenarios used for the second workshop.

The Society Scenario was presented as a press release from the fictitious federal state of "Brandenberg". It emphasizes qualities that call for multi-functionality in forest management and the provision of a diverse set of FES.

Brandenberg
Menschen, Leben, Natur

Pressemitteilung

25.10.2040 | Pressestelle der Stadt Brandenberg

Multifunktionale Wälder sind zukunftsfähig

Die Stadt Brandenberg präsentiert die Fortschritte ihrer "Alles für alle"-Philosophie bei der Umsetzung ihrer Waldbewirtschaftungsstrategie

Multifunktionalität – das ist Brandenbergs Geheimnis für den Einklang von wirtschaftlicher Prosperität und Umweltschutz. Während der Klimawandel im Rest des Landes und in der ganzen Welt verheerende Folgen für Mensch und Umwelt hat, ist es Brandenberg gelungen, seiner Bevölkerung unter dem Motto „Alles für alle" sowohl wirtschaftlichen Wohlstand als auch eine intakte Natur zu bieten und dadurch ganz nebenbei das soziale Wohlbefinden zu steigern.

„Unser Ansatz, die Forderungen unserer Bürgerinnen und Bürger zu berücksichtigen und unsere Waldbewirtschaftungsstrategien an diese anzupassen, war ein Erfolg", sagt Jasmine Müller, Oberbürgermeisterin von Brandenberg. Hauptaufgabe der Revierleitung ist inzwischen weniger die Bewirtschaftung des Waldes, sondern vor allem die Moderation von Konflikten zwischen den beteiligten Parteien und der Flächenverwaltung im Sinne der Erholungssuchenden.

„Unser mehrstufiger, partizipativer Ansatz und die Bildung eines sogenannten Waldkomitees haben allen das Gefühl gegeben, einbezogen zu werden. Das hat dazu geführt, dass alle ein Interesse an dem haben, was wir tun", fasst Müller zusammen. Wichtig dabei ist, dass die Beschlüsse des Waldkomitees bindend für die Arbeit der Gemeinde sind.

Heute sind rund 80% der städtischen Waldfläche langfristig, über mehrere Generationen als Erholungswald ausgewiesen und gesichert. Dies hat zu einer überwältigenden Zufriedenheit der Brandenbergerinnen und Brandenberger geführt, die ihre gesellschaftlichen Ansprüche an den Wald klar erfüllt sehen und dadurch gerne zu seinem Erhalt beitragen. So zahlen die Waldnutzenden auch gerne das von der Gemeinde angesetzte Eintrittsgeld, das unter anderem für den Bau und die Instandhaltung von erstklassigen Wander- und Radwegen verwendet wird. Damit ist beispielsweise auch der lokale Mountainbike Verein sehr zufrieden. Darüber hinaus hat sich eine Walderlebnisgenossenschaft gegründet, deren Mitglieder die Infrastruktur des Waldes mitgestalten und sich um deren Pflege kümmern.

Brandenberg

Menschen, Leben, Natur

Doch der Wald dient nicht nur als Naherholungsgebiet für die Bürger. In den nächsten Jahren sollen unter anderem mehr als 10 Hektar der Waldfläche als Friedwald für die städtische Bevölkerung und die Region ausgewiesen werden. Darüber hinaus werden mehrere Waldflächen schon heute an Waldkindergärten verpachtet, woraus erhebliche Einnahmen erzielt werden.

Diese vielfältigen Nutzungen des Waldes miteinander zu vereinbaren war nicht immer leicht und stellte die Stadt vor erhebliche Herausforderungen. Vor allem die Holzerzeugung war dabei nicht immer einfach, da auf den von Bürgerinnen und Bürgern genutzten Waldflächen der Holzeinschlag nur in sehr begrenztem Umfang durchgeführt werden kann. Doch auch dafür hat man in Brandenberg eine Lösung gefunden.

Neben der Förderung von Mischwäldern war dabei die Suche nach dem Baum der Zukunft ein entscheidender Schritt. Gefunden wurde dieser in Mittelamerika. Der sogenannte Retterbaum (Saviorus Laubbaumus Gar.) zeichnet sich vor allem durch seine Widerstandsfähigkeit gegenüber eben jenen Insekten und Pathogenen aus, die vor 10 Jahren 98% der Kiefern in Deutschland zum Absterben brachten. „Der Retterbaum hat uns im wahrsten Sinne des Wortes gerettet", sagt Müller. „Er wächst deutlich schneller als unsere heimische Kiefer, sodass wir bereits in 15 bis 20 Jahren erste kostendeckende Holzernten durchführen können, was die Forstwirtschaft in unserer Region sehr zu schätzen weiß."

Durch den Retterbaum kann Brandenberg auf deutlich kleinerer Fläche als bisher seinen Holzbedarf decken und damit seine Rohstoffversorgung autark bewerkstelligen. Das hat wiederum zur Folge, dass zukünftig noch mehr Fläche für die übrigen Bedarfe der Bevölkerung zur Verfügung gestellt werden kann.

Die steigenden Holzerträge haben darüber hinaus einen weiteren interessanten Ansatz möglich gemacht: Brandenberg ist die erste Stadt in Deutschland, die erfolgreich und dauerhaft eine Bioökonomie etabliert hat. Der städtische Verkehr wurde auf Erneuerbare Energien (Strom und Biokraftstoff) umgestellt. Die dafür benötigten Kraftstoffe werden aus den stadteigenen Wäldern gewonnen und der Strom für die Herstellung der Biokraftstoffe wird aus Windenergieanlagen im Stadtwald erzeugt.

Müller ist überzeugt davon, dass ihre Stadt den einzige richtigen Weg gewählt hat: „Durch unseren Dialogprozess konnten alle Bürgerinnen und Bürger ihre Meinung dazu äußern, welche Aktivitäten für sie wichtig sind und wie sie unsere Waldflächen gerne nutzen möchten. Das ist alles sehr harmonisch verlaufen, und alle sind zufrieden", resümiert sie und blickt positiv in die Zukunft. Es überrascht daher nicht, dass sich inzwischen Gemeinden und Städte im ganzen Land den Brandenberger Ansatz abgucken.

The Nature Conservation Scenario was written as a press release from the fictitious "Ministry for Forest and Nature Conservation". It depicts a society that supports the protection of biodiversity and nature.

Bundesministerium
für Wald
und Naturschutz

Pressemitteilung

19.03.2040, Pressestelle des BMWN

Wir müssen auf den Fortschritten der letzten zehn Jahre aufbauen

Zum Internationalen Tag der Wälder fordert der Bundesminister die Naturschutzanstrengungen zur Bekämpfung des Klimawandels fortzusetzen

Bundesministerium
für Wald
und Naturschutz

Gutleben: Wir müssen auf den Fortschritten der letzten zehn Jahre aufbauen

Zum Internationalen Tag der Wälder fordert der Bundesminister die Naturschutzanstrengungen zur Bekämpfung des Klimawandels fortzusetzen

„Wir dürfen uns nicht auf dem Erreichten ausruhen", sagt Peter Gutleben, der als Bundesminister im Ministerium für Wald und Naturschutz (BMWN) die Umsetzung der bundesweiten Naturschutzpolitik in den letzten zehn Jahren federführend begleitet hat. Angesichts der sechsten sommerlichen Hitzewelle in Folge und der damit verbundenen Waldbrände sowie angesichts des nahezu vollständigen Verlustes der Fichte in Deutschland war der Kampf um die Rettung der deutschen Wälder nicht einfach.
„Es war nur mit Hilfe aller Bereiche der Gesellschaft und vor allem der Gemeinden, die um die Wälder herum leben, möglich, mit den von uns eingeleiteten Maßnahmen den Grundstein für eine stärkere Resilienz der Wälder unseres Landes zu legen", erklärt Gutleben.
Die bisherigen Anstrengungen – verstärkte Aufforstungsmaßnahmen kombiniert mit der Stilllegung von 20% der deutschen Waldfläche – haben bis heute bereits zu einer Vorratszunahme in unseren Wäldern von 28,5 %, zu einer Zunahme der einheimischen Laubbäume um 30 % und insgesamt zu einer Zunahme der Kohlenstoffspeicherung im Wald in Form von lebender Biomasse, Totholz und Boden um 45 % geführt.

Auf seinem Weg ist Gutleben jedoch auf einigen Widerstand gestoßen. In der Tourismusbranche musste beispielsweise viel Überzeugungsarbeit geleistet werden. Die Ausdehnung der Waldschutzgebiete und die Nutzung strengerer Qualitätskriterien für Waldwildnisgebiete haben den Zugang der Besucherinnen und Besucher zum Wald eingeschränkt und die Möglichkeiten der touristischen Nutzung von Wäldern deutlich verringert.
Auch im Kleinprivatwald gab es zunächst erhebliche Bedenken. Doch Steuerfinanzierte Systeme zur Honorierung von Ökosystemleistungen, einschließlich der Kohlenstoffbindung, der Wasserfilterung und des Bodenschutzes und weitere ähnliche Initiativen haben sich am Ende als mehr als ausreichend erwiesen, um die Einkommensverluste durch die geringere Holzernte und den Verzicht auf die Nutzung von invasiven Baumarten wie Roteiche oder Douglasie auszugleichen.

Vor allem aus der Holzwirtschaft gibt es jedoch immer noch Gegenwind für Gutlebens Kurs.
„Wir befinden uns in einer Übergangsphase und wir hören die Bedenken laut und deutlich", sagt er. „Es ist wichtig festzuhalten, dass wir hart daran arbeiten, unsere Wirtschaft umzubauen, und wir sollten das Gesamtziel im Auge behalten. Es lässt sich jedoch nicht bestreiten, dass die Qualität der Waldökosysteme Deutschlands noch nie so gut war wie heute und sie wird sich in den kommenden Jahrzehnten erfreulicherweise durch unsere Maßnahmen sogar weiter verbessern."

Darüber hinaus konnten die negativen gesamtwirtschaftlichen Effekte durch den Abbau von signifikanten Einschnittkapazitäten und Arbeitsplätzen mangels Rohstoff in der Holzindustrie und die politische Vorgabe der ausschließlichen Nutzung regionalen Holzes, die immer wieder befürchtet wurden, durch die eingeleiteten Maßnahmen bisher mehr als ausgeglichen werden. Dies wird durch eine Studie des BfN unterstützt, die zu dem Schluss kommt, dass die Klimawirksamkeit ungenutzter Wälder die Wirksamkeit genutzter Wälder um ein Vielfaches übertrifft.
Bislang verfolgte Ansätze der Bioökonomie wie z.B. die Biokraftstoffproduktion aus Holz haben sich damit als wirkungslos erwiesen.

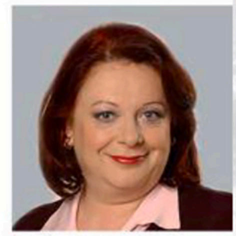
The Economic Scenario was depicted as a newsletter from a fictitious timber company. Forests here are used mainly for timber production.

Gerrer
Das Magazin

Jubiläumsausgabe
zum 80-jährigen Bestehen

05.03.2040

Seit mehr als 20 Jahren auf dem Holzweg – und das mit Erfolg!



Produktionsleiterin
Sylvia Schlegl

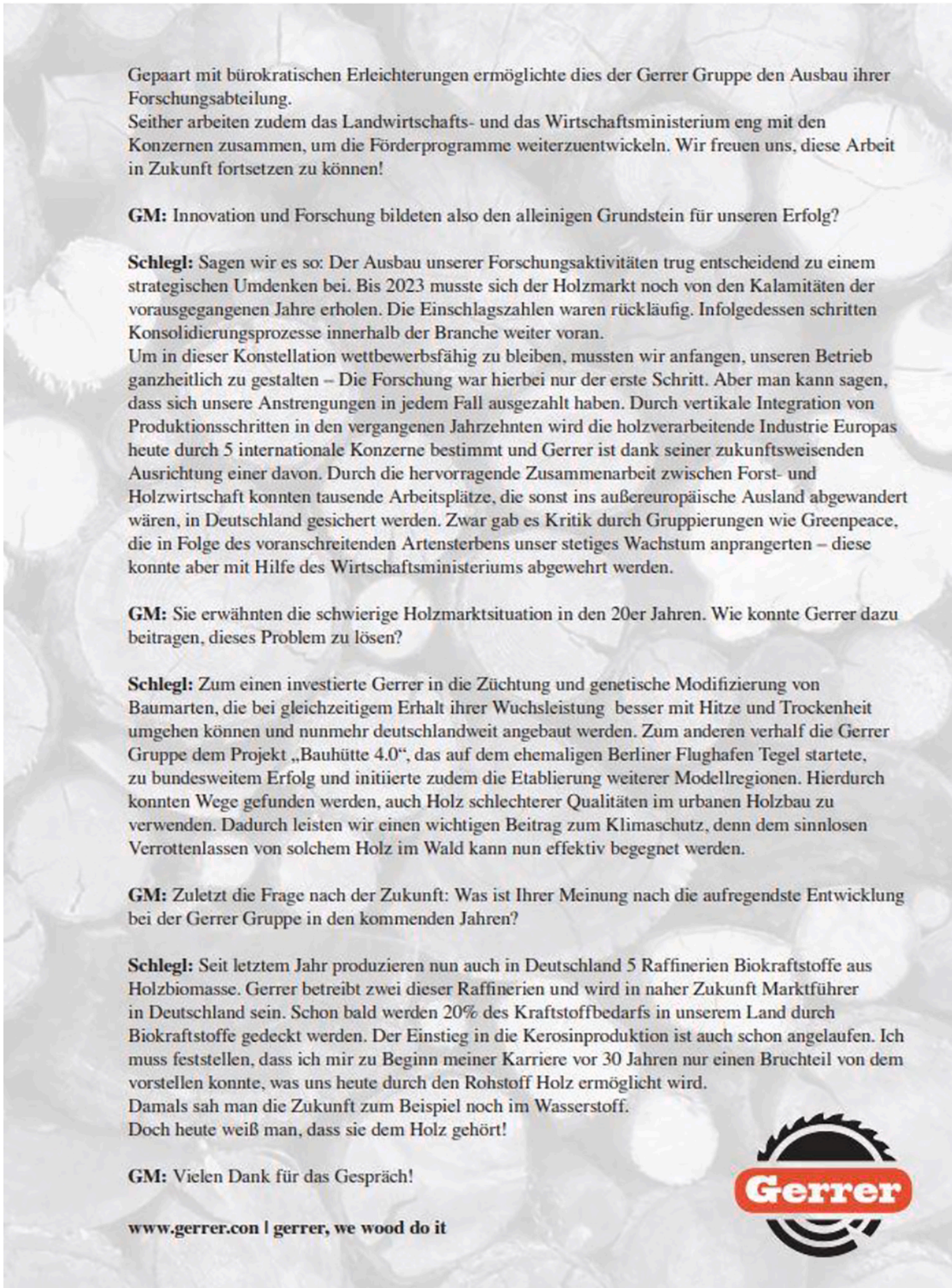
Auch 80 Jahre nach Firmengründung ist bei der Gerrer Gruppe, einem der größten Konzerne der europäischen Holzindustrie, kein Stillstand in Sicht. Vor allem die letzten 20 Jahre sahen das größte Wachstum der Firmengeschichte.
Auf diese fulminante Zeit und jüngst getroffene richtungsweisende Entscheidungen blicken wir gemeinsam mit unserer **Produktionsleiterin Sylvia Schlegl zurück.**

GM: Frau Schlegl, worin sehen Sie den Impulsgeber für den Erfolg der Gerrer Gruppe in den vergangenen 20 Jahren?

Schlegl: In den frühen 20er Jahren gab es da zum einen richtungsweisende Entscheidungen der öffentlichen Hand zur Förderung von Holz als nachhaltigem Werk- und Rohstoff. Hierzu gehörte vor allem die EU-Bioökonomiestrategie und ihre ausgesprochen kluge Umsetzung auf nationaler Ebene in attraktiven Förderprogrammen. Nicht nur die klassischen Bereiche, wie zum Beispiel der Holzbau, wurden hierbei gefördert, sondern auch die Fertigung innovativer Holzprodukte, die gerade durch die Gerrer Gruppe entwickelt und zur Marktreife geführt wurden. Sehr geholfen hat hierbei die Aufstockung der zur Verfügung stehenden Mittel zur Erforschung von Holzprodukten als CO2-Speicher im Rahmen des Waldklimafonds.
Die Substitution von herkömmlichen Rohstoffen durch Holz wurde dabei am stärksten honoriert. Das ließ die Forderungen nach Vergütung von Ökosystemleistungen vollständig verhallen. Wenn ich mich recht erinnere, konnte das Fördervolumen für unsere Branche in nur fünf Jahren beinahe um den Faktor 6 vervielfacht, also auf insgesamt 60 Millionen Euro erhöht werden.

Gerrer

www.gerrer.con | gerrer, we wood do it



Gepaart mit bürokratischen Erleichterungen ermöglichte dies der Gerrer Gruppe den Ausbau ihrer Forschungsabteilung.
Seither arbeiten zudem das Landwirtschafts- und das Wirtschaftsministerium eng mit den Konzernen zusammen, um die Förderprogramme weiterzuentwickeln. Wir freuen uns, diese Arbeit in Zukunft fortsetzen zu können!

GM: Innovation und Forschung bildeten also den alleinigen Grundstein für unseren Erfolg?

Schlegl: Sagen wir es so: Der Ausbau unserer Forschungsaktivitäten trug entscheidend zu einem strategischen Umdenken bei. Bis 2023 musste sich der Holzmarkt noch von den Kalamitäten der vorausgegangenen Jahre erholen. Die Einschlagszahlen waren rückläufig. Infolgedessen schritten Konsolidierungsprozesse innerhalb der Branche weiter voran.
Um in dieser Konstellation wettbewerbsfähig zu bleiben, mussten wir anfangen, unseren Betrieb ganzheitlich zu gestalten – Die Forschung war hierbei nur der erste Schritt. Aber man kann sagen, dass sich unsere Anstrengungen in jedem Fall ausgezahlt haben. Durch vertikale Integration von Produktionsschritten in den vergangenen Jahrzehnten wird die holzverarbeitende Industrie Europas heute durch 5 internationale Konzerne bestimmt und Gerrer ist dank seiner zukunftsweisenden Ausrichtung einer davon. Durch die hervorragende Zusammenarbeit zwischen Forst- und Holzwirtschaft konnten tausende Arbeitsplätze, die sonst ins außereuropäische Ausland abgewandert wären, in Deutschland gesichert werden. Zwar gab es Kritik durch Gruppierungen wie Greenpeace, die in Folge des voranschreitenden Artensterbens unser stetiges Wachstum anprangerten – diese konnte aber mit Hilfe des Wirtschaftsministeriums abgewehrt werden.

GM: Sie erwähnten die schwierige Holzmarktsituation in den 20er Jahren. Wie konnte Gerrer dazu beitragen, dieses Problem zu lösen?

Schlegl: Zum einen investierte Gerrer in die Züchtung und genetische Modifizierung von Baumarten, die bei gleichzeitigem Erhalt ihrer Wuchsleistung besser mit Hitze und Trockenheit umgehen können und nunmehr deutschlandweit angebaut werden. Zum anderen verhalf die Gerrer Gruppe dem Projekt „Bauhütte 4.0", das auf dem ehemaligen Berliner Flughafen Tegel startete, zu bundesweitem Erfolg und initiierte zudem die Etablierung weiterer Modellregionen. Hierdurch konnten Wege gefunden werden, auch Holz schlechterer Qualitäten im urbanen Holzbau zu verwenden. Dadurch leisten wir einen wichtigen Beitrag zum Klimaschutz, denn dem sinnlosen Verrottenlassen von solchem Holz im Wald kann nun effektiv begegnet werden.

GM: Zuletzt die Frage nach der Zukunft: Was ist Ihrer Meinung nach die aufregendste Entwicklung bei der Gerrer Gruppe in den kommenden Jahren?

Schlegl: Seit letztem Jahr produzieren nun auch in Deutschland 5 Raffinerien Biokraftstoffe aus Holzbiomasse. Gerrer betreibt zwei dieser Raffinerien und wird in naher Zukunft Marktführer in Deutschland sein. Schon bald werden 20% des Kraftstoffbedarfs in unserem Land durch Biokraftstoffe gedeckt werden. Der Einstieg in die Kerosinproduktion ist auch schon angelaufen. Ich muss feststellen, dass ich mir zu Beginn meiner Karriere vor 30 Jahren nur einen Bruchteil von dem vorstellen konnte, was uns heute durch den Rohstoff Holz ermöglicht wird.
Damals sah man die Zukunft zum Beispiel noch im Wasserstoff.
Doch heute weiß man, dass sie dem Holz gehört!

GM: Vielen Dank für das Gespräch!

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2.2. Article 2

A Systematic Literature Review on the use of the

Ecosystem Services concept in Sustainability Assessments

for Forestry

by

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Keywords: forest ecosystem services, forest, sustainability assessment, systematic literature review, sustainability

Structure

1. Introduction

The concept of sustainability emerged in the field of forestry in Germany in the 18th century (Hölzl, 2010). Its meaning and operationalization has been noted as a rapidly evolving concept since the 1980s (Wiersum, 1995), yet there is to date no consensus definition, which on one hand makes it open for inclusivity, but at the same time vulnerable to misuse (Ove Tøllefsen, 2021). In forestry, the plurality of the term led to diverse understandings and perspectives that permeate through different forest stakeholders and their varied interests (Rosenkranz et al., 2017). These forest stakeholders rely on these ecosystems to provide a wide range of goods and services, for example water regulation, wood provision, biodiversity and various cultural services, which is why the debate on the sustainability of forest management is timely as it could trigger conflicts if unaddressed (Garcia et al., 2025).

The plurality of the meaning of sustainability seems to also apply to the methodologies that set out to appraise it. Bond and Morrison-Saunders (2011) have defined sustainability assessment as "any process that steers decision-making towards sustainability". Research has already taken stock of sustainability assessment methodologies (e.g. Ness et al., 2007; Singh et al., 2009) highlighting the wide-range of possibilities, for example substance flow analysis, life cycle cost assessment, cost benefit analysis or environmental impact assessment. The application of these methods, in essence, informs decision-makers about the benefits and consequences of human actions and could contribute to achieving sustainability. Effort has been made to distinguish sustainability assessment from other appraisal methodologies (e.g. Pope et al., 2015; Sala et al., 2015).

Ecosystem services can be defined as the benefits that humans receive from the environment (MA, 2005). The concept emerged in the 1970s and was meant to display how much society depends on the environment (Daily, 1997; De Groot et al., 2002; Gómez-Baggethun et al., 2010). The concept has been mainstreamed in recent decades most notably through the Millennium Ecosystem Assessment (MA), which was a study carried out from 2001 to 2005 that focused on the changes of ecosystems globally and how they affect human well-being (MA, 2005). Geneletti et al. (2015) have stated that the inclusion of the ecosystem services concept could bolster sustainability assessment methodologies by making society's dependence on the functioning of ecosystems more apparent.

Meanwhile, the transdisciplinary approach calls for the involvement of non-academic practitioners/stakeholders as well as experts from different disciplines in tackling a particular problem (Brandt et al., 2013). This approach seeks to increase stakeholder involvement, which in turn improves a project's chances of success in development towards sustainability. There are, however, acknowledged barriers that need to be overcome for the concept to be mainstreamed (Jahn et al., 2012; Lang et al., 2012).

This review tackles the following research questions (RQ):

RQ1: What comprises a forest sustainability assessment?
RQ2: How is the ecosystem services concept used in forest sustainability assessments?
RQ3: How is sustainability measured in forest sustainability assessments?
RQ4: How is transdisciplinary research integrated in forest sustainability assessments?

2. Methodology

This paper aims to answer the stated research questions by employing the Systematic Literature Review (SLR) methodology. SLR is a particular type of literature review in that it follows specific steps using inclusion (and exclusion) criteria to identify the text that would be involved for a study. This paper follows the PRISMA protocol by Moher et al. (2009) as employed by several researchers in recent years (e.g. Ackerschott et al., 2023; Apetrei et al., 2021; Hintz et al., 2018).

2.1. Dataset Selection

Only empirical papers were considered for this study as the focus was on the application of the sustainability assessment concept for generating primary data. However, publications that employ modelling techniques, which would mostly be considered conceptual, but make use of empirical data were also included. In addition, only peer-reviewed journal articles were considered.

The articles reviewed for this paper were identified using the Web of Science and Scopus databases. The search was conducted on April 2024 and included papers published until 2023. In line with the concepts relevant to this review, three distinct keywords were used: “sustainability assessment”, “forest”, and “ecosystem service”. In order to accommodate the NCP concept, a separate search was conducted using the following keywords: “sustainability assessment”, “forest” and “nature contribution people”. The initial search resulted in the identification of a combined 840 papers from both databases. A total of 193 duplicates were found and removed, which yielded 647 records that were then included for the screening phase. During the screening phase, all 647 abstracts were downloaded and assessed. A total of 305 abstracts were rejected for being false positives or a lack of access to the entire paper. In the eligibility phase, the full text for the 342 records were assessed. Records that did not use any ecosystem service indicators, were lacking a focus on forests, or did not assess sustainability were excluded. This led to the rejection of 233 records. In the end, a total of 109 papers were deemed for inclusion in this study. Figure 1 shows an overview of the review process.

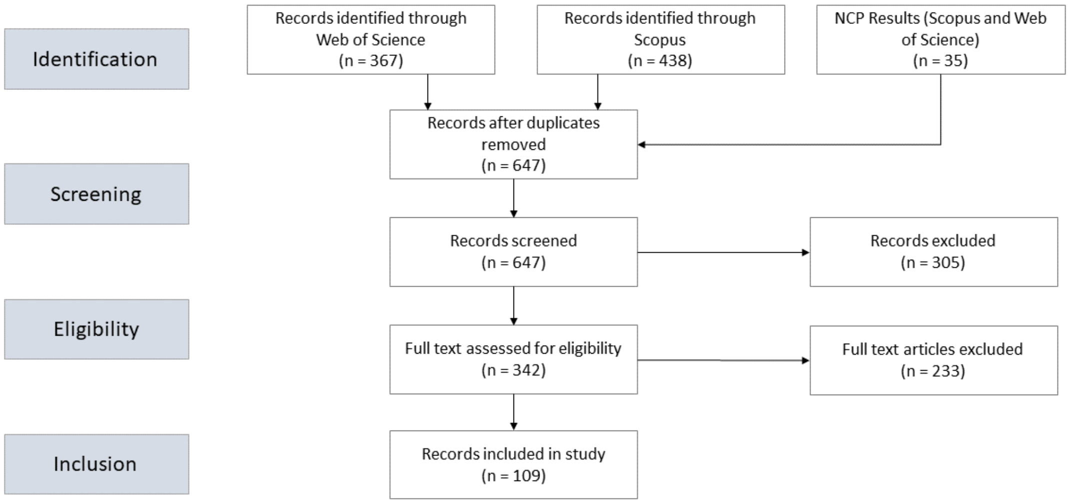

Figure 1. PRISMA methodology adapted from Moher et al. (2009)

2.2. Data Analysis

In order to answer RQ1, the 109 papers were coded according to which indicators were used to assess sustainability. Regardless of the methodology used, the indicators show which metric the authors deemed relevant for each particular case and gives this study a picture as to what could comprise a sustainability assessment (RQ1). Nested within this exercise is the identification of which forest ecosystem services are being measured, which would answer RQ2. Through the selection process, the 109 papers included in this study all make use of the ecosystem service concept in their research. The aggregate findings of which FES have been considered in the studies show how the ecosystem services concept could contribute to defining a sustainability assessment. In order to answer RQ3, the papers were coded according to how sustainability is measured – which methods were used and what aggregate statements can be made accordingly. Finally, for RQ4, the transdisciplinarity of the papers was assessed by checking for (1) the participation of non-academic stakeholders in each study and (2) their respective level of participation.

The coding of the papers follow the deductive and inductive content analysis methodologies outlined by Mayring (2015). First, the FES indicators were coded according to four ecosystem services classification systems: (1) the aforementioned MA system, (2) the Economics of Ecosystems and Biodiversity (TEEB) classification system, which was developed to apply economics to ecosystem benefits as a means to assure societal prosperity and environmental protection (TEEB, 2010), (3) the Common International Classification of Ecosystem Services (CICES) system, which can be used for ecosystem accounting methods and aims at easing comparability in different settings (Haines-Young & Potschin, 2018), and finally (4) Nature's Contribution to People (NCP), which is the ES classification system put forth by the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) that increases the social sciences aspects of ES (IPBES, 2017). For the purposes of this review, the harmonization of the MA, TEEB, and CICES classification systems as done by Forest Europe (2014) was used as reference. This was amended by the authors to include NCP (see Appendix 2).

An inductive approach was then used to code the rest of the non-FES indicators, which were first grouped and then classified according to appropriate category headings. The inductive approach was also used in analyzing the assessment methodologies utilized in the 109 papers. The methods were first grouped and then a category heading was defined.

The deductive approach was again used in coding the transdisciplinary findings. The level of involvement of non-academic practitioners was categorized as information, consultation, collaboration, or empowerment as outlined by Krütli et al. (2010) and utilized by Brandt et al. (2013).

The coding was done using a combination of Microsoft Excel and MaxQDA. The visuals for this paper were generated using the programming language R and Microsoft Excel.

3. Results

Based on the 109 publications, 1324 indicators were analyzed and sorted into two main groups: FES and non-FES indicators. The papers were also assessed in terms of the methodology used and for transdisciplinarity.

3.1. Forest Ecosystem Services (FES) Indicators

A total of 678 forest ecosystem services indicators were found in the 109 papers included in this study. Regulating services were the most discussed FES type with 318 total mentions, followed by provisioning, 229, and cultural, 107. Supporting services were specifically mentioned 24 times. Among the regulating services, climate regulation/carbon sequestration was mentioned the most, 66 times, followed closely by water regulation, 64 times. Biodiversity was mentioned 53 times, while soil protection and soil formation were mentioned 34 and 22 times respectively. Water purification and waste was mentioned 24 times, while pollination had 11. The rest of the regulating services had single digit frequencies except for disease regulation which was never mentioned. Figure 2 gives an overview of the findings.

For the provisioning services, non-wood forest products were utilized the most being mentioned 132 times. This was followed by industrial wood and fresh water provision with 38 and 32 mentions respectively. Fuelwood provision was mentioned 21 times, and the rest of the provisioning services had single digit mentions.

As for cultural ecosystem services, recreation was mentioned the most with a total of 32 mentions followed by cultural and spiritual with 27 and 16 each. Aesthetic services were mentioned 13 times. The rest of the cultural indicators had single digit mentions.

Supporting ecosystem services were mentioned 24 times with 14 of these referring directly to nutrient cycling. Primary production was mentioned 9 times and supporting services in a general sense was mentioned once.

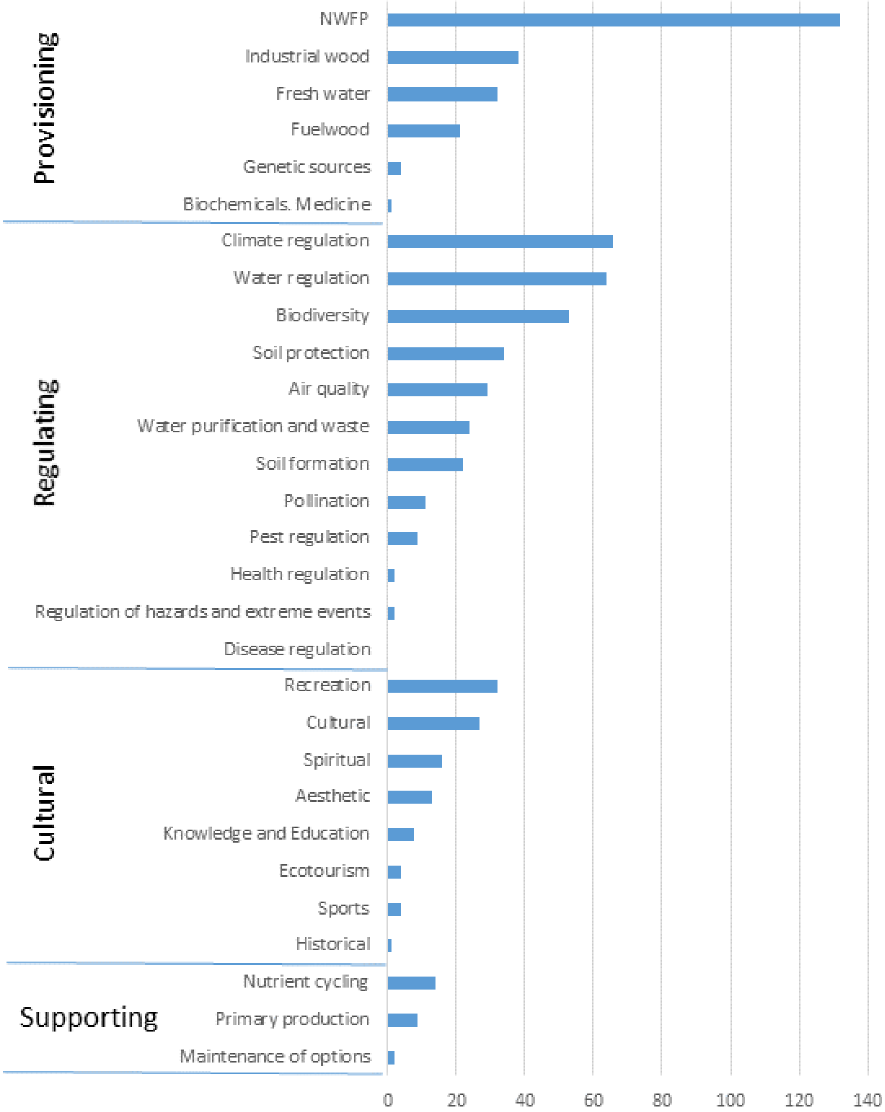

Figure 2. Forest Ecosystem Services found in the 109 publications and the number of times each one was mentioned

The publications included in this review focused on varying iterations of FES categories. Publications that focused on only one FES category (provisioning, regulating, cultural, or supporting) accounted for 29% (n=28) of the studies. Meanwhile, 28% (n=27) of the publications included two of the four FES categories in their studies, though there were no studies that focused on the combination of cultural and supporting FES indicators. Similarly, 28% (n=27) also focused on three categories. Finally, 14% of the studies (n=13) tackled all four categories.

Among the studies that only used one FES category, 61% (n=17) of them focused on regulating services, while 29% (n=8) were on provisioning services. There were only two studies (7%) that focused solely on supporting services and one (4%) that focused cultural services. Meanwhile, 63%

(n=17) of those studies that focus on two FES categories use provisioning and regulating indicators, 18% (n=5) use regulating and cultural, and 7% (n=2) each go to provisioning and cultural, as well as regulating and supporting. A sole study used provisioning and supporting indicators.

There were 25 studies that used provisioning, regulating and cultural FES indicators, and two which used provisioning, regulating and supporting indicators. Figure 3 shows how the FES indicators were distributed according to FES categories.

Figure 3. The distribution of FES indicators among the publications included in this review.

3.2. Non-FES Indicators

The non-FES indicators (n=565) were categorized according to the three pillars of sustainability – social, economic, environment, which respectively constitute 24%, 32%, and 22%. This step was undertaken to simplify the analysis, however, it is acknowledged that many of these indicators have direct or indirect overarching effects on the other pillars of sustainability. Meanwhile, cross-cutting indicators make up 21% of the non-FES indicators. Figure 4 shows the distribution of the non-FES indicators among the studies investigated according to the three pillars of sustainability.

3.2.1. Social Indicators

Several indicators refer to elements of project management and were therefore categorized as such. These comprise around 38% (n=52) of the social indicators and were further split into two groups: “Project Management” and “Logistics”. “Project Management” includes indicators that refer to skills needed by project managers in order to ensure the success of a project, namely technical skills, strategic management, and leadership, otherwise known as the Talent Triangle in project management studies (Project Management Institute, 2017). Examples of such indicators include information management, risk control, developing expertise/capacity building, conflict mitigation, and goal-setting. Closely related to this and also falling under the umbrella of project management is “Logistics”. These are indicators that refer to the logistical details of forest operations, e.g. transport network connectivity of forests including calculations for the distance to the highway, railway and local roads, the cost of labor and road maintenance, among others.

The indicators categorized as “Governance” are socio-political in nature and constitute 22% (n=30) of the social indicators. These refer to policy requirements needed for forest management such as land tenure, the enforcement of forestry and wildlife laws, conservation status, also acknowledging the community and national institutions that directly have an influence on forest operations. The category “Administrative delineation” (20%, n=28) pertains to indicators that emphasize the need to know the land use types and their respective statuses are in relation to the forest being managed. For example – is there agricultural land in the area, are there habitats for threatened species, or protected areas, even flood zones and natural parks. “Demographic information” (11%, n=15) refers to the socio-economic background of the people who utilize a given forest. Population density, growth rate, living standards are some examples.

“Demand for ES” indicators (4%, n=6) emphasize the need to account for which FES are important to forest users and “Stakeholder cooperation” (3%, n=5) is on whether the relevant actors who use the forest or have a direct influence on forest management are engaged and involved in the forest management process.

3.2.2. Economic Indicators

The majority of the economic indicators, 57% (n=108), are relevant to three industries – agriculture, timber, and tourism. “Agriculture industry” (30%, n=56) examples are irrigated area/km^2 of agricultural land, and amount of fodder. “Timber industry” indicators (20%, n=38) include timber length/ha, time needed for harvesting, and number of commercial species. “Tourism industry” (7%, n=14) examples are the number of recreated people, rural accommodation availability, and recreational hiking density.

Indicators under the category “Financial gain” enforce the idea that forests contribute to the financial well-being of human society. Whether it be through the three aforementioned industries, or from other means such as the sale of fresh fruit, palm oil, or ecosystem services valuation, these indicators constitute 23% (n=44) of all economic indicators.

“Financial market” (12%, n=23) refers to the general state of the economy which affects commerce related to forests. Examples of these are the market prices for fuelwood, forestry products and agricultural products.

“Input needed” (5%, n=10) are indicators that acknowledge the need for investments and other materials in order to run a forest management operation. Finally, “Employment” (2%, n=4) refers to how much the forest in general contributes to providing jobs to society.

3.2.3. Environmental Indicators

Most of the non-FES environmental indicators fall under the “Biophysical characteristics of the forest” category, 89% (n=112). They describe the characteristics of the forest in question such as amount of forest cover, elevation, slope, forest type, etc. “GHG emissions” calls for the accounting of the greenhouse gas (GHG) emissions of the forest operations (8%, n=10), and “Biodiversity” refers to indicators that describe the richness of biodiversity in the forest such as species richness of birds, vascular plants and amphibians (2%, n=3).

3.2.4. Cross-cutting Indicators

A number of indicators refer to concepts that have direct implications for each of the sustainability pillars. “Threats” (60%, n=71) is a category that takes into account to which threats a forest is vulnerable to. This encompasses social (illegal logging, illegal mining), economic (loss of income, industry losses), and environmental threats, such as (soil erosion, forest fire, desertification, water shortage).

“Project impact” indicators (20%, n=24) refer to positive and negative effects of forest operations. Examples include impact on air quality, soil and water, the restoration of landscape, or the project’s contribution to nature conservation or degradation. The “Land use dynamics” category (n=12%, n=15) refers to indicators monitoring the land use patterns and changes through time in a forested area. This encompasses natural cover and agricultural expansion, and habitat loss, among others. Sustainability was also mentioned as a general concept (7%, n=9).

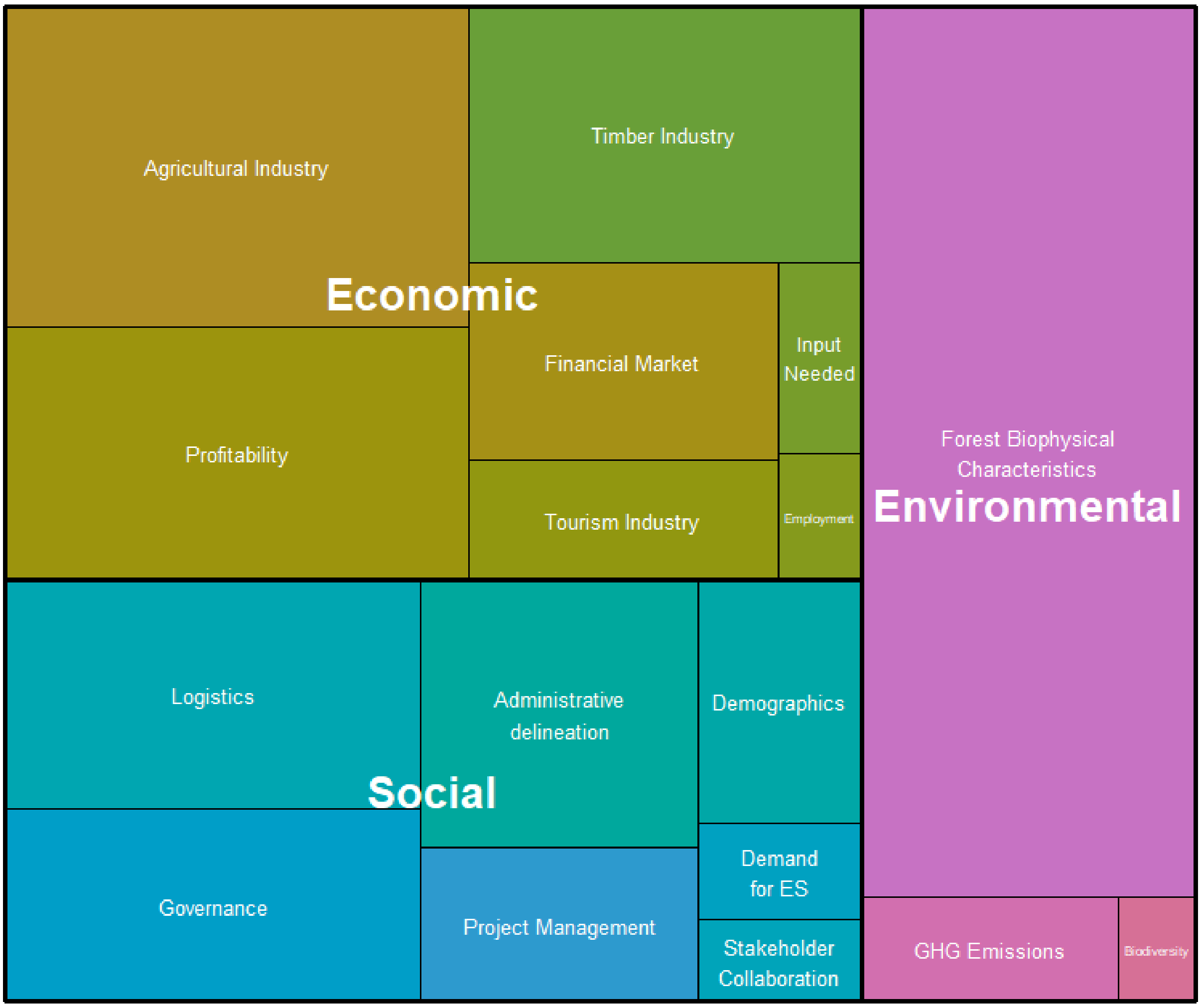

Figure 4. Tree map showing the distribution of non-FES indicators according to the three pillars of sustainability among the studies investigated

3.3. Measuring Sustainability

There was a wide array of methodological approaches utilized in the 109 articles. From a temporal standpoint, the sustainability assessments investigated in this paper can be classified into three: ex-post (n=70), ex-ante (n=24), or a combination of both (n=15). Ex-post assessments are done after a plan has been implemented, that is to say it describes the consequences of activities, while ex-ante assessments attempt to foresee the possible outcomes of planned activities (Patton & Sawicki, 2013). There are nuances, however, within these approaches and several papers have been found to combine them in their respective contexts.

Ex-post forest sustainability assessments, in order to make a conclusion on the sustainability of particular activities, have three approaches. First, the proponents look into *historical data and assess the changes over time*. This is applied, for example, to a bundle of FES and measuring the changes in abundance of its provision for a certain population. Second, the proponents could merely measure the *current state of provision for certain FES* and comment on whether or not this is ideal or, ultimately, sustainable. Finally, one could also *measure the ecological carrying capacity* of a forest, measure the current state of a set of indicators, and then make a sustainability conclusion.

Meanwhile, ex-ante forest sustainability approaches can also be grouped into two. First, the proponents could aim to *predict the effect* of a particular development plan on the provision of FES. In many cases, this is done with the help of modelling approaches with a time horizon of several decades. Second, proponents could *compare different management scenarios* with each other and decide which scenario could be ideal in terms of FES provision. A combination of both approaches was also found in several cases where different management scenarios were simulated for the future.

3.4. Transdisciplinary Approach in Sustainability Assessments

Out of the 109 publications, 47.7% (n=52) demonstrate various levels of transdisciplinarity. Consultation was the most common, found in 57% (n=28) of the publications. Meanwhile, empowerment was demonstrated in 22% (n=11) and collaboration in 20%(n=10).

4. Discussion

This review indicates that the ecosystem services concept is already being used in certain sustainability assessments applied to forests though in varying degrees. Out of the 109 journal articles included, 95 of them include at least one FES indicator in their investigations, while the rest utilized the ecosystem services concept in general. However, the extent of how the ecosystem services concept is used in the studies bears investigation. Only 42% of the studies include at least three of the ecosystem services categories, which means that majority of the studies investigated, from a strictly ecosystem services perspective, offer an incomplete picture as to what forests contribute to a particular population. These findings are in line with Geneletti et al. (2015) who noted the unexploited potential of integrating this concept into decision-making processes such as sustainability assessments, stating that the application was limited at that point in time. This limitation in the application of the ecosystem services concept is mainly because most of these investigations have a particular focus, e.g. soil, land use change, timber productivity. However, it can be argued that in order to grasp the full message of the ecosystem services concept, which is to convey society's dependence of ecosystems and their functioning to deliver goods and services, the approach has to be holistic. Depending on the category system being used (supporting is not present in all three), the three major categories, provisioning, regulating, and cultural, should be included in a sustainability assessment. By doing so, implementers would gain a better account of what forest goods and services a population benefits from, i.e. recognizing forest multi-functionality. However, perhaps more importantly, a holistic application of ecosystem services in sustainability assessments could make the trade-offs that are sure to ensue between goods and services in any forest development project more evident, which would be valuable for decision-making processes. A similar rationale is applied to the Sustainable Development Goals, which call for an integrated approach to the application of all its targets (United Nations General Assembly, 2015).

This review shows that the ecosystem services concept is only a part of the overall picture. Non-FES indicators make up around half of all indicators and demonstrate the need for an interdisciplinary approach to forest sustainability assessments. A non-exhaustive list of social, economic, environmental, and cross-cutting indicators was found, the integration of which would bolster a planned forest sustainability assessment and raise a project's chances of achieving sustainability. Considering Bond et al.'s (2012) definition of sustainability assessments as "any process that directs decision-making towards sustainability" and as demonstrated in this review where a wide array of methodologies was utilized in carrying out the 109 studies , it can be argued that the specific methodology in which a forest sustainability assessment is conducted is secondary. More crucial is the broader consideration of factors that (1) forests could affect and (2) could affect forests. Topics such as land tenure, market prices for products, and GHG emissions, but also societal demand for multi-functional forests need to be taken into account for effective project management.

With respect to the temporal considerations of a sustainability assessment, this review shows that it can be ex-ante, ex-post, or a combination of both. This goes a step further from the work of Ness et al. (2007) who did not consider the combinatory aspect. The studies showcase how to evaluate sustainability for all three possibilities, but an argument can be made that the combination of both ex-ante and ex-post assessments could have the most potential impact for forest management (e.g. Abd El-Hamid et al., 2022; Ooba et al., 2015; Yang et al., 2018). First, any forest management plan should undergo an ex-ante sustainability assessment in order to evaluate how the plan could contribute to the achievement of the management goals. Second, regularly carrying out ex-post sustainability assessments would be effective in informing management of the plan's impact, effectiveness, and whether adaptive measures need to be taken. This, in effect, is monitoring and evaluation (M&E), a practice implemented in several fields, for example in conservation (Wahlén, 2014), and development work (Crawford & Bryce, 2003).

Less than half of the reviewed articles show evidence of transdisciplinarity though there are a number of papers that showcase it prominently (e.g. 24, 29, 34, 80). This is a gap that was already identified by Jahn et al. (2012) and it needs more attention. As Bond et al. (2012) have pointed out –

the definition of sustainability and people's understanding of it are very much context-specific. This phenomenon can be observed in the forest sector as well (Rosenkranz et al., 2017). The transdisciplinary approach of involving non-academics is key to achieving sustainability as it opens the door towards collaboration between a broader range of stakeholders that should be involved in decision-making processes (Lang et al., 2012). In forestry, the participatory forest management approach shows promise in this regard as it recognizes that need for stakeholder involvement in the management of forests (e.g. Kabir et al., 2019; A. F. Marques et al., 2013; M. Marques et al., 2020). Forest sustainability assessments, in essence, should guide forest management towards improved sustainability and this review highlights the need not just for more transdisciplinarity, but more collaboration and empowerment as well in order to increase stakeholder involvement beyond mere consultation in the setting of sustainability assessment goals, methodologies and creation of knowledge. There is evidence that ignoring this aspect could contribute to a failure of achieving sustainability (Bull et al., 2018; Kull et al., 2024; Leach, 2008).

5. Conclusion

This review is an attempt at gaining a comprehensive view of what constitutes forest sustainability assessments and how the ecosystem services concept is utilized. It shows how forest ecosystem services are key to showcasing how society depends on forest goods and services, but are also only one part of sustainability assessments. Interdisciplinary considerations that encompass all three pillars of sustainability need to be taken into account. Furthermore, the transdisciplinary approach offers the opportunity to engage key stakeholders and increase the chances of success for any forest management plan. This work contributes to making forest sustainability assessments more effective by calling for the use of inter- and transdisciplinary approaches.

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7. Appendix

7.1. Appendix 1: List of publications included in this review

Search string used in the Scopus and Web of Science databases. TITLE-ABS-KEY sustainability AND assessment AND forest AND ecosystem AND service

For NCP: TITLE-ABS-KEY sustainability AND assessment AND forest AND nature AND contribution AND people

No.	Authors	Title	Year	DOI
1	Abd El-Hamid H.T.; Mustafa E.K.; Osman H.E.	An evaluation of ecosystem services as a result of land use changes in inland and coastal areas: a comparative study of Beijing and Freetown	2022	10.1007/s11852-022-00927-7
2	Aggarwal, Ashish	Revisiting the land use assumptions in forest carbon projects through a case from India	2020	10.1016/j.jenvman.2020.110673
3	Alamgir M.; Turton S.M.; Macgregor C.J.; Pert P.L.	Assessing regulating and provisioning ecosystem services in a contrasting tropical forest landscape	2016	10.1016/j.ecolind.2016.01.016
4	Alcon, Francisco; Albaladejo-Garcia, Jose A.; Zabala, Jose A.; Marin-Minano, Cristina; Martinez-Paz, Jose M.	Understanding social demand for sustainable nature conservation. The case of a protected natural space in South-Eastern Spain	2019	10.1016/j.jnc.2019.125722
5	Almenar, Javier Babi; Petucco, Claudio; Gutierrez, Tomas Navarrete; Chion, Laurent; Rugani, Benedetto	Assessing Net Environmental and Economic Impacts of Urban Forests: An Online Decision Support Tool	2023	10.3390/land12010070
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7.2. Appendix 2: Comparison of MA, TEEB and CICES classifications of forest ecosystem services by Forest Europe (2014).

The authors have added the NCP column, entries based on IPBES (2017), to the table.

MA	TEEB	CICES	NCP
PROVISIONING	PROVISIONING	PROVISIONING	MATERIAL CONTRIBUTIONS
Industrial wood	Raw materials	Materials / Biomass, fibre	Materials and assistance
Fuelwood		Energy / Biomass-based energy	Energy
Non-wood forest products (NWFP)	Food / Raw materials	Nutrition / Biomass	Food and feed
		Materials / Biomass, fibre	Materials and assistance
Fresh water (water purification) (also Regulation service)	Water supply	Materials / Water	
		Nutrition / Water	
Genetic resources	Genetic resources	Materials / Biomass, fibre (genetic resources)	Medicinal, biochemical and genetic resources
			Medicinal, biochemical and genetic resources
REGULATION	REGULATING	REGULATION AND MAINTENANCE	REGULATING CONTRIBUTIONS
Pest regulation	Biological control	Maintenance of physical, chemical, biological conditions / Pest and disease control	Regulation of organisms detrimental to humans
Disease regulation			
Health protection			
Water regulation	Regulation of water flow	Mediation of flows / Liquid flows	Regulation of freshwater quantity, location and timing

	Disturbance prevention or moderation	Mediation of flows / Air flows (storms)	Regulation of hazards and extreme events
Water purification and waste treatment	Waste treatment (water purification)	Maintenance of physical, chemical, biological conditions / Water conditions	Regulation of freshwater and coastal water quality
Air quality regulation	Air purification	Maintenance of physical, chemical, biological conditions / Atmospheric composition and climate regulation	Regulation of air quality
Climate regulation (incl. C sequestration)	Climate regulation (incl. C sequestration)	Maintenance of physical, chemical, biological conditions / Atmospheric composition and climate regulation	Regulation of climate
Soil protection (erosion regulation)	Erosion prevention	Mediation of flows / Mass flow	Regulation of hazards and extreme events
Soil formation (supporting service)	Maintaining soil fertility	Maintenance of physical, chemical, biological conditions / Atmospheric composition and climate regulation	Formation, protection and decontamination of soils and sediments
Pollination	Pollination	Maintenance of physical, chemical, biological conditions / Lifecycle maintenance, habitat and gene pool protection	Pollination and dispersal of seeds and other propagules
	HABITAT		
Biodiversity repository	Maintenance of genetic diversity (especially in gene pool protection)	Maintenance of physical, chemical, biological conditions / Lifecycle maintenance, habitat and gene pool protection	Habitat creation and maintenance
	Lifecycle maintenance		

CULTURAL	CULTURAL & AMENITY	CULTURAL	NON-MATERIAL CONTRIBUTIONS
Spiritual	Spiritual experience	Spiritual, symbolic and other interactions with ecosystems and landscapes / Spiritual and/or emblematic	Supporting identities
Cultural	Inspiration for culture, art & design	Spiritual, symbolic and other interactions with ecosystems and landscapes / Intellectual and representative interactions	
Historical			
Ecotourism	Recreation & Tourism	Physical and intellectual interactions with ecosystems and landscapes / Physical and experiential interactions	Physical and psychological experiences
Recreation			
Sports: fishing/hunting			
Aesthetic values	Aesthetic information	Spiritual, symbolic and other interactions with ecosystems and landscapes / Other cultural outputs	
Knowledge systems & Education	Information for cognitive development	Physical and intellectual interactions with ecosystems and landscapes / Intellectual and representative interactions	Learning and inspiration
SUPPORTING (in MA services necessary for the production of all other ES)			
Nutrient cycling			Maintenance of options
Primary production			
			Maintenance of options

2.3. Article 3

Market-based instruments, ecosystems,

and the European Green Deal:

a cross-sector policy analysis

By

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Structure

1. Introduction

Climate change is one of the major causes for biodiversity loss and ecosystem degradation in Europe encompassing both terrestrial, e.g. forests and peatlands, and freshwater ecosystems, e.g. rivers and lakes (European Environment Agency, 2024). European society, meanwhile, has been impacted in many ways. It is estimated that from 1980 to 2023, extreme weather events have amounted to an estimated EUR 790 billion in economic losses across Europe (European Environment Agency, 2025). The effects of climate change are foreseen to continue in Europe and globally in the coming decades (Calvin et al., 2023, p.69) and must therefore be immediately addressed.

The European Green Deal is the European Union's (EU) policy response to these climate-related threats. It was approved in 2019 and is building towards achieving climate neutrality for the EU by 2050. Through the Green Deal, the EU aims to transform its economy by promoting sustainability across all sectors. This entails the updating or approval of key policies that further sustainability goals including the Sustainable Development Goals (The European Green Deal, 2019).

Ecosystem services (ES) are the goods and services provided by ecosystems for society (Millennium Ecosystem Assessment (Program), 2005). These can be categorized as provisioning (timber, water), regulating (carbon sequestration, water regulation), and cultural (tourism, aesthetics). The provision of ES is crucial for human well-being and society (Millennium Ecosystem Assessment (Program), 2005). However, the lack of market value for many of these ES, in particular regulating and cultural, has led to market failure and has strongly influenced how ecosystems are managed, for example the lucrative timber industry against other ES in forests (Mann et al., 2022; Lovrić et al., 2025). The Green Deal recognizes the importance of ecosystems and their delivery of ES by naming the preservation and restoration of ecosystems and biodiversity as one of its main objectives (The European Green Deal, 2019). Apart from the delivery of ES, healthy ecosystems also provide substantial defense against the effects of climate change, which would benefit communities (Martin & Watson, 2016). The same is stated in one of the landmark laws approved within the framework of the Green Deal, the Nature Restoration Law, which states that the restoration of ecosystems will deliver services that will be benefit society economically and socially (*Nature Restoration Law*, 2024).

Meanwhile, market-based instruments (MBIs) in its various forms have been in place in Europe for several years as a means to address market failure (Chobotová, 2013; European Environment Agency, 2005, 2006; Sponagel et al., 2024). Currently, a notable use of MBIs is the eco-schemes under the

Common Agricultural Policy (CAP). It is a mechanism in which farmers are financially compensated for implementing actions that benefit the climate, environment and animals ((EU) 2021/2115, 2021, p.41).

Though MBIs are already in place in the current EU policy and financial landscape, it is not known to what extent these measures are designed to address the needs of ecosystems. In this paper, we therefore have the following research questions:

> **RQ1:** Which market-based instruments (MBIs) are embedded in the European Green Deal policy documents?
>
> **RQ2:** Which of these policies use MBIs for ecosystems and ecosystem service provision?
>
> **RQ3:** What is the role of Payments for Ecosystem Services (PES) in the Green Deal policy documents?

2. Relevant Concepts

This section explains the several concepts that were used in carrying out the study.

2.1. Emphasis on ecosystems

Society is dependent on ecosystems to deliver goods and services in order to sustain human life (Daily, 1997). Ecosystems worldwide continue to degrade (IPBES, 2019) and policies are in place seeking to address this. The Green Deal explicitly addresses ecosystems and their importance for Europe. Under the heading “transforming the EU’s economy for a sustainable future”, “preserving and restoring ecosystems and biodiversity” is stated as one of the objectives (The European Green Deal, 2019). The topic, of course, is of global interest. Internationally, 2021-2030 has been declared by the United Nations as the decade on ecosystem restoration (United Nations, 2025).

Meanwhile, as part of the European Green Deal, the Nature Restoration law came into force in August 2024. It advocates for the restoration of natural ecosystems recognizing the importance of ecosystem services for the functioning of society, and ultimately for human well-being (*Nature Restoration Law*, 2024). In addition, the law also directly calls for the use of market-based instruments to help in achieving the law’s objectives (*Nature Restoration Law*, 2024).

2.2. Market-based instruments for the supply of ecosystem services

There have been several types of MBIs in place in the last decades worldwide. In taking stock of the various types of MBIs, Pirard (2012) states that the common thread between them is the assignment of monetary value to nature for transactions. He offers six main categories under which most MBIs can be classified.

Direct markets refer to commodities, for example ES, that are directly available for use to consumers (non-timber forest products, eco-tourism). Tradable permits entail setting an upper limit for the use of a specific resource and creating scarcity (carbon market, EU Emissions Trading Scheme). Reverse auctions have sellers competing amongst themselves in response to public authorities offering remuneration for service provision (PES). Coasean-type agreements are transactions between rights holders for ecosystem goods and services, sellers, and interested parties, buyers, where they can exchange the rights among themselves (PES). Regulatory price changes are policy changes that lead to a change in price of products that have environmental impacts (carbon tax). Voluntary price signals are producers' attempts to communicate the attributes of their goods or services to consumers to increase market competitiveness (eco-labels, certification schemes). Table 1 provides an overview of Pirard's MBI categories.

MBIs are seen as a means to address market failure. PES, through specific framework conditions, could benefit society by securing the supply of ES and even the restoration of ecosystems (Dong et al., 2024). PES has five characteristics that define it (Wunder, 2005). First, it has to be voluntary for the ES provider and seller. Second, the ES being offered needs to be well-defined. Then, there has to be an ES provider and seller. Finally, the payment for the ES provided needs to be conditional upon the fulfillment of specific conditions.

Table 1. MBI categories according to Pirard (2012)

MBI categories	Description
Direct markets	A market where an environmental product can be directly traded between producers and consumers (or processors)
Tradable permits	environmental resource need to purchase ''permits'' that can be further exchanged among resource users, thereby creating artificial scarcity

Reverse auctions	A mechanism whereby candidates to service provision set the level of payment (if accepted) in response to a call by public authorities to remunerate landholders
Coasean-type agreements	Ideally spontaneous transactions (free of public intervention) for an exchange of rights in response to a common interest of the beneficiary and the provider
Regulatory price signals	Consists in regulatory measures that lead to higher or lower relative prices
Voluntary price signals	Consists in schemes whereby producers send a signal to consumers that environmental impacts are positive (in relative terms) and consequently gain a premium on the market price

2.3. Policy integration of MBIs in the Green Deal

Dealing with policy-making challenges that go beyond the confines of recognized policy sectors is known as policy integration (PI) (Meijers & Stead, 2004). These challenges, or issues, encompass a wide-range of topics, for example gender (Howland et al., 2021), that need to be holistically addressed in order to foster a desired change. PI analysis has two general types: vertical and horizontal (Sotirov & Arts, 2018; Teebken et al., 2021). Vertical PI analysis refers to the assessment of policy integration across various levels, for example in politics where one could investigate how well policies are being addressed in the different tiers of government (national to local). Meanwhile, horizontal PI analysis assesses the policy integration across policy sectors (cross-sectoral), for example the measurement of horizontal policy coherence across multiple sectors of government (e.g. Bogers et al., 2022; Fleckenstein, 2024). Horizontal PI is largely underutilized (Candel & Biesbroek, 2016; Nilsson et al., 2012) and is particularly appropriate albeit challenging for environmental topics, which have a tendency to cut across governance “boxes” (Mickwitz & Kivimaa, 2007; Pham-Truffert & Pfund, 2024).

The work of Kettunen et al. (2014) demonstrate another approach to assessing policy integration. The authors ascertain the level of integration of a certain concept, in their context ES and natural capital, based on how explicitly it is embedded in sectoral policy. This was further demonstrated in the work of Neill et al. (2022) in their empirical analysis of Irish national policy regarding the ES concept. In essence, explicit use of relevant terminology in policy documents equates to higher policy integration.

3. Methodology

The next chapter outlines the integrated study design for assessing the level of cross-sectoral policy integration of MBIs and PES in the European Green Deal.

3.1. Data sources

A sample of 130 policy documents was compiled based exclusively on the European Green Deal timeline[1] (see Appendix 1). Data gathering was done on 28.09.2024. The documents were published between December 2019 starting with the presentation of the European Green Deal and end on August 2024 with the entry into force of the Nature Restoration Law. Relevant annexes to the policy documents were included in the analysis, and duplications were duly removed. The sectoral classification of the policy documents was also based on the official EU website and are as follows: climate, energy, agriculture, environment & oceans, finance, industry, and transport. Two documents were unclassified – the Bauhaus and the European Green Deal.

The European Green Deal timeline utilized in this study includes only top-level laws, policies, and strategies. We found hundreds of documents under each policy sector that also refer to the Green Deal but are not included in the timeline. This study is primarily a horizontal policy integration analysis of the main documents to which most others in their respective policy contexts refer to.

3.2. Data collection and analysis

For this analysis, a three-step methodology employing the qualitative content analysis approach by Mayring (2015) was used, specifically the deductive approach which entails the use of predetermined categories for coding. For this paper, this means that, for each level of analysis, a set of coding categories were used which were agreed upon by the authors. First, the policy documents were coded in order to identify which documents show evidence of MBIs. Next, the focus was on which of the MBIs in the previous step explicitly mention ecosystems. Finally, it was determined which of the MBIs would qualify as PES schemes, and which PES characteristics can be found in the documents. Figure 1 provides the overview of the methodological steps.

[1] https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal_en

The coding for the content analysis was conducted using both Microsoft Excel and MaxQDA. This entails searching each policy document for a unique set of keywords. For every keyword found, a citation is extracted from the document. The inclusion of each citation in the study is based on a consensus agreement among the authors.

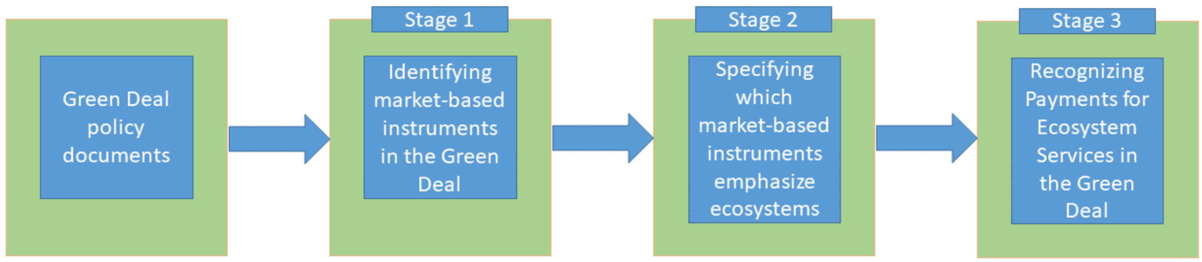

Figure 1. Methodology overview

3.2.1. Stage 1: Identification of market-based instruments in the European Green Deal

The coding for MBIs was guided by the work of Pirard (2012), which was used for identifying and classifying the MBI types in the text. However, acknowledging the work of other scholars on the topic, further relevant literature was included to broaden the analysis. The works of Windle et al. (2005), Stavins (2003), and Prokofieva and Wunder (2014) bolstered the study by widening the range of relevant keywords and widening our understanding of MBIs. With these sources, a list of keywords for each MBI classification was compiled.

Primary examples for direct markets include eco-tourism, non-timber forest products, and genetic sources. Tradable permits pertain mostly to cap-and-trade schemes and related terminologies. For the EU, this is the Emissions Trading Scheme (EU-ETS). PES and competitive tenders and auctions are the keywords for reverse auctions. For Coasean-type agreements, the focus was on PES and related terminology, but was also expanded to include eco-schemes as it is a known PES mechanism under the CAP of the EU. Various taxation schemes and terminologies are the focus for regulatory price signals, but water pricing was included as it is a much used mechanism in the EU. Voluntary price signals pertain to various standards and guidelines for sustainability, as well as keywords referring to awareness raising and education. Table 2 shows an overview of the keywords used for this study.

For this stage, R was used in order to aid with the coding. We wrote a script to search for the keywords in table 2 and all possible permutations of each of them. The full passage of each positive match with the search string was then read and classified according to MBI type. All passages and classifications were discussed and agreed upon by the authors. False positives were then discarded from the analysis. The complete R search string can be found in Appendix 2.

The search for MBIs in the policy documents was non-exhaustive. Not every single mention of MBIs was included in this study. Instead, evidence of each type of MBI for every policy document was sought.

Table 2. Keywords used for searching for market-based instruments

MBI classification according to Pirard (2012)	Keywords
Direct markets	Genetic resources, non-timber forest products, eco-tourism, ecosystem service market/scheme/pricing
Tradable permits	tradable permits and offsets, cap-and-trade schemes, mitigation banking for biodiversity, emission quotas, emissions trading scheme, transferable quotas for fisheries, tradable development rights for land, voluntary carbon markets, offset schemes
Reverse auctions	payments for ecosystem services, competitive tenders and auctions
Coasean-type agreements	payments for ecosystem services, PES-like schemes, conservation easements, conservation concessions, eco-schemes, result-based payments
Regulatory price signals	water pricing, eco-tax, agro-environmental measures, price-based incentives, subsidies and grants, tax exemptions and rebates
Voluntary price signals	Private investments, Voluntary investments, Public-private funds (in connection to ES), Ecosystem service certification, Mitigation Banking, Soft Loans, Definition of Standards and Liability Rules, Public-private management contracts, public procurement schemes, Corporate Social Responsibility, voluntary certification schemes, branding, promotion,

	sponsoring, technical assistance, education and training, consumers' awareness raising
Other terminologies used	Market based measure, market based instrument, instruments for reducing market friction

3.2.2. Stage 2: Identification of MBIs related to ecosystems and ecosystem services

For the next level of analysis, the identified MBIs in the previous step were analyzed for references to ecosystems in its respective text. This step is inspired by the work of Kettunen et al. (2014) and was demonstrated by Neill et al. (2022). There is a differentiation between explicit and implicit use of terminology. The direct use of the term “ecosystem” or “ecosystem services” qualifies it to be classified as explicit. For implicit classification, terms related to both were identified. For ecosystems, naming its different examples, like forests, grasslands, marine, etc., qualifies it as implicit. The same goes for ES. Using the different types of ES, for example air purification, water regulation, carbon sequestration, etc., qualifies it as implicit.

3.2.3. Stage 3: Current use of PES in the European Green Deal

In this final level of analysis, the focus was on the state of PES, as an MBI that inherently emphasizes the importance of ecosystems and the delivery of ES, in the policy documents. The PES characteristics identified by Wunder (2005) were then identified in the Green Deal policy documents. It was determined if the ES providers have the choice to sell ES (or not), if there is a well-defined, specific ES that is to be offered, who are the buyers and sellers, and, finally, if the transaction is conditional. The five guiding questions utilized in this stage are outlined in table 3.

Table 3. The five characteristics of PES

PES characteristics (guiding questions) based on Wunder (2005)
Is it voluntary?
Is there a well-defined ecosystem service?

Is there an ecosystem service buyer?
Is there an ecosystem service provider?
Is it conditional?

4. Results

Our analysis of the European Green Deal policy documents provided insights into the current use of MBIs and the extent to which they translate to ecosystems and FES provision, with a focus on PES.

4.1. MBIs are utilized in the Green Deal

Out of the 130 policy documents harvested from the European Green Deal timeline, 50 of them contained evidence of MBIs. Overall, policy documents containing MBIs were found in six of the seven policy sectors in this study. The communication of the European Green Deal document was not categorized since it is an umbrella document that encompasses all policy sectors. The environment & oceans sector leads with 16 policy documents, 32.7% of all findings. This is followed by the climate and energy sectors with 14 (28.5%) and 11 (22.4%) policy documents respectively. Four documents (8%) were found in the industry sector, while two (4%) each were under the agriculture, and finance & rural development sectors. No MBIs were found in the documents under the transport sector. Figure 2 shows an overview of the results.

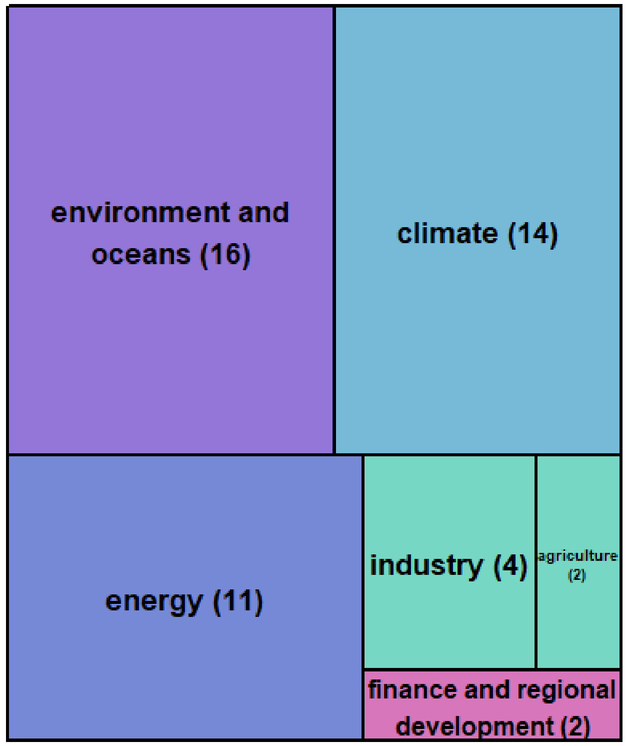

Figure 2. Distribution of policy documents with market-based instruments according to policy sectors

Five out of the six MBI types described by Pirard were found in the policy documents. The environment & oceans sector showcased voluntary price signals, Coasean-type agreements, regulatory price signals, tradable permits, and direct markets. Except for direct markets, the climate and energy sectors also showed the aforementioned MBIs. Meanwhile, the agriculture sector had voluntary price signals, Coasean-type agreements, and regulatory price signals. Finally, the finance & rural development, and industry sectors each had three types of MBIs – voluntary price signals, regulatory price signals, and tradable permits. Table 4 shows the summary of results.

Table 4. Overview of MBI types according to policy sector

MBI Type	**Policy Sector**						
	Environment & oceans	**Climate**	**Energy**	**Agriculture**	**Finance & rural development**	**Industry**	**Transport**
Voluntary price signals	✓	✓	✓	✓	✓	✓	

Coasean-type agreement	✓	✓	✓	✓			
Regulatory price signals	✓	✓	✓	✓	✓	✓	
Tradable permits	✓	✓	✓		✓	✓	
Direct markets	✓						
Reverse auction							

Looking further into the distribution of MBI types, voluntary and regulatory price signals were found in six of the seven policy sectors (no MBIs in the transport sector). Tradable permits were referenced in five of the sectors, the exceptions being agriculture and transport. Meanwhile, Coasean-type agreements were described in four sectors – environment & oceans, climate, energy, and agriculture. Finally, one policy document describing direct markets was found under the environment & oceans sector. No evidence of reverse auction was found. Appendix 3 shows the MBIs found in the Green Deal documents classified according to its respective policy sector.

4.2. Limited number of MBIs address ecosystems

From the 50 policy documents in stage 1 of the analysis, 23 of them showcase MBIs explicitly mentioning ecosystems or ES. The policy documents encompass six of the seven policy sectors outlined in the European Green Deal, namely environment and oceans (14), climate (3), agriculture (2), energy (2), industry (1), and finance and regional development (1). Appendix 4 outlines the policy documents with a direct citation which refers to MBIs, ecosystems and ES, the MBI classification done by the authors, and the policy sector to which each document is classified.

The environment & oceans sector demonstrates the most frequent use of MBIs that refer to ecosystems with 60%. A number of documents here are policies that refer to specific ecosystems such as forests (a new forest monitoring law that aims to improve resilience of European forests) and oceans (Sustainable blue economy), but also topics such as biodiversity and pollination.

The climate sector, with 13% of all documents, is led by the EU Emissions Trading System reform, which targets marine ecosystems. The New EU strategy on adaptation to climate change directly names peatlands, coastal and marine ecosystems and acknowledges the carbon removal benefits that they offer, which would be showcased by the carbon removal certification scheme to help decision-makers.

Both the policy documents under agriculture, which accounts for 9%, refer to the Common Agricultural Policy's (CAP) eco-schemes. The eco-scheme is a voluntary scheme that aims to promote more sustainable agricultural practices for farmers through financial incentives.

The findings in the energy sector are less about ecosystems but more on the provision of ES. The "Guidelines on State aid for climate, environmental protection and energy 2022" calls for the rehabilitation of degraded sites but specifically for ES provision rather than restoration of ecosystems. Similarly, the "actions to accelerate the roll-out of electricity grids" elaborates on permitting schemes that encompass environmental impact assessments. Further investigation has shown that one of the goals of environmental assessments for energy infrastructure is to stop loss of biodiversity and ES.

The lone policy for industry, the Net-Zero Industry Act, specifically states that the environmental assessments for net-zero technologies granting process are included for ecosystems and habitats, biodiversity and others. For finance and regional development, the "Framework to facilitate sustainable investment" outlines six environmental objectives for environmental sustainability. The final objective is on the protection and restoration of biodiversity and ecosystems. Figure 3 further illustrates how the documents are distributed across the policy sectors.

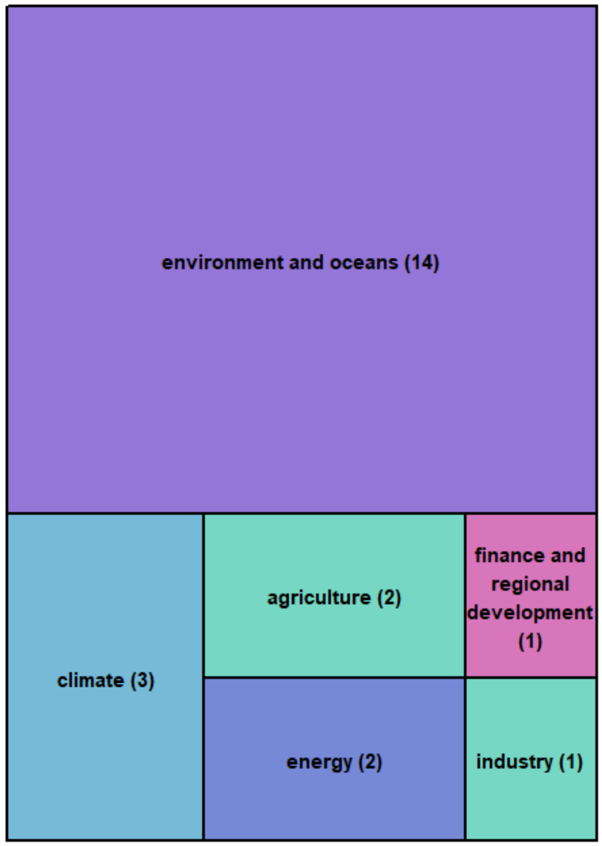

Figure 3. Distribution of policy documents with market-based instruments that refer to ecosystems according to policy sectors

Out of the six types of MBIs, five were described in the Green Deal policy documents being applied in connection with ecosystems. The environment & oceans sector shows evidence of voluntary price signals, Coasean-type agreements, regulatory price signals, tradable permits, and direct markets. This is followed by the climate sector which also showcases those MBIs aside from direct markets. The energy sector illustrates the use of voluntary price signals, Coasean-type agreements, and regulatory price signals. The agriculture, finance & rural development, and industry sectors show only one type of MBI each namely Coasean-type agreements, and regulatory price signals for the latter two. No evidence of MBIs associated with ecosystems was found in the transport sector. Table 5 gives the overview of which MBI type can be found in each policy sector.

Looking at table 5 from another perspective, voluntary price signals shows the highest level of policy integration being shown in five of the seven policy sectors. This is followed by Coasean-type agreements, four, regulatory price signals, three, tradable permits, 2, and direct markets, 1. No evidence was found for reverse auction MBIs. The voluntary price signals here are usually standards or guidelines for activities that could have an impact to ecosystems usually associated with permit and certification schemes. The Coasean-type agreements are mostly associated with the CAP's eco-scheme, which is referenced and supported under several Green Deal policies. The regulatory price signals consist mostly of taxation against for ecosystem-harmful practices. The tradable permits refer to the EU ETS. The lone direct market example comes from new forest monitoring law where forest managers are supported to market the ES being provided by their forests.

Table 5. Overview of MBIs applied to ecosystems according to policy sector

MBI Type	Policy Sector						
	Environment & oceans	**Climate**	**Energy**	**Agriculture**	**Finance & rural development**	**Industry**	**Transport**
Voluntary price signals	✓	✓	✓		✓	✓	
Coasean-type agreement	✓	✓	✓	✓			
Regulatory price signals	✓	✓	✓				
Tradable permits	✓	✓					
Direct markets	✓						
Reverse auction							

4.3. PES is present in the Green Deal

From the 23 Green Deal policy documents that contain MBIs that reference ecosystems, 11 describe Coasean-type agreements, particularly, PES. Most of the policies fall under the environment & oceans policy sector (7), followed by agriculture (2), then climate (1), and energy (1).

All 11 documents prescribe PES schemes voluntarily. Meaning that no ES providers are forced to implement or use the scheme.

There are considerable discrepancies in terms of ES identification. More than half, six, do not sufficiently define which ES are being targeted by the PES scheme. Four of the six, however, indirectly target ES provision through other means, e.g. carbon sequestration through carbon farming (Farm to Fork strategy and New EU strategy on adaptation to climate change), ES provision through soil health (Soil Monitoring Law), and ES provision in general through ecosystem improvement (Guidelines on State aid for climate, environmental protection and energy 2022). Out of the five documents that do clearly define the ES being targeted by PES, four of them refer to biodiversity (Organic action plan, A new deal for pollinators, Nature restoration law, targeted review of Common Agricultural Policy to support EU farmers), while the fifth mentions carbon sequestration (Commission proposals to remove, recycle and sustainably store carbon).

The EU Commission and EU Member States were identified as the ES buyer in nine out of the 11 documents, all of which refer to the CAP's eco-schemes as their main mechanism for PES. The New EU strategy on adaptation to climate change and the soil monitoring law refer to the possibility of ES buyers being public or private entities.

In nine policy documents, farmers are identified as the ES sellers. Under the Commission proposals to remove, recycle and sustainably store carbon and Soil Monitoring Law, forest managers are identified as ES sellers alongside farmers. The Zero pollution action plan identifies no specific ES seller. The Guidelines on State aid for climate, environmental protection and energy 2022 is vague in that it identifies projects that restore ecosystems as potential ES sellers.

All 11 policy documents state that the PES scheme within their respective frameworks is conditional. Table 6 provides an overview of the findings regarding PES characteristics found in the policy documents.

Table 6. PES characteristics of Coasean-type agreements in Green Deal policy documents

Policy Sector	CN	Document	Is it voluntary?	Is there a well-defined ES?	Is there an ES buyer?	Is there an ES provider?	Is it conditional?
Environment & oceans	9	EU Biodiversity Strategy for 2030	Yes	No	The commission and member states	Farmers	Yes
	19	Organic action plan	Yes	Biodiversity, habitat, landscapes	The commission and member states	Farmers	Yes
	20	Zero pollution action plan	Yes	No	The commission and member states	No	Yes
	39	Commission proposals to remove, recycle and sustainably store carbon	Yes	Carbon sequestration	public or private	Land managers (e.g. farmers and forest holders/foresters)	Yes
	59	A New Deal for Pollinators	Yes	Pollinator (biodiversity) conservation	The commission and member states	Farmers	Yes
	88	Soil Monitoring Law	Yes	No (indirectly: soil health which in turn supports ES)	Public or private (indirectly indicated through the Carbon	Farmers, forest holders, land managers (indirectly	Yes (indirectly indicated

					Removal Framework Certification (CRFC))	indicated through the CRFC)	through the CRFC)
	130	Nature restoration law	Yes	Biodiversity, ecosystem services in general, habitat	The commission and member states	Farmers	Yes
Agriculture	8	Farm to Fork strategy	Yes	No (indirectly: carbon sequestration through carbon farming)	The commission and member states	Farmers	Yes
	122	targeted review of Common Agricultural Policy to support EU farmers	Yes	Biodiversity, ecosystem services in general, habitat	Member States	Farmers	Yes
Climate	18	New EU strategy on adaptation to climate change	Yes	No (indirectly: carbon sequestration through carbon farming)	The commission and member states	Farmers	Yes
Energy	73	Guidelines on State aid for climate, environmental	Yes	No (on ecosystem improvement, not on ecosystem services)	Member States finance through State Aid	All projects with measures that	Yes

		protection and energy 2022				restore ecosystems	

5. Discussion

The European Green Deal set out the objective of achieving climate neutrality for European Union by 2050. This study explores the idea of using MBIs for preserving and restoring ecosystems, which is a primary objective of the Green Deal for transforming the EU's economy towards sustainability. It focuses on the top-most, umbrella policies outlined by the Green Deal timeline.

5.1. Discussion of findings

Market-based Instruments

In this investigation, it was found that out of the 50 policy documents that contain MBIs, only 23 of them explicitly mention its application on ecosystems or ES, with 17 of those belonging to the environment & oceans and climate sectors. This indicates a lack of cross-sectoral policy integration for utilizing MBIs for ecosystem preservation and restoration. There are several studies that show how MBIs could contribute to ecosystem and biodiversity conservation as part of a policy mix (e.g. Ranjan, 2024; Sponagel et al., 2024). It can be argued that, in the interest of policy coherence, MBIs across all policy sectors should be more aligned with the ecosystem-related objectives of the Green Deal by emphasizing how each can contribute to its preservation and restoration. In line with this, the European Commission has guidelines on the integration of ecosystems into decision-making that encompasses the policy sectors discussed in this paper as well as the private sector (EU Guidance on Integrating Ecosystems and Their Services into Decision-Making, 2019). This document also endorses designing MBIs to better include the topic of ecosystems.

The emphasis on ecosystems is rooted upon the rationale that human well-being, and by extension human society, is dependent upon its functioning and delivery of goods and services (Millennium Ecosystem Assessment (Program), 2005). The latest assessments indicate that ecosystems are still deteriorating at an alarming rate globally, and economic instruments, for example harmful subsidies, are still having negative effects on nature (IPBES, 2019). As such, the connection between MBIs and ecosystems across policy sectors should be strengthened. In line with this, the state of PES in the Green Deal was also investigated.

Payments for Ecosystem Services

Out of the 23 Green Deal policy documents that mention ecosystems and ES, only 11 refer to PES, with 8 of those belonging to the environment & oceans and climate sectors. This indicates that the concept has yet to gain widespread acceptance across policy sectors. PES is a means of addressing market failure. It does this by assigning an economic value to non-market ES, for example water regulation or aesthetics, thereby making their provisioning financially valuable. Its implementation could be transformative for the management of ecosystems.

In the case of forest ecosystems, for example, many ES are public goods and have no economic value (Nichiforel et al., 2018). This has led to timber production being the primary source of revenue for forest owners, influencing how forests are managed (Lovrić et al., 2025). An example of this would be the prevalence of monoculture forest plantations that are primed for the lucrative timber industry. However financially rewarding they maybe, monoculture forests may cause soil degradation, disrupt the hydrological cycle and be susceptible to pests and diseases, while mixed-species forests enhance certain ES such as carbon sequestration (Liu et al., 2018). However, there is still a lack of attention given to carbon sequestration and other regulating ES, as well as cultural ES from forests (Mann et al., 2022), which also have stakeholders depending on their provision. As failing to address the varying ES needs of forest stakeholders could lead to conflicts (Garcia et al., 2025), utilizing PES to address this market failure could contribute to promoting sustainability.

It should be emphasized, however, that there is not one policy instrument that can solve all sustainability problems. MBIs should be applied in the appropriate context and policy mix in order to maximize its effectiveness, in concert with other instruments such as command-and-control (Alt et al., 2024; Beiser-McGrath et al., 2023). That said, and in the interest of policy harmonization, more could be done to align MBIs with ecosystem preservation and restoration across all policy sectors being that it is one of the objectives of the Green Deal. The policy documents discussed in this study are supposed to be "umbrella" policies under which other subsequent policies align themselves to. As such, the potential far-reaching impact of including ecosystems in the application of MBIs cannot be understated.

5.2. Discussion of study design & further research recommendations

This horizontal cross-sectoral policy integration investigation allows for a coherent overview of the Green Deal policy landscape across multiple sectors. Concentrating on top-level policies upon which all others should orient themselves also provides for an indication of their respective policy objectives. For this study, it was useful for gaining orientation for assessing the level of policy integration of MBIs and PES in the Green Deal policy landscape. However, it is, by design, limited in terms of sectoral analysis. The focus of the investigation was on the policies contained in the Green Deal timeline, which meant excluding several documents under each respective sector that are relevant to MBIs and ecosystems. Under the environment and agricultural sectors, for example, are the Water Directive Framework, several CAP-related regulations, Urban Agenda Action Plan, and numerous other that could enrich the discussion on the topic. The decision to limit the scope was due to the challenge of covering thousands of policy documents spread across numerous administrative levels.

For further research, it is therefore recommended to conduct a vertical PI analysis for each of the policy sectors. This would determine if MBIs connected to ecosystems are elsewhere to be found in each sector's respective policy landscape. If indications are found in other sectoral documents, we argue that the topic of utilizing MBIs for ecosystem preservation and restoration should be brought more into the forefront of policy discourse and should be recognized as a primary cross-sectoral objective.

Further research could also be done in designing MBIs to address ecosystems. Each of the six types of MBIs discussed in this study offer unique possibilities in terms of their respective parameters, applications, and monitoring and evaluation. A nuanced investigation into this would advance the discussion on using MBIs for this purpose, but should also address the need to contextualize its use in the appropriate policy mix.

6. Conclusion

This study sought to investigate the policy documents outlined in the European Green Deal timeline with the aim of assessing the cross-sectoral policy integration (PI) of market-based instruments (MBI), especially Payments for Ecosystem Services (PES), that have a connection to ecosystems. It was found that more can be done to mainstream the introduction of MBIs and PES that contribute to ecosystem preservation and restoration in the policy mix across policy sectors. There is a need to create platforms for practitioners to exchange on their experiences on MBI and PES design and implementation in order to foster the wider use of these instruments. This work contributes to the sustainability discourse in Europe by highlighting the level of integration not just of MBIs, but specifically MBIs that emphasize ecosystems in the Green Deal. With the recent approval of the Nature Restoration Law, this study is timely in that it shows a way forward for aligning MBIs to ecosystem restoration. This study is limited in that it is a horizontal PI analysis and, by design, does not go in depth into each policy sector. In line with this, future research can be done towards conducting vertical PI analysis for each of the policy sectors, and investigating how each MBI type can be designed to further emphasize ecosystems in their application.

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8. Appendix

8.1. Appendix 1. Full list of European Green Deal policy documents included in the study

Control Number	Document	Year	Source
1	European Green Deal	2019	https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52019DC0640
1-A	European Green Deal Annex	2019	https://eur-lex.europa.eu/resource.html?uri=cellar:b828d165-1c22-11ea-8c1f-01aa75ed71a1.0002.02/DOC_2&format=PDF
2	European Green Deal Investment Plan	2020	https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52020DC0021
3	Proposal for Just Transition Mechanism	2020	https://ec.europa.eu/commission/presscorner/detail/en/fs_20_50
4	European climate law	2021	https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32021R1119
5	European climate pact	2020	https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52020DC0788
6	European Industrial Strategy	2020	https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52020DC0102
7	Circular Economy Action Plan	2020	https://eur-lex.europa.eu/resource.html?uri=cellar:9903b325-6388-11ea-b735-01aa75ed71a1.0017.02/DOC_1&format=PDF
7-A	Annex Circular Economy Action Plan	2020	https://eur-lex.europa.eu/resource.html?uri=cellar:9903b325-6388-11ea-b735-01aa75ed71a1.0017.02/DOC_2&format=PDF
8	Farm to fork strategy	2020	https://eur-lex.europa.eu/resource.html?uri=cellar:ea0f9f73-9ab2-11ea-9d2d-01aa75ed71a1.0001.02/DOC_1&format=PDF
9	EU Biodiversity Strategy for 2030	2020	https://eur-lex.europa.eu/resource.html?uri=cellar:a3c806a6-9ab3-11ea-9d2d-01aa75ed71a1.0001.02/DOC_1&format=PDF
9-A	Annex-EU Biodiversity Strategy for 2030	2020	https://eur-lex.europa.eu/resource.html?uri=cellar:a3c806a6-9ab3-11ea-9d2d-01aa75ed71a1.0001.02/DOC_2&format=PDF

10	Powering a climate-neutral economy: An EU Strategy for Energy System Integration	2020	https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52020DC0299
11	A hydrogen strategy for a climate-neutral Europe	2020	https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52020DC0301
12	Renovation Wave	2020	https://eur-lex.europa.eu/resource.html?uri=cellar:0638aa1d-0f02-11eb-bc07-01aa75ed71a1.0003.02/DOC_1&format=PDF
13	Methane Strategy	2020	https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52020DC0663
14	Chemical strategy for sustainability	2020	https://eur-lex.europa.eu/resource.html?uri=cellar:f815479a-0f01-11eb-bc07-01aa75ed71a1.0003.02/DOC_1&format=PDF
15	Offshore renewable energy	2020	https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52020DC0741
16	European Battery Alliance - concerning batteries and waste batteries	2020	https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:52020PC0798
17	New European Bauhaus	2021	https://new-european-bauhaus.europa.eu/system/files/2021-09/COM%282021%29_573_EN_ACT.pdf
18	New EU strategy on adaptation to climate change	2021	https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52021DC0082
19	Organic Action Plan – An organic plan for the development of organic production	2021	https://eur-lex.europa.eu/resource.html?uri=cellar:ebb94528-8d5b-11eb-b85c-01aa75ed71a1.0001.02/DOC_1&format=PDF
20	Zero pollution Action Plan	2021	https://eur-lex.europa.eu/resource.html?uri=cellar:a1c34a56-b314-11eb-8aca-01aa75ed71a1.0001.02/DOC_1&format=PDF
21	Sustainable blue economy	2021	https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52021DC0240
22	3 billion trees factsheet	2021	https://commission.europa.eu/publications/delivering-european-green-deal_en
23	Architecture Factsheet	2021	https://commission.europa.eu/publications/delivering-european-green-deal_en

24	Buildings Factsheet	2021	https://commission.europa.eu/publications/delivering-european-green-deal_en
25	CBAM factsheet	2021	https://commission.europa.eu/publications/delivering-european-green-deal_en
26	EGD brochure	2021	https://commission.europa.eu/publications/delivering-european-green-deal_en
27	Energy System Factsheet	2021	https://commission.europa.eu/publications/delivering-european-green-deal_en
28	ETD factsheet	2021	https://commission.europa.eu/publications/delivering-european-green-deal_en
29	Europe's 2030 climate and energy targets	2021	https://commission.europa.eu/publications/delivering-european-green-deal_en
30	FF55 Delivering On The Proposals Factsheet	2021	https://commission.europa.eu/publications/delivering-european-green-deal_en
31	Hydrogen Factsheet	2021	https://commission.europa.eu/publications/delivering-european-green-deal_en
32	Industry Factsheet	2021	https://commission.europa.eu/publications/delivering-european-green-deal_en
33	Nature Factsheet	2021	https://commission.europa.eu/publications/delivering-european-green-deal_en
34	Social factsheet	2021	https://commission.europa.eu/publications/delivering-european-green-deal_en
35	Transport Factsheet	2021	https://commission.europa.eu/publications/delivering-european-green-deal_en
36	Proposal for a Regulation on deforestation-free products	2021	https://environment.ec.europa.eu/document/download/5f1b726e-d7c4-4c51-a75c-3f1ac41eb1f8_en?filename=COM_2021_706_1_EN_ACT_part1_v6.pdf
36-A	Annexes to the Proposal for a Regulation on deforestation-free products	2021	https://environment.ec.europa.eu/document/download/7d6df0b5-6373-4ee1-9a31-e557d5bb842d_en?filename=COM_2021_706_1_EN_annexe_proposition_part1_v4.pdf
37	Proposal for a new Regulation on waste shipments	2021	https://environment.ec.europa.eu/document/download/aa0c5923-78fe-4a9d-b2ca-be95541d7e33_en?filename=proposal-for-a-new-regulation-on-waste-shipments_0.pdf

37-A	Annexes to the Proposal for a new Regulation on waste shipments	2021	https://environment.ec.europa.eu/document/download/d56e6377-27b4-4813-91f1-de64a03332ca_en?filename=proposal-for-a-new-regulation-on-waste-shipments-annexes.pdf
38	New transport proposals target greater efficiency and more sustainable travel	2021	https://eur-lex.europa.eu/resource.html?uri=cellar:7b299e69-5dc8-11ec-9c6c-01aa75ed71a1.0001.02/DOC_1&format=PDF
39	Commission proposals to remove, recycle and sustainably store carbon	2021	https://climate.ec.europa.eu/document/download/26c00a03-41b0-4d35-b670-fca56d0e5fd2_en
40	REPowerEU: Joint European action for more affordable, secure and sustainable energy	2022	https://eur-lex.europa.eu/resource.html?uri=cellar:71767319-9f0a-11ec-83e1-01aa75ed71a1.0001.02/DOC_1&format=PDF
41	Options to mitigate high energy prices with common gas purchases and minimum gas storage obligations	2022	https://eur-lex.europa.eu/resource.html?uri=cellar:2f3116bc-aaa3-11ec-83e1-01aa75ed71a1.0001.02/DOC_1&format=PDF
42	Proposals to make sustainable products the norm in the EU, boost circular business models and empower consumers for the green transition	2022	https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52022DC0140
43	Proposals to modernise EU industrial emissions rules to steer large industry in long-term green transition	2022	https://eur-lex.europa.eu/resource.html?uri=cellar:6a2e6b16-b5a9-11ec-b6f4-01aa75ed71a1.0001.02/DOC_1&format=PDF
44	Proposals to phase down fluorinated greenhouse gases and ozone depleting substances	2022	https://eur-lex.europa.eu/resource.html?uri=cellar:ecf2b875-b59f-11ec-b6f4-01aa75ed71a1.0001.02/DOC_1&format=PDF
44-A	Annex to Proposals to phase down fluorinated greenhouse gases and ozone depleting substances	2022	https://eur-lex.europa.eu/resource.html?uri=cellar:ecf2b875-b59f-11ec-b6f4-01aa75ed71a1.0001.02/DOC_2&format=PDF

45	REPowerEU plan: affordable, secure and sustainable energy for Europe	2022	https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:52022DC0230
46	Save gas for a safe winter' proposal	2022	https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52022PC0361
47	Proposal for an emergency market intervention to reduce energy bills for Europeans	2022	https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52022PC0473
48	Commission proposes stronger rules for cleaner Water	2022	https://environment.ec.europa.eu/document/download/6e618dec-c528-4ba8-8900-1e020eefe393_en?filename=Proposal%20for%20a%20Directive%20amending%20the%20Water%20Framework%20Directive%2C%20the%20Groundwater%20Directive%20and%20the%20Environmental%20Quality%20Standards%20Directive.pdf
49	Commission proposes stronger rules for cleaner Wastewater	2022	https://environment.ec.europa.eu/document/download/a936c2d5-2e3a-4eb1-a7c6-41ec98f3e72f_en?filename=Proposal%20for%20a%20Directive%20concerning%20urban%20wastewater%20treatment%20%28recast%29.pdf
50	Commission proposes stronger rules for cleaner Air	2022	https://eur-lex.europa.eu/resource.html?uri=cellar:2ae4a0cc-55f8-11ed-92ed-01aa75ed71a1.0001.02/DOC_3&format=PDF
51	Action plan against wildlife trafficking	2022	https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52022DC0581
52	Proposal for new Euro 7 standards to reduce pollutant emissions from vehicles and improve air quality	2022	https://ec.europa.eu/commission/presscorner/detail/en/ip_22_6495
52-A	Annex to Euro 7 standards	2022	https://ec.europa.eu/commission/presscorner/detail/en/ip_22_6495
53	EU Algae Initiative	2022	https://oceans-and-fisheries.ec.europa.eu/document/download/4d5a28c9-8720-45e7-84f0-b1d076d60a60_en?filename=COM-2022-592_en.pdf

54	Proposal for a first EU-wide voluntary framework to reliably certify high-quality carbon removals	2022	https://climate.ec.europa.eu/document/download/fad4a049-ff98-476f-b626-b46c6afdded3_en?filename=Proposal_for_a_Regulation_establishing_a_Union_certification_framework_for_carbon_removals.pdf
55	Circular Economy: Packaging and Packaging Waste Regulation	2022	https://eur-lex.europa.eu/resource.html?uri=cellar:de4f236d-7164-11ed-9887-01aa75ed71a1.0001.02/DOC_1&format=PDF
56	EU agrees law to fight global deforestation and forest degradation driven by EU production and consumption	2021	https://environment.ec.europa.eu/publications/proposal-regulation-deforestation-free-products_en
56-A	Annex EU agrees law to fight global deforestation and forest degradation driven by EU production and consumption	2021	https://environment.ec.europa.eu/publications/proposal-regulation-deforestation-free-products_en
57	New rules on applying the EU emissions trading system in the aviation sector	2021	https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52021PC0552
58	Social Climate Fund	2021	https://eur-lex.europa.eu/resource.html?uri=cellar:9e77b047-e4f0-11eb-a1a5-01aa75ed71a1.0001.02/DOC_3&format=PDF
58-A	Annex Social Climate Fund	2021	https://eur-lex.europa.eu/resource.html?uri=cellar:9e77b047-e4f0-11eb-a1a5-01aa75ed71a1.0001.02/DOC_4&format=PDF
59	A New Deal for Pollinators	2021	https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52023DC0035
60	Green Deal Industrial Plan	2023	https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52023DC0062
61	Rules for renewable hydrogen part 1	2023	https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32023R1184
62	Rules for renewable hydrogen part 2	2023	https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32023R1185
63	Proposal 2030 zero-emissions target for new city buses and 90% emissions reductions for new trucks by 2040	2023	https://climate.ec.europa.eu/document/download/d22bdaca-102f-4ce7-aa8a-1399ddba359d_en?filename=policy_transport_hdv_20230214_proposal_en.pdf

63-A	Annex proposal 2030 zero-emissions target for new city buses and 90% emissions reductions for new trucks by 2040	2023	https://climate.ec.europa.eu/document/download/76ba42bc-27a1-447d-8194-a69496ce8686_en?filename=policy_transport_hdv_20230214_annexes_en.pdf
64	The common fisheries policy today and tomorrow: a Fisheries and Oceans Pact towards sustainable, science-based, innovative and inclusive fisheries management	2023	https://oceans-and-fisheries.ec.europa.eu/document/download/c0fb4dfe-7769-456a-8c2c-436c99ed2d10_en?filename=COM-2023-103_en.pdf
65	SWD/2023/103 Common Fisheries Policy - State of play	2023	https://oceans-and-fisheries.ec.europa.eu/document/download/a4538bac-753f-4a7b-93cd-0e9b33238242_en?filename=SWD-2023-103_en_0.pdf
66	Communication on the Energy Transition of the EU Fisheries and Aquaculture sector	2023	https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52023DC0100
67	Action Plan to protect and restore marine ecosystems for sustainable and resilient fisheries	2023	https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52023DC0102
68	Communication on the common fisheries policy today and tomorrow	2023	https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52023DC0103
69	Report on the Common Market Organisation for fishery and aquaculture products.	2023	https://oceans-and-fisheries.ec.europa.eu/document/download/4db2971d-0289-49a3-9e8c-d4d3437b589a_en?filename=COM-2023-101_en.pdf
70	Communication from the Commission EU Action Plan Protecting and restoring marine ecosystems for fisheries	2023	https://ec.europa.eu/commission/presscorner/detail/en/ip_23_828
71	Establishment and operation of a market stability reserve for the Union greenhouse gas emission trading scheme and Regulation (EU) 2015/757	2023	https://eur-lex.europa.eu/resource.html?uri=cellar:618e6837-eec6-11eb-a71c-01aa75ed71a1.0001.02/DOC_1&format=PDF

72	Electricity Market Design revision: Proposal to amend the Electricity Market Design rules	2023	https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52023PC0148
73	Guidelines on State aid for climate, environmental protection and energy 2022	2022	https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52022XC0218(03)
74	Electricity Market Design revision: Proposal to amend the Wholesale Energy Market Integrity and Transparency (REMIT) Regulation	2023	https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52023PC0147
75	Net-Zero Industry Act	2023	https://eur-lex.europa.eu/resource.html?uri=cellar:6448c360-c4dd-11ed-a05c-01aa75ed71a1.0001.02/DOC_1&format=PDF
75-A	Annex Net-Zero Industry Act	2023	https://eur-lex.europa.eu/resource.html?uri=cellar:6448c360-c4dd-11ed-a05c-01aa75ed71a1.0001.02/DOC_2&format=PDF
76	Critical Raw Materials Act	2023	https://eur-lex.europa.eu/resource.html?uri=cellar:903d35cc-c4a2-11ed-a05c-01aa75ed71a1.0001.02/DOC_1&format=PDF
76-A	Annex Critical Raw Materials Act	2023	https://eur-lex.europa.eu/resource.html?uri=cellar:903d35cc-c4a2-11ed-a05c-01aa75ed71a1.0001.02/DOC_2&format=PDF
77	New proposal on common rules promoting the repair of goods	2023	https://eur-lex.europa.eu/resource.html?uri=cellar:cdbeaa83-c94e-11ed-a05c-01aa75ed71a1.0001.02/DOC_1&format=PDF
77-A	Annex new proposal on common rules promoting the repair of goods	2023	https://eur-lex.europa.eu/resource.html?uri=cellar:cdbeaa83-c94e-11ed-a05c-01aa75ed71a1.0001.02/DOC_2&format=PDF
78	Consumer protection: enabling sustainable choices and ending greenwashing	2023	https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52023PC0166

79	Cutting maritime transport emissions by promoting sustainable fuels for shipping	2023	https://eur-lex.europa.eu/resource.html?uri=cellar:078fb779-e577-11eb-a1a5-01aa75ed71a1.0001.02/DOC_1&format=PDF
79-A	Annex Cutting maritime transport emissions by promoting sustainable fuels for shipping	2023	https://eur-lex.europa.eu/resource.html?uri=cellar:078fb779-e577-11eb-a1a5-01aa75ed71a1.0001.02/DOC_2&format=PDF
80	Revise the existing marketing standards of agri-food products	2023	https://ec.europa.eu/transparency/documents-register/detail?ref=COM(2023)201&lang=en
81	Revision of the ETS Directive	2023	https://data.consilium.europa.eu/doc/document/PE-9-2023-INIT/en/pdf
82	Amendment of the MRV shipping Regulation	2023	https://data.consilium.europa.eu/doc/document/PE-10-2023-INIT/en/pdf
83	Revision of the ETS Aviation Directive	2023	https://data.consilium.europa.eu/doc/document/PE-8-2023-INIT/en/pdf
84	Regulation establishing a Social Climate Fund	2023	https://data.consilium.europa.eu/doc/document/PE-11-2023-INIT/en/pdf
85	Regulation establishing a Carbon Border Adjustment Mechanism	2023	https://data.consilium.europa.eu/doc/document/PE-7-2023-INIT/en/pdf
86	The European Parliament and the Council reach a political agreement on the ReFuelEU Aviation proposal	2023	https://eur-lex.europa.eu/resource.html?uri=cellar:00c59688-e577-11eb-a1a5-01aa75ed71a1.0001.02/DOC_1&format=PDF
87	Revision of the Energy Labelling Regulation	2023	https://single-market-economy.ec.europa.eu/document/download/bd4c1891-8a8a-4afa-9335-e0977268945a_en?filename=C_2023_1672_1_EN_ACT_part1_v7.pdf
88	Soil Monitoring Law	2023	https://eur-lex.europa.eu/resource.html?uri=cellar:01978f53-1b4f-11ee-806b-01aa75ed71a1.0001.02/DOC_1&format=PDF
88-A	Soil Monitoring Law annex	2023	https://eur-lex.europa.eu/resource.html?uri=cellar:01978f53-1b4f-11ee-806b-01aa75ed71a1.0001.02/DOC_2&format=PDF

89	New techniques in biotechnology	2023	https://food.ec.europa.eu/document/download/c03805a6-4dcc-42ce-959c-e4d609010fa3_en?filename=gmo_biotech_ngt_proposal_2023-411_en.pdf
90	Plant reproductive Material	2023	https://eur-lex.europa.eu/resource.html?uri=cellar:02951036-1cac-11ee-806b-01aa75ed71a1.0001.02/DOC_1&format=PDF
91	Forest reproductive material	2023	https://eur-lex.europa.eu/resource.html?uri=cellar:d36ab0dd-1c06-11ee-806b-01aa75ed71a1.0001.02/DOC_1&format=PDF
91-A	Forest reproductive material Annex	2023	https://eur-lex.europa.eu/resource.html?uri=cellar:d36ab0dd-1c06-11ee-806b-01aa75ed71a1.0001.02/DOC_2&format=PDF
92	EU Strategy for Sustainable and Circular Textiles	2023	https://environment.ec.europa.eu/document/download/74126c90-5cbf-46d0-ab6b-60878644b395_en?filename=COM_2022_141_1_EN_ACT_part1_v8.pdf
93	Measures to make freight transport more efficient and sustainable, by improving rail infrastructure management, offering stronger incentives for low-emission lorries, and better information on freight transport greenhouse gas emissions	2023	https://transport.ec.europa.eu/document/download/9393e22e-72ee-440d-a983-e2ee116e11ba_en?filename=COM_2023_443_0.pdf
94	An initiative to enhance the circularity of the automotive sector	2023	https://eur-lex.europa.eu/resource.html?uri=cellar:8e016dde-215c-11ee-94cb-01aa75ed71a1.0001.02/DOC_1&format=PDF
95	Transitional phase of the Carbon Border Adjustment Mechanism (CBAM)	2023	https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32023R0956
96	EU Emissions Trading System reform (including Market Stability Reserve, maritime and separate ETS system for buildings and road transports)	2023	https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32023L0959
97	Social Climate Fund	2023	https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32023R0955

98	Revised EU Emission Trading System for aviation	2023	https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32023L0958
99	Notification on the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA)	2023	https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32023D0136
100	Monitoring, Reporting and Verification (MRV) Maritime Regulation	2023	https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32023R0957
101	Effort Sharing Regulation (ESR)	2023	https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32023R0857
102	Land Use, Land Use Change and Forestry Regulation (LULUCF)	2023	https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32023R0839
103	Renewable Energy Directive	2023	https://data.consilium.europa.eu/doc/document/PE-36-2023-INIT/en/pdf
104	Energy Efficiency Directive	2023	https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32023L1791
105	CO2 emission standards for new cars and vans	2023	https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32023R0851
106	Alternative Fuels Infrastructure Regulation (AFIR)	2023	https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32023R1804
107	ReFuelEU Aviation Regulation	2023	https://data.consilium.europa.eu/doc/document/PE-29-2023-INIT/en/pdf
108	FuelEU Maritime Regulation	2023	https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32023R1805
109	European Wind Power Action Plan	2023	https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52023DC0669
110	A new forest monitoring law that aims to improve resilience of European forests	2023	https://ec.europa.eu/transparency/documents-register/detail?ref=COM(2023)728&lang=en
111	Actions to accelerate the roll-out of electricity grids	2023	https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52023DC0757

111-Footnote	"Streamlining environmental assessment procedures for energy infrastructure Projects of Common Interest (PCIs)"	2012	https://energy.ec.europa.eu/document/download/0c682e37-7e10-4812-b5ef-a81abe89835f_en?filename=20130919_pci-en-guidance.pdf
112	Modernising management of industrial emissions	2023	https://eur-lex.europa.eu/resource.html?uri=cellar:6a2e6b16-b5a9-11ec-b6f4-01aa75ed71a1.0001.02/DOC_1&format=PDF
113	Global Pledge on Renewables and Energy Efficiency	2023	https://energy.ec.europa.eu/document/download/33f1a6a1-10be-45dc-80fd-4cf1c98fea4d_en?filename=Global_Renewables_and_Energy_Efficiency_Pledge.pdf
114	Improving classification, labelling and packaging of hazardous chemicals	2023	https://environment.ec.europa.eu/document/download/13dc2e9b-15b2-47cb-bf97-fd7af56a13d9_en?filename=Proposal%20for%20a%20Regulation%20amending%20Regulation%20%28EC%29%20No%2012722008.pdf
115	Promotion of energy from renewable resources	2023	https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=OJ:L_202302413
116	Political agreement on strong EU targets to reduce CO2 emissions from new trucks and urban buses	2023	https://eur-lex.europa.eu/resource.html?uri=cellar:4a3b2136-ad3e-11ed-8912-01aa75ed71a1.0001.02/DOC_1&format=PDF
117	Common rules to promote the repair of goods for consumers	2023	https://eur-lex.europa.eu/resource.html?uri=cellar:cdbeaa83-c94e-11ed-a05c-01aa75ed71a1.0001.02/DOC_1&format=PDF
117-A	Annex common rules to promote the repair of goods for consumers	2023	https://eur-lex.europa.eu/resource.html?uri=cellar:cdbeaa83-c94e-11ed-a05c-01aa75ed71a1.0001.02/DOC_2&format=PDF
118	Inclusion of greenhouse gas emissions and removals from land use, land use change and forestry in the 2030 climate and energy framework Consolidated Text	2023	https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:02018R0841-20230511
119	Energy Taxation Directive	2021	https://eur-lex.europa.eu/resource.html?uri=cellar:1b01af2a-e558-11eb-a1a5-01aa75ed71a1.0001.02/DOC_1&format=PDF

120	Recommendation for 2040 emissions reduction target to set the path to climate neutrality in 2050	2024	https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52024DC0063
121	EU Industrial Carbon Management Strategy	2024	https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52024DC0062
122	Targeted review of Common Agricultural Policy to support EU farmers	2024	https://ec.europa.eu/transparency/documents-register/detail?ref=COM(2024)139&lang=en
123	Directive on empowering consumers for the green transition	2024	https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=OJ:L_202400825
124	Principles on limiting most harmful chemicals to essential uses	2024	https://op.europa.eu/en/publication-detail/-/publication/90926c62-0365-11ef-a251-01aa75ed71a1/language-en
125	Regulation on CO2 emission standards for heavy-duty vehicles	2024	https://data.consilium.europa.eu/doc/document/PE-29-2024-REV-1/en/pdf
126	Right-to-repair directive	2023	https://data.consilium.europa.eu/doc/document/ST-7767-2023-INIT/en/pdf
127	Net-zero industry act	2024	https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=OJ:L_202401735
128	Directive on repair of goods	2024	https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=OJ:L_202401799
129	Framework to facilitate sustainable investment	2020	https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32020R0852
130	Nature restoration law	2024	https://data.consilium.europa.eu/doc/document/PE-74-2023-REV-1/en/pdf

8.2. Appendix 2: R search string

“Market based instrument”, “market based instrument”, “Market-based instrument”, “market-based instrument”, “Market based measure”, “market based measure”, “Market-based measure”, “market-based measure”, “Market-based”, “market-based”, “Market based”, “market based”, “Private investment”, “private investment”, “investment”, “Voluntary investment”, “voluntary investment”, “investment”, “Investment”, “Public-private fund”, “public-private fund”, “Public private fund”, “public private fund”, “Public-private”, “public-private”, “Public private”, “public private”, “Private-public”, “private-public”, “private public”, “Private public”, “Water pricing”, “water pricing”, “water”, “Water”, “Pricing”, “pricing”, “Price”, “price”, “Certificate”, “certificate”, “certification”, “Certification”, “Ecosystem service”, “ecosystem service”, “scheme”, “Scheme”, “Result-based payment”, “result-based payment”, “Results-based”, “results-based”, “results based”, “Results based”, “Result based”, “result based”, “result”, “Result”, “Ecoscheme”, “ecoscheme”, “Eco-scheme”, “eco-scheme”, “Eco scheme”, “eco scheme”, “scheme”, “Scheme”, “Permits and offsets”, “permit”, “offset”, “Mitigation banking”, “mitigation banking”, “Mitigate”, “mitigate”, “Bank”, “bank”, “Cap-and-trade”, “Cap and trade”, “cap-and-trade”, “cap and trade”, “Offset”, “offset”, “Price-based”, “price-based”, “Price based”, “price based”, “Subsidies”, “subsidies”, “subsidy”, “Subsidy”, “Grant”, “grant”, “Subsidies and grants”, “subsidies and grants”, “Tax exemption”, “tax exemption”, “Rebate”, “rebate”, “Soft loan”, “soft loan”, “Tender”, “tender”, “auction”, “Auction”, “Market friction”, “market friction”, “Standard”, “Liability”, “standard”, “liability”, “PES”, “PES-like”, “PES like”, “Payment for ecosystem service”, “payment for ecosystem service”, “Payments for ecosystem service”, “payments for ecosystem service”, “Payment for ecosystem services”, “payment for ecosystem services”, “Payments for ecosystem services”, “payments for ecosystem services”, “payment”, “Payment”, “Payments”, “payments”, “ecosystem service”, “Ecosystem service”, “Ecosystem services”, “ecosystem services”, “environmental service”, “environmental services”, “Environmental service”, “Environmental services”, “Procurement”, “procurement”, “Responsibility”, “responsibility”, “Certification scheme”, “certification scheme”, “Branding”, “branding”, “Brand”, “brand”, “Promotion”, “promotion”, “Sponsoring”, “sponsoring”, “Sponsor”, “sponsor”, “Technical assistance”, “technical assistance”, “Education”, “education”, “Educate”, “educate”, “Training”, “training”, “Train”, “train”, “Awareness raising”, “awareness raising”, “Raise”, “raise”, “awareness”, “Awareness”, “aware”, “Aware”

8.3. Appendix 3. Green Deal policies that contain Market-based Instruments

Policy sector	Control Number	Document	MBI type found in document
n/a	1	European Green Deal	tradable permits
			regulatory price signals
			voluntary price signals
Finance & rural development	2	European Green Deal Investment Plan	tradable permits
			regulatory price signals
			voluntary price signals
Climate	4	European climate law	tradable permits
			regulatory price signals
			voluntary price signals
Climate	5	European climate pact	regulatory price signals
Environment & oceans	7	Circular Economy Action Plan	voluntary price signals
			regulatory price signals
Agriculture	8	Farm to fork strategy	regulatory price signals
			Coasean-type agreements
			voluntary price signals
	9	EU Biodiversity Strategy for 2030	Coasean-type agreements

Environment & oceans			voluntary price signals
			regulatory price signals
Energy	10	Powering a climate-neutral economy: An EU Strategy for Energy System Integration	regulatory price signals
			tradable permits
			voluntary price signals
Energy	11	A hydrogen strategy for a climate-neutral Europe	tradable permits
			voluntary price signals
Energy	13	Methane Strategy	voluntary price signals
Climate	18	New EU strategy on adaptation to climate change	voluntary price signals
			Coasean-type agreements
			regulatory price signals
Environment & oceans	19	Organic Action Plan – An action plan for the development of organic production	Coasean-type agreements
			voluntary price signals
			regulatory price signals
Environment & oceans	20	Zero pollution Action Plan	Coasean-type agreements
			regulatory price signals
			voluntary price signals
	21	Sustainable blue economy	voluntary price signals

Environment & oceans			tradable permits
Environment & oceans	36	Proposal for a Regulation on deforestation-free products	regulatory price signals
Environment & oceans	39	Commission proposals to remove, recycle and sustainably store carbon	voluntary price signals
			Coasean-type agreements
			tradable permits
Energy	40	REPowerEU: Joint European action for more affordable, secure and sustainable energy	tradable permits
			regulatory price signals
Industry	43	Proposals to modernise EU industrial emissions rules to steer large industry in long-term green transition	voluntary price signals
Climate	44	Proposals to phase down fluorinated greenhouse gases and ozone depleting substances	voluntary price signals
Environment & oceans	51	Action plan against wildlife trafficking	voluntary price signals
Environment & oceans	53	EU Algae Initiative	voluntary price signals
Climate	54	Proposal for a first EU-wide voluntary framework to reliably certify high-quality carbon removals	voluntary price signals
			tradable permits
Environment & oceans	59	A New Deal for Pollinators	Coasean-type agreements

Climate	63	Proposal 2030 zero-emissions target for new city buses and 90% emissions reductions for new trucks by 2040	regulatory price signals
			tradable permits
Environment & oceans	67	Action Plan to protect and restore marine ecosystems for sustainable and resilient fisheries	regulatory price signals
Energy	72	Electricity Market Design revision: Proposal to amend the Electricity Market Design rules	voluntary price signals
Energy	73	Guidelines on State aid for climate, environmental protection and energy 2022	Coasean-type agreements
			regulatory price signals
			voluntary price signals
			tradable permits
Industry	75	Net-Zero Industry Act	regulatory price signals
			voluntary price signals
Industry	76	Critical Raw Materials Act	voluntary price signals
Energy	79	cutting maritime transport emissions by promoting sustainable fuels for shipping	regulatory price signals
			tradable permits
Climate	84	Regulation establishing a Social Climate Fund	voluntary price signals
Environment & oceans	88	Soil Monitoring Law	Coasean-type agreements
Climate	95	Transitional phase of the Carbon Border Adjustment Mechanism (CBAM)	regulatory price signals
Climate	96	EU Emissions Trading System reform (including Market Stability Reserve, maritime and separate ETS system for buildings and road transports)	tradable permits
			regulatory price signals

			voluntary price signals
Climate	98	Revised EU Emission Trading System for aviation	tradable permits
			regulatory price signals
Climate	99	Notification on the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA)	tradable permits
Climate	101	Effort Sharing Regulation (ESR)	tradable permits
			voluntary price signals
Environment & oceans	102	Land Use, Land Use Change and Forestry Regulation (LULUCF)	tradable permits
			regulatory price signals
Energy	104	Energy Efficiency Directive	voluntary price signals
			tradable permits
			regulatory price signals
Energy	107	ReFuelEU Aviation Regulation	voluntary price signals
Energy	108	FuelEU Maritime Regulation	voluntary price signals
			regulatory price signals
Climate	109	European Wind Power Action Plan	voluntary price signals
Environment & oceans	110	A new forest monitoring law that aims to improve resilience of European forests	direct markets
Energy	111	Actions to accelerate the roll-out of electricity grids	voluntary price signals

Environment & oceans	118	Inclusion of greenhouse gas emissions and removals from land use, land use change and forestry in the 2030 climate and energy framework Consolidated Text	voluntary price signals
Climate	120	Recommendation for 2040 emissions reduction target to set the path to climate neutrality in 2050	tradable permits
			regulatory price signals
Industry	121	EU Industrial Carbon Management Strategy	regulatory price signals
			tradable permits
Agriculture	122	Targeted review of Common Agricultural Policy to support EU farmers	Coasean-type agreements
Finance & rural development	129	Framework to facilitate sustainable investment	voluntary price signals
Environment & oceans	130	Nature restoration law	Coasean-type agreements

8.4. Appendix 4. Green Deal policies that contain market-based instruments which explicitly refer to ecosystems

Policy Sector	CN	Policy Documents	Citation	MBI types
Environment and oceans	7	Circular Economy Action Plan	Carbon removals can be nature based, including through restoration of ecosystems, forest protection, afforestation, sustainable forest management and carbon farming sequestration, or based on increased circularity, for instance through long term storage in wood construction, re-use and storage of carbon in products such as mineralisation in building material. To incentivise the uptake of carbon removal and increased circularity of carbon, in full respect of the biodiversity objectives, the Commission will explore the development of a regulatory framework for certification of carbon removals based on robust and transparent carbon accounting to monitor and verify the authenticity of carbon removals.	Voluntary price signals
	9	EU Biodiversity Strategy for 2030	To support the long-term sustainability of both nature and farming, this strategy will work in tandem with the new Farm to Fork Strategy and the new Common Agricultural Policy (CAP), including by promoting eco-schemes and result-based payment schemes. In implementing the Biodiversity and the Farm to Fork Strategies, the Commission will closely monitor progress and improvements in terms of food security and farmers income.	Coasean-type agreements

			Tackling biodiversity loss and restoring ecosystems will require significant public and private investments at national and European level. This will mean making the most of all relevant EU programmes and financing instruments. The Commission will strengthen its biodiversity proofing framework , inter alia by using in an appropriate way the criteria established under the EU taxonomy, to ensure that EU funding supports biodiversity-friendly investments.	Voluntary price signals
			The EU sustainable finance taxonomy will help guide investment towards a green recovery and the deployment of nature-based solutions. In 2021, the Commission will adopt a delegated act under the Taxonomy Regulation to establish a common classification of economic activities that substantially contribute to protecting and restoring biodiversity and ecosystems.	Voluntary price signals
	19	Organic Action Plan - An action plan for the development of organic production	For the future CAP, Member States will have the flexibility to support organic operators in a tailored manner under both the rural development funds and with targeted direct income support eco-schemes. The budget for support measures to organic conversion and maintenance as well as that for investment support in CAP strategic plans should align with the national ambition to increase organic production.	Coasean-type agreements

	20	Zero pollution Action Plan	This review will also support the concrete implementation of the future integrated nutrient management action plan, addressing holistically a long-standing environmental challenge, maximising synergies between policies and making best use of the green architecture of the new common agricultural policy, especially via conditionality and eco-schemes	Coasean-type agreements
	21	Sustainable blue economy	…release a stable methodology to integrate the concept of 'natural capital' in economic decisions. This implies assessing and quantifying both the economic value of marine ecosystem services and the socio-economic costs and benefits derived from keeping the marine environment healthy;	voluntary price signals
	39	Commission proposals to remove, recycle and sustainably store carbon	A fundamental step to make this possible is to put in place a regulatory framework for a clear and transparent identification of the activities that unambiguously remove carbon from the atmosphere and can decrease the atmospheric CO2 concentration, therefore developing a EU framework for the certification of carbon removals, based on robust accounting rules, for high-quality sustainable carbon removals from both natural ecosystems and industrial solutions (section 4).	voluntary price signals
			Carbon farming incentives should then contribute to give financial recognition to these co-benefits. This was also highlighted in the new	Coasean-type agreements, voluntary price signals

			EU Forest Strategy for 2030, which promoted the setting up of ecosystem services payment schemes and the roll out of carbon farming practices under the Common Agricultural Policy and other public funding, as well as the various co-benefits of a carbon removal certification for private finance of carbon farming.	
			CAP Eco-schemes and rural development agri environment-climate measures or investments can directly support carbon farming practices The European Innovation Partnership for agricultural productivity and sustainability (EIP-AGRI) helps land managers cooperate and test new approaches Support to advisory services brings knowledge to land managers LIFE Programme Focuses on pilot projects for the upscaling of carbon farming elements (e.g. three new projects to start in 2021 on better monitoring tools; existing Carbon Farming Scheme project testing incentives to enable the trading of removal certificates). Cohesion Policy Investments into e.g. restoration and conservation of peatland (also Just Transition Fund)	Coasean-type agreements
	53	EU Algae Initiative	Despite its current marginal share in the global seaweed market, given the favourable business prospects, Europe can develop a strong algae industry centred on aquaculture production and innovative	voluntary price signals

			seaweed mariculture (marine permaculture). Such an industry may harness the potential of vast European seas while creating jobs for local communities, producing healthy low-carbon products, regenerating coastal ecosystems (e.g. fixing CO2 and nutrients and generating oxygen) and providing ecosystem services.	
	59	A New Deal for Pollinators	The CAP is one of the main instruments to support such a transition, through measures such as organic farming, maintaining and developing landscape features, agro-forestry, reduced chemicals use, and protection of pollinator-friendly plants on pastures and buffer strips. In 2023-27, the CAP will be governed by a new green architecture with strengthened baseline requirements and new ecoschemes under its Pillar I, in combination with measures under Pillar II, such as agri-environment-climate management commitments.	Coasean-type agreements
	67	Action Plan to protect and restore marine ecosystems for sustainable and resilient fisheries	By the end of 2023, start developing a modelling tool to incorporate the concept of ‘natural capital’ in economic decisions. This implies assessing and quantifying both the economic value of marine ecosystem services and the socio-economic costs and benefits derived from keeping the marine environment healthy	regulatory price signals
			While enhancing the standards of conservation of marine biological resources and the protection of marine biodiversity and ecosystems as described above, the EU should hold its vessels to at least the same	voluntary price signals

			standards when they fish on the high seas or in the exclusive economic zone of non-EU countries as when they fish in EU waters. In addition to the work done in RFMOs, sustainable fisheries partnership agreements (SFPAs) also contribute to fostering international fisheries governance through promotion of sustainable fisheries in partner countries. The MSFD also requires regionalised decision-making, including through cooperation with non-EU countries, bilaterally and/or through relevant international instruments such as regional sea conventions (99).	
	88	Soil Monitoring Law	The benefits of healthy soils and measures to achieve this will also help boost private financing, as food industry and other business have already started putting in place programmes to pay for ecosystem services and support sustainable practices related to soil health. At the same time, soil certified as healthy is likely to increase the value of the land, e.g. for the purposes of collateral, sale or succession	Coasean-type agreements
			Economic instruments, including those under the Common Agricultural Policy (CAP) that provide support to farmers, have a crucial role in the transition to the sustainable management of agricultural soils and, to a lesser extent, forest soils. The CAP aims to support soil health through the implementation of conditionality, eco-schemes and rural development measures.	Coasean-type agreements

	102	Land Use, Land Use Change and Forestry Regulation (LULUCF)	Given the importance of providing financial support to land and forest owners or managers to achieve the targets set out in this amending Regulation, the Commission should, when assessing the draft updates of the latest notified integrated national energy and climate plans under Regulation (EU) 2018/1999, ensure that the financial support, including the relevant share of revenues generated from the auctioning of EU ETS allowances under Directive 2003/87/EC and that are used for LULUCF, is directed to policies and measures that are tailor-made to achieve the budgets and targets of the Member States set out in this amending Regulation. In its assessment, the Commission should pay particular attention to the promotion of ecosystem-based approaches and the need to ensure permanence of additional greenhouse gas removals, taking into account existing legislation	tradable permits
	110	a new forest monitoring law that aims to improve resilience of European forests	This effective and cost-efficient forest monitoring system would serve multiple purposes: - improving data for policy making and policy implementation, including by providing more up-to-date information on natural disturbances and forest disasters across Member States; and	Direct markets

			- enabling individual forest managers to market their ecosystem services, such as carbon removals, based on comparable and credible data.	
	118	inclusion of greenhouse gas emissions and removals from land use, land use change and forestry in the 2030 climate and energy framework Consolidated Text	Member States shall be entitled to compensate net emissions or net removals, or both, accounted for as emissions against the targets set for those Member States in accordance with Article 4(3) or against the budget set for those Member States in accordance with Article 4(4), up to the amount unused by other Member States of the full amount of compensation for the period from 2021 to 2030 set out in Annex VII, after taking into account Article 13(4) and paragraph 5 of this Article, provided that those Member States: (c) have included in their latest integrated national energy and climate plans submitted pursuant to Article 14 of Regulation (EU) 2018/1999 specific measures to ensure the conservation or enhancement, as appropriate, of all land sinks and reservoirs, and to reduce the vulnerability of land to ecosystem perturbations driven by climate change.	voluntary price signals
	130	Nature restoration law	In addition, under the CAP, Member States have the possibility to set up eco-schemes for agricultural practices carried out by farmers on agricultural areas that may include maintenance and creation of landscape features or non-productive areas. Similarly, in their CAP strategic plans, Member States can also include agri-environment-	Coasean-type agreements

			climate commitments, including the enhanced management of landscape features going beyond the GAEC standard or eco-schemes.	
Climate	18	New EU strategy on adaptation to climate change	Implementing nature-based solutions on a larger scale would increase climate resilience and contribute to multiple Green Deal objectives. Blue-green (as opposed to grey) infrastructures are multipurpose, “no regret” solutions and simultaneously provide environmental, social and economic benefits and help build climate resilience. For example, protecting and restoring wetlands, peatlands, coastal and marine ecosystems; developing urban green spaces and installing green roofs and walls; promoting and sustainably managing forests and farmland will help adapt to climate change in a cost-effective way. It is vital to better quantify their benefits, and to better communicate them to decision-makers and practitioners at all levels to improve take-up. In addition, the Commission will develop a certification mechanism for carbon removals, which will enable robust monitoring and quantification of the climate benefits of many nature-based solutions.	voluntary price signals
			Europe needs to leverage more investments in nature-based solutions to generate gains for adaptation, mitigation, disaster risk reduction, biodiversity, and health. Investments in nature-based solutions must be viable over the long-term, because climate change is amplifying stresses on ecosystems. This can be done through new and innovative financing approaches and products under InvestEU,	Coasean-type agreements, regulatory price signals

			targeted support under Cohesion Policy programmes, and support for investments, eco-schemes and advisory services in the Common Agricultural Policy. Through carbon farming, the Commission will promote a new business model for land-based carbon removals, including financial incentives to rollout nature-based solutions.	
	54	Proposal for a first EU-wide voluntary framework to reliably certify high-quality carbon removals	The EU certification framework on carbon removals will either build on or play an important role to enable the following Union policies: • The proposed Nature Restoration Law sets out the goal that 20% of the EU's land and sea should be covered by restoration measures by 2030 and that all ecosystems in need of restoration should be covered by restoration measures by 2050. There are many synergies among carbon removal activities, particularly carbon farming, and nature restoration measures. The proposed certification framework for carbon removals will contribute to achieve the restoration targets and fulfil the obligations set out in the Nature Restoration Law. For instance, carbon farming activities that enhance carbon storage can contribute to meeting the obligation to ensure an increasing trend at national level of the stock of organic carbon in forest ecosystems and in cropland mineral soils in agricultural ecosystems	voluntary price signals
	96	EU Emissions Trading System reform	Member States' auctioning revenues will increase as a result of the inclusion of maritime transport in the EU ETS.	Tradable permits

		(including Market Stability Reserve, maritime and separate ETS system for buildings and road transports)	Therefore, Member States are encouraged to increase the use of EU ETS revenues pursuant to Article 10(3) of Directive 2003/87/EC to contribute to the protection, restoration and better management of marine-based ecosystems, in particular marine protected areas.	
			Member States' auctioning revenues will increase as a result of the inclusion of maritime transport under the EU ETS. Therefore, Member States are encouraged to increase the use of EU ETS revenues pursuant to Article 10(3) of Directive 2003/87/EC to contribute to the protection, restoration and better management of marine-based ecosystems, in particular marine protected areas.	Tradable permits
Agriculture	8	Farm to fork strategy	In addition to CAP measures, such as eco-schemes, investments and advisory services, and the Common Fisheries Policy (CFP) measures, the Commission will put forward an Action Plan on organic farming. This will help Member States stimulate both supply and demand for organic products.	Coasean-type agreements
	122	targeted review of Common Agricultural Policy to support EU farmers	thorough impact assessment for the reform of the CAP that was agreed in 2021 was carried out. This assessment accompanied the proposals tabled by the Commission in 2018. This impact assessment also provides important background to the adjustments contained in this proposal. More specifically, key differences between the options	Coasean-type agreements

			assessed in 2018 related to the balance of voluntary ("eco-scheme") or obligatory ("conditionality") environmental requirements	
Energy	73	Guidelines on State aid for climate, environmental protection and energy 2022	'rehabilitation' means environmental management actions that aim to reinstate a level of ecosystem functioning on degraded sites, where the goal is renewed and ongoing provision of ecosystem services rather than the biodiversity and integrity of a designated natural or semi-natural reference ecosystem;	Coasean-type agreements
			Financial support in the form of State aid can contribute substantially to the environmental objective of protecting and restoring biodiversity and ecosystems, in several ways, including by providing incentives to repair the damage to contaminated sites, rehabilitate degraded natural habitats and ecosystems or undertake investments for the protection of ecosystems.	Regulatory price signals
	111	actions to accelerate the roll-out of electricity grids	At the latest by mid-2025, in view of the permitting obstacles encountered by energy infrastructure projects, the Commission will provide guidance on the designation of dedicated infrastructure areas for grid projects necessary to integrate renewables as provided by the revised RED. The Commission will update by Q4 2024, if necessary, the existing guidance on streamlining environmental impact	voluntary price signals

			assessments for PCIs[2] and PMIs and the guidance on energy transmission infrastructure and EU nature legislation as necessary to adapt them to the revised legislative frameworks of TEN-E and RED and their streamlining permitting provisions.	
Industry	75	Net-Zero Industry Act	The environmental assessments and authorisations required under Union law, including in relation to water, air, ecosystems, habitats, biodiversity and birds, are an integral part of the permit granting procedure for a net zero technologies manufacturing project and an essential safeguard to ensure negative environmental impacts are prevented or minimised.	voluntary price signals
Finance and regional development	129	Framework to facilitate sustainable investment	For the purpose of determining the environmental sustainability of a given economic activity, an exhaustive list of environmental objectives should be laid down. The six environmental objectives that this Regulation should cover are: climate change mitigation; climate change adaptation; the sustainable use and protection of water and marine resources; the transition to a circular economy; pollution prevention and control; and the protection and restoration of biodiversity and ecosystems.	voluntary price signals

[2] The document „Streamlining environmental assessment procedures for energy infrastructure Projects of Common Interest (PCIs)" states that "Of particular relevance for energy policy are the targets of halting the loss of biodiversity and degradation of ecosystem services by 2020…"

			An economic activity shall qualify as contributing substantially to the protection and restoration of biodiversity and ecosystems where that activity contributes substantially to protecting, conserving or restoring biodiversity or to achieving the good condition of ecosystems, or to protecting ecosystems that are already in good condition, through: (a) nature and biodiversity conservation, including achieving favourable conservation status of natural and semi-natural habitats and species, or preventing their deterioration where they already have favourable conservation status, and protecting and restoring terrestrial, marine and other aquatic ecosystems in order to improve their condition and enhance their capacity to provide ecosystem services; (b) sustainable land use and management, including adequate protection of soil biodiversity, land degradation neutrality and the remediation of contaminated sites; (c) sustainable agricultural practices, including those that contribute to enhancing biodiversity or to halting or preventing the degradation of soils and other ecosystems, deforestation and habitat loss;	voluntary price signals

			(d) sustainable forest management, including practices and uses of forests and forest land that contribute to enhancing biodiversity or to halting or preventing degradation of ecosystems, deforestation and habitat loss; or (e) enabling any of the activities listed in points (a) to (d) of this paragraph in accordance with Article 16.	

2.4. Article 4

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transdisciplinary education for sustainable development

in UNESCO Biosphere Reserves in the Global South

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Current Opinion in Environmental Sustainability

Review

The need for transnational networks and transdisciplinary education for sustainable development in UNESCO Biosphere Reserves in the Global South

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As learning sites for sustainable development, United Nations Educational, Scientific, and Cultural Organization (UNESCO) Biosphere Reserves (BRs) are unique sites that promote human–nature interactions in biodiversity conservation. BRs are part of a World Network of BRs, which provide opportunities for transnational collaborations. With the 50th anniversary of UNESCO's Man and Biosphere Programme, we systematically analyzed literature on BRs in the Global South and assessed whether transnational connections emerged from the network especially in fulfilling the shared goal of being learning sites for sustainable development. We found little evidence of transnational networking between BRs in the Global South. While there are nonformal environmental education initiatives in BRs, there is a lack of reported transdisciplinary approaches and formal education about BRs in BRs. Furthermore, Indigenous and local knowledge (ILK) is rarely integrated into initiatives. Equitable and inclusive partnerships, integration of ILK, and co-production of knowledge could be enabling factors for transdisciplinary education.

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Introduction

The United Nations Educational, Scientific and Cultural Organization (UNESCO) Biosphere Reserves (BRs) are known as 'learning sites for sustainable development.' As social-ecological systems, BRs promote human–nature interactions as essential to biodiversity conservation as opposed to the strict 'fortress conservation' model where protected areas are completely isolated from human activities [1]. As of the end of 2024, BRs can be found in 136 countries and are connected through the World Network of BRs or WNBR, which covers diverse ecosystems and cultures. The WNBR is intended to foster transnational partnerships and collaboration to address common sustainability challenges or pursue shared goals related to biodiversity conservation, economic development, and learning [2]. The WNBR is made up of a total 759 BRs, 55 of which are transboundary or BRs sharing borders with different countries. However, looking closely at the distribution of country-specific BRs or BRs that are not transboundary, only 152 (22%) are present in the Global South, while 552 (78%) can be found in the Global North [3], indicating a large disparity in the distribution of BRs in relation to countries' socioeconomic development status (see SM1 for detailed count of BRs per country).

As part of the UNESCO Man and Biosphere (MAB) Programme that celebrated its 50th anniversary in 2021, BRs can provide an overview of the success of the WNBR's shared goals. In this paper, we focus on the learning or logistic support function of BRs and assess the current status of BRs transnational partnerships in their role of being co-learning sites for sustainable development, particularly UNESCO's education for sustainable development (ESD) for 2030. The priority action areas of UNESCO's ESD for 2030 framework closely align with the learning function of the BRs, such as transforming learning environments, building capacities of educators, and empowering youth [4]. As BRs have context- and site-specific characteristics, we believe that education in BRs should also be transdisciplinary, that is, designed with the learning needs of its local communities in mind. Moreover, since BRs are networked in the WNBR, we see that it can benefit from transnational partnerships; we use the term 'transnational' to highlight that nonstate actors can also initiate BR educational partnerships in contrast to 'international', which is often associated with political or economic state-driven action [5].

In order to understand the state of transnational networks and transdisciplinary ESD in BRs, we conducted a systematic literature review of scientific articles published in the English language between the years 2022 and 2023 in BRs with a focus on lower middle- to low-income countries, or the so-called Global South (see SM1 for methodology and search terms). We sought to understand whether BRs in the Global South have transnational ESD programs that are shared in partnership between or among each other. Our search resulted in 28 peer-reviewed articles that discuss BRs and education (both formal and informal) and report on the presence or absence of transnational partnership networks and transdisciplinary approaches as well as consideration of Indigenous and local knowledge (ILK). In relation to these results, we also briefly reflect upon our own learnings as practitioners and researchers on BRs.

Trends in education research in Biosphere Reserves in the Global South

Our systematic literature search resulted in a majority (61%) of articles published in 2023 and the rest (39%) published in 2022. Almost all the articles (99%) were case studies, with only one study focusing on a review of the literature [6]. There were no conceptual papers in the selection. Most of the studies were done at the local level (79%), followed by studies conducted at the national scale (14%). There were two studies involving multiple countries: one conducted a macro-level analysis of BRs and UNESCO Global Geoparks in Japan and Russia [7] and the other a systematic literature review of BRs in Africa, Asia-Pacific, and Europe [6]. The review did not find any paper explicitly focusing on transnational networks; this signals an important opportunity for collaboration among BRs on the theme of ESD, which reflects the unique character of BRs.

Among the papers reviewed, Asia was the most studied region, with India and Vietnam being the most studied countries followed by Indonesia. There were individual case studies on China, Japan (with Russia) [7], and Malaysia. The other case studies were on Argentina, Brazil, Congo, Ethiopia, Mexico, Nigeria, Russia, South Africa, Turkey, and the United States of America (an exception as a Global North article captured by the systematic literature review algorithm; the paper has not been excluded from further analysis). The majority (82%) of the first authors and co-authors came from the countries of the areas studied, showing limited transnational collaboration on the topic. In terms of ecosystems, terrestrial ecosystems were the most studied, with only a few papers looking at freshwater, marine, and coastal ecosystems. Education research in BRs seems to follow the dominance of terrestrial research in mainstream ecology [8].

This finding underlines the importance of the MAB program's thematic networks in transnational partnerships of BRs. Thematic networks are composed of BRs that share ecological, environmental, geopolitical, or cultural similarities [9]. Along with regional networks, thematic networks are where the MAB program implements one of its main objectives of 'international, regional, subregional, and thematic cooperation' [9]. Given the importance of ecological connectivity for the conservation of ecosystems, a stronger partnership between and within thematic networks can be beneficial in achieving the objectives of the MAB Program [10]. Among the existing thematic networks, the Mediterranean Biosphere Reserves Network (MedMAB), through its Edu-BioMed project, is a good example of transnational partnerships in ESD, which other thematic networks can replicate especially for BRs in the Global South.

Dominance of nonformal education in Biosphere Reserves in the Global South

All the papers we reviewed mentioned education but used the term in diverse contexts. Some papers referred to educational levels to describe demographics of respondents or Indigenous Peoples and local communities (IPLCs) in their case studies (e.g. [11,12]), while other papers referred to education in nonformal settings, such as communication, education, and public awareness activities with IPLCs [13,14], BR managers [15•], and the general public [16]. These nonformal education methods (e.g. onsite training, participatory workshops, counseling, and excursions) are more common in BRs, while innovative approaches such as serious computer games (e.g. [15•]) are also used to foster a more informed decision-making in BRs management. However, we observed a lack of published articles on formal education 'in BRs about BRs' as a major knowledge gap that needs to be addressed for achieving the shared goals of conservation, economic development, and learning in BRs in the Global South. Although established at the same time as the other UNESCO designations of World Heritage Sites and Ramsar Sites, the BR label is less well known, although admittedly more popular than UNESCO Global Geoparks, which has only been ratified as a UNESCO designation in 2015 [16,17]. This is corroborated by a UNESCO review of BRs in Asia and the Pacific, which called for improved visibility and recognizability of BRs [18]. Visibility of BRs is important in increasing governmental and public support for its three functions of conservation, economic development, and learning; after all, BRs are supposed to be learning laboratories for sustainable development where conservation goes hand-in-hand with human development.

We believe that both formal and nonformal education are important in BRs (and outside of BRs) if we are to advance sustainability action and knowledge on BRs. Formal education in BRs about BRs at any educational level could help not only in building the profile of BRs but also in increasing legitimacy and support to BRs locally. There have been cases where local communities do not support BRs because of fear of restrictions and a misconception that a 'reserve' is just another strictly protected area [19,20]. This emphasizes the need for weaving different types of knowledge and value systems in both formal and nonformal education. Transdisciplinary co-production approaches, which integrate multiple disciplines and a wide range of actors (academia, IPLC, policy-makers, citizen science, etc.) [21,22] can enhance inclusivity and participation. In many instances, however, this is yet a gap to be addressed, as pointed out in a paper on Sheka BR in Ethiopia: "higher education institutions have no motive to explore and support indigenous knowledge (…)" [23]. The formal education in many BRs is yet to recognize that IPLCs living there are the primary knowledge holders who have sustainably managed their landscapes and seascapes for generations. Their place-based observations and ILK are crucial to supplementing and, in some cases, validating theoretical expert knowledge about a given BR site [24••].

Transnational partnership networks and transdisciplinary education

The concepts of transnational networks and transdisciplinary education build upon collaboration as an essential component for achieving sustainability especially in BRs, which share similar objectives under the MAB program and are networked under the WNBR. In the papers we reviewed, collaboration is also a crucial element for management effectiveness within BRs or protected areas. A social network analysis in Tambora National Park in Indonesia showed that a strong partnership network means an even distribution of tasks and benefit sharing among multiple stakeholders while avoiding concentration of resources within the hands of a limited few [25]. In the Dong Nai BR in Vietnam, an exploratory factor analysis and a logistic regression model were conducted to identify the factors that lead to positive engagement of locals in human–elephant conflict [26•]. The results show that improved elephant habitat and land use lead to increased participation by the locals, showing that collaboration in BRs should also extend to nonhumans such as elephants and other wildlife. Despite existing debates, the concepts of convivial and compassionate conservation all call for respecting all forms of life whether human or nonhuman [27,28].

As practitioners and researchers on BRs, our experiences show that transnational networks and transdisciplinary education are an effective multiplier of sustainable development in BRs within formal educational institutions. The Transdisciplinary Education Collaboration for Transformations in Sustainability (TRANSECTS) in BRs led by the University of Saskatchewan enabled some of us to deepen our understanding of sustainability challenges in BRs in Canada, Germany, and South Africa and build skills to tackle these challenges by co-learning in Transdisciplinary International Learning Labs [29••,30]. TRANSECTS is a North-North-South collaboration that is the first of its kind; as such, it provides a transnational partnership model that can be replicated in other formal educational institutions working in and with BRs. The European Union Global Diaspora Facility of the International Centre for Migration Policy Development provided one of us, a member of the diaspora, with an opportunity to collaborate with the Palawan State University (PalSU) on the Palawan BR in the Philippines on updating their environmental science curriculum in line with UNESCO's ESD for 2030 [31•]. With a student body of over 25 000 students, PalSU as a formal educational institution is an avenue through which transdisciplinary ESD can be efficiently implemented. In addition, this engagement also showed how BRs can benefit not only from international partners but also from members of the diaspora who transcend national affiliations and initiate transnational partnerships through education [32].

Enabling factors of future progress toward transdisciplinary education in Biosphere Reserves

After reviewing and analyzing 28 articles, we identified enabling factors that can drive progress toward transdisciplinary ESD in BRs:

- Equitable partnerships: Enhanced multistakeholder engagement is repeatedly mentioned as a central element of transdisciplinary approaches. However, what is good on paper should also be good in reality. The study in the Pantanos de Centla BR in Mexico highlighted the importance of involving local communities in all stages of an ecological restoration project and respecting their capacity to implement projects on their own [33]. Equitable partnerships are the opposite of paternalistic relationships in which project proponents solely decide on the direction of project implementation.

- Integration of ILK: While more than half of the papers (68%) mentioned IPLCs, most of these refer to IPLCs as recipients of interventions, such as environmental education. Transdisciplinary education respects and integrates ILK into learning materials especially in the BRs where IPLCs live. The case of the Sheka BR in Ethiopia where higher education institutions seem to have no interest in ILK could also be seen as an opportunity to progress toward a more inclusive educational system [23].
- Learning opportunities for local communities: The case of the Penang Hill BR in Malaysia shows how its ecotourism activities provide an opportunity for local communities to learn about BRs [34]. Involving local communities is essential to extending the reach of BRs; a case study in China showed how providing informal education through skills training to local communities could help support the conservation objectives of BRs [12]. Local communities were trained in livelihood activities that were not dependent on resource use in the core areas of the BRs [12]. This case demonstrated how the learning and logistical support function of BRs through informal education and skills training can support their other functions of conservation and economic development.

Conclusion

BRs have been promoted as learning sites for sustainable development, in an effort to show that these areas are not isolated sites that perpetuate the fortress conservation model, but rather geographic regions that are interconnected globally, with the aim of jointly achieving global targets such as the Kunming-Montreal Global Biodiversity Framework or the Agenda 2030. However, our review finds that BRs in the Global South have yet to benefit from the potential transnational networks of the WNBR. We see the need for enhanced attention to this matter in research, practice, and decision-making. First, we call upon more transnational and transdisciplinary research and practitioner collaborations, rooted in on-the-ground action, learning-by-doing approaches, and social networks supported by mobility (e.g. through tourism or the Global South diaspora). Second, we highlight the equal role of formal and (no less important) nonformal education within and about BRs for the IPLCs, BRs managers, and the general public. The lack of formal education about BRs in current scientific literature signals a crucial but missing step that can support legitimacy and local ownership of BRs. Finally, we point out the need for addressing existing challenges and barriers toward achieving conservation and development goals in the BRs of the Global South through informed and integrated decision-making, including IPLCs and diverse knowledge and value systems. We view transnational networks within the WNBR and transdisciplinary education as main pillars in increasing local ownership and legitimacy of BRs in the Global South.

CRediT authorship contribution statement

Denise Margaret S. Matias: Conceptualization, Methodology, Formal analysis, Writing. **Mukona Kone, Paulina G. Karim, Diana San Jose, Andrea Monica D. Ortiz, Bryan Joel S. Mariano, Pradeep Kumar Dubey, and Gino Carlo Garcia:** Formal analysis, Writing.

Data Availability

Data will be made available on request.

Declaration of Competing Interest

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

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Supporting information

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References and recommended reading

Papers of particular interest, published within the period of review, have been highlighted as:

- • of special interest
- •• of outstanding interest

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3. Synthesis

This dissertation proposes a sustainability assessment approach for the provision of FES. It builds on three elements: (1) the basic sustainability assessment steps outlined by Morrison-Saunders & Pope (2013), (2) the nested system approach to sustainable development according to Ibisch et al. (2018) and the ecosystem services concept, and (3) the new empirical knowledge generated from four distinct, but interconnected, research articles. The following section explains which aspects of each research article are integrated in the sustainability assessment approach, a brief article summary, and the lessons learned from each.

3.1. The conflicts between stakeholders for FES (article 1)

Sustainability assessment approach in context

Conflicts can emerge due to competing stakeholder demands for limited natural resources. The sustainability assessment approach proposed in this dissertation highlights conflicts between forest stakeholders as a topic that needs to be addressed in forest management plans. This is a complex matter since stakeholders have varying perspectives on sustainability as they have their respective priorities (Rosenkranz et al., 2017). That said, inadequately addressing stakeholder conflicts could lead to the failure of achieving sustainability goals (Bahadorestani et al., 2020) and is therefore included as a crucial step in the sustainability assessment.

Article summary

We implemented an integrated conflict analysis approach designed around the backdrop of a hypothetical increase in harvesting of forest biomass for biofuel production in Germany. We found that various forest stakeholders are dependent upon different types of FES, most of which would be affected by increased forest biomass extraction (Garcia et al., 2025). We also determined that the various stakeholder groups had varying conflict prioritization patterns. Unresolved conflicts between stakeholders could threaten the sustainability of a forest management plan and as such, mapping out stakeholder interests is a crucial fundamental step that should be taken towards cooperation (Pelyukh et al., 2021). Without cooperation, individual stakeholders could negatively affect others within the same forest arena and could lead to unmitigated losses.

Lessons learned

We identified three conflict management strategies which are central to the proposed sustainability assessment for FES provision. First, the strengthening of participatory processes in forest management through the formation of forest committees was seen as a means for stakeholders to be able to have a stake in decision-making processes. This is key as the lack of inclusion in decision-making processes for natural resources management contributes to conflicts, though it is by far not the only reason (Matiru et al., 2000). . The forest committee is a means to foster cooperation between conflicting stakeholders by offering a venue by which individuals can discuss their interests and identify conflicts. It enables stakeholders to identify possible synergies in order to mitigate trade-offs. Second, a more systematic use of market-based instruments and compensation systems could be a way to address market failure, which is crucial since most FES are public goods (Nichiforel et al., 2018). Addressing market failure would address the economic needs of particular stakeholders especially those depending on regulating and cultural FES, since there is a lack of innovation for their provision (Mann et al., 2022). Finally, a harmonized strategy for the provision of the wide range of FES is needed. Public policies have an effect on forest health (Wuepper et al., 2024) and addressing conflicts between sectors and levels of governance is an important step towards improved forest governance (Edwards & Kleinschmit, 2013).

3.2. Holistic approach to sustainability - FES and other crucial indicators (article 2)

Sustainability assessment approach in context

There is a wide range of approaches that can be considered sustainability assessments (Ness et al., 2007; Singh et al., 2009). Many of these have been used in combination with the ecosystem services concept and applied to forests worldwide in different contexts. The proposed sustainability assessment approach integrates the FES indicators found in sustainability assessments, as well as non-FES indicators that exhibit the wide range of topics that need to be taken into account when assessing the sustainability of forests.

Article summary

By means of a systematic literature review covering 109 peer-reviewed publications on sustainability assessments and encompassing 1324 total indicators, we determined that the FES concept is used in varying degrees of depth in sustainability assessments. We found that 42% of sustainability assessments cover three to four of the FES categories as outlined by MA (provisioning, regulating, cultural, and supporting). This finding is integrated into the proposed sustainability assessment in this dissertation as it aims at providing the wide range of ES provided by forests and therefore includes all MA FES categories.

We also found that the other half of indicators were non-FES related that address various economic, environmental, social, and cross-cutting indicators. These topics were also incorporated into the sustainability assessment approach as they have an impact on sustainability.

Lessons learned

A holistic approach is necessary to capture the complexity of interacting factors that affect sustainability (J. Liu et al., 2015). Singer (2016) demonstrates this for sustainable forest management financing. We apply this in our study by casting a wide net and showing which environmental, social and economic elements are addressed in forest sustainability assessments. It is an attempt to take unintended consequences and trade-offs into account, which would ideally then lead to long-term gains for forest stakeholders. Our findings are representative of the interactions between social and ecological factors that need to be addressed for forest management planning. It is, in essence, a systems approach but is, however, non-exhaustive.

We also found that, in terms of the temporal aspect, the investigated forest sustainability assessment approaches were ex-post, ex-ante, or a combination of both. The proposed assessment is designed for all three possibilities. Finally, a transdisciplinary approach was observed in 47.7% of all articles to varying degrees. This in line with the findings of Garcia et al. (2025) that participatory processes play an crucial role in sustainability discussions and is therefore also incorporated in the assessment design in this dissertation.

3.3. Money talks - addressing market failure with MBIs and PES (article 3)

Sustainability assessment approach in context

The economic needs of forest stakeholders influence how forests are managed. Currently, timber production continues to be the primary source of revenue for forest owners, and the income gap for regulating and cultural FES needs to be addressed (Lovrić et al., 2025; Mann et al., 2022). The proposed sustainability assessment explores MBIs, in particular PES, as a potential policy response, which is needed in order to address the market failure on the lack of economic incentive for the regulating and cultural FES.

Article summary

Recognizing that functioning ecosystems are needed to deliver the wide range of FES, in this article, we investigated high-level policies of the European Green Deal. We employed a cross-sectoral policy analysis and found evidence that MBIs are being employed across multiple policy sectors. However, we found that only 23 out of the 130 policy documents include MBIs that refer to ecosystems, and only 11 of those involve PES. The Green Deal argues for the mainstreaming of environment and climate in all policy sectors. This study shows that, at the top-most level, there is still a lack of emphasis on utilizing MBIs and PES as part of a policy mix in order to address ecosystem degradation.

Lessons learned

Addressing market failure in forestry is a critical issue. Most FES are public goods (Nichiforel et al., 2018), and therefore offer little financial incentive for forest owners. In formulating management scenarios under the frame of a sustainability assessment, economics plays a crucial role. Until this is addressed, there can be no tangible discussion on alternatives for forest managers. PES is an opportunity to address the market failure associated with FES, and influence how forests are managed. If regulating and cultural FES were given their due financial value, forest managers could be incentivized to restore ecosystems or manage their forests to be more near to nature.

3.4. A transdisciplinary approach is key for sustainability (article 4)

Sustainability assessment approach in context

In essence, sustainability assessments promote sustainable development. Transdisciplinary learning, meanwhile, is key for moving society towards sustainability (Barth et al., 2023) and is an essential aspect of the proposed forest sustainability assessment approach. The proposed design could be applied to forests worldwide with the acknowledgement that local contexts vary and present a wide range of possible framework conditions. Employing a transdisciplinary approach is essential for involving local communities and understanding the specific context of an area (Matias et al., 2025).

Article summary

Being that BRs are primarily known as "learning sites for sustainable development" (UNESCO, 2025), we sought to find out, through a systematic literature review, if BRs in the Global South utilize the transdisciplinary approach for education for sustainable development and the prevalence of transnational partnerships. We found little evidence for both. These are gaps that, if addressed, would further the objective of promoting sustainable development in BRs. First, using a transdisciplinary approach would be instrumental in involving local communities and their knowledge about the context of their respective areas, which is crucial for any sustainability initiative. Next, promoting the cooperation between BRs in the Global South is key as it enables them to cooperate and exchange knowledge on common sustainability challenges and take advantage of opportunities.

Lessons learned

The transdisciplinary approach was tackled in the second article and participatory approaches in the first article. This fourth article focuses more on the topic within the context of BRs. Even in BRs, which are supposed to be beacons for sustainable development, the transdisciplinary approach seems to be underutilized. The sustainability assessment approach I propose should be applied with this approach in mind as a means to increase its effectiveness in adapting the prescribed steps to various forest framework conditions. The inclusion of indigenous peoples, for example, in the development of forest management plans through a transdisciplinary approach would be a step towards increased equity for local communities. In addition, BRs are also meant as living laboratories where innovations for sustainable development could be tested. As such, BRs are also potential areas where the proposed sustainable assessment design could be implemented, and improved upon, in the future.

Table 1 offers an overview of the specific elements of each of the four articles that were integrated into the sustainability assessment approach. It further identifies which sustainability dimension each one primarily addresses.

Table 1. Overview of scientific articles and the specific elements used for the proposed sustainability assessment approach

Scientific article	Elements integrated into the sustainability assessment	Sustainability dimension addressed
1	Conflicts between FES stakeholders	Social
	Participatory processes	
	FES provided by forests	Environmental
	FES compensation systems	Economic
2	FES provided by forests	Environmental

	Biophysical characteristics	
	Forest profitability indicators	Economic
	Governance and administrative indicators	Social
3	MBIs and PES as sources of income	Economic
4	Transdisciplinary education for sustainable development - participatory processes	Social

3.5. A sustainability assessment approach for FES provision

Building on the basic steps outlined by Morrison-Saunders & Pope (2013), I propose a process for conducting a sustainability assessment for the provision of FES. For this design, forest managers and other stakeholders need a unified vision at the outset that the forest management plan(s) to be formulated and evaluated are to be designed for the primary objective of providing the wide range of FES offered by a specific forest. This entails that a stakeholder analysis that identifies the relevant actors that are dependent upon the FES offered by a particular forest must already have taken place before conducting the assessment. This recommendation is based mainly on our findings that (1) stakeholders have varying demands from forests ranging from provisioning, regulating and cultural FES and the conflicts between them could have adverse effects on the sustainability of a management plan, and (2) that participatory approaches for forest management decision-making could mitigate potential conflicts between stakeholders and could enhance a project's sustainability (Garcia et al., 2025).

3.5.1. The sustainability assessment approach

In the following section, a step-wise sustainability assessment is presented. There are seven steps in total. However, steps 2 to 4 make up the core of the design as they are based on the empirical findings of the four scientific articles in this thesis, and are structured according to sustainable development as a nested system as proposed by Ibisch et al. (2018).

The **first step** is to decide to conduct a sustainability assessment for the provision of the wide range of FES. This entails identifying stakeholders who have varying demands for FES provision and coming to a common understanding of (1) their respective dependence on FES, (2) the dependence of FES provision on functioning forest ecosystems, and (3) the importance of addressing conflicts between competing stakeholder demands. The objective of providing for the wide range of FES has to be agreed upon by the stakeholders with this sustainability assessment approach being presented as a tool that could help improve the sustainability of future forest management plans.

Next, a biophysical and FES assessment needs to be conducted encompassing all FES categories (see MA, TEEB, CICES and NCP). In this **second step**, the forest's general health, with specific indicators from the environmental indicators from the 2nd scientific article, and its capacity to provide FES is assessed. Also, the wide range of FES provided by the forest are identified. It is important to note in this step that many FES possibly receive little to no attention from stakeholders, namely regulating and cultural FES (Mann et al., 2022). This sustainability assessment approach aims to recognize their value by bringing these FES into the forefront of forest management discussions, integrating them into decision-making processes.

Once the forest's condition is determined and FES identified, a thorough conflict analysis needs to be conducted. This entails the identification of stakeholders, matching their respective demand for FES, and determining conflict lines that exist between varying demand **(step 3)**. In addition, social and cross-cutting non-FES indicators in the second scientific article of this dissertation need to be taken into account as they could have long-term effects on sustainability. In this step, conflict mitigation solutions should be discussed.

Acknowledging that the economic needs of forest stakeholders influence how forests are managed (Lovrić et al., 2025), **step 4** entails the identification of alternative sources of income primarily to address market failure. Here, MBIs, specifically PES schemes, can be explored together with stakeholders. As demonstrated by the third research article in this dissertation, MBIs and PES show potential for providing viable financial alternatives. The economic indicators from the second scientific article pertaining to the profitability of the forest are also included here.

The **fifth step** is the formulation of forest management alternatives, which should encompass the findings of steps 2 to 4, but also reflect crucial nuances. First, FES that have no demand from stakeholders need to be taken into account and decisions to forgo their provision need to be rationalized and documented. Second, as each forest management alternative will have varying impact on stakeholders, the respective trade-offs for each one need to be documented and discussed. In this step, solutions for mitigating the trade-offs need to be formulated together with the stakeholders.

Step 6 entails the evaluation of each forest management alternative, and selecting the one to be implemented. Here the forest management plans formulated in the previous step, including conflict mitigation solutions, are to be presented and evaluated. Ideally, the criteria for evaluating the plans should be agreed upon with the stakeholders and carried out in a participative process by forest managers together with other stakeholders.

Finally, **step 7** is the implementation of the chosen forest management plan. The forest management plan should include a monitoring plan which assesses (1) forest health, (2) FES provision, and (3) stakeholder conflicts. Figure 4 shows the proposed sustainability assessment approach.

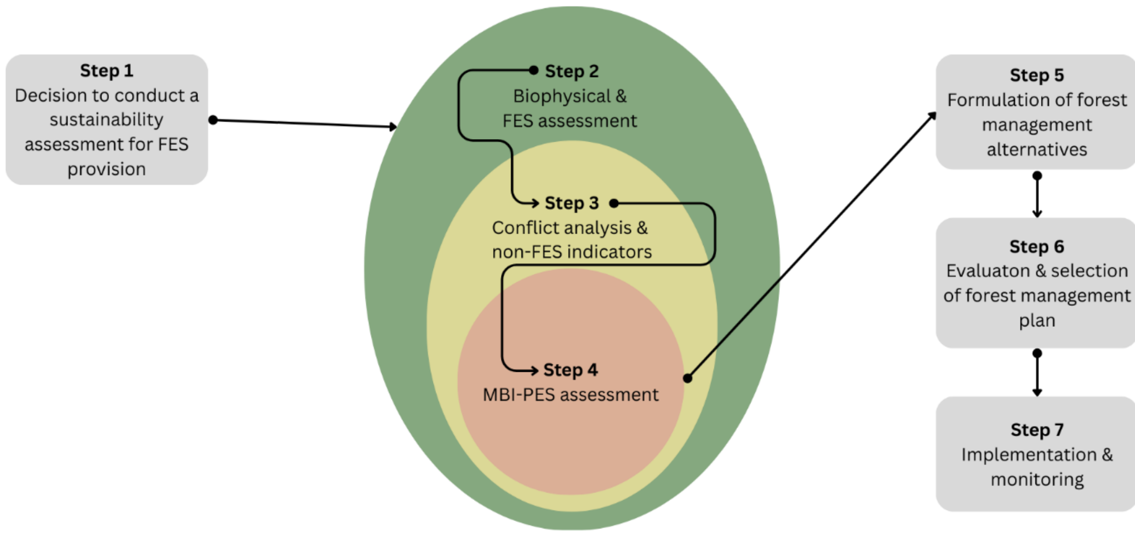

Figure 4. A proposed sustainability assessment approach for the provision of the wide range of forest ecosystem services (partially adapted from Ibisch et al. (2018) and Morrison-Saunders & Pope (2013))

3.5.2. The core of the approach: steps 2 to 4

The focus of this thesis lies in the biophysical and FES assessments (step 2), conflict analysis and non-FES indicators (step 3), and the MBI-PES assessment (step 4). Step 2 is comprised mostly from the learnings from scientific articles 1 and 2. Article 2 emphasizes the need for assessing the biophysical characteristics of the forest and forest health as these have significant roles in the forest's capacity to deliver ecosystem services. Article 1, meanwhile, establishes that forest stakeholders are dependent upon various FES, which therefore have to be inventoried. Article 2 lays out the wide range of ecosystem services offered by forests according to the MA, TEEB, CICES and NCP classification systems.

Step 3, conflict analysis and non-FES indicators, draws learnings from all four articles. Article 1 focuses on determining which conflicts arise between stakeholders competing for a wide range of FES, but also explains that mitigation actions are needed as conflicts between stakeholders could have negative consequences for the sustainability of a forest management plan. Article 2 shows that there are numerous non-FES indicators that need to be taken into account when assessing forest sustainability.

These encompass several social and cross-cutting indicators. Article 2 and article 4 illustrate that a transdisciplinary approach is needed in order to more effectively integrate local communities and local knowledge on their forests into the forest management plan.

Finally, step 4 on MBI-PES assessment is discussed in articles 1, 2, and 3. In article 1, MBIs are established as a means to address market failure and that it has the potential to mitigate conflicts between competing stakeholders. In article 2, economic indicators are laid out as an important part of sustainability assessments. Sustainability, after all, also entails addressing the economic dimension. A number of industries are address here including tourism and timber. In article 3, it was determined that policy support for MBIs and PES within the framework of the European Green Deal is lacking. It calls for more attention on PES as a means to restore ecosystems, including forests, which would in turn enhance the provision of ecosystem services for the benefit of society. Table 2 shows an overview of the core steps of the sustainability assessment and the cross-section with the scientific articles.

Table 2. Overview of each scientific article's contribution to the sustainability assessment approach

Sustainability assessment steps	**Scientific Article**			
	1	2	3	4
Step 2 Biophysical & FES assessments	x	x		
Step 3 Conflict analysis & non-FES indicators	x	x		x
Step 4 MBI-PES assessment	x	x	x	

3.6. Further research needs & outlook

The sustainability assessment approach proposed is a work in progress that necessitates further investigation. Referring to figure 4, the steps decision to conduct a sustainability assessment for the provision of FES (step 1), formation of forest management alternatives (step 5), evaluation and selection of forest management plan (step 6), and implementation and monitoring (step 7) are touched upon in this dissertation but call for exploration. Meanwhile, the biophysical and FES assessments (step 2), conflict analysis and non-FES indicators (step 3), and MBI-PES assessment (step 4) have to be applied and tested. The topics can be organized in four research lines.

Research line 1: Conducting a stakeholder analysis and setting framework conditions

It is a pre-requisite of this sustainability assessment approach that stakeholders agree upon the common objective of providing the wide range of FES offered by a particular forest. The research done in this dissertation points towards transdisciplinary and participatory processes in forest management as the way forward. In terms of methodology, further research can be conducted by carrying out a thorough stakeholder analysis, and then convening the identified parties. Through a series of workshops or focus groups, each one's interests can be assessed and we can identify the opportunities and challenges of cooperation between them. As a final step, a roadmap for cooperation can be co-designed by the stakeholders with the overall objective of providing the wide range of FES.

Research line 2: Applying the FES sustainability assessment

The findings of this dissertation should be applied in a particular forest as an empirical case study for testing. As an initial step, biophysical and FES assessments can be conducted in order to determine the state of the forest and what services it offers to stakeholders. Second, a thorough conflict analysis needs to be conducted, which identifies possible hindrances but also opens opportunities for cooperation between stakeholders. Finally, financing options need to be explored with a focus on MBIs and PES.

Research line 3: Assessing forest management alternatives

Research can be done on the formulation of forest management alternatives. Each alternative should identify varying scenarios that identify the prioritization of FES which in turn determine the level of conservation, timber production, recreation, etc. All stakeholders should be involved in this stage of the process so as to give each one the opportunity to represent their interests and to co-design solutions and alternatives. The trade-offs of each scenario for each stakeholder should be assessed. Finally, the evaluation and selection process for the forest management option that will be implemented should done using commonly agreed upon criteria. The process of formulating the criteria should be done in a collaborative, transparent process. Involving a third party evaluator to include a non-biased perspective could be beneficial.

Research line 4: Establishing a monitoring and evaluation system for FES provision

A monitoring and evaluation system for long-term FES provision needs to designed. The findings in this dissertation could be seen as a starting point for an ex-post monitoring methodology that can be implemented in varying timeframes. It is crucial to provide evidence of how effective (or ineffective) the implementation of the forest management plan is, and to adapt the plan as needed. This would encompass the impact on the forest, as well as the people who demand its goods and services. The transparency and accountability of such a process would be key to its success.

4. Conclusion

Forests continue to degrade at an alarming rate worldwide. Sustainability and sustainable development are seen as means to balance the environmental, social, and economic dimensions of a prosperous society. In this dissertation, I integrate the ecosystem service concept into a sustainability assessment approach for forest ecosystems. It is meant as a contribution towards improving sustainability in forest management. Based on the empirical findings of this dissertation, various conclusions for particular target groups can be drawn.

Conclusion for target groups

Policy-makers

For policy-makers, this sustainability assessment approach could be considered as an approach that is in line with policies that prioritize forest health and forest functioning, for example the EU Nature Restoration Law, and uses this as a basis to build up the other aspects of sustainable development. It does this by using the ecosystem services concept to communicate the wide range of goods and services that forests offer, which are essential for society and human well-being. Since it is set within the framework of sustainable development and its three dimensions, one can see the cross-sectoral importance of forests and how they could contribute to achieving sectoral goals. In addition, by identifying the diverse FES offered by a particular forest, this approach helps to make trade-offs between FES prioritization more transparent, which allows for a more open discussion on forest management policies and strategies.

Forest managers

For forest managers, this sustainability assessment could be considered as a means to operationalize a reorientation of forest management priorities from economics-first (e.g. monoculture) to diverse FES provisioning (e.g. close-to-nature). This is done through mapping out the diverse ecosystem services offered by the forest, many of which are enhanced by close-to-nature conditions. Then by undertaking the conflict analysis, one is able to identify which FES are important to which stakeholders and which FES lack recognition or prioritization. This then establishes a foundation for a more informed debate as to the opportunities and limitations of forest management plans. Essentially, this assessment enables forest managers to act not just as stewards of forest resources, but rather as mediators between competing forest stakeholders and facilitators of sustainable development.

Science

The proposed design is meant as an incremental contribution to the on-going research on and development of sustainability assessments. As the debate on sustainability and sustainable development continues, sustainability assessments, as a means to guide decision-makers in various organizations and capacities, are very much needed. The proposed design demonstrates how the protection of forests can be argued for in the context of economic pressure and social demand in the context of a sustainability assessment. However, a possibly decisive factor in the design is the MBI-PES dimension. It essentially the one concept that is largely understudied as part of a sustainability assessment. Considering the potential that it holds for addressing market failure in forests, more research can be done in this regard.

Limitations

This thesis is limited primarily since it has not yet been tested in any practical context. As it is now, it is purely conceptual. Its empirical application would yield deeper insights in how robust or adaptive this assessment is. Future research can be done in this regard. Another limitation is that this thesis does not delve into the Sustainable Development Goals (SDGs). In the last several years, the SDGs have been at the forefront in mainstreaming sustainability in most facets of society on a global scale. Its lack of integration into this thesis stems from the foundation of the design presented here – the nested system approach to sustainability, which prioritizes the health and functioning of ecosystems. This is how this design is thought out. The SDGs do not address the various contradictions between several of its goals and ecosystem preservation. As such, it was deemed better to limit its integration into this thesis.

Final word

A forest management plan anchored on a sustainability assessment that aims for the provision of the wider range of FES would benefit stakeholders, and could be seen as an opportunity to guide forest management decisions towards sustainability. The approach laid out here and further elaborated in each of the four articles illustrates a non-exhaustive list of factors that should be taken into account when managing forests. It is indicative of the complexity of social-ecological systems.

5. Position statement

There is a lot of criticism on the lack of equity in international cooperation partnerships between global north and global south countries. I have seen this first hand during my time at the GIZ in Manila many years ago now. I witnessed European, mostly German, researchers come to our country to investigate specific cases and having the opportunity to learn, but mostly it was to implement whichever agenda was determined in Germany as being important at the time. For the most part, the Filipino counterparts had little say in the overall direction of projects. It was a double-edged sword as foreign-aid projects provide employment and finance infrastructure.

Well, I am, in a way, the reverse of that paradigm. I am a Filipino investigating Germany and Europe, making policy recommendations on European forest management. The difference is that I am working within the framework of what Germany and Europe need, as they have set the objectives themselves. As a scientist from one of the most climate vulnerable countries in the world, I do believe I have a unique perspective to offer, one that is rooted in having experienced the negative consequences of climate change first hand (on several occasions) and this is being welcomed within the arena of debate I currently find myself in. I try my best to find avenues to bring in my views and connecting whatever I am working on to benefit my home. In many ways, this is what anchors me in my research.

When it comes to the climate, Germany and the Philippines are interconnected, though we experience its effects in vastly different scales. Trying to solve the climate crisis, however, must start with Germany and other global north countries being that they are the source of most greenhouse gas emissions historically, and currently (along with China). This is now where I see my contribution. I am working towards improving the sustainability of forests in Europe which then contributes to reducing climate change on a global scale, benefitting the Philippines.

I can see the connection of how improving carbon sequestration in Germany, emphasizing ecosystem restoration in European policy, or resolving conflicts between forest stakeholders contributes to the big picture. Though, of course, negative externalities need to be taken into account. Through my work, I represent the interests of my family and country. I can only hope that whatever incremental contribution I make serves to improve the lives of people back home.

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