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# Economic Evaluation of Different Implementation Variants and Categories of the EU Biodiversity Strategy 2030 Using Forestry in Germany as a Case Study

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**Abstract:** The EU Biodiversity Strategy 2030 (EUBDS) aims to preserve and restore biodiversity by protecting large areas in the EU. An extensive part of these protected areas will presumably be covered by forests. This study analyses the economic effects of EUBDS implementation on German forestry in two scenarios, based on different possible interpretations of the EUBDS' key commitments, using a forest economic simulation model. A special focus is placed on the opportunity costs of coarse wood debris (*CWD*). Over a simulated 200-year period, a decrease in timber harvest of 13% and 44% is estimated under the respective scenario assumptions. This leads to a reduction in the silvicultural contribution margin (SCM) of on average 0.25 B EUR $a^{-1}$ (14%) and 0.79 B EUR $a^{-1}$ (45%). In terms of the total SCM, protected forests contribute 35% and 15% in the two scenarios. The accumulation and preservation of *CWD* incurs a substantial loss of utility, as 15% and 19% of annual logging is required for conservation purposes. However, the EUBDS may also provide economically tangible benefits. A rational decision would be to implement a scenario if the "net benefit" from the protected status exceeds the losses from set-aside and conservation requirements.

**Keywords:** nature conservation; EU biodiversity strategy 2030; economic impact; evaluation; forest economic simulation; forestry in Germany; coarse woody debris; old-growth forests

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## 1. Introduction

The EU Biodiversity Strategy 2030 (EUBDS) with its objectives of the conservation and restoration of ecosystems and biodiversity, is an important pillar of the European Green Deal [1]. Its key commitments are to:

> "(1) Legally protect a minimum of 30% of the EU's land area and 30% of the EU's sea area and integrate ecological corridors, as part of a true Trans-European Nature Network,
>
> (2) Strictly protect at least a third of the EU's protected areas, including all remaining EU primary- and old-growth forests, and
>
> (3) Effectively manage all protected areas, defining clear conservation objectives and measures, and monitoring them appropriately" [2] (p. 6).

In accordance with the EU principle of subsidiarity, the strategy serves as a non-binding memorandum or general guideline for future action for the EU and Member States. With a share of 39% of the EU land area [3], forests and forestry will undoubtedly play a vital role in implementing the EUBDS. In this matter, an extension of forest areas, managed according to nature protection regulations, and of set-aside forest areas as unmanaged woodland (= strictly protected areas) can be expected to be necessary in many EU member states. Yet, the strategy leaves a wide scope of interpretation for the European and national implementation processes. On one hand, there are no definitions for certain important categories, such as old-growth forests [4–7]. Additionally, specifications on the partitioning of the protected areas shared by the member states as well as the assignment of protected areas to different types of land-use are lacking. Furthermore, it is unclear whether it is necessary to strictly protect more than one-third of the already existing protected areas if that area to date already exceeds the required 30%. Finally, it is ambiguous as to which protected areas already meet the EUBDS requirement for effective management with clear conservation objectives and measures.

Despite the protection of biodiversity in the EU playing a major role, the implementation of the EUBDS is expected to have far reaching economic consequences for forestry and subsequently the forest industry. Set aside forest land leads to foregone revenue from timber production, whereas in protected areas, where forestry is still possible, regulatory constraints due to nature protection measures entail various additional financial charges for forest owners [8].

Coarse woody debris (*CWD*) or deadwood represents a peculiarly important component in the forest ecosystem, as it is used as a habitat and source of nourishment for numerous species, as well as being a significant part of the carbon and nutrient cycle [9]. For some years now, *CWD* has been used as an indicator of the degree of closeness of forest ecosystems to nature and also represents an important metric in the assessment of habitat types under the Natura 2000 protected area concept [10,11].

Different studies exist on the policy impact assessments of various nature conservation laws or proposed laws [8,12–16]. Current research on these issues encompasses modelling on single matters or case studies, such as [12], which discusses opportunity costs from forest conservation on a local/regional level in Finland, while simultaneously focusing more on the implications on the forestry job market (social costs) in rural areas. Several studies have explored the implications of forestry versus nature conservation in national parks, specifically highlighting the Bavarian Forest National Park [13]. Rosenkranz et al. (2014) investigated the economic effects of implementing the Habitats Directive in beech forests in Germany [14]. In a subsequent study, researchers examined the notion of "new multifunctionality" and its correlated expenses and decreased revenues in Germany [8]. Moreover, research works exists that examines the effects of bird protection areas [15] as well as the additional costs and diminished revenues resulting from forest protection and its recreational functions [16].

The effects of the implementation of the EUBDS on raw wood production in Germany and in the EU and their trickle effect into other countries under two different scenarios have been estimated by Dieter et al. (2020), Timm et al. (2022) and Schier et al. (2022) using the Global Forest Products Model [7,17–19]. A percentage reduction factor was applied to the simulated results for the potential volume of raw wood in the German Forest Development and Timber Volume Modelling (Waldentwicklungs- und Holzaufkommensmodellierung (WEHAM)) baseline scenario in 2012 [7,18,19], and this reduction was extrapolated to other EU countries to estimate a decrease in the proportion of raw wood production. The WEHAM 2012 baseline scenario was simulated using Forest Development and Wood Supply Modelling, based on data from the National Forest Inventory (NFI) 2012 on forest status and forest conservation levels [20]. It was developed by federal and state governments and represents the standard silvicultural practices at the time.

As the above-mentioned studies of Dieter et al. (2020), Timm et al. (2022) and Schier et al. (2022) aim and focus on the detailed modelling and assessment of the impacts of the EUBDS on global timber markets, and their estimation of its effects on forestry has a servicing function and is so far calculated roughly and statically. The implementations of individual conservation measures were not calculated independently and only alterations in logging volumes were estimated. Economic effects on forestry, such as opportunity costs compared to forest management, according to the current forest nature conservation level, were not included [7,18,21]. Additionally, the physical and economic estimates of changes in wood stock as well as *CWD* stock under EUBDS implementation were not calculated. Despite increasing uncertainties, the long-term effects of EUBDS implementation also remain unknown in these studies, because the WEHAM 2012 baseline scenario is only available for a simulation period of 40 years. Additionally, no change in tree species was assumed in the WEHAM 2012 baseline scenario. Further, WEHAM does not model climate sensitivity and no mortality predictor exists for the managed forests. Although the nationwide *CWD* supply was captured by the NFI 2012, the important structural category of *CWD* has not been independently modelled with WEHAM to date. The dynamic changes of the *CWD* stock over time or the effects of changing supply quantities are not represented by the WEHAM baseline scenario.

Therefore, the objective of the study at hand is to fill the gap of these publications by analysing the economic effects on forestry in Germany through the two previously developed EUBDS implementation scenarios. Complementary to these three studies, we now conduct an in-depth comprehensive analysis of the long-term effects on key economic and natural forestry figures, considering nature protection requirements, such as *CWD* retention, set-aside forest, and the designation of habitat trees, as well as changes in tree species composition and tree survival probabilities in climate change [7,18]. A special focus is given to the economic effects of *CWD* retention on forestry as a major nature protection requirement. With our study, we aim to answer the following research question:

What are the long-term economic impacts of different implementation variants and categories of the EU-BDS 2030 on German forestry with special regard to coarse woody debris?

We are aware that the implementation of nature protection legislation also results in a number of non-marketable values, which are categorized into use values (direct and indirect) and non-use values, such as bequest value and existence value [22,23]. However, these are not easily observable and difficult to quantify in congruent form [12,24]. Therefore, this paper does not conduct a cost–benefit analysis but rather focuses on the long-term opportunity costs of the EUBDS implementation for forest enterprises. It would be a scientifically sound decision to opt for biodiversity conservation services if the incremental advantages derived from them surpass the associated opportunity costs related to raw wood production and utilization.

## 2. Materials and Methods

For our purpose, a climate-sensitive, partly dynamic forest economic simulation model was expanded with a *CWD* calculator and applied to the EUBDS-implementation scenarios developed by Timm et al. (2022) and Schier et al. (2022) [7,19,20]. In order to assess the effects on the entire German forestry landscape, a "Forest enterprise Germany" was simulated using data from the National Forest Inventory (NFI 2012) and uniform assumptions on forest management.

### *2.1. The Case Study: Germany*

In our case study, focused on Germany, we constructed the "Forest enterprise Germany" using the average values derived from the NFI 2012 [20]. As described in previous sections, we utilized the accessible forest area of the Federal Republic of Germany as the initial parameter for evaluating the total area (10.6 million hectares). This encompasses all ownership types within Germany, with the state forest accounting for approximately 32 % of the forested areas, corporate forests covering around 19.5%, and private forests representing about 48.5% [20]. To analyze the specific tree species distribution, we applied area vectors to four distinct groups: oak (approximately 11%), beech (approximately 34%), spruce (approximately 30%), and pine (approximately 26%) [20]. The economic data utilized for our analysis were obtained from the FADN (Forest Accountancy Data Network), encompassing both harvesting costs and revenues across Germany as a whole [25].

Germany was very suitable as a case study regarding the economic impacts of EUBDS implementation, as it is one of the largest producers of roundwood in the EU-27

[26]. Germany is also about average for other forestry and nature conservation parameters in the EU-27: for example, an evaluation of the database of the "Global Forest Resources Assessment" from 2020 showed that Germany is approximately on par with the European average in terms of both the size of protected areas and biomass in *CWD* [27]. For instance, Germany is slightly above the European average of 13.5 $m^3$ ha $ha^{-1}$ for *CWD* stocks with 20.6 $m^3$ ha $ha^{-1}$ [27]. According to FRA, the European minimum is 2.33 $m^3$ ha $ha^{-1}$ for Portugal, and Slovakia has the highest *CWD* stocks with about 28 $m^3$ $ha^{-1}$ [27]. Furthermore, initial policy impact assessments have already been conducted, which will be complemented in this study [7,18,19]. This case study of Germany can therefore serve as a reference for the economic impact assessment of different implementation scenarios in other EU states. Moreover, by utilizing and, respectively, extending a forest economic simulator, such as FESIM (Forest Economic Simulation Model), it is feasible to assess conservation measures by means of indicators, such as *CWD*, both economically and ecologically. To date, there have been a limited number of studies that examine the impact of supranational policy at the national level, incorporating biodiversity indicators, such as *CWD*, the permanent preservation of habitat trees, and various land conservation categories, into an economic evaluation. In conjunction with the aforementioned studies, our study provides a holistic overview on the potential impacts of the EUBDS on forestry and, as a result, can assist other member states in the implementation of their strategies.

### *2.2. Simulation Model*

As forest production is characterized by long-life cycles, the consequences of silvicultural decisions and changes in management are multifaceted and often become visible only after decades or centuries. Therefore, we conducted long-term modelling for our study, as it is essential for analysing impacts on economic and natural key figures [14,16,28].

As a basis for the modelling, the Forest Economic Simulation Model (FESIM) was used. The FESIM, also referred to as the Strugholtz–Englert Simulation Model in previous publications, is used to calculate the effects of different possibilities of forest management for a period of up to 200 years [8,14,16,29]. To date, the FESIM has been used to calculate the opportunity costs of nature conservation requirements and the provision of protective and recreational forest functions [16]. The model is not based upon individual stands or trees but rather on entire forestry regions and enterprises while calculating results using average values. The FESIM is a multi-input model consisting of the following:

1. a forest-growth model that has been developed utilizing Sloboda functions derived from yield tables, which incorporates the silvicultural treatment technique of moderate thinning from below [30];
2. a forest management model, with variable settings of different management parameters, such as harvesting type, rotation age, basal area, number of trees planted, and intended age structure;
3. mean survival probabilities for each tree species, based on Weibull functions as the hazard rate and the survival probability models of Brandl et al. (2020) [31];
4. an economic evaluation model which handles the financial–mathematical calculation of the economic key figures based on cost and revenue functions.

FESIM can simultaneously update the timber stock and run an economic analysis of the biological production processes while simulating the utilization measures. The simulations run in discrete 5-year steps over a 200-year period and are linked with Markov chains. Ending each rotation cycle, the stands are regenerated according to an adaptable tree species matrix. The model consists of four main tree species groups: spruce, pine, beech, and oak. The tree species groups are specified in the following Table 1:

**Table 1.** Tree species groups with data sources of yield tables used in the FESIM.

| Tree Species | Representative For | Data Source |
|---|---|---|
| **Spruce** | All spruce and fir species (*Picea spec* and *Abies spec.*), Douglas fir (*Pseudotsuga menziesii*) and all other fast-growing, neophyte coniferous species | [32] |
| **Pine** | All pine and larch species (*Pinus spec.* and *Larix spec.*) | [32] |
| **Beech** | Beech and all deciduous tree species of high longevity except oak (e.g., maple (*Acer spec.*), lime (*Tilia spec.*), ash (*Fraxinus spec.*), and others) and low longevity (e.g., birch (*Betula spec.*), aspen (*Populus tremula*), willow (*Salix spec.*), or rowan (*Sorbus aucuparia*)) | [32] |
| **Oak** | All oak species (*Quercus spec.*) | [32] |

## *2.3. Model Developments and Advancements*

### 2.3.1. Choice of the CWD Calculator

As an important indicator of biodiversity and closeness to nature, a fixed *CWD* calculator was integrated into FESIM as a key extension for the purpose of this study. The build-up and permanent maintenance of this adequate *CWD* stock depends on the growth and use of the forest as well as on the decomposition of *CWD* [10]. This is essentially determined by the rate of decomposition and the dynamics of the surrounding ecosystem [9]. The level of *CWD* stocks is related to several factors. Above all, the wood properties of the tree species and the site are the main factors determining the rate of decomposition of the *CWD*. The German NFI 2012 [20] shows a *CWD* stock of 20.6 $m^3$ per hectare across all tree species. *CWD* stocks in European beech forest reserves can be up to 10 to 20 times (max. 550 $m^3$ $ha^{-1}$) higher than in comparable intensively managed forests [33]. However, these local case studies often raise the question as to whether the reported *CWD* stocks represent a snapshot or a long-term stock level under Central European conditions. In order to represent *CWD* development, a suitable decay model under German conditions was searched for in a first step. Besides linear decay models [34,35], there are also exponential [10,36] and LAG-exponential models [34], as well as models based on Weibull distributions [34]. The *CWD* model of Meyer et al. (2009) was the only model reviewed in this study that distinguishes between standing and lying *CWD* [34]. However, due to the comparatively long and implausible decay times (see comparative graphs in the Appendix A) and the exclusively regional validity (the empirical data are mainly from north-western Germany), this model was deemed unsuitable for our purposes. Furthermore, many models were only suitable for regional applications and did not represent plausible decay times for total German conditions. Some examples of models that had only empirical data validation at the regional level are, e.g., Beneke (2002), Kahl (2003), Kahl (2008), and Müller-Using (2005) [37–40]. The model developed by Mues et al. (2017) has relatively short decay times in comparison to the other reviewed models [35] (see Appendix A). The models according to Rock et al. (2008) and Kroiher and Oehmichen (2010) were in the intermediate range and are applicable for the entire federal territory of Germany [10,36]. However, the publication of Kroiher and Oehmichen (2010) does not differentiate between tree species and has an average decay rate across all species [10].

The Intergovernmental Panel on Climate Change (IPCC) also uses *CWD* as one of the carbon compartments in the forest for the official recording of "Land Use, Land-Use Change and Forestry" (LULUCF) sector reports [41,42]. The stock-difference method is used in that case, however. This method calculates the *CWD* as the difference between the last two carbon inventories, which, in addition to the NFI, are also carried out every 10 years at an offset of 5 years. Since, in this study, the *CWD* is simulated for a time period of 200 years, the stock difference method was deemed unsuitable for our purposes.

The model of Rock et al. (2008) is applicable for the entire federal territory, as it differentiates between tree species, and since the model provides plausible results for Germany in the model comparison and can be integrated in long-term modelling, it was decided to integrate this model into FESIM [36]. The publication of Rock et al. (2008) relies on numerous empirical studies on *CWD* in Germany and neighbouring countries [36]. A comparison of the various *CWD* models and decay rates reviewed in the scope of this study is provided in Appendix A.

### 2.3.2. Implementation in the Model

In a second step, the chosen model was integrated in FESIM. This was performed using a simple exponential decay model of the following set of equations:

$$V_{CWD}(t) = V_{CWD}\ \mathrm{e}^{-kt}$$

Where $V_{CWD}$ represents the *CWD* stock, $k$ represents the decomposition rate constant, and t represents the decomposition period in years [36].

Average *CWD* stocks per hectare from the NFI 2012 are used as initial values [20]. These amount to 20.6 $m^3$ $ha^{-1}$ on average (also containing rootstocks and removal residues) and are allocated to idealised pure stands for the individual tree species. However, since we only use the technically utilisable wood for the supply of *CWD* in our forest economics calculations, rootstocks and removal residues are subtracted from this. This leaves the following initial values for the four tree species groups and the utilised k-Factors [20]:

The initial stocks are inputted into the *CWD* calculator as undecomposed, due to a lack of quantifiable information regarding their decomposition levels. Although the NFI data indicate varying levels of decomposition that are visually evaluated during the inventory process, these observations cannot be reliably assigned to the specific decomposition levels as defined in the *CWD* calculator. As a result, a default assumption of undecomposed status is made.

In the scenarios, different *CWD* minimums are estimated for the different scenario categories depending on the presumed regulations for these areas (see setting Table 2). In a first step, these required amounts are built up from the supply of annual calamity timber and timber from regular felling. Once the required amounts are reached, the level of dead wood is maintained for the remaining runtime of the simulation. Since the EUBDS aims to achieve the desired goals by 2030, the *CWD* calculator is set in such a way that the desired amounts are achieved by 2030 by reducing the utilization factors from raw wood production. The stock of *CWD* is kept for the following periods in order to take account of any deterioration in the areas relevant to nature conservation.

**Table 2.** Input data for the *CWD* calculator.

| Input Data | Unit | Spruce | Pine | Beech | Oak | Source |
|---|---|---|---|---|---|---|
| Initial values of *CWD* (without rootstocks and residues) | $m^3$ $ha^{-1}$ | 16.61 | 16.61 | 14.22 | 10.60 | [20] |
| k-Factor for *CWD* decay | Factor | 0.0525 | 0.0575 | 0.0670 | 0.0372 | [36] |

For this purpose, the utilization factors for the calamity wood and the final harvest wood were iteratively adjusted downward using a solver until the target stock of *CWD* was reached in the specified realisation period. For the areas without special nature protection requirements (MF), this procedure was also followed, with the difference that the initial stock of *CWD* is maintained but not further increased. For the *CWD* build-up, the accrued calamity wood is used first in the simulation, if this amount is not sufficient then the final harvest wood is also used in second place.

## *2.4. Database*

As a natural database for the start of the simulation, the accessible and stocked forest area, grouped by tree species area per age class, was taken from the latest German NFI 2012 [20]. It is important to note that the NFI data were not updated in regard to the severe forest damage of the years 2018–2022 [43], as a current federal forest inventory is in progress and as the associated uncertainties were considered to be too high. As the results of a more recent NFI are not yet available, the start of the simulation had to be set in the year

2012. This is mainly a data problem and should be resolved after the current NFI is published.

The FESIM uses a distribution and not a fixed age for final felling. The final harvest distribution is characterized by a normal distribution with a specified standard deviation and mean rotation time. For the latter, the median values from the WEHAM baseline scenario 2012 were taken. This approach was adopted as it best reflects the German forest development observed in NFI data and does not aim to optimize forestry practices. However, it is truncated at a maximum age of 200 years for all tree species.

The economic database consists mainly of regeneration, thinning, and felling costs as well as timber revenues. The costs for pre-commercial thinning and regeneration were taken from forest valuation guidelines of three German Federal States [44–47]. For the regeneration of the same species, we primarily assumed natural regeneration, leading to lower costs. For changes in tree species composition in regularly harvested areas, higher costs for planting and plant protection (e.g., fencing) were incorporated. Conversely, in areas affected by calamities, additional costs for clearing were included. Average felling costs and timber revenues were taken from the German forest accountancy data network [29] for the pre-calamity years 2013–2017. For protected forest areas (PF), 1 EUR per $m^3$ additional timber harvesting costs were added per habitat tree to capture the added costs due to hazard tree felling. To incorporate the economic impacts of calamities, factors for revenue shortfalls and additional expenses induced by disasters were obtained from Möhring et al., 2021 [43]. To represent the forest decline resulting from climate change, survival probabilities of all tree species groups based on the RCP 8.5 scenario were taken into account (Table 3) [31,48].

**Table 3.** Economic input data of the FESIM.

| Economic Input Data | Unit | Spruce | Pine | Beech | Oak | Source |
|---|---|---|---|---|---|---|
| Costs of regeneration for same tree species after regular felling | EUR $ha^{-1}$ | 1300 | 1900 | 1800 | 2600 | [44–46] |
| Costs of regeneration for changing tree species after regular felling | EUR $ha^{-1}$ | 4300 | 5800 | 10,200 | 16,500 | |
| Costs of regeneration after calamity in | EUR $ha^{-1}$ | 5100 | 7500 | 12,400 | 18,900 | |
| Pre-commercial thinning costs | EUR $ha^{-1}$ | 500 | 500 | 500 | 500 | |
| Average felling costs (BAU) | EUR $m^{-3}$ | 24.7 | 24.7 | 24.7 | 24.7 | [25] |
| Average timber prices | EUR $m^{-3}$ | 78.4 | 62.6 | 58 | 95 | |
| Calamity-induced shortfalls in revenue | % | −4 | −20 | −20 | −10 | [43] |
| Calamity-induced additional expenses | % | 15 | 15 | 15 | 15 | |
| Factor of tree species survival after 100 years: | | 0.31 | 0.62 | 0.69 | 0.44 | [31,44,48] |

### 2.5. Scenarios

In scenario building, different model extrapolations into the future are distinguished: predictions extrapolate fixed past data linearly, while projections utilize hypothetical scenarios with varied variables and assumptions [49,50]. Predictions rely on present knowledge and initial conditions, whereas projections allow changes to the initial conditions [49,50]. Scenarios combine historical data with future elements, representing hypothetical future implementation trajectories in policy impact assessments [49,50].

In order to illustrate the range of the EUBDS implementation framework, two contrasting scenarios were developed by Timm et al. (2022) and Schier et al. (2022), namely a moderate scenario (MSC) and an intensive scenario (ISC), which were based on different possible interpretations of the EUBDS' key commitments but are subject to the assumption that all EU Member States have to achieve the EUBDS targets in equal proportions according to the EU requirements [7,19]. Further, the authors developed a business-as-usual

(BAU) scenario based on the NFI 2012 and the WEHAM 2012 baseline scenario [20]. Reflecting the aim of the EUBDS, the authors divided the forests into three categories:

(1) **Strictly protected forests (SPF)** that are set aside for natural processes protection and are unavailable for raw wood production;

(2) **Protected forests (PF),** which include all legally protected area categories with nature protection as the priority function, on which (restricted) raw wood production is permitted;

(3) **Multifunctional forests with minimum standards of nature conservation (MF)**, which include all forest areas without the priority function of biodiversity protection, in which multifunctional forest management is applicable and raw wood production is possible in compliance with the generally valid, legal requirements of biodiversity protection.

As an improvement to Timm et al. (2022) and Schier et al. (2022), the underlying assumptions for nature protection measures in the scenarios have been refined, deepened and extended with long-term simulations by the authors for a more detailed assessment of their economic impacts on forestry [7,19]. The two scenarios below reflect different imputation of protection categories (EU and national). Therefore, the existing classifications of individual protected areas in the opening balance vary as a result of differing interpretations and definitions of the EUBDS key commitments. These differences in understanding contribute to a diverse status quo among the protected area categories.

(1) The **BAU Scenario** represents the status quo of the German forest area and forest management practices and therefore serves as a reference to the MSC and ISC scenarios. It comprises a total of protected and strictly protected forests of 2.8 M ha, which includes Natura 2000, process protection, and other areas with a strong protection statuses [20,51]. The present SPF category comprises all forests where forest utilization is not allowed or not to be expected due to their off-site classification as nature conservation forest or protection forest [20]. In BAU, the SPF area therefore amounts in total to 178 K ha of set-aside forest. The PF area in this scenario is 882 K ha, comprising forest habitat types under the Habitats Directive of roughly 816 K ha [52], in addition to an assumed further lump sum of 66 K ha for species protection sites [8]. The remaining area of 1.74 M ha (2.8 M ha less SPF and Habitat area) is managed as filling and buffer zones. Furthermore, this scenario follows the statement of Sabatini et al. (2018 and 2020) that Germany features no old-growth forests [5,6].

(2) In the **Moderate Scenario (MSC)**, the initial status quo of total protected forest area also amounts to 2.8 M ha. Here, the PF area includes only designated European protected area categories (2.57 M ha, i.e., all Natura 2000 areas) and SPF areas include forests under natural development (227 K ha, National Strategy on Biological Diversity). With these potential settings, the EUBDS minimum target area share of protected forest area (SPF and PF) is not yet fulfilled. For the additional demand of protected area, it is assumed that all land use types must designate process conservation areas proportionally according to their share in the German land area. In this case, a further 1.03 M ha of forest area has to be set aside for the SPF area and a further 1.57 M ha of forests for the PF area [7]. Same as in BAU, no old-growth forests are designated in Germany in this scenario [5,6].

(3) In the **Intensive Scenario (ISC)**, Timm et al. (2022) and Schier et al. (2022) assume that, in addition to the European protected area categories, national protected area categories (e.g., nature reserves, nature parks, or landscape conservation areas) are also recognised as protected forest areas in the opening balance as status quo [7,19]. With a total of, in this case, 14.7 M ha of protected land area (of which 6.5 M ha are forests), the required protected area share of first EUBDS objective ("Legally protect a minimum of 30% of the EU's land area…") is therefore already exceeded in this scenario [53]. Consequently, the relative application of the second EUBDS target ("strictly protect at least a third of the EU's protected areas…") entails the designation

of an extensive additional SPF area. Opposed to the MSC scenario, it is assumed here that only 500 K ha of non-forest land-use, mainly consisting of peatland restoration area, can be contributed to strictly protected land [54] and that all other areas (4.16 M ha) have to be supplied by forests [7,19]. In contrast to the moderate scenario (MSC), German "development old growth forests", which are here all defined as old-growth forests above the usual rotation periods of the tree species groups [7,19], are included in the SPF category. Additionally, in this scenario, the nature conservation management requirements of all existing PF areas with a low protection status (e.g., nature parks or landscape conservation areas) are raised to Natura 2000 protection level and nature conservation measures are implemented accordingly.

Further details on scenario settings and parameters can be found in Timm et al. (2022) and Schier et al. (2022) as well as in Tables 4–6 below [7,19]. In the present context, it is noteworthy that the sub-items "Status quo" and "Objective" listed in the tables represent stock variables, while the sub-item "Scenario changes" pertains to a flow variable. The corresponding sources for the initial and final balances, as well as the assumptions underlying the changes, are indicated in the "Source" column enclosed within square brackets.

**Table 4.** Overview of the central scenario and category specifications with associated area proportions and sources for the SPF.

| | **BAU** | **MSC** | | | **ISC** | | | **Source** |
|---|---|---|---|---|---|---|---|---|
| | **Status Quo** | **Status Quo** | **Scenario Changes** | **Objective** | **Status Quo** | **Scenario Changes** | **Objective** | |
| **Total protected forests (SPF and PF)** | | | | | | | | |
| **Area [1000 ha]** | **2800** | **2800** | **+2600** | **5400** | **6471** | **0** | **6471** | [7,19,20,51,53] |
| **Strictly protected forests (SPF)** | | | | | | | | |
| **Total SPF Area [1000 ha]** | **178** | **227** | **+1031** | **1258** | **161** | **+4164** | **4325** | [7,19,20,51,53] |
| **of which process protection area** | **178** | **227** | **+1031** | **1258** | **161** | **+3100** | **3261** | |
| **Area deduction** | all forests with the NFI-status "forest utilization not allowed or not to be expected" due to their off-site classification as nature conservation or protection forest | all-natural forest protection development sites according to the definition of Engel et al., 2016 | additional 1031 ha taken from MF areas; proportionate designation across all of all age groups and tree species | sum of status quo and scenario changes | core zones of national parks and biosphere reserves, according to Röder and Laggner 2020 | additional 3261 ha taken from PF areas; proportionate designation across all of all age groups and tree species | sum of status quo and scenario changes | |
| **Conservation measures** | SPF areas are defined as process protection areas without additional preservation measures | | | | | | | [5,6,7,19,20,53] |
| **of which primary and old growth forest area** | **0** | **0** | **0** | **0** | **0** | **+1064** | **1064** | |
| **Area deduction** | do not exist in Germany | do not exist in Germany | | | --- | designation of "development old growth forests" of all age classes above the regular rotation period: oak > 160 y., beech > 120 y., spruce > 120 y. and pine > 140 y. | sum of status quo and scenario changes | |
| **Conservation measures** | SPF areas are defined as process protection areas without additional preservation measures | | | | | | | |

### 2.6. Forest Economic Assessment

In order to identify the potential implementation pathways of the EUBDS and assess their opportunity costs, the two scenarios described above are considered. The opportunity costs arise from the difference between a scenario and the baseline scenario (BAU). The net present value (NPV) of foregone wood production is a commonly used method for calculating opportunity costs in the literature [12,55]. However, in our investigation, we employ the silvicultural contribution margin (SCM) as a measure of opportunity costs rather than the NPV. This distinction lies in the fact that we aimed to examine changes in cash flows over the given time period, whereas the NPV consolidates the changes over time into a single value for the initial year. The SCM refers to the contribution margin derived from timber revenue generated through harvesting, excluding any associated harvest costs. It also includes product-specific costs, such as planting and maintaining the forest stand, including pre-commercial thinning operations. Administrative costs are excluded in the SCM calculation.

The liquidation value (LV) represents the estimated value of the forest stand in terms of its break-up value at the valuation date. It should be noted that the LV differs from the harvest value at the rotation age of the forest stand, as the LV considers the possible immaturity of the stands. This represents the aggregated standing value of the timber at the valuation date.

**Table 5.** Overview of the central scenario and category specifications with associated area proportions and sources for the PF.

| | BAU | MSC | | | ISC | | | Source |
|---|---|---|---|---|---|---|---|---|
| | **Status Quo** | **Status Quo** | **Scenario Changes** | **Objective** | **Status Quo** | **Scenario Changes** | **Objective** | |
| **Protected forest (PF)** | | | | | | | | |
| **Total PF Area [1000 ha]** | **2622** | **2573** | **+1569** | **4142** | **6311** | **−4164** | **2147** | [7,20,54] |
| **of which habitat type with conservation measure** | **882** | **882** | **+819** | **1701** | **882** | **+1265** | **2147** | [52,53] |
| **Area deduction** | all forests designated as forest habitat types under the Habitats Directive plus further areas for species protection | all forests designated as forest habitat types under the Habitats Directive plus further areas for species protection | proportion of existing tree species groups in habitat types transferred to expansion area, deduction over all age classes | sum of status quo and scenario changes | all forests designated as forest habitat types under the Habitats Directive plus further areas for species protection | area decrease for additional SPF area designation and habitat type requirements across the PF area | sum of status quo and scenario changes | [7,9,20] |
| **Conservation measures**<br>(i) Tree species composition | min. 80% deciduous | min. 80% deciduous | no further change | min. 80% deciduous | min. 80% deciduous | no further change | min. 80% deciduous | [11,20] |
| (ii) Permanent habitat trees (age class 100 yrs. and above; 100 m$^2$ per habitat tree) | 2 trees per ha, | 2 trees/ha on already existing and 0.5 trees per ha on newly designated PF areas | +3 trees per ha on already existing and + 4.5 tree per ha on newly designated PF areas | 5 trees per ha | 2 trees per ha | +3 trees per ha | 5 trees per ha | [8] |
| (iii) *CWD* | beech: 14.22 m$^3$ ha$^{-1}$<br>oak: 10.6 m$^3$ ha$^{-1}$<br>spruce: 16.61 m$^3$ ha$^{-1}$<br>pine: 16.61 m$^3$ ha$^{-1}$ | beech: 14.22 m$^3$ ha$^{-1}$<br>oak: 10.6 m$^3$ ha$^{-1}$<br>spruce: 16.61 m$^3$ ha$^{-1}$<br>pine: 16.61 m$^3$ ha$^{-1}$ | beech: +35.78 m$^3$ ha$^{-1}$<br>oak: +39.40 m$^3$ ha$^{-1}$<br>spruce: +33.39 m$^3$ ha$^{-1}$<br>pine: +33.39 m$^3$ ha$^{-1}$<br>in 20 years | beech: 50 m$^3$ ha$^{-1}$<br>oak: 50 m$^3$ ha$^{-1}$<br>spruce: 50 m$^3$ ha$^{-1}$<br>pine: 50 m$^3$ ha$^{-1}$ | beech: 14.22 m$^3$ ha$^{-1}$<br>oak: 10.6 m$^3$ ha$^{-1}$<br>spruce: 16.61 m$^3$ ha$^{-1}$<br>pine: 16.61 m$^3$ ha$^{-1}$ | beech: +35.78 m$^3$ ha$^{-1}$<br>oak: +39.40 m$^3$ ha$^{-1}$<br>spruce: +33.39 m$^3$ ha$^{-1}$<br>pine: +33.39 m$^3$ ha$^{-1}$<br>in 20 years | beech: 50 m$^3$ ha$^{-1}$<br>oak: 50 m$^3$ ha$^{-1}$<br>spruce: 50 m$^3$ ha$^{-1}$<br>pine: 50 m$^3$ ha$^{-1}$ | [11,20,56] |
| (iv) Rotation period | 20 years above the average on MF areas | already existing PF areas: 20 years above average of MF areas | newly designated PF areas: +20 years | 20 years above average on existing and newly designated areas | 20 years above average of MF areas | no further change | 20 years above average of MF areas | [8,33] |
| **of which filling and buffer zones** | **1740** | **1691** | **+750** | **2441** | **5429** | **−5429** | **0** | |
| **Area deduction** | all forests designated as forest habitat types under the Habitats Directive plus further areas for species protection | European Natura 2000 protected area categories and all-natural forest development sites | proportion of existing tree species groups in habitat types transferred to expansion area, deduction over all age classes | sum of status quo and scenario changes | all protected area categories are treated as forest habitat types | area decrease for additional SPF area designation and habitat type requirements across the PF area | sum of status quo and scenario changes | [7,8,20] |
| **Conservation measures** | see multifunctional forests with minimum standards of nature conservation | | | | | | | |

**Table 6.** Overview of the central scenario and category specifications with associated area proportions and sources for the MF.

| | BAU | MSC | | | ISC | | | Source |
|---|---|---|---|---|---|---|---|---|
| | Status Quo | Status Quo | Scenario Changes | Objective | Status Quo | Scenario Changes | Objective | |
| **Multifunctional forests with minimum standards of nature conservation (MF)** | | | | | | | | |
| **MF Area [1000 ha]** | **7828** | **7828** | **−2600** | **5228** | **4156** | **0** | **4156** | own calculation |
| **Area deduction** | total accessible forest area less SPF and PF areas | total accessible forest area less SPF and PF areas | | | total accessible forest area less SPF and PF areas | | | |
| **Conservation measures** | | | | | | | | [8,20,29] |
| (i) Tree species composition | status quo according to NFI 2012 | status quo according to NFI 2012 | change according to development between NFI 2002 and 2012 | change according to development between NFI 2002 and 2012 | status quo according to NFI 2012 | change according to development between NFI 2002 and 2012 | change according to development between NFI 2002 and 2012 | |
| (ii) Permanent habitat trees (age class 100 yrs. and above; 100 m$^2$ per habitat tree) | 0.5 trees per ha | 0.5 trees per ha | no further change | 0.5 trees per ha | 0.5 trees per ha | no further change | 0.5 trees per ha | |
| (iii) *CWD* | beech: 14.22 m$^3$ ha$^{-1}$<br>oak: 10.6 m$^3$ ha$^{-1}$<br>spruce: 16.61 m$^3$ ha$^{-1}$<br>pine: 16.61 m$^3$ ha$^{-1}$ | beech: 14.22 m$^3$ ha$^{-1}$<br>oak: 10.6 m$^3$ ha$^{-1}$<br>spruce: 16.61 m$^3$ ha$^{-1}$<br>pine: 16.61 m$^3$ ha$^{-1}$ | no further change | beech: 14.22 m$^3$ ha$^{-1}$<br>oak: 10.6 m$^3$ ha$^{-1}$<br>spruce: 16.61 m$^3$ ha$^{-1}$<br>pine: 16.61 m$^3$ ha$^{-1}$ | beech: 14.22 m$^3$ ha$^{-1}$<br>oak: 10.6 m$^3$ ha$^{-1}$<br>spruce: 16.61 m$^3$ ha$^{-1}$<br>pine: 16.61 m$^3$ ha$^{-1}$ | no further change | beech: 14.22 m$^3$ ha$^{-1}$<br>oak: 10.6 m$^3$ ha$^{-1}$<br>spruce: 16.61 m$^3$ ha$^{-1}$<br>pine: 16.61 m$^3$ ha$^{-1}$ | |
| (iv) Rotation period | averages per tree species group taken from WEHAM 2012 | averages per tree species group taken from WEHAM 2012 | no further change | averages per tree species group taken from WEHAM 2012 | averages per tree species group taken from WEHAM 2012 | no further change | averages per tree species group taken from WEHAM 2012 | |
| **Sum of area [1000 ha]** | **10,628** | **10,628** | **0** | **10,628** | **10,628** | **0** | **10,628** | |

## 3. Results

In this chapter, the results from the simulation for the BAU as well as the MSC and ISC scenario are described, over the entire simulation period of 200 years, comprised to average values of 20-year periods. For each scenario, the total felling amounts and the corresponding SCM, the timber stock and the LV as well as the supply and losses of SCM for *CWD* are shown in comparison to the EUBDS categories PF and MF. Furthermore, the opportunity costs of felling amounts and the corresponding silvicultural contribution margins are presented as differences between the MSC and BAU as well as the ISC and BAU.

The stacked and grouped bar charts of each figure include both the scenarios (on the *x*-axis: BAU, MSC, and ISC) and the individual scenario categories (shown in colour: PF and MF). The present compendium does not involve a discrete presentation of the SPF, because these areas have lost their status as viable fiscal resources and have consequently been depreciated. They are no longer utilised for the production of raw timber and are instead leveraged towards fulfilling legal conservation objectives set by the scenarios of the EUBDS. This holds particular relevance for the growing stock and the liquidation value. In this context, the initial devaluation rates in the simulation's inception year of 2012 are presented within the corresponding section, with the intention of contextualizing the entire matter. There are two y-axes in each figure representation type. The left *y*-axis shows the absolute values for "German Forest Enterprise". When interpreting the results, it must be considered that the BAU, the MSC, and the ISC are each based on different absolute areas for PF and MF due to the scenario assumptions. The *y*-axis on the right side of the graph represents the relative sizes in relation to one hectare. These values and their corresponding data points are highlighted in purple. The average values per 20-year period of these data points are printed above the abscissa. The simulation results for the scenarios can also be found in Appendix B. In accordance with German raw timber categorisation, the felling volumes are shown in cubic metres of raw wood larger than 7 cm in diameter without bark (m$^3$ ub) and the timber stock in cubic metres of raw wood larger than 7 cm in diameter with bark (m$^3$ ob). The German nomenclature diverges from international standards in terms of its methodology for incorporating branches into the calculation of timber stock. Specifically, the German system adds branches proportionally to the total timber stock, while international practices adhere to a definition that considers the volume of all living trees with a minimum diameter of 10 cm at breast height, including the stem from ground level up to a top diameter of 0 cm, while excluding branches [56].

## *3.1. Total Fellings and Contribution Margin*

### 3.1.1. Total Fellings

Figure 1 shows the development of the annual fellings over the simulation time frame of 200 years in 20-year periods. The annual logging starts with about 89 M m$^3$ (ub) for the BAU, 78 M m$^3$ (ub) for the MSC, and 43 M m$^3$ (ub) for the ISC scenario and range between 63 M m$^3$ (ub) for the reference scenario (BAU), 55 M m$^3$ (ub) for the MSC, and 34 M m$^3$ (ub) for the ISC for the 200-year period. If we now set the total accessible and stocked forest area as the reference for the relative values per unit area, we obtain the following results: the values located on the right *y*-axis show an initial annual logging of 8.37 m$^3$ ha$^{-1}$ (ub) for the BAU, 7.32 m$^3$ ha$^{-1}$ (ub) for the MSC, and 4.44 m$^3$ ha$^{-1}$ (ub) for the ISC. These then transition to a long-term average of 5.96 m$^3$ ha$^{-1}$ (ub) for the BAU 5.18 m$^3$ ha$^{-1}$ (ub) for the MSC, and 3.34 m$^3$ ha$^{-1}$ (ub) for the ISC. If we exclude the total area of stocked and accessible forests, which amounts to 10.6 M ha, as a point of reference for the relative values per unit area, and instead only consider the areas of PF and MF within each respective scenario, the resulting average values over the whole projection period differ from those displayed in the plot and are as follows (although not illustrated): BAU 6,06 m$^3$ ha$^{-1}$ (ub), MSC 5.88 m$^3$ ha$^{-1}$ (ub), and ISC 5.64 m$^3$ ha$^{-1}$ (ub). If the average values are compared, this means that the MSC has a total felling amount of approximately 87% and the ISC has a total felling amount of 56% compared to the BAU. In ISC, these differences are mainly due to the large areas set aside for reaching Objective 2 of the EUBDS. In the MSC, the set-aside areas are smaller in comparison; however, here, nature protection requirements such as the designation of habitat trees, *CWD*-increase, and extensions of the rotation period are dispositive in terms of the difference to BAU. Regarding the impact of the scenario categories, in BAU, MF areas account for about 78% of the annual peak impact and PF areas provide about 22% of the annual felling amounts. In MSC, the ratio of MF to PF in annual logging is 62% to 38%. For the ISC scenario, MF areas provide 77% of the timber harvest, whereas PF areas contribute 23%.

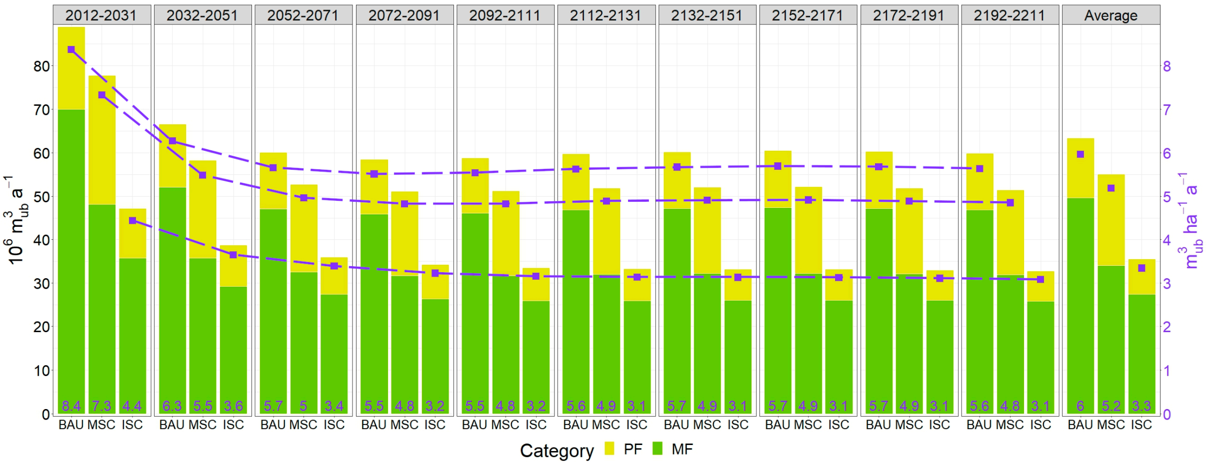

**Figure 1.** Total fellings in 10$^6$ m$^3$ ha$^{-1}$ a$^{-1}$ (ub) for the left *y*-axis, starting in 2012, simulating 200 years in periods of 20 years, displaying the three different scenarios, i.e., BAU, MSC, and ISC, and the corresponding scenario categories, PF and MF. The right *y*-axis shows the relative numbers per unit area in m$^3$ ha$^{-1}$ a$^{-1}$ (ub).

### 3.1.2. Silvicultural Contribution Margin

The associated economic valuation of annual logging (SCM) is shown in Figure 2. The SCM starts in the first projection period at about 2.93 B EUR a$^{-1}$ for the BAU scenario, with 2.56 B EUR a$^{-1}$ for the MSC, and 1.58 B EUR a$^{-1}$ in the ISC. Over the 200-year period, the SCM reaches a long-term average of 1.76 B EUR a$^{-1}$ for the reference scenario (BAU), 1.51 B EUR a$^{-1}$ for the MSC, and 0.96 B EUR a$^{-1}$ for the ISC. Per unit area (right y-scale), with the long-term average for the total stocked and accessible forest area of 10.6 M ha as relative reference, we obtain values of 165 EUR ha$^{-1}$ a$^{-1}$ in BAU, 142 EUR ha$^{-1}$ a$^{-1}$ for MSC and 91 EUR ha$^{-1}$ a$^{-1}$ for ISC. If we exclude the total area of stocked and accessible forests, which amounts to 10.6 M ha, as a point of reference for the relative values per unit area, and instead only consider the areas of PF and MF within each respective scenario, the resulting average values over the whole projection period differ from those displayed in the plot and are as follows (although not illustrated): BAU 168 EUR ha$^{-1}$ a$^{-1}$, MSC 161 EUR ha$^{-1}$ a$^{-1}$, and ISC 153 EUR ha$^{-1}$ a$^{-1}$. Apart from the changes described above for the timber felling, here the felling costs increase due to extended safety measures caused by *CWD* and habitat trees accounting for changes in the SCM.

Looking at the SCMs of the different scenarios in relation to the reference scenario, the long-term average for the moderate scenario (MSC) is 86% compared to the reference and 55% for the intensive scenario (ISC). A comparison of the scenario categories within the scenarios reveals for the BAU that the MF area contributes 80% of the SCM and the PF area contributes 20%. For the MSC, the ratio of MF to PF in relation to the SCM is 65% to 35%. For the ISC, the MF area accounts for 85% of the SCM, whereas the PF area contributes 15%.

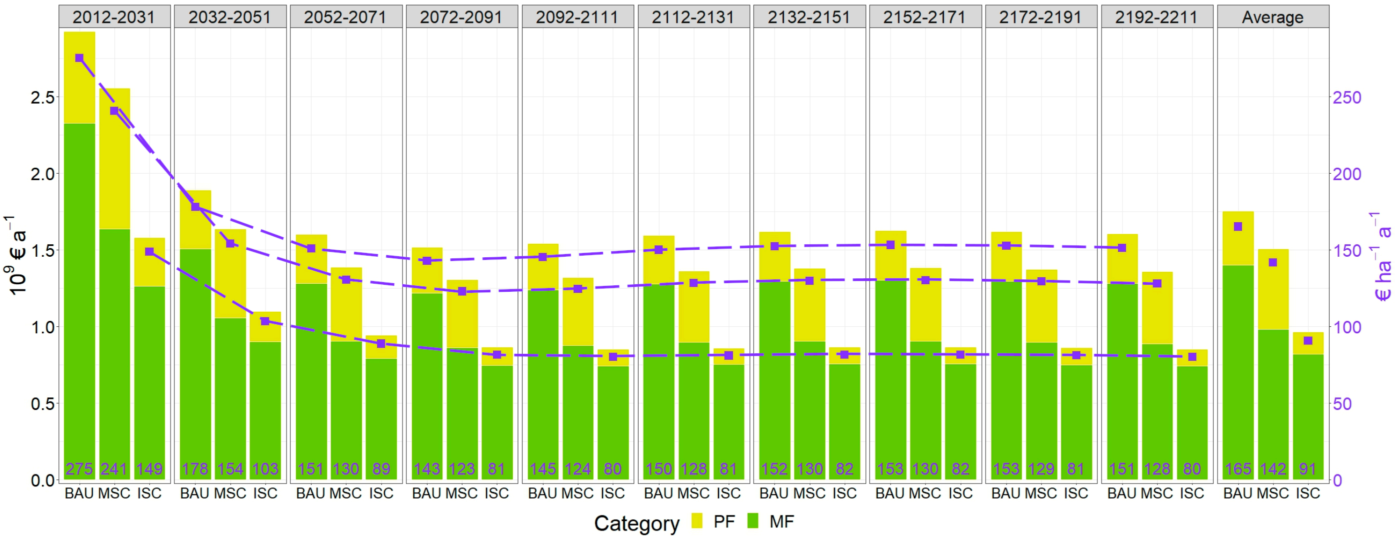

**Figure 2.** Silvicultural contribution margin in 10$^9$ EUR a$^{-1}$ for the left *y*-axis, starting in 2012, simulating 200 years in periods of 20 years, displaying the three different scenarios, namely BAU, MSC, and ISC, and the corresponding scenario categories, PF and MF. The right *y*-axis shows the relative numbers per unit area in EUR ha$^{-1}$ a$^{-1.}$

## *3.2. Timber Stock and Liquidation Value*

### 3.2.1. Timber Stock

In Figure 3 the initial simulation year of 2012, the BAU exhibits a natural depreciation value for the SPF of 63 M m$^3$ (ob). On the other hand, under the MSC scenario, the growing stock's natural depreciation value for the SPF amounts to 410 M m$^3$ (ob), while the ISC scenario results in a considerably higher value of 1.57 B m$^3$ (ob).

The timber stock initiates in the middle of first projection period with about 3.31 B m$^3$ over bark (ob) for the BAU, 3.01 B m$^3$ (ob) for the MSC, and 2.04 B m$^3$ (ob) for the ISC. This declines until the third projection period (until about 2052–2071, as a result of the initial model effect) and then reaches a more static state with a slight growth tendency toward the end of the simulation period. This static condition is reached after the initial model effect and is presumably due to the setting of scenarios being fixed (more on this in the discussion). As a long-term average, this corresponds to a timber stock of about 2.73 B m$^3$ (ob) for the BAU, 2.47 B m$^3$ (ob) for the MSC, and 1.7 B m$^3$ (ob) in the ISC. Comparing the timber stocks in relation to the total forest area of 10.6 M ha (right *y*-axis), we obtained long-term average values of 257 $m^3$ $ha^{-1}$ (ob) for the BAU, 232 $m^3$ $ha^{-1}$ (ob) for the MSC, and 160 $m^3$ $ha^{-1}$ (ob) for the ISC. If we exclude the total area of stocked and accessible forests, which amounts to 10.6 M ha, as a point of reference for the relative values per unit area and instead only consider the areas of PF and MF within each respective scenario, the resulting average values over the whole projection period differ from those displayed in the plot and are as follows (although not illustrated): BAU 261 $m^3$ $ha^{-1}$ (ob), MSC 264 $m^3$ $ha^{-1}$ (ob), and ISC 269 $m^3$ $ha^{-1}$ (ob).

If we compare the long-term mean values of the timber stocks of the different scenarios with the BAU, we obtain 91% of the timber stocks for the MSC compared to the reference and 62% for the ISC. It is necessary to emphasise that the depreciated set-aside areas (SPF) are not included in this analysis. Depending on the assumed growth model and mortality of the SPF, these may have higher stocks than the managed areas (MF, PF). Regarding the relation of the scenario categories, the timber stock in BAU has a ratio of 76% MF to 24% PF. For the MSC timber-stock, the long-term average ratio is 58% MF to 42% PF. In the ISC, the ratio is similar to the BAU at 69% MF to 31% PF, as a higher area of former PF forest was set aside for SPF and the PF area with stricter conservation measures.

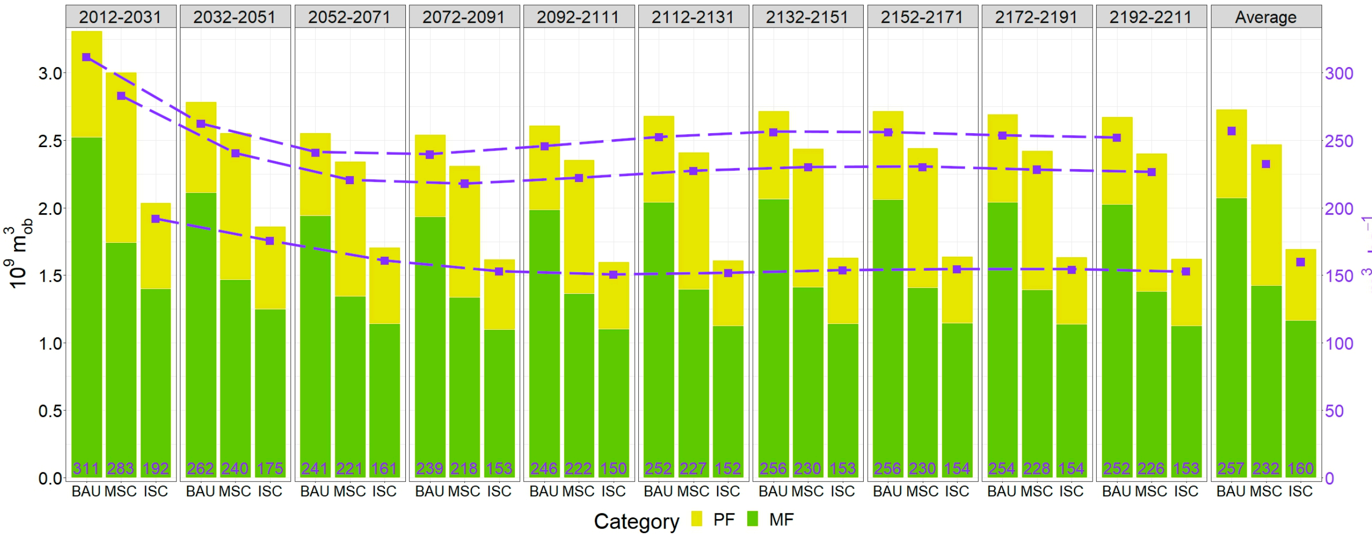

**Figure 3.** Timber stock in $10^9$ $m^3$ $ha^{-1}$ (ob) for the left *y*-axis, starting in 2012, simulating 200 years in periods of 20 years, displaying the three different scenarios, namely BAU, MSC, and ISC, and the corresponding scenario categories, PF and MF. The right *y*-axis shows the relative numbers per unit area in $m^3$ $ha^{-1}$ (ob).

### 3.2.2. Liquidation Value

Figure 4 shows the economic valuation of the timber stock in the form of the liquidation value. In the initial simulation year of 2012, the depreciated LV of the SPF for the BAU scenario was determined to be 2.1 B EUR. However, the MSC scenario resulted in a depreciation value for the SPF amounting to 14 B EUR, while the ISC scenario resulted in a significantly higher depreciation value of 51.6 B EUR.

In the first projection period, there is a LV of around 111.4 B EUR for the BAU, 101.1 B EUR for the MSC, and around 69.9 B EUR for the ISC. These values decrease until the third projection period, mainly due to the initial model effect, and then rise slightly again in the long term. The long-term average LV is 84.5 B EUR for the BAU, 76.2 B EUR for the MSC, and about 53 B EUR for the ISC. In regard to LV per hectare, using the total stocked and accessible forest area of 10.6 M ha as reference, we reach average values of around 8 K EUR $ha^{-1}$ for the BAU, 7.2 K EUR $ha^{-1}$ for the MSC, and 5 K EUR $ha^{-1}$ for the ISC. It is noteworthy that the SPF areas have been deemed as devalued assets, and thus have been excluded from the calculation. However, if these areas were considered, the MSC and ISC scenarios could potentially yield higher output values, contingent upon the specific year and the extent of the development of the unutilized areas. If we exclude the total area of stocked and accessible forests, which amounts to 10.6 M ha as a point of reference for the relative values per unit area, and instead only consider the areas of PF and MF within each respective scenario, the resulting average values over the whole projection period differ from those displayed in the plot and are as follows (not illustrated): BAU 8.1 K EUR ha$^{-1}$, MSC 8,1 K EUR ha$^{-1}$, and ISC 8,4 K EUR ha$^{-1}$. Comparing the scenarios to the reference (BAU), this results in a relation of 90% of the MSC and around 63% for the ISC compared to BAU. The relationships of the different categories of the EUBDS are as follows: in BAU the relationship is 77% for the MF to 23% for the PF. In the MSC, the proportion of MF to PF is 60:40. In the ISC is similar to the BAU, ranging from 73% MF to 27% PF.

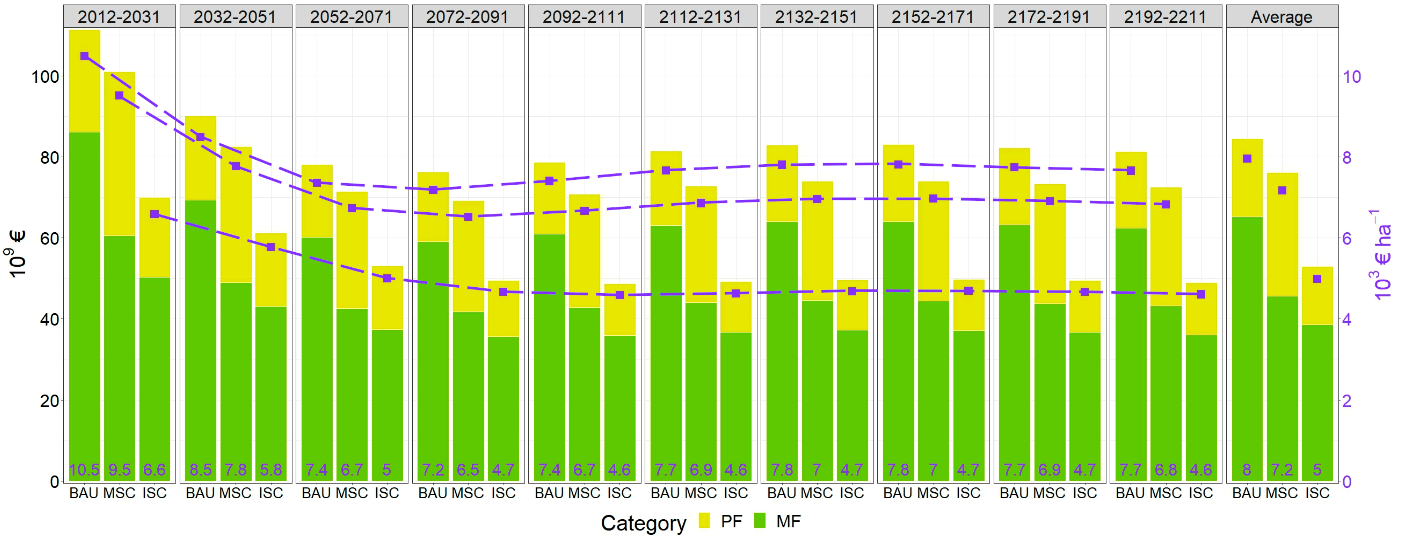

**Figure 4.** Liquidation value in $10^9$ EUR for the left *y*-axis, starting in 2012, simulating 200 years in periods of 20 years, displaying the three different scenarios, namely BAU, MSC, and ISC, and the corresponding scenario categories, PF and MF. The right *y*-axis shows the relative numbers per unit area in EUR ha$^{-1.}$

### *3.3. Supply and Development of Coarse Woody Debris*

#### 3.3.1. Supply of Coarse Woody Debris

Figure 5 shows the supply of coarse woody debris (*CWD*) of the unutilised timber. This indicator is to be implicitly compared with the mortality of the forest stands in addition to unutilised timber from the final harvest, i.e., the value that is input into the *CWD* calculator in the individual projection periods.

In the first projection period, the annual supply of *CWD* is 17.1 M m$^3$ a$^{-1}$ (ob) for the BAU, 16.7 M m$^3$ a$^{-1}$ (ob) for the MSC, and 11.5 M m$^3$ a$^{-1}$ (ob) for the ISC. This decreases to a long-term average of 10.1 M m$^3$ a$^{-1}$ (ob) for the BAU, 10.4 M m$^3$ a$^{-1}$ (ob) for the MSC, and 8.3 M m$^3$ a$^{-1}$ (ob) for the ISC by the third period on average. The long-term mean values for the different scenarios per hectare are a supply of 1.9 m$^3$ ha$^{-1}$ a$^{-1}$ (ob) to maintain the *CWD* amount for the BAU and for increasing and maintaining the *CWD* supply in MSC and ISC 2.2 m$^3$ ha$^{-1}$ a$^{-1}$ (ob) for the MSC and 2.6 m$^3$ ha$^{-1}$ a$^{-1}$ (ob) for the ISC. In comparison to the BAU and ISC, the MSC scenario exhibits a larger absolute quantity of *CWD* resupply. This discrepancy arises from the exclusion of a greater extent of land from SPF classification within the ISC, while the proportion of PF areas is relatively higher in the MSC. In this context, it seems reasonable to put these values in relation to the logging in order to examine the total outflow of the living forest stock in the scenarios. In the context of sustainable forestry practices, the long-term average felling rate for the BAU (as illustrated in Figure 1) is 63.3 M m$^3$ a$^{-1}$ (ub), and there is an unutilised discard of 8.1 M m$^3$ a$^{-1}$ (10.1 M m$^3$ a$^{-1}$ (ob) * 0.8 = 8.1 M m$^3$ a$^{-1}$ (ub)). In the reference scenario, approximately 13% of the timber felled as a result of calamities or human activity is left unused and accumulates as *CWD*. For the MSC scenario, the long-term average logging rate is 55.1 M m³ a⁻¹ (ub), resulting in 8.4 M m³ a⁻¹ (ub) of *CWD* accumulation and preservation (10.4 m³ a⁻¹ (ob)). Hence, approximately 15% of the felled timber remains unutilised. Finally, for the ISC scenario, the mean annual logging rate is approximately 35.6 M m³ a⁻¹ (ub), and the unutilised discard is about 6.6 M m³ a⁻¹ (ub) (8.3 M m³ a⁻¹ (ob)). As a result, around 19% of the living forest stock outflow remains unused in the forest, intending to promote the further establishment and preservation of *CWD*.

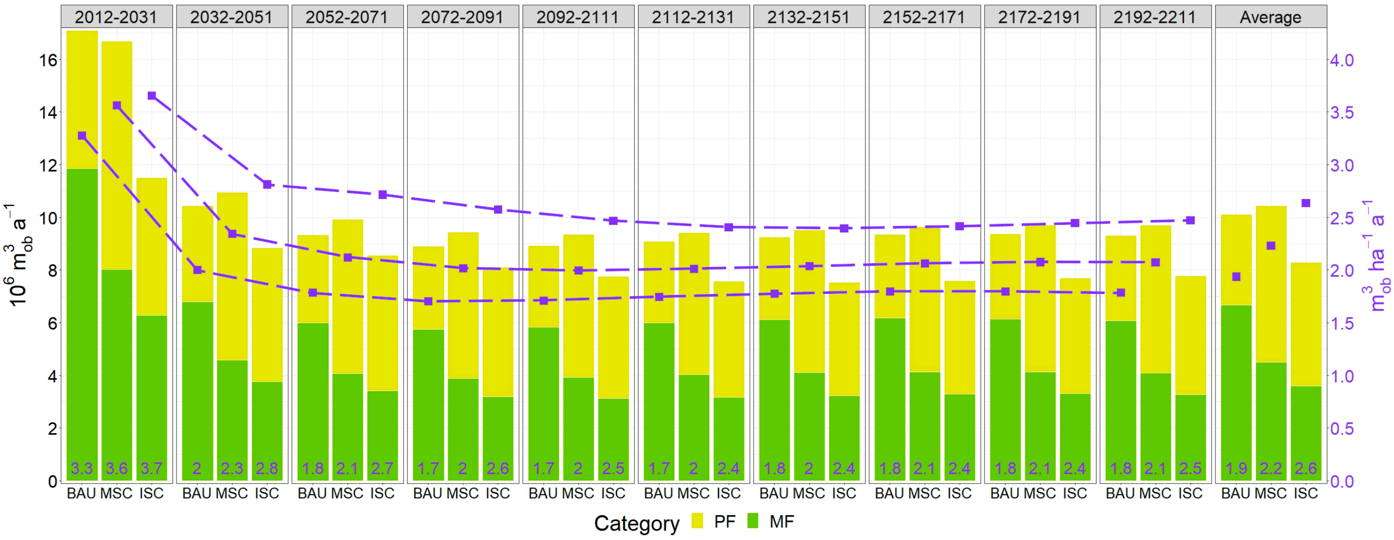

**Figure 5.** Supply of coarse woody debris in 10⁶ m³ ha⁻¹ a⁻¹ (ob) for the left *y*-axis, starting in 2012, simulating 200 years in periods of 20 years, displaying the three different scenarios, namely BAU, MSC, and ISC, and the corresponding scenario categories, PF and MF. The right *y*-axis shows the relative numbers per unit area in m³ ha⁻¹ a⁻¹ (ob).

### 3.3.2. Economic Evaluation of Coarse Woody Debris

The objective of Figure 6 is to conduct an economic assessment of the quantities of unused timber for *CWD* illustrated in Figure 5 by evaluating their economic value in the context of SCM. Specifically, Figure 6 depicts the magnitude of financial detriment that arises due to the non-utilization of raw wood designated for the maintenance and development of *CWD*.

Again, the first projection periods start higher than the rest. This signifies a decrease in utilization, amounting to approximately 615 M EUR a⁻¹ for the BAU, 554 M EUR a⁻¹ for the MSC, and 382 M EUR a⁻¹ for the ISC. These values fall sharply by the third projection period and reach a long-term average of 336 M EUR a⁻¹ for the BAU, 347 M EUR a⁻¹ for the MSC, and 276 M EUR a⁻¹ for the ISC. If we put these values in relation to the forest area under observation, the long-term average is 32 EUR ha⁻¹ a⁻¹ for the BAU, 37 EUR ha⁻¹ a⁻¹ for the MSC, and 44 EUR ha⁻¹ a⁻¹ for the ISC. A comparison with the SCM would be helpful in this context. For example, the long-term average of the SCM for the BAU is 165 EUR ha⁻¹ a⁻¹, which compares to 32 EUR ha⁻¹ a⁻¹ loss of utility due to the unutilised wood. This means that 16% of the potential SCM remains in the forest for *CWD* preservation and establishment. For the MSC, the SCM is 142 EUR ha⁻¹ a⁻¹ and the loss of utility of the unused wood is 37 EUR ha⁻¹ a⁻¹. This means a loss of utility in the SCM of 21%. For ISC, the ratio is 91 EUR ha⁻¹ a⁻¹ SCM to 44 EUR ha⁻¹ a⁻¹ of unused wood. The financial losses in terms of utilization are thus 33%.

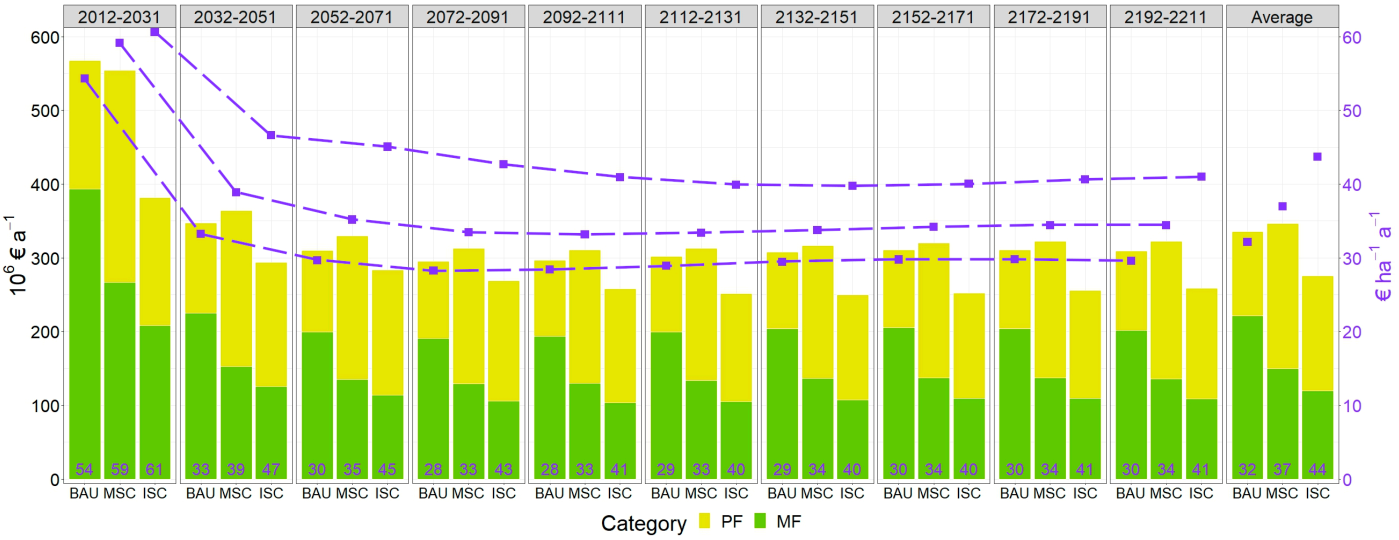

**Figure 6.** Economic value of the supply of coarse woody debris in $10^6$ EUR $a^{-1}$ for the left *y*-axis, starting in 2012, simulating 200 years in periods of 20 years, displaying the three different scenarios, namely BAU, MSC, and ISC, and the corresponding scenario categories, PF and MF. The right *y*-axis shows the relative numbers per unit area in EUR $a^{-1}$.

### 3.4. Opportunity Costs of MSC und ISC

The following section is intended to present the delta of the results obtained in Sections 3.1.1 and 3.1.2. Specifically, the delta of the MSC and ISC scenarios, in comparison to the reference scenario BAU, will be displayed. These deltas provide valuable insights into the variations and deviations of the respective scenarios from the baseline scenario, shedding light on the opportunity costs and differences between different scenario implementations.

Figure 7 exhibits the opportunities resulting from the overall timber fellings for two scenarios, namely MSC and ISC, relative to the BAU scenario. These opportunity costs include all added conservation needs, such as set-aside forests for SPF areas, extra habitat trees, *CWD*, and higher timber harvesting costs for each respective scenario category. The bars in the figure show the total opportunities, while the number on the abscissa's top indicates the corresponding relative number. From this graph, we can infer that MSC offers an average decrease of 8.26 M $m^3$ $a^{-1}$ (ub) throughout all projection periods, while ISC leads to an absolute decline of 27.8 M $m^3$ $a^{-1}$ (ub). The MSC scenario results in a 13% decrease in logging in relative terms and averaged over all projection periods, while the ISC scenario causes a 44% decrease.

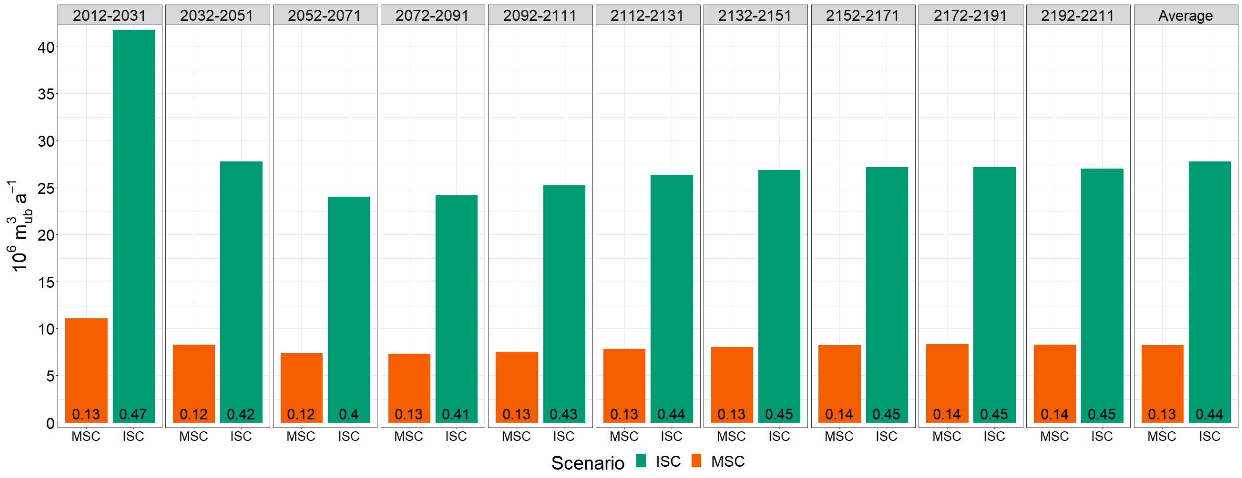

**Figure 7.** Opportunities of the total felling in $10^6$ $m^3$ $ha^{-1}$ $a^{-1}$ (ub), starting in 2012, simulating 200 years in periods of 20 years, displaying the data of the BAU in comparison to the different scenarios MSC and ISC.

Figure 8 shares the same format as Figure 7; however, it showcases the economic valuation of opportunity costs of the SCM. On average, across all projection periods, the MSC scenario results in an absolute decrease in SCM of 0.25 B EUR $a^{-1}$, while the ISC scenario produces a decline of 0.79 B EUR $a^{-1}$. This indicates a relative reduction in SCM of 14% and 45% for MSC and ISC, respectively.

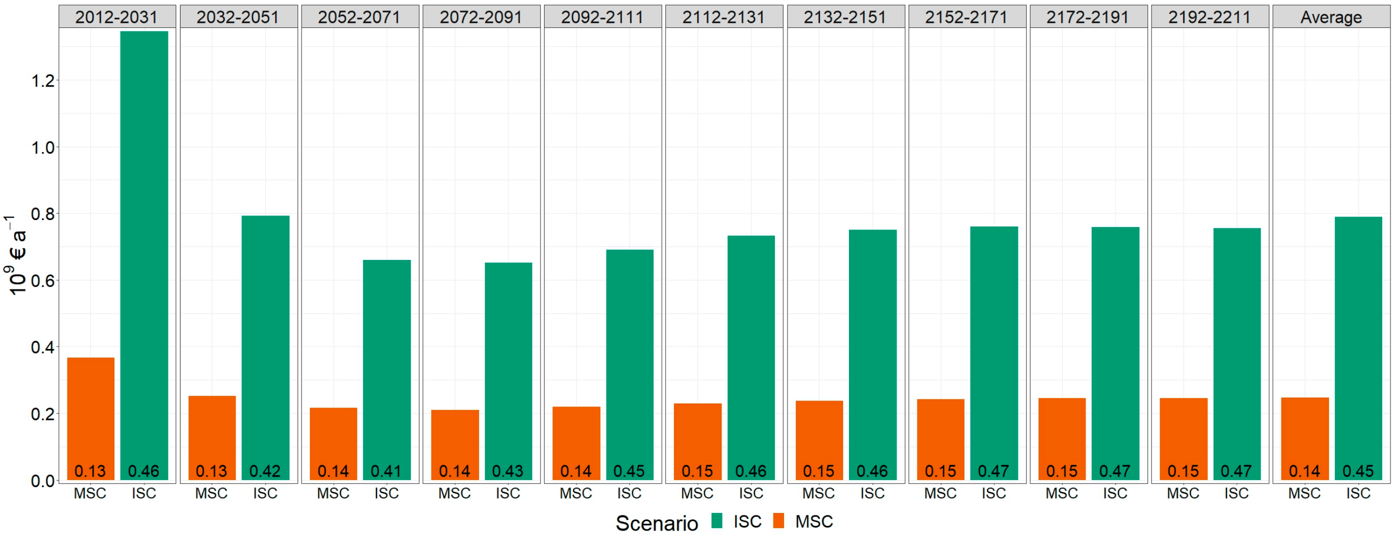

**Figure 8.** Opportunity costs of the silvicultural contribution margin in $10^6$ EUR $a^{-1}$, starting in 2012, simulating 200 years in periods of 20 years, displaying the data of the BAU in comparison to the different scenarios MSC and ISC.

## 4. Discussion

### 4.1. Discussion of Methods

#### 4.1.1. Constraints and Limitations of the Model

In our study, we aimed to assess the long-term economic impacts of the implementation of the EUBDS on the forestry sector in Germany. The FESIM was used as a basic model that could be further enhanced with a *CWD* calculation module in order to meet our scientific requirements. However, there are some constraints and limitations of the model that need to be discussed.

The parameterised growth functions in the model are yield tables of out-of-date forest management methods (e. g. moderate thinning from below). These do not exactly reflect today's climate change-related forest growth and management conditions. Updated yield tables were published by Albert et al. (2022) shortly before the study was finalised [57] and are not yet integrated in the model. Due to the regional area of validity for northwest Germany, the updated yield tables must be retested for the FESIM if they are to be implemented throughout the entirety of Germany [57].

The FESIM model is a deterministic model that encompasses both static and dynamic elements. The biological–technical production is modelled dynamically using discrete simulation periods connected via Markov chains. However, the economic evaluation module is implemented statically, meaning that current price elasticity of supply and demand is assumed to be statically extrapolated into the future, resulting in a constant price. It can be argued that, depending on the scenario, if demand for raw wood remains constant while supply is constrained due to decommissioning, the price should increase. Implementing dynamic timber prices would be desirable for future studies.

A critique of the model is evident in the results section regarding the initial projection period. Deviations from the remaining periods are primarily caused by the initial model effect, where the input data encounters the model settings. This effect leads to higher logging rates due to rotational time distributions in FESIM, particularly when the initial forest condition differs from the scenario assumptions. These deviations can be justified by the substantial forest damage during 2018–2022, resulting in significant logging and stock reduction, especially in coniferous forests [43].

The methodology employed in this study could be modified for use in other countries, allowing for the evaluation of the impact of EUBDS or other comparable policies aimed at preserving biodiversity in forested areas. This can be achieved through the parameterisation of nationally standardized yield tables and the incorporation of inventory data from national forest inventories into the utilized simulation model (FESIM). However, it is important to note that extending the FESIM model to encompass the entire EU-27 presents challenges. Firstly, NFI data are not publicly available in many EU-27 countries, which hinders the inclusion of comprehensive information from these nations. Depending on the quality of NFI data, the accuracy and reliability of the model outcomes may be limited when applied to these specific regions.

### 4.1.2. CWD Calculator

By integrating a *CWD* component into FESIM, the structural element *CWD* can be dynamically simulated in the model itself, and its effects on the operational execution of raw timber production can be analysed synoptically in terms of forest economics for the first time under different management conditions. The decay functions of Rock et al. (2008) appear to be well suited to quantitatively model the inflows and outflows of the *CWD* stock at the national level [36]. However, since *CWD* can have very different qualities for biodiversity conservation, at least a differentiation into standing and lying *CWD* would be desirable. Such differentiation could serve as an important biodiversity indicator as different species of conservation concern inhabit the different *CWD* types. However, the data basis (mainly inventory data) of biodiversity research is (still) lacking for this. Furthermore, the type of *CWD* has an influence on the level of logging costs. In particular, standing *CWD* causes additional work protection measures due to a higher risk during logging, which increases the logging costs.

### 4.1.3. Scenarios

Methodologically, the question also arises as to why the authors of the study only used two scenarios (moderate and intensive scenario) and why, for instance, no “middle path” scenario was also developed. The aim of the study is to cover the possible angles of this policy impact assessment, to show what would occur if the following assumptions were true. A middle scenario would embody the epitome of an “optimal paradigm”. This impression is to be avoided. The authors of the study are aware that the two scenarios MSC and ISC represent extrema. However, they were chosen deliberately in order to be able to define the possible implementation paths of the EUBDS and to evince limitations.

Unlike previous studies, the present study incorporates climate change using the RCP 8.5 scenario. This scenario assumes higher global warming levels of 4.1 °C, which may overestimate the long-term effects on forestry. Alternative climate scenarios, such as those aligned with the Paris Agreement’s goals, would result in lower mortalities and require less intact wood for *CWD*. However, to account for worst-case risks, the study opted for the RCP 8.5 scenario. It is worth noting that the effectiveness of future mitigation efforts is uncertain and even the PCC predicts a rise of around 3 °C by the end of the 21st century [48].

The results were influenced by the assumption that the additional PF areas were predominantly located in broadleaved forests, which are parallel to the existing areas. If these areas had been evenly distributed across all tree species groups, higher costs would have resulted from forest conversion to fulfil habitat requirements, as coniferous forests usually reach higher contribution margins in Germany than broadleaved forests. Additionally, the species changes from the NFI 2002 to NFI 2012 were extrapolated and remained constant in the PF areas, thus not allowing for active forest conversion, such as the increased cultivation of Douglas fir, to increase productivity on the remaining MF areas in the ISC. These limitations reflect the claims of relevant stakeholder groups in Germany and, moreover, ensure consistency with previous studies, such as Timm et al. (2022) and Schier et al. (2022) [7,19]. With regard to habitat trees and *CWD*, the authors assumed that the increase in these categories would be necessary to meet nature protection requirements in habitat type areas within protected forests. However, given that the Habitats Directive has been in effect for over a decade, it could be argued that these requirements have already been partially satisfied in such areas, thus leading to an overestimation of the calculated costs for PF areas. On the other hand, the calculation did not account for administrative costs, which is likely to result in an underestimation of the actual costs for designating and managing PF areas.

A question frequently raised pertains to the significant disparity in the allocation of protective measures between different land cover types, such as forests and agricultural land, across the entire land area of the Federal Republic of Germany. There are several factors contributing to this situation. Firstly, agricultural land generally entails higher opportunity costs [58,59]. Secondly, a substantial portion of forests in Germany are under state ownership, either directly by the federal government or indirectly by state or local governments [20]. In contrast, over 90% of agricultural land is privately owned, which would introduce greater conflicts and costs when implementing protection measures [60]. Moreover, the cultivation of animal feed and food appears to hold a higher priority than timber provision. Additionally, the author team possesses expertise primarily focused on assessing forestry areas, and including other land cover types would necessitate alternative models and datasets. Alternatively, one could argue that the foremost land cover types deserving preservation are those that are likely to exhibit substantial enhancements upon receiving protection. According to the findings outlined in the report of the German Sustainability Strategy, forests presently exhibit the most favorable performance among diverse land cover types when considering indicator values related to "biodiversity and landscape quality" [61]. As a result, it could be argued that allocating land specifically non-forest land cover types would result in greater incremental benefits for overall biodiversity in Germany. Nevertheless, to definitively address this inquiry, additional scientific investigations would be imperative, surpassing the confines of the current study.

### *4.2. Discussion of Results*

#### 4.2.1. Natural Results

An examination of the available literature indicates that limited comparable studies exist at a national level. Instead, a preponderance of studies is either regional or examines only partial aspects (e.g., such as the development of *CWD* in a specific geographic region or a single forest plot). As a result, the ability to make meaningful comparisons between natural results is limited to the two studies conducted by Timm et al. (2022) and Schier et al. (2022) [7,19]. Subsequently, a general discussion of the natural outcomes is conducted, and they are classified based on the German FADN and the European Forest Accounts.

Comparing the natural results of our study with the results of the previous study of Schier et al. (2022), who use the WEHAM 2012 baseline scenario as a basis for their calculation, it becomes apparent, that they are in a similar range [7]. This underlines the relatively high precession of the calculations of Timm et al. (2022) and Schier et al. (2022), although compared to the present study, only lump-sum deductions were applied.

When comparing the timber stock amounts in the BAU scenario (first period: 3.31 B $m^3$, 200-year average: 2.73 B $m^3$) to the results of the NFI 2012 (3.66 B $m^3$) greater discrepancies become visible. The reduced timber stocks of the simulation compared to the NFI 2012 seem plausible if the reduced survival probabilities due to climate change are considered. However, our use of the RCP 8.5 scenario could also overestimate the long-term influence of climate change on survival probabilities, because it assumes hardly any effective measures of international climate protection.

Compared to the previous studies [7,19], only few discrepancies in the natural results become visible for the first two simulation periods. This is mainly due to the choice of scenario and area specifications, which were set according to Timm et al. (2022) and Schier et al. (2022) [7,19]. Drivers that strongly influence the results, such as major tree species changes are not calculated in these studies and the same areas of PF and SPF were chosen. Only the *CWD* calculation, which was not included in the previous studies, has a larger impact in the deviations. This becomes visible in the deviation of the ISC results from those of the previous studies, as, here, *CWD* is increased to 50 $m^3$ $ha^{-1}$ on a larger area than in the MSC.

Regarding the development of total natural results over the 200-year period, it becomes obvious that (besides the first simulation period due to the initial model effect) no great fluctuations of timber fellings and timber stock occur. This is also due to the scenario specifications. The main driver of changes is the large-scale forest area set aside as SPF and the small-scale area of set-aside habitat trees (but adding up to larger scale in sum) per hectare of PF areas. Both remain constant during the simulation. The rotation period, as another potential driver of change and fluctuations, on the other hand, is only increased in newly designated PF areas (819 K ha or 7% of the total German forest area) so the delayed final use and the according stock changes hardly become visible in the overall picture of German forestry.

Since no natural or active forest conversion is assumed in the simulation to adapt to the changed growing conditions of the tree species as a result of climate change, the output values in the scenarios are also likely to be overestimated, since higher proportions of low-yielding hardwoods at the expense of high-yielding conifers are to be expected in many places.

To classify the results, the German European Forest Accounts can be used. Looking at the timber felling amounts in all of Germany, the European Forest Accounts show an average felling amount of roughly 65 M $m^3$ $a^{-1}$ (ub) for the time period of 2014 to 2018 (before the calamity years) [62]. Comparing the relationship of the MSC and ISC scenarios' reductions in timber felling to BAU (13%, resp. 44%), the average felling amounts in Germany would be reduced to 56 M $m^3$ $a^{-1}$ (ub) in MSC and 36 M $m^3$ $a^{-1}$ (ub) in ISC. As discussed in detail in the studies of Timm et al. (2022) and Schier et al. (2022), this amount of raw wood would have to be acquired from third world countries in order to meet the German timber demand [7,19].

#### 4.2.2. Economic Results

As a step beyond the studies of Timm et al. (2022) and Schier et al. (2022), we calculated the possible economic impact of the EUBDS implementation scenarios on German forestry for the first time [7,19].

For this, average timber prices and harvesting costs were used in the study. Yet, this can have a distorting effect on results, as using average values is likely to lead to an overestimation of timber revenues in the lower age classes and to an underestimation of timber revenues in the upper age classes. For timber harvesting costs, the opposite is likely to be the case.

Retaining and building up *CWD* is an important category of nature protection measures. However, as our scenarios show, building and maintaining a defined deadwood supply for biodiversity conservation involves the appreciable opportunity costs of raw wood production. From a conservation perspective, old, standing trees with large diameters are desired, especially broadleaved species such as oak, which can in turn be highly economically valuable. In our simulations, using only these kinds of trees for *CWD* could not be modelled, instead we simulate *CWD* over all diameter classes and tree species. Therefore, our opportunity costs for *CWD* retention could be underestimated.

In both scenarios, but especially in the ISC scenario, reductions in the SCM of MSC and ISC compared to the BAU become visible, amounting to 0.25 B EUR $a^{-1}$ (14%) and 0.79 B EUR $a^{-1}$ (45%), respectively, on average. The German Economic Accounts for Forestry shows an average production value of roughly 5.2 B EUR $a^{-1}$ for the economic sector forestry in the years 2013–2017. The production of raw wood accounts for an average share of 80% in this period, amounting to 4.2 B EUR $a^{-1}$. Comparing our results of SCM reductions due to the implementation of EUBDS, the average production value could then be reduced to 4.5 B EUR $a^{-1}$ in MSC and 2.9 B EUR $a^{-1}$ in ISC. The net entrepreneurial income in forestry, which has only been positive since the mid-noughties, amounted to an average of 1.3 B EUR $a^{-1}$ during the same time period. Again, according to the study's results, this could mean a reduction to 1.1 B EUR $a^{-1}$ (MSC) or 0.7 B EUR $a^{-1}$ (ISC). Between 2018 and 2020, however, a decline in the production value as well as the net entrepreneurial income of the German forestry sector was noted, due to primary (storm, draught) and secondary (bark beetle and fungi) calamities and the resulting market reactions. While the production value of German forestry amounted to 3.9 B EUR $a^{-1}$ in 2020, the net entrepreneurial income declined to a negative -27 M EUR $a^{-1}$ [62]. As the anticipated frequency of climate change-related calamities increases in the future, the enforcement of nature conservation regulations, such as the EUBDS, may result in recurring negative net entrepreneurial incomes in the short to medium term, necessitating appropriate compensation measures.

The reductions in SCM remain largely constant after the second simulation period up to the end in both scenarios. This shows that the large-scale area set aside as well as the losses of income through the implementation of conservation measures cannot be compensated in the MF areas, assuming that changes in tree species composition will continue in the same manner as between NFI 2002 and 2012. If income losses cannot not be permanently compensated via subsidies in the future, one solution could be an increased insertion of profitable, high-yield (foreign) tree species on MF areas to balance out felling reductions in PF and SPF areas. This, however, would in turn require large investment costs for planting and plant protection.

In our study, we examined the effects of two scenarios for implementing the EUBDS into German forestry as an example for other EU member states. The economic impact of EUBDS implementation can vary based on the composition of tree species and ownership types. An undesired tree species composition from a nature conservation angle (e.g., a large proportion of non-native coniferous trees) can result in higher costs due to the potential need for conversion to a higher proportion of deciduous trees. In cases where PF and SPF areas cannot be designated in state forests, private forest owners may face the projected costs, many of them relying on income from forestry. The social impact varies depending on the distribution of private and public forests among EU countries. Moreover, an evaluation of the standing timber stock (as demonstrated in this study with the liquidation value) and land value is necessary, as compensation for timber utilization alone is inadequate. Depending on the extent of the necessary areas, the state might have to allocate a substantial amount of fiscal resources to compensate or even to acquire suitable land.

## 5. Conclusions

### 5.1. Summary of the Results

The possible effects of EUBDS on the raw wood production of the German forestry industry have so far been estimated by Timm et al. (2022) and Schier et al. (2022) by transferring aggregate deductions of the potential raw wood volume of the WEHAM 2012 baseline scenario to the entire EU [7,19,29]. The aim of the present study, however, was to analyse in more detail the long-term economic effects of different implementation variants and categories of the EUBDS on the German forestry sector with special regard to *CWD*. The two EUBDS implementation scenarios developed by Timm et al. (2022) and Schier et al. (2022) were operationalised from a more detailed German conservation perspective and modelled with FESIM over the long term, with particular attention to *CWD* and climate change [7,19]. Both EUBDS implementation scenarios were compared with a BAU scenario based on the WEHAM 2012 baseline scenario [29]. The scenarios are intended to show possible paths of EUBDS implementation in their range but do not claim to be forecasts for real implementation [7,19].

Through a simulated 200-year period, we found that the implementation of the EUBDS resulted in a decrease in timber harvest of 13% under the MSC scenario and 44% under the ISC scenario, based on the respective assumptions. Consequently, there was a significant reduction in the SCM, with an average annual decrease of 0.25 B EUR (14%) for the MSC scenario and 0.79 B EUR (45%) for the ISC scenario. Our findings indicate that protected forests played a crucial role in the total SCM, contributing 35% and 15% in the two scenarios, respectively. Moreover, we identified several key factors that could further contribute to the economic impacts of the EUBDS 2030 implementation in the German forestry sector:

Firstly, the high opportunity costs associated with forests already exhibiting high "biodiversity and landscape quality" as evidenced in the indicator report of the German sustainability strategy [61]. This observation prompts the question of whether greater incremental benefits can be obtained by primarily prioritizing the preservation of forests over other land cover types. Secondly, it should be noted that the incurred losses would necessitate significant fiscal resources for compensation, which should be carefully weighed against the manageable marginal utility. In the past, private and corporate forestry enterprises in Germany have generated about 80% of their revenues from timber sales, while other ecosystem services have been provided free of charge, as these are generated as a secondary product [63]. The reduced economic viability of forest enterprises in Germany resulting from the EUBDS could therefore have a negative impact on the availability of these biodiversity and other ecosystem services. The article authored by Schier et al. (2022) has effectively expounded upon the linked phenomenon of timber production leakage and the consequent repositioning of the value chain to alternative countries.

This finding of our study also clarifies the need for an economically efficient implementation of biodiversity protection issues in the forest, e.g., by considering the quality of the *CWD* for biodiversity protection (e.g., tree species, standing or lying *CWD* or degrees of decay) and not only the definition of quantitative thresholds. The implementation of pure volume requirements, as demonstrated in this study, results in a significant loss of utility associated with the accumulation and preservation of *CWD* for conservation purposes. This loss is evident by the need for 15% and 19% of annual logging to meet the requirements in the two scenarios. Another approach to mitigate the EUBDS opportunity costs in raw wood production could be to increase the proportion of high-yielding tree species in the remaining MF areas. Such an approach would presumably accelerate the segregation of forest functions, since numerous climate-resilient and high-yield (surrogate) tree species are in conflict with current biodiversity aims in Germany.

### 5.2. Outlook and Research Desiderata

Public funding for biodiversity protection and other ecosystem services have so far hardly been made available to German forest enterprises [64]. A new development is emerging with the "Climate-adapted forest management" funding program of the German Federal Ministry of Food and Agriculture (BMEL), which was published in 2022. This allows German forestry enterprises to receive substantial funding over several years for complying with additional climate and biodiversity protection requirements in forest management. These management requirements of this program are above the legal standard and the standards of voluntary certification schemes for forest management (e.g., Program for the Endorsement of Forest Certification Schemes (PEFC) or Forest Stewardship Council (FSC)) However, it should be noted that our long-term estimates of the annual opportunity costs of maintaining *CWD* stock already exceed current BMEL program volumes in all scenarios. It can be concluded that in order to compensate for the determined opportunity costs in raw wood production, high financial resources must be made available for EUBDS implementation in Germany.

A particular challenge for the German implementation of the EUBDS is likely to be the high demand for additional strictly protected areas. A permanent and legally secured process protection requires the property rights to these forest areas. If the forest areas that are valuable in terms of nature conservation are privately owned, they would probably have to be bought or these areas would have to be placed under public forest ownership. However, the additional area required for SPF areas in the ISC already exceeds the entire forest property of the federal and state governments.

One of the main objectives of this study was to examine the opportunity costs of different scenarios with set assumptions for policy impact analysis. This could give the impression that only the negative aspects of this policy impact assessment were to be highlighted. However, this is not the case. The EUBDS can also generate an economically tangible benefit (value of ecosystem services) in addition to the opportunity costs due to reduced use of raw wood. It would be a rational decision to implement a scenario if the "net benefit" from the protected status is higher than the yield loss from set-aside areas and conservation requirements. Nevertheless, the benefits derived from ecosystem services necessitate distinct economic valuation methodologies for varying ecosystems. Each of these would call for its own study.

**Author Contributions:** Conceptualisation, B.S. and C.R.; methodology, C.R.; software, C.R.; validation, L.R., B.S., M.D., and C.R.; data curation, C.R.; writing—original draft preparation, L.R., B.S., M.D., and C.R.; writing—review and editing, L.R., B.S., M.D., and C.R.; visualization, C.R..; supervision, L.R. and B.S..; project administration, L.R. All authors have read and agreed to the published version of the manuscript.

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**Conflicts of Interest:** The authors declare no conflicts of interest.

## Appendix A. (Plots)

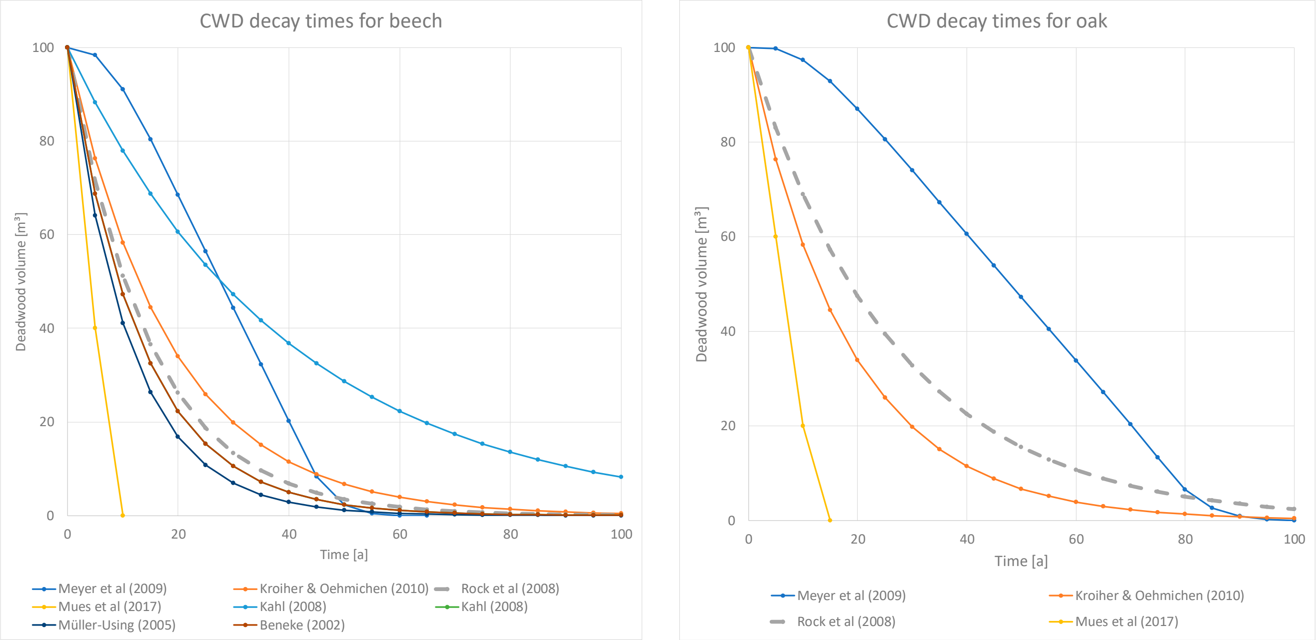

**Figure A1.** *CWD* decay times from different studies for beech and oak [10,34–37,39,40].

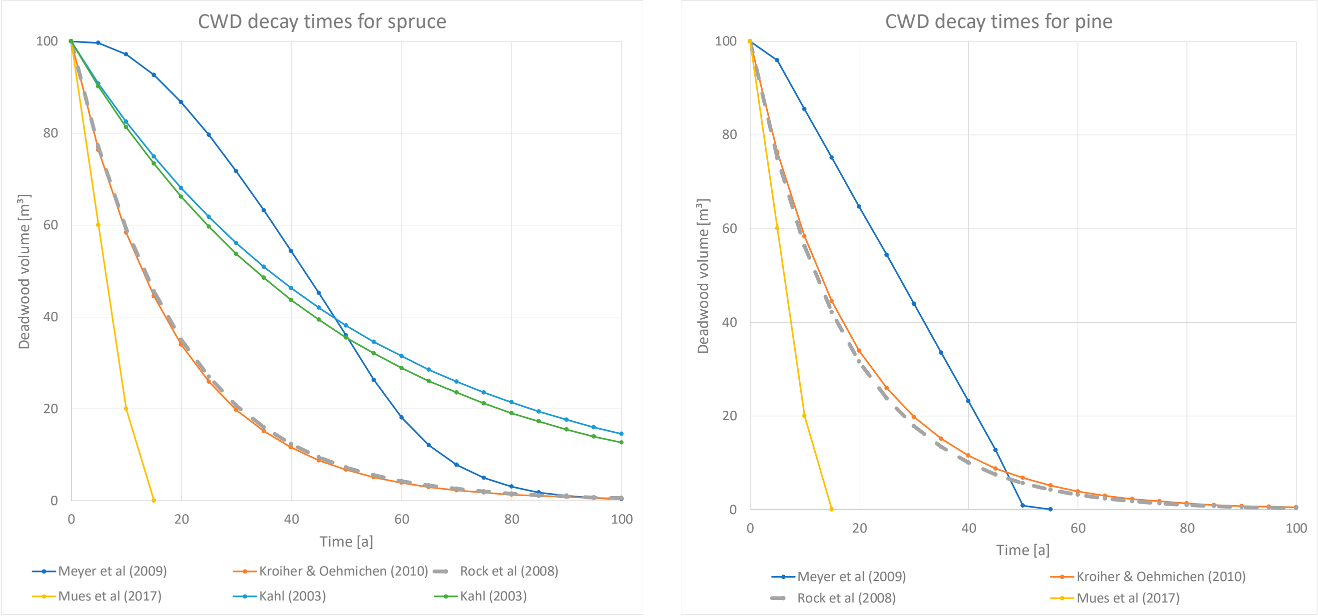

**Figure A2.** *CWD* decay times from different studies for spruce and pine [10,34–36,38].

## Appendix B. (Tables)

**Table A1.** Results table of the BAU scenario.

| **Growing Stock ob [1000 $m^3$]** | **2012–2031** | **2032–2051** | **2952–2071** | **2072–2091** | **2092–2111** | **2112–2131** | **2132–2151** | **2152–2171** | **2172–2191** | **2192–2211** | **Average** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| PF | 786,479 | 670,392 | 614,960 | 608,396 | 622,441 | 640,220 | 651,623 | 654,594 | 651,452 | 647,144 | 654,770 |
| MF | 2,523,706 | 2,115,370 | 1,941,847 | 1,934,424 | 1,987,860 | 2,041,609 | 2,066,163 | 2,062,795 | 2,043,188 | 2,027,707 | 2,074,467 |
| Total | 3,310,185 | 2,785,763 | 2,556,807 | 2,542,820 | 2,610,301 | 2,681,829 | 2,717,786 | 2,717,389 | 2,694,640 | 2,674,851 | 2,729,237 |
| Total fellings ub [1000 $m^3$ $a^{-1}$] | 2012–2031 | 2032–2051 | 2952–2071 | 2072–2091 | 2092–2111 | 2112–2131 | 2132–2151 | 2152–2171 | 2172–2191 | 2192–2211 | Average |
| PF | 19,020 | 14,459 | 12,967 | 12,603 | 12,694 | 12,923 | 13,069 | 13,105 | 13,063 | 12,978 | 13,688 |
| MF | 69,933 | 52,117 | 47,119 | 45,914 | 46,127 | 46,815 | 47,148 | 47,353 | 47,194 | 46,852 | 49,657 |
| Total | 88,954 | 66,576 | 60,087 | 58,517 | 58,822 | 59,738 | 60,217 | 60,457 | 60,257 | 59,829 | 63,345 |
| Total *CWD* [1000 $m^3$] | 2012–2031 | 2032–2051 | 2952–2071 | 2072–2091 | 2092–2111 | 2112–2131 | 2132–2151 | 2152–2171 | 2172–2191 | 2192–2211 | Average |
| PF | 55,862 | 64,226 | 67,593 | 69,424 | 70,378 | 70,608 | 70,376 | 69,885 | 69,171 | 68,399 | 67,592 |
| MF | 132,331 | 138,118 | 140,687 | 141,295 | 140,318 | 138,519 | 135,920 | 133,238 | 130,348 | 127,756 | 135,853 |
| Total | 188,193 | 202,344 | 208,279 | 210,720 | 210,696 | 209,127 | 206,295 | 203,123 | 199,519 | 196,155 | 203,445 |
| Outflow of unutilized timber [1000 $m^3$ $a^{-1}$] | 2012–2031 | 2032–2051 | 2952–2071 | 2072–2091 | 2092–2111 | 2112–2131 | 2132–2151 | 2152–2171 | 2172–2191 | 2192–2211 | Average |
| PF | 5248 | 3661 | 3326 | 3149 | 3095 | 3095 | 3136 | 3192 | 3231 | 3234 | 3437 |
| MF | 11,854 | 6789 | 6002 | 5750 | 5834 | 6004 | 6130 | 6174 | 6138 | 6079 | 6675 |
| Total | 17,101 | 10,450 | 9328 | 8899 | 8929 | 9098 | 9266 | 9366 | 9369 | 9314 | 10,112 |
| Silvicultural contribution margin [1000 EUR $a^{-1}$] | 2012–2031 | 2032–2051 | 2952–2071 | 2072–2091 | 2092–2111 | 2112–2131 | 2132–2151 | 2152–2171 | 2172–2191 | 2192–2211 | Average |
| PF | 598,221 | 385,679 | 321,278 | 298,508 | 303,343 | 315,791 | 323,710 | 326,793 | 326,789 | 324,645 | 352,476 |
| MF | 2,328,294 | 1,506,284 | 1,282,414 | 1,218,974 | 1,238,788 | 1,278,187 | 1,294,902 | 1,301,340 | 1,294,389 | 1,282,435 | 1,402,601 |
| Total | 2,926,515 | 1,891,963 | 1,603,691 | 1,517,482 | 1,542,131 | 1,593,979 | 1,618,612 | 1,628,134 | 1,621,178 | 1,607,080 | 1,755,076 |
| Liquidation value [1000 EUR $a^{-1}$] | 2012–2031 | 2032–2051 | 2952–2071 | 2072–2091 | 2092–2111 | 2112–2131 | 2132–2151 | 2152–2171 | 2172–2191 | 2192–2211 | Average |
| PF | 25,306,578 | 20,761,455 | 17,925,798 | 17,233,069 | 17,654,021 | 18,345,160 | 18,846,568 | 19,052,115 | 19,002,235 | 18,851,434 | 19,297,843 |
| MF | 86,099,494 | 69,401,900 | 60,211,039 | 59,026,933 | 60,982,949 | 63,051,216 | 64,025,184 | 63,952,030 | 63,200,358 | 62,470,957 | 65,242,206 |
| Total | 111,406,072 | 90,163,355 | 78,136,837 | 76,260,002 | 78,636,970 | 81,396,376 | 82,871,751 | 83,004,145 | 82,202,593 | 81,322,391 | 84,540,049 |

**Table A2.** Result table of the MSC scenario.

| **Growing Stock ob [1000 $m^3$]** | **2012–2031** | **2032–2051** | **2952–2071** | **2072–2091** | **2092–2111** | **2112–2131** | **2132–2151** | **2152–2171** | **2172–2191** | **2192–2211** | **Average** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| PF | 1,262,221 | 1,086,122 | 995,790 | 977,665 | 991,839 | 1,013,682 | 1,028,556 | 1,033,393 | 1,029,139 | 1,022,174 | 1,044,058 |
| MF | 1,744,817 | 1,467,921 | 1,348,172 | 1,336,923 | 1,367,069 | 1,399,231 | 1,413,551 | 1,409,856 | 1,395,513 | 1,383,355 | 1,426,641 |
| Total | 3,007,039 | 2,554,043 | 2,343,962 | 2,314,587 | 2,358,908 | 2,412,913 | 2,442,107 | 2,443,250 | 2,424,652 | 2,405,529 | 2,470,699 |
| Total fellings ub [1000 $m^3$ $a^{-1}$] | 2012–2031 | 2032–2051 | 2952–2071 | 2072–2091 | 2092–2111 | 2112–2131 | 2132–2151 | 2152–2171 | 2172–2191 | 2192–2211 | Average |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| PF | 29,663 | 22,447 | 20,087 | 19,431 | 19,496 | 19,777 | 19,880 | 19,858 | 19,733 | 19,565 | 20,994 |
| MF | 48,136 | 35,837 | 32,609 | 31,748 | 31,774 | 32,114 | 32,259 | 32,329 | 32,188 | 31,935 | 34,093 |
| Total | 77,799 | 58,284 | 52,696 | 51,178 | 51,270 | 51,890 | 52,139 | 52,186 | 51,921 | 51,500 | 55,086 |
| Total *CWD* [1000 $m^3$] | 2012–2031 | 2032–2051 | 2952–2071 | 2072–2091 | 2092–2111 | 2112–2131 | 2132–2151 | 2152–2171 | 2172–2191 | 2192–2211 | Average |
| PF | 91,451 | 106,441 | 113,430 | 117,761 | 120,376 | 121,672 | 121,977 | 121,757 | 120,978 | 120,037 | 115,588 |
| MF | 89,929 | 93,799 | 95,571 | 96,038 | 95,441 | 94,281 | 92,572 | 90,785 | 88,859 | 87,105 | 92,438 |
| Total | 181,380 | 200,239 | 209,001 | 213,799 | 215,817 | 215,953 | 214,549 | 212,541 | 209,837 | 207,142 | 208,026 |
| Outflow of unutilized timber [1000 $m^3$ $a^{-1}$] | 2012–2031 | 2032–2051 | 2952–2071 | 2072–2091 | 2092–2111 | 2112–2131 | 2132–2151 | 2152–2171 | 2172–2191 | 2192–2211 | Average |
| PF | 8663 | 6374 | 5859 | 5549 | 5426 | 5389 | 5421 | 5504 | 5586 | 5617 | 5939 |
| MF | 8026 | 4592 | 4067 | 3886 | 3923 | 4026 | 4109 | 4144 | 4126 | 4090 | 4499 |
| Total | 16,689 | 10,966 | 9926 | 9435 | 9349 | 9415 | 9530 | 9648 | 9712 | 9706 | 10,438 |
| Silvicultural contribution margin [1000 EUR $a^{-1}$] | 2012–2031 | 2032–2051 | 2952–2071 | 2072–2091 | 2092–2111 | 2112–2131 | 2132–2151 | 2152–2171 | 2172–2191 | 2192–2211 | Average |
| PF | 922,035 | 582,797 | 481,087 | 442,279 | 446,949 | 465,191 | 475,808 | 479,386 | 477,475 | 473,100 | 524,611 |
| MF | 1,635,781 | 1,055,920 | 904,513 | 863,380 | 874,890 | 897,486 | 904,355 | 904,491 | 897,270 | 887,601 | 982,569 |
| Total | 2,557,816 | 1,638,717 | 1,385,600 | 1,305,660 | 1,321,839 | 1,362,677 | 1,380,163 | 1,383,877 | 1,374,746 | 1,360,702 | 1,507,180 |
| Liquidation value [1000 EUR $a^{-1}$] | 2012–2031 | 2032–2051 | 2952–2071 | 2072–2091 | 2092–2111 | 2112–2131 | 2132–2151 | 2152–2171 | 2172–2191 | 2192–2211 | Average |
| PF | 40,482,730 | 33,529,666 | 28,915,573 | 27,529,186 | 27,881,470 | 28,727,232 | 29,372,543 | 29,651,460 | 29,568,510 | 29,324,740 | 30,498,311 |
| MF | 60,588,285 | 48,946,785 | 42,578,481 | 41,734,672 | 42,910,168 | 44,103,172 | 44,576,767 | 44,390,206 | 43,789,812 | 43,216,797 | 45,683,515 |
| Total | 101,071,015 | 82,476,451 | 71,494,055 | 69,263,859 | 70,791,638 | 72,830,404 | 73,949,310 | 74,041,666 | 73,358,322 | 72,541,537 | 76,181,826 |

**Table A3.** Results table of the ISC scenario.

| **Growing Stock ob [1000 $m^3$]** | **2012–2031** | **2032–2051** | **2952–2071** | **2072–2091** | **2092–2111** | **2112–2131** | **2132–2151** | **2152–2171** | **2172–2191** | **2192–2211** | **Average** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| PF | 635,758 | 613,015 | 566,259 | 522,325 | 494,036 | 483,977 | 486,876 | 494,331 | 499,346 | 498,294 | 529,422 |
| MF | 1,401,565 | 1,249,802 | 1,141,784 | 1,100,215 | 1,105,390 | 1,127,829 | 1,144,442 | 1,146,842 | 1,137,851 | 1,126,199 | 1,168,192 |
| Total | 2,037,323 | 1,862,817 | 1,708,043 | 1,622,540 | 1,599,426 | 1,611,806 | 1,631,318 | 1,641,174 | 1,637,197 | 1,624,493 | 1,697,614 |
| Total fellings ub [1000 $m^3$ $a^{-1}$] | 2012–2031 | 2032–2051 | 2952–2071 | 2072–2091 | 2092–2111 | 2112–2131 | 2132–2151 | 2152–2171 | 2172–2191 | 2192–2211 | Average |
| PF | 11,329 | 9420 | 8560 | 7901 | 7528 | 7306 | 7192 | 7091 | 6974 | 6853 | 8015 |
| MF | 35,811 | 29,310 | 27,464 | 26,407 | 26,007 | 26,004 | 26,093 | 26,146 | 26,089 | 25,929 | 27,526 |
| Total | 47,140 | 38,730 | 36,024 | 34,307 | 33,535 | 33,310 | 33,286 | 33,237 | 33,062 | 32,782 | 35,541 |
| Total *CWD* [1000 $m^3$] | 2012–2031 | 2032–2051 | 2952–2071 | 2072–2091 | 2092–2111 | 2112–2131 | 2132–2151 | 2152–2171 | 2172–2191 | 2192–2211 | Average |
| PF | 53,033 | 65,387 | 74,130 | 81,598 | 87,282 | 92,137 | 95,551 | 98,463 | 100,214 | 101,642 | 84,944 |
| MF | 71,054 | 73,613 | 75,286 | 76,316 | 76,687 | 76,596 | 75,996 | 75,157 | 74,063 | 72,898 | 74,767 |
| Total | 124,086 | 139,000 | 149,416 | 157,913 | 163,968 | 168,733 | 171,547 | 173,620 | 174,277 | 174,540 | 159,710 |
| Outflow of unutilized timber [1000 $m^3$ $a^{-1}$] | 2012–2031 | 2032–2051 | 2952–2071 | 2072–2091 | 2092–2111 | 2112–2131 | 2132–2151 | 2152–2171 | 2172–2191 | 2192–2211 | Average |
| PF | 5226 | 5086 | 5125 | 4912 | 4640 | 4412 | 4299 | 4310 | 4401 | 4500 | 4691 |
| MF | 6280 | 3771 | 3427 | 3193 | 3122 | 3165 | 3241 | 3295 | 3307 | 3284 | 3608 |
| Total | 11,507 | 8856 | 8551 | 8105 | 7762 | 7576 | 7540 | 7605 | 7707 | 7785 | 8299 |
| Silvicultural contribution margin [1000 EUR $a^{-1}$] | 2012–2031 | 2032–2051 | 2952–2071 | 2072–2091 | 2092–2111 | 2112–2131 | 2132–2151 | 2152–2171 | 2172–2191 | 2192–2211 | Average |
| PF | 317,212 | 197,778 | 151,262 | 120,112 | 109,551 | 108,092 | 110,028 | 111,766 | 111,690 | 109,261 | 144,675 |
| MF | 1,262,410 | 900,478 | 791,122 | 744,989 | 740,955 | 751,863 | 756,618 | 754,982 | 749,007 | 741,025 | 819,345 |
| Total | 1,579,621 | 1,098,256 | 942,385 | 865,100 | 850,506 | 859,955 | 866,646 | 866,748 | 860,698 | 850,286 | 964,020 |
| Liquidation value [1000 EUR $a^{-1}$] | 2012–2031 | 2032–2051 | 2952–2071 | 2072–2091 | 2092–2111 | 2112–2131 | 2132–2151 | 2152–2171 | 2172–2191 | 2192–2211 | Average |
| PF | 19,637,920 | 18,176,834 | 15,752,977 | 13,876,581 | 12,817,770 | 12,436,113 | 12,458,344 | 12,681,086 | 12,853,709 | 12,825,281 | 14,351,662 |
| MF | 50,300,654 | 43,107,954 | 37,400,136 | 35,641,581 | 35,937,995 | 36,745,175 | 37,205,299 | 37,138,624 | 36,671,318 | 36,114,620 | 38,626,336 |
| Total | 69,938,574 | 61,284,788 | 53,153,113 | 49,518,163 | 48,755,765 | 49,181,288 | 49,663,643 | 49,819,709 | 49,525,027 | 48,939,901 | 52,977,997 |

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