D4.4 Report on EU forest management costing module and green jobs calculator

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Abstract

This report presents an updated EU scale forestry cost model. This update is designed to more comprehensively capture relevant management activities such as regeneration and forest roads. Unlike previous models, which focused mainly on rotational forestry and timber supply, the updated model incorporates alternative management systems such as continuous cover forestry (CCF), distinguishes afforestation between tree species groups, and better accounts for spatial variability across the EU27. Furthermore, the model generates labor demand indicators, enabling integration with broader socioeconomic analyses and macroeconomic tools like GLOBIOM and MAGNET.

The model reveals how different management options impact both cost and employment, offering new insights into the financial competitiveness of forest management options. These advancements support a more informed decision-making for forest owners, policymakers, and industry stakeholders navigating trade-offs between profitability, employment, and ecosystem services in Europe's forest-based bioeconomy.

Keywords

Forestry cost, forest management, climate change adaptation

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Abbreviations

BFW	Bundesforschungs- und Ausbildungszentrum für Wald, Naturgefahren und Land
CC	Clearcutting/Clearfelling-based forest management
CCF	Continuous cover forest management
CPI	Consumer Price Index
EC	European Commission
EU	European Union
FAWS	Forest available for wood supply
FTE	Full Time Equivalent
G4M	Global Forest Model
GAMS	General Algebraic Modeling System
GLOBIOM	Global Biosphere Management Model
KTBL	Kuratorium für Technik und Bauwesen in der Landwirtschaft
KWF	Kuratorium für Waldarbeit und Forsttechnik
NPV	Net Present Value
PCT	Pre-commercial thinning
RF	Rotational-based forest management
SIMU	Simulation unit
WP	Work Package

1. Introduction

The cost of forest management is a critical determinant of forest profitability, directly influencing decision-making in silviculture and forest operations. Harvesting costs typically represent the largest share of cost components, making them a central focus in both operational planning and economic modelling. However, there are other costs—such as those related to regeneration activities and the maintenance of forest roads—that are also relevant when assessing the overall forest management profitability.

For example, harvesting operations (including thinnings and final fellings) in Sweden make up about 62% of total management costs at the national level (Skogsstyrelsen, 2023). The remaining costs are divided between regeneration and early care operation activities (21%), and road maintenance or new infrastructure investments (15%) (Skogsstyrelsen, 2023). These figures underscore the need for a holistic approach to forest management costs modelling. Focusing solely on harvesting overlooks significant expenses that forest owners and managers incur, which are crucial when evaluating alternative management options or establishing new forest areas (afforesting land).

In the past, global forest modelling tools such as G4M (Global Forest Model) and GLOBIOM (Global Biosphere Management Model) incorporated a spatially explicit forest costing module developed by Di Fulvio et al. (2016). The input from the costing model is used in the land use models as an estimate of the direct forest activity costs, which enter the calculation of forest management profitability. However, the two models also endogenously account for other costs included in land use management decisions (e.g. agricultural land prices/land rent). The original costing model focused primarily on timber supply, including thinnings, final fellings, and wood transportation costs. The costing model partially addressed the costs of forest regeneration. Additionally, the model was based on rotational forestry practices—specifically clear-felling management systems—and did not comprehensively account for the costs associated with road infrastructure or alternative management systems. Moreover, it did not differentiate between tree species groups in the regeneration module (e.g., broadleaves vs. conifers) nor fully represented accessory costs (such as protection/sheltering of young forests), which can be significant, particularly in afforestation or restoration. Despite its limitations, the earlier cost model proved valuable for assessing afforestation costs and informing relevant policies, such as the guidelines accompanying the "3 Billion Trees" pledge (EC, 2021a).

As forest policy goals have evolved, particularly with the increasing emphasis on climate change adaptation (EC, 2021b) and closer-to-nature forest management (EC, 2023), the demand for a more advanced modelling framework able to reflect forest management system alternatives is rising. In particular, a refined costing approach to fully evaluate economic opportunities related to changing tree species composition and increasing forest structural complexity is needed.

In this context, a series of studies (Jonsson, 2015; Bianchi et al., 2023; Rautio et al., 2025) have examined the implementation of continuous cover forestry (CCF) and similar management systems based on selective harvesting of trees in EU forests. The CCF systems tend to rely more extensively on natural regeneration processes than rotational forest systems. Though this may reduce forest regeneration costs, CCF systems may require higher operational costs for forest harvesting (Rautio et al., 2025). The rise in harvesting costs per unit of volume is linked to lower timber removals per hectare in individual forest operations (Jonsson, 2015), which may subsequently increase the complexity of forest operations when trying to match the wood production of rotational forests in a given landscape. Thus, the financial competitiveness of selective systems compared to conventional rotational management systems remains highly uncertain to model (Bianchi et al., 2023). Given this uncertainty, there is a need for a framework able to bring together the various cost components consistently.

Afforestation is recognized as one of the most cost-effective land use-based strategies for mitigating climate change (Austin et al., 2020; Doelman et al., 2020). However, in Europe, the costs of establishing new forests and their financial competitiveness compared to other land uses, particularly agriculture, remain insufficiently understood (Kryszk et al., 2024). To address this, the G4M model compares agricultural land prices with the net present value (NPV) of new forests, including both the direct costs and revenues associated with forest establishment, and generates decisions on afforestation/deforestation (Gusti and Kindermann, 2011). The G4M model considers the spatially explicit direct costs (0.5-degree grid) for establishing new forests. Consequently, there is an urgent need for more spatially detailed afforestation cost data to better inform land-use transition decisions, particularly to assess the viability of afforesting agricultural land. Such data would provide information about this land transition's contribution to climate and biodiversity goals.

In this study, we employed an engineering-based costing approach, which not only estimates the financial costs of forestry activities but also allows for the assessment of labor demands under alternative forest management and afforestation scenarios. Employment indicators derived from such an approach can complement broader socio-economic assessments of employment conducted using macroeconomic models, such as the MAGNET CGE model. This approach provides a more nuanced insight into the employment impacts associated with forest management scenarios.

1.1. Aim

This report presents an updated version of the forestry costing model (Di Fulvio et al., 2016) developed as part of the ForestNavigator project. In contrast to the earlier version, the following updates were made:

- Captures more comprehensively the relevant management activity cost components (i.e., regeneration and road infrastructure maintenance),
- Enhances differentiation between tree species groups and silvicultural management systems,
- Improved understanding of costs of afforestation and financial competitiveness with other land uses,
- Include as output the labor demand for forest operations under alternative management scenarios.

The model covers the EU27 region, operates at fine spatial resolution (5 arcmin), and ensures compatibility with G4M-X forest model output variables. These enhancements facilitate a more detailed representation of costs, improving the capability to support assessments of forest management profitability in land-use models (GLOBIOM/G4M-X).

In this report, we first present the main methodological advancements, which include new management systems, the improved representation of tree species groups impacts on costs, road maintenance costs, and indicators related to labor needs and employment in forest operations.

Second, we present the results of the model application stylized scenarios of forest management and afforestation, demonstrating the sensitivity of the costs/employment variables to changes in forest structural attributes output of forest management models.

2. Methods

2.1. Costing model structure

The costing model, comprising three sub-modules (engineering, logistics, and cost adaptation), assesses and spatializes forest management costs. The modules combine engineering relations between terrain topography, forest structural attributes, and operational efficiencies, and a series of econometric relations for adapting costs across country borders (Table 1). Figure 1 provides an overview of the costing model structure and the relationship between the databases and modules.

Table 1: Input, process, and output for each sub-module of the costing model

Module	Input	Process	Output
Engineering	• Terrain variables • Forest Variables	Computation of operational efficiency for each operation, based on engineering relations	Hourly production efficiency for each operation: • Per hour [m^3/hour] • Per hectare [ha/hour]
Logistics	• Forest simulation units • Location of cities • Road network	Computation of the shortest road distance between the forest simulation unit and the nearest city	Wood transportation travelling time: • To the nearest city [hour]
Cost adaptation	• Hourly operational production • Travelling time for wood transport • Unitary costs for machinery, labor, and fuels in the reference country • National econometrics	Combine output from the engineering and logistic modules with economic information from the cost database for computation of costs per produced wood unit and per hectare of forest.	Cost for each operation: • Per unit of product [EUR/m^3] • Per unit of forest area [EUR/ha]

Source: ForestNavigator WP 4

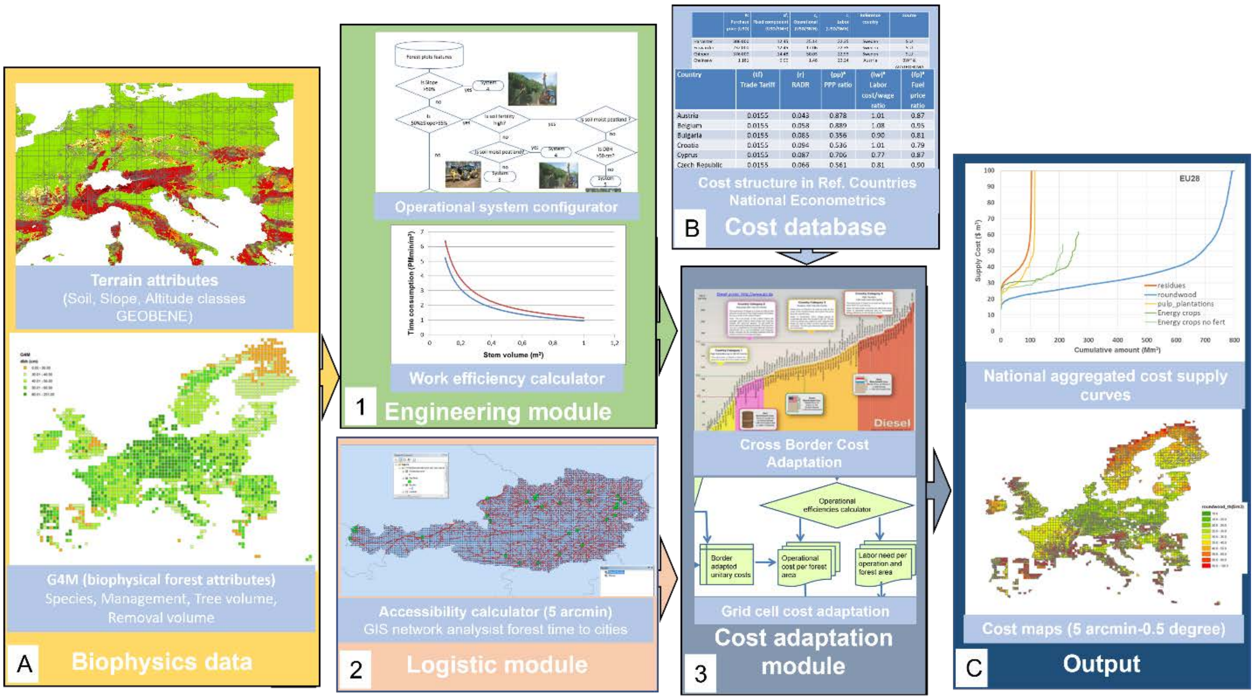


Figure 1. Structure of the forestry costing model: databases (A, B) sub-modules (1,2,3), and output (C).

The databases (indicated by A and B in Figure 1) and sub-modules (indicated by 1, 2, and 3 in Figure 1) are further described next:

A) Biophysics data encompass biophysical forest structural attributes: soft link to forest models (G4M, 3PGMIX) at 5-arcmin to 0.5-degree spatial resolution to transfer forest structural attributes at the SIMU (Simulation Unit) level.

The biophysics data include terrain layers (Figure 1, section A): spatial explicit terrain features (i.e., soil class, slope class, and altitude class) consistent with the IIASA GEOBENE geodatabase (IIASA) underlying the GLOBIOM model, composed of homogeneous response units (SIMU) of variable size (5 arcmin-0.5 degree) classified according to country borders and dominant soil texture, slope, and altitude classes.

The slope and altitude classes are used to select the mechanization level and adapt the efficiencies of forest operations to the SIMU using engineering factors contained in the engineering module.

The key forest structural parameters derived from the forest model G4M-X and used in the costing model as input variables are:

- Tree species group (Conifer, Broadleaves)
- Management operation type (Final Felling, Thinning)
- Removed tree volume (average removal tree size) [m^3]
- Removal volume per hectare (roundwood removal per hectare) [m^3/ha]

These variables are complementary to the terrain variables and are used to select the mechanization of forest operations and adapt operational efficiency (empirical literature relations) to forest structural conditions in the engineering module.

1) The **Engineering module** consists of two parts: one part selects forest machinery systems (Annex I, Table 1) based on terrain topography and forest structural attributes from the

biophysics data, the other part assesses operational time consumption and operational efficiency based on a set of empirical literature equations controlling the relation between terrain/forest variables and efficiency in forest operations (Supplement of Di Fulvio et al., 2016). Operational efficiency was assumed to be independent of the country's border.

2) The **Logistics module** provides transportation distances from forest SIMU centroids to closest cities (as a proxy for forest products markets), derived from a GIS road Network Analysis. The travelling time from SIMU to the closest city is computed using the computed travelling distance.

B) Cost database includes unitary costs for machinery (capital investments), fuel, and labor collected in reference countries[i] (Annex I, Table 2-3) and a collection of econometrics (Annex I, Table 4) used for benefit transfer across country borders at the EU27 scale. Unitary costs for capital, labor, and fuel for forest operations are collected in reference countries and based on a standardized calculation approach to derive operational costs per hour (Ackerman et al., 2014). These unitary hourly costs are independent of the efficiency of each operation.

3) The **Cost adaptation module** combines the input (hourly operational efficiencies) from the engineering module and the cost database (hourly costs of capital, labor, and fuels). Unitary operational costs (capital, fuel, labor) are adapted to country borders by means of an econometric relation as in *Table 2*, while the operational efficiencies are assumed to be independent of the country's border. Next, the hourly operational costs are combined with the operational efficiencies in each SIMU (from the engineering module) to return the cost per unit of land or unit of product in each SIMU [EUR/m^3, EUR/ha]. Overheads for the organization of forest work are also included using cost inflators (percentage applied to the total direct costs).

Table 2: Countries' border adaptation methods applied to cost items using the econometrics listed in Annex I, Table 4 (approach based on Di Fulvio et al., 2016)

Cost item in EUR/hour	Cross-border adaptation method
Machinery depreciation cost	$\frac{r_j \times \left(\frac{(PC_{ref} - S_{ref})(N+1)}{2N} + S_{ref}\right)}{U}$
Fuel cost (Diesel, Gasoline, Lubricants)	$Fuel\ Price_{\ j} \times Fuel\ consumption_i$
Labor cost (Wage, indirect salary costs)	$Wage\ Forest_{\ ref} \times \frac{Wage\ sectorial\ j}{Wage\ sectorial\ ref} \times Social\ charge\ rate_{\ j}$

Source: ForestNavigator WP 4 **Where: PC = purchase price, S = salvage value, N = lifetime, U = yearly utilization, j = country of application, i= operation, ref. = reference country for prices/costs, r = interest rate*

The final output of the forestry costing model is a forest management cost per unit of product (wood) and hectare of land (managed forest area). Costs are represented in 2024 prices updated

[i] Countries that have access to full cost structures for forest operations (Annex I, Table 5-6) are used as "reference" ones from where unitary costs are transferred to other ones using adaptation methods.

using CPI (Consumer Price Index) as described in D4.2 where appropriately. Single cost components (activities/operations) are aggregated into cost maps according to SIMU borders.

In each SIMU, the total forest management costs are summed based on costs for regeneration, thinning, final felling, and road maintenance. In conclusion, the sum of all these costs at the landscape level represents total management costs incurred over a forest rotation/cycle using the following equation:

$$\text{Total management cost [EUR/ha, EUR/m}^3\text{]} = \sum \text{(Regeneration, PCT, Thinning, Final Felling, Road maintenance)}$$

The forestry costing model is written in General Algebraic Modeling System (GAMS). GAMS allows for combining heterogeneous sets of input (heterogeneous in spatial scales and dimensions) and performs rapid simulations and aggregations across scales.

2.2. Advancements in modelling harvesting operations

Forest harvesting efficiency calculations in the engineering module (i.e., tree felling, processing, and wood extraction) are strongly influenced by forest structural characteristics that depend on the forest management system. We capture the effect of CCF on operational efficiencies using updated efficiency equations for tree felling and processing used in the engineering module. The equations were updated based on a review of studies analyzing and comparing clearcutting systems and selective logging systems (CCFs) in conifers and broadleaf forests.

Tree felling and processing operations

In the updated version of the costing module, we consider two types of machinery for felling and processing (i.e., chainsaw and harvester), applied in motor-manual and mechanized operations respectively (Annex I, Table 1). For each machinery system, as in the original module, time consumption is calculated using empirical equations that depend on harvested tree stem volume [m^3], harvest type (clearfelling or thinning), tree species group (conifer or broadleaf), and slope class. For harvesters, the applicability is further constrained by an upper bound slope class (40% slope) and maximum stem volume per removed tree (1.5 m^3).

In the new formulation, we have applied specific deflators for mechanized and motor-manual operations to simulate a loss in efficiency in CCF operations, a modification of the original productivity model for clear-felling in Di Fulvio et al. (2016). In Scandinavia, mechanized selective logging (a type of harvesting applied to CCF) led to a significant reduction in harvester productivity compared to clearfelling operations, according to a recent study by Laitila et al. (2025). This reduction is similar to the drop observed when comparing thinning operations to clearfelling in a rotational forest. According to the Eriksson & Lindroos productivity model (2014) for single-grip harvesters in rotational forests, the drop in productivity ranged between 15% and 24% when comparing thinning and final felling (at the same removal stem volume). Hence, we have applied this difference to the original equations for mechanized felling and processing.

We improved the differentiation between the processing of broadleaves and conifers using single-grip harvesters. Recent studies have shown that a reduction in work productivity between 15% and 29% can be observed when processing broadleaves compared to conifers in Central EU (Labelle et al., 2019; Berendt et al., 2020). Accordingly, in the case of broadleaves' processing, we have applied shifters for reducing work efficiencies in the original equations sourced from conifer processing. In motor-manual processing operations, given the uncertainty when comparing conifer and broadleaves processing. In this conservative approach, work productivity differences were maintained as in the original empirical equations' findings (i.e. 0%-5% according to Erni et al., 2003).

Wood extraction operations

For wood extraction operations, we have included four systems, namely, forest forwarder, farm tractor-based, skidder, and cable yarder. The productivity of wood extraction machinery is controlled by empirical equations where the main variable is the volume of wood removal per hectare [roundwood m^3/ha] in each operation and by type of operation (thinning vs. clearfelling).

A pilot study by Manner and Ersson (2023) has shown that forwarding productivity in selection harvesting is dependent on log concentration on strip roads, while the density of remaining trees had very little effect compared to efficiencies in clearfelling. Similar effects on forwarding productivity were observed in case of patch-cutting, where decreasing wood density compared to clear felling (Eliasson et al., 2021). Accordingly, for wood extraction operations, in case of selective logging (CCF), we apply the general empirical productivity model for wood extraction in clear-felling areas (Nurminen et al., 2006), where the density of assortments (roundwood volume per hectare) controls the level of efficiency. In this way, efficiency is adapted to the CCF conditions by the relative change in the level of removal per hectare compared to a clearfelling.

As a new development, cost minimization was also included in the allocation of harvesting systems to SIMU, as part of the cost adaptation module. This implies that, after pre-computing harvesting costs for all systems compatible with a specific SIMU according to terrain and forest characteristics, the costing module performs a final selection of felling/processing and extraction systems and assigns the one with the lowest operational cost per unit of product.

Table 3: Overview of introduced modifications to adapt tree felling/processing and wood extraction operations in case of CCF or Broadleaves species (reference is clearcutting and conifers).

Introduced modification	CCF	Broadleaves
Time consumption increases in tree felling/processing	+15%/+24% in Mechanized & Motor-manual	+15% to 29% in Mechanized 0-5% increase in Motor-manual
Time consumption increases in wood extraction	According to wood removal volume per hectare	According to wood removal volume per hectare

Source: ForestNavigator WP 4

2.3. Advancements in the modeling of regeneration and afforestation

The costing module distinguishes two categories of costs for the establishment of forests:

1) Regeneration cost = costs associated with regenerating forests after final felling on land previously occupied by forests.

2) Afforestation cost = costs for establishing new forests on land not previously classified as forest, which also includes additional costs for ground preparation and forest establishment.

Regeneration

We have introduced a differentiation of regeneration costs according to tree-species group (conifers vs. broadleaves) and management regime (rotational vs. CCF system).

To differentiate between species groups (broadleaves and conifers), we reviewed seedling costs according to existing average differences of seedling costs per unit (i.e. 1 seedling), as reported in commercial catalogues (Unitary prices in regeneration/afforestation materials from the BFZ 2024, Austria, available in Annex I, Table 7). From this analysis, the unitary cost of broadleaf seedlings was 40% more expensive than for conifers, when considering typically planted forest species (e.g. Norway spruce vs. European beech).

In the rotational (clearfelling-based) system, we have included a cost for assisted regeneration, based on manual and mechanized planting methods. Whereas, in the CCF (selective) system, we have assumed that forests are naturally regenerated, according to the most common regeneration approach prescribed in similar forest management in the EU (see D3.1 ForestNavigator).

The time consumption for manual planting was based on the Kuratorium für Waldarbeit und Forsttechnik (KWF) online calculator of work efficiencies (KWF, Germany), and the efficiency of mechanized planting was based on a recent literature review (Ghaffariyan, 2021). These sources resulted in a time consumption of 18.8 h/ha (manual) and 7.0 h/ha (mechanized) at a standardized planting density of 1,800 seedlings/ha. In each SIMU, these efficiencies were adjusted according to slope class by engineering inflators. The total regeneration cost per hectare was calculated by summing the cost of seedlings together with labor and machinery costs using country-specific hourly labor rates for manual and mechanized operations (Annex I, Table 4).

As for the harvesting system, also for regeneration, we have compared the two alternative systems (manual and mechanized) and applied a cost minimization approach, but in this case, by comparing the cost per hectare.

In the regeneration costs, we have also included a cost for pre-commercial thinning (PCT), as a complementary operation in the forest stand establishment phase. PCT time consumption was based on the KWF (Germany) online calculator and was assumed to be 17.8 h/ha. The PCT cost per hectare was based on the efficiency per hectare and the hourly cost for a motor-manual operation (operator with a cleaning saw).

Afforestation

In the case of afforestation, we have included all costs listed above for regeneration, and we have also included additional costs for land preparation (vegetation shredding and deep ploughing), plant protection (sheltering) and irrigation (South EU). Agricultural machinery efficiencies were retrieved from the Kuratorium für Technik und Bauwesen in der Landwirtschaft (KTBL) database. Additional costs for tree sheltering/protection were based on manuals used for costing afforestation interventions according to public subsidy schemes (Regione Veneto, 2022). Irrigation costs were included for Bulgaria, Greece, Italy, Portugal, and Spain. Irrigation costs were based on an application of a total of 300 m^3/ha of water, where water prices (EUR/liter) were originally based on Giannakis et al. (2016) in reference countries (Cyprus, Greece, Italy, France, Portugal, and Spain).

The unitary water costs were extrapolated to the other EU27 countries not included in Giannakis et al. (2016) using a water and price level derived from the ALICE H2020 (ALICE, 2018) and IBNET water price database (Annex I, Table 4).

Table 4: Operations included in regeneration and afforestation

Operation	Regeneration	Afforestation
Cleaning of vegetation	NO	YES
Ploughing	NO	YES
Planting of trees	YES	YES
Irrigation at establishment	NO	YES
Sheltering of seedlings	NO	YES
Pre-Commercial Thinning (PCT)	YES	YES

Source: ForestNavigator WP 4

2.4. Forest road maintenance costs

The new version of the costing model includes a representation of costs for existing road infrastructure maintenance, which can be related to managed forests. This cost usually represents more than 50% of the total forest road costs (when considering existing roads and establishment of new ones) (Toscani et al., 2020). The costs for building new roads require local-scale modelling and were not included in this costing module.

Two reference cost statistics on average road maintenance from Sweden and Austria were used. For both countries, we have retrieved the average maintenance cost per m^3 of harvested wood (2.2 EUR/m^3 in Sweden and 4.8 EUR/m^3 in Austria). For regions characterized by flatter terrains, average road maintenance costs in Sweden were adopted (Skogstryrelsen, 2023). For regions where terrain topography (altitude and slope) affects maintenance costs, we used the Austrian cost statistics (Toscani et al., 2020).

The cost in reference countries was adapted to the rest of countries in the respective regions by means of the relative difference in hourly operational costs of an excavator-based operation (i.e. a national scale adaptation of unitary costs).

The costs of road maintenance were not differentiated by management system. While CCF relies on a higher number of interventions than Rotational Forestry (RF), CCF removes less wood per intervention. Therefore, these two effects could potentially cancel each other out.

2.5. Cost adaptation module update

The cost adaptation module received updated reference unitary prices/costs for forest machinery, labor, and fuels in reference countries considered across the different operations. Furthermore, the single unitary cost components (machinery depreciation, fuel cost, labor cost) were adapted to each EU27 country using econometric approaches.

A net wage for forest machinery in Austria of 23 EUR/hour and a gross wage of 35 EUR/hour were calculated using forest machinery reference purchase prices (BFW database, 2022) and forest machinery operator reference wages (AUSTROFOMA catalogue, 2023). For specialized machine operators (harvesters, forwarders, skidders, and cable yarders), the wages were increased by 25%, according to the data catalogue. Reference unitary costs for other agricultural machinery employed in regeneration/afforestation used Germany (KTBL database, 2024). Reference costs for road maintenance were sourced from Austria (Toscani et al. 2020) and Sweden (Skogstyrelsen, 2023). All reference costs/prices are represented in 2024 prices updated using CPI as described in D4.2.

Unitary costs adaptation from the reference countries to other ones relied on benefit transfer approaches as explained in *Table 2*. The econometric indicators utilized in the cost adaptation, fuel price, labor costs, and interest rate were updated as described in ForestNavigator Deliverable 4.2. Each listed econometric indicator was retrieved for each EU27 country (Annex I, Table 4) and applied to all SIMUs within a country's administrative border. This collection reflects the most up-to-date indicators for recent years and is indicative of economic conditions from 2022 to 2024.

Table 5: Economic indicators and data sources applied for cross-border unitary costs adaptation.

Indicator	**Data source**
Fuel price (EURO/l)	Average fuel price per country for 2023-2024; Source: EC Energy Price bulletin https://energy.ec.europa.eu/data-and-analysis/weekly-oil-bulletin_en#price-developments
Labor cost (EURO/hour)	Labor cost based on monthly earnings per country 2023 (agriculture, forestry, fishery); Source: ILOSTAT database https://rshiny.ilo.org/dataexplorer
Interest rate (%)	Interest rate per country (long-term government bond yields) for 2023-2024; Source: EUROSTAT https://ec.europa.eu/eurostat/databrowser/view/teimf050/default/table?lang=en&category=shorties.teieuro_mf.teimf_mm

Source: ForestNavigator, WP 4

Overheads are the organizational costs for planning and organizing forest operations and depend on the size of forest companies and operating market conditions. In Austria, overheads could be as high as 25-30% (AUSTROFOMA, 2023) of direct costs. In our analysis, we have added an extra 15% in all countries and SIMU to reflect a standard overhead level across the EU in the cost calculation. No further differentiation was made as no assessment was made based on the differential size of forest business across the EU.

2.6. Employment module

The costing model for its deployment can be flexibly linked to forest structural variables from an EU-scale forest model. It simultaneously outputs forest management system costs per unit of land or product (EUR/ha, EUR/m^3) and the corresponding labor needs, expressed as full-time equivalents (FTE) per unit of forest land or product (FTE/ha, FTE/m^3).

The relationship between costs and employment is mediated by an engineering module that calculates the labor and machinery needs for each forest operation (see Figure 2). For each operation, we have included an adjustment factor to convert the scheduled machine hours, estimated using empirical forest operations equations, into actual working hours.

For road maintenance, we applied a labor requirement of 0.5 hour/ha/year, based on Enache & Stampfer (2023), which assumes a good level of forest road accessibility (ca. 12 m of road/ha).

For planning tasks, we assumed a 15% overhead, consistent with the overhead level used in operational cost estimations.

Total annual labor requirements per operation were aggregated and converted to FTEs by dividing total labor hours by a standard annual workload of 1,800 hours per full-time worker.

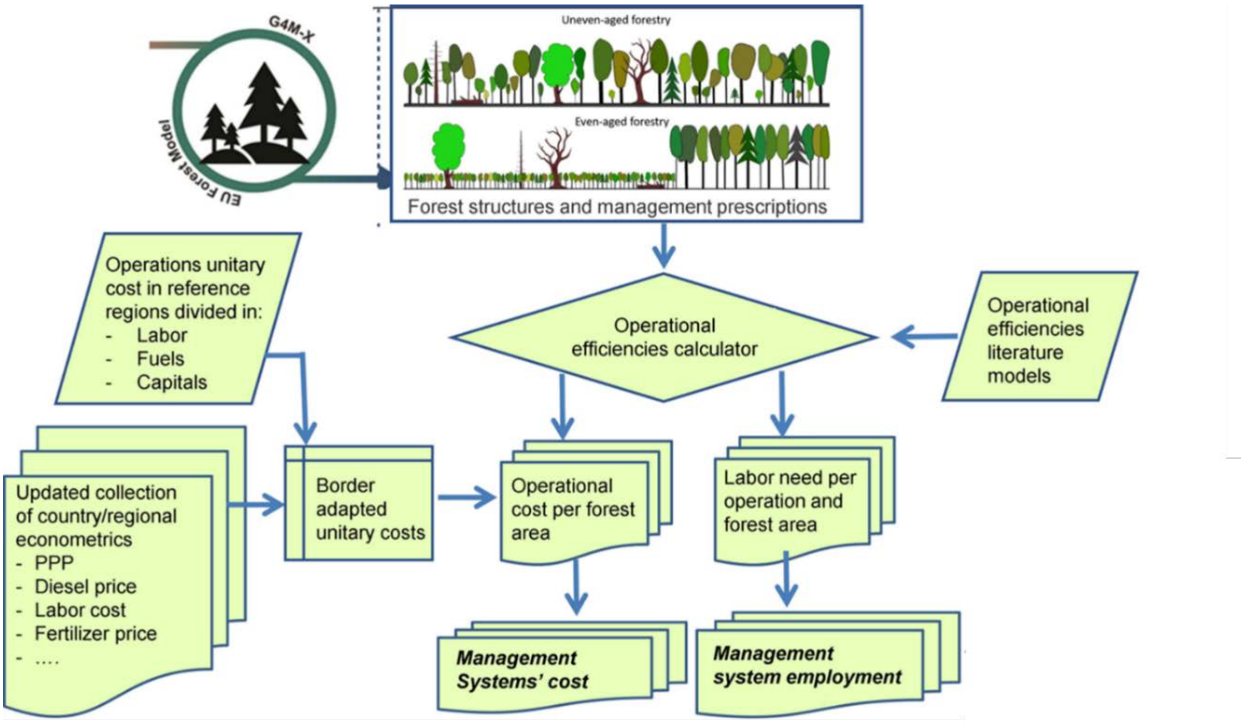


Figure 2. Schematic relation between the costing and employment module.

2.7. Testing Scenarios

For testing purposes, we designed two theoretical forest management scenarios. Both scenarios relied on the projected forest management potential area and harvest volume projection from the G4M forest model for the EU27, where wood demands were set to infinity. In the resulting scenario, all SIMU grid cells within the forest area available for wood supply (based on 2020 forest land) were considered to be under optimal management, represented in the model by RF system. For CCF scenario, we set to achieve the same total removal volume per SIMU with that of a full RF rotation. To achieve this, we set the intervention frequency at every 20 years and derived the corresponding wood removal per hectare per operation. In the RF system, assisted regeneration was included, whereas it was not included in the CCF scenario.

Forest management costs per hectare and m^3 were computed for the potential supply area of EU27 forests by summing the costs of operations listed in *Table 6* for each SIMU. For both management systems, we compared costs incurred over an entire rotation. As a result, we needed to adapt some of the primary model output to obtain a fair cost comparison, which equalizes production per hectare over the rotation in both systems (described in the equation below). Harvest costs for a single operation (i.e., cost per m^3 of roundwood over bark) were obtained directly from the raw output from the costing model. Subsequently, the unitary cost per operation for CCF was scaled to match the same removal volume per hectare as the RF/CC system over an entire rotation. This was done by first converting CCF costs to a per-hectare basis and then multiplying by the number of operations needed to achieve the same removal volume as RF/CC.

$$\text{Final Cost CCF [EUR/ha]} = Prel.Cost\ CCF\ x\ RhaCCF\ x\ \frac{RThaRF}{RhaCCF};$$

where *Prel. Cost CCF* = Preliminary Cost per unit of volume as output of the cost model [EUR/m^3]; *RhaCCF* = Removal per Hectare per operation in CCF [m^3/ha]*; RThaRF* = removal per hectare in RF over the entire rotation (including thinning and final felling) [m^3/ha].

Table 6: Forest management scenarios assumptions.

Management System	Regeneration	Thinning	Final felling	Road maintenance
Clearcutting/Rotational Forest (CC/RF)	Planting-Assisted &PCT	Separate operation	All trees are removed in a single operation	Reference maintenance cost
Continuous Cover Forest (CCF)	Natural (no-cost) &PCT	Simultaneous with other fellings	Groups/single trees removed (20-year frequency)	Reference maintenance cost

Source: ForestNavigator, WP 4

For afforestation scenarios, we used a G4M forest model land projection, where available land for afforestation was activated (SIMUs where afforestation could be extended under the model's biophysical and economic constraints). The projection of afforestation used the current species composition of forests in neighboring potential forest areas according to the current species mapping included in the G4M model from Brus et al. (2012). This area was used for computing afforestation potential over the entire EU27 region. The total afforestation costs were obtained by summing the cost per hectare for all operations listed in *Table 4*.

3. Results

3.1. Forest management costs

Out of the four cost components captured, harvest costs are the largest cost component per m³ of wood supplied in rotational forest (harvesting includes felling, processing and extraction of roundwood in thinning and final felling) (Figure 3). Harvesting (final felling and thinning) represents on average 59% of total costs and has the largest variability across grid cells (min 14 EUR/m³ to max 179 EUR/m³). The second largest cost component is regeneration, representing 23% of the total costs and with a more limited variability (min. 7 EUR/m³ to max 17 EUR/m³). Road maintenance accounted for an average of 13% (min. 3.8 EUR/m³- max 17 EUR/m³), and pre-commercial thinning (PCT) for 5% (min. 1 EUR/m³- max. 4 EUR/m³). As a result, the total costs varied between 26 EUR/m³ and 197 EUR/m³.

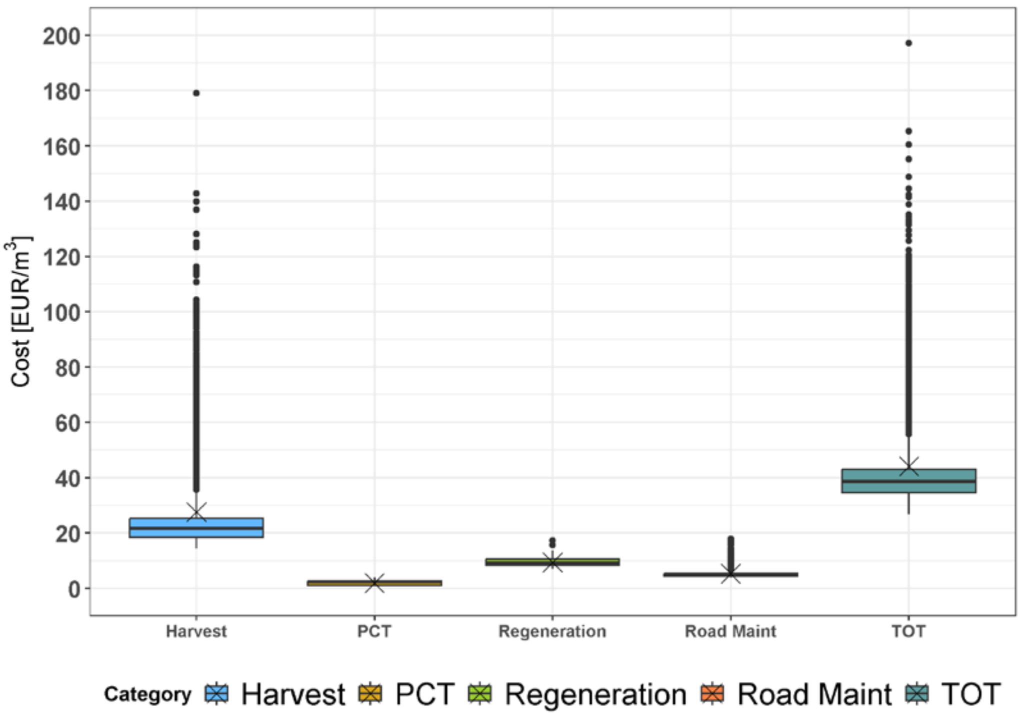


Figure 3. Management cost per m³ for CC/RF by cost component across the EU: Grid cell variability (harvest = final felling and commercial thinning). Box representing 25%(Q1 and 75% (Q3) percentiles, central line represents the median and "X" the average. Whiskers extend Q1 − 1.5×IQR and Q3 + 1.5×IQR (IQR= Q3-Q1).

Spatially explicit cost patterns show that mountain regions (e.g., Alpine region) have the highest total costs, due to the difficult topography that affects the harvest costs (exceeding 75 EUR/m³), which require a more complex and labor-intensive system, like cable-based ones (Figure 4). This finding aligns with the recent EU mapping of harvest systems in Pucher et al. (2023).

Lower harvest costs are observed in the Nordic region (Sweden and Finland), due to the high efficiency in mechanized operations on flate terrains, and in Eastern EU, where unitary costs for labor and equipment are relatively low. In these regions, harvest costs were below 25 EUR/m³ in a large share of SIMUs. Other costs (apart from harvesting) are mostly represented by forest regeneration. These costs are higher in regions dominated by broadleaf species in Central EU (based on a comparison of Figure 4 and Figure 5).

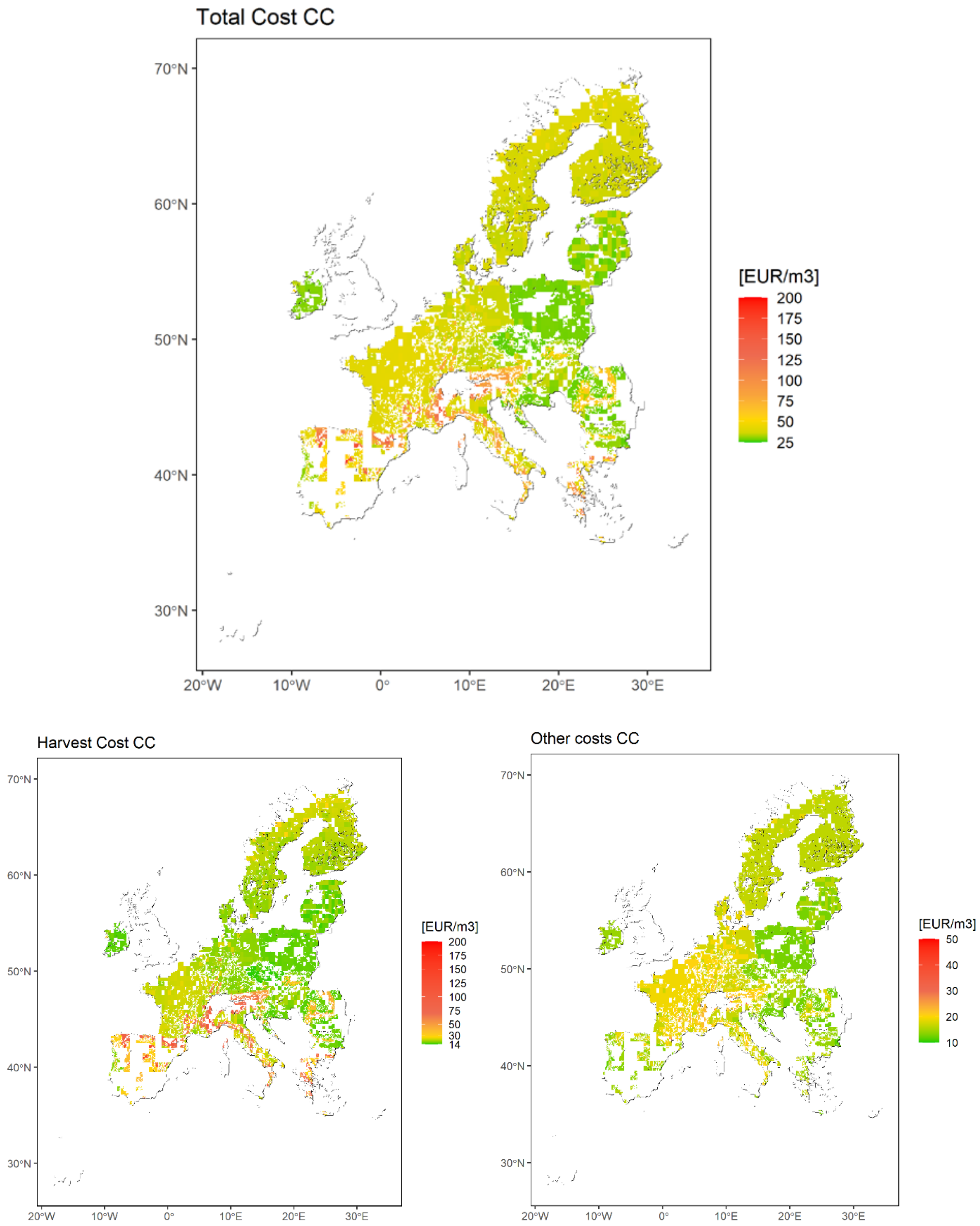


Figure 4. Spatial distribution of costs per m³ in RF/CC in the EU, total management cost (on the top), harvest (bottom-left) and other costs (bottom-right)

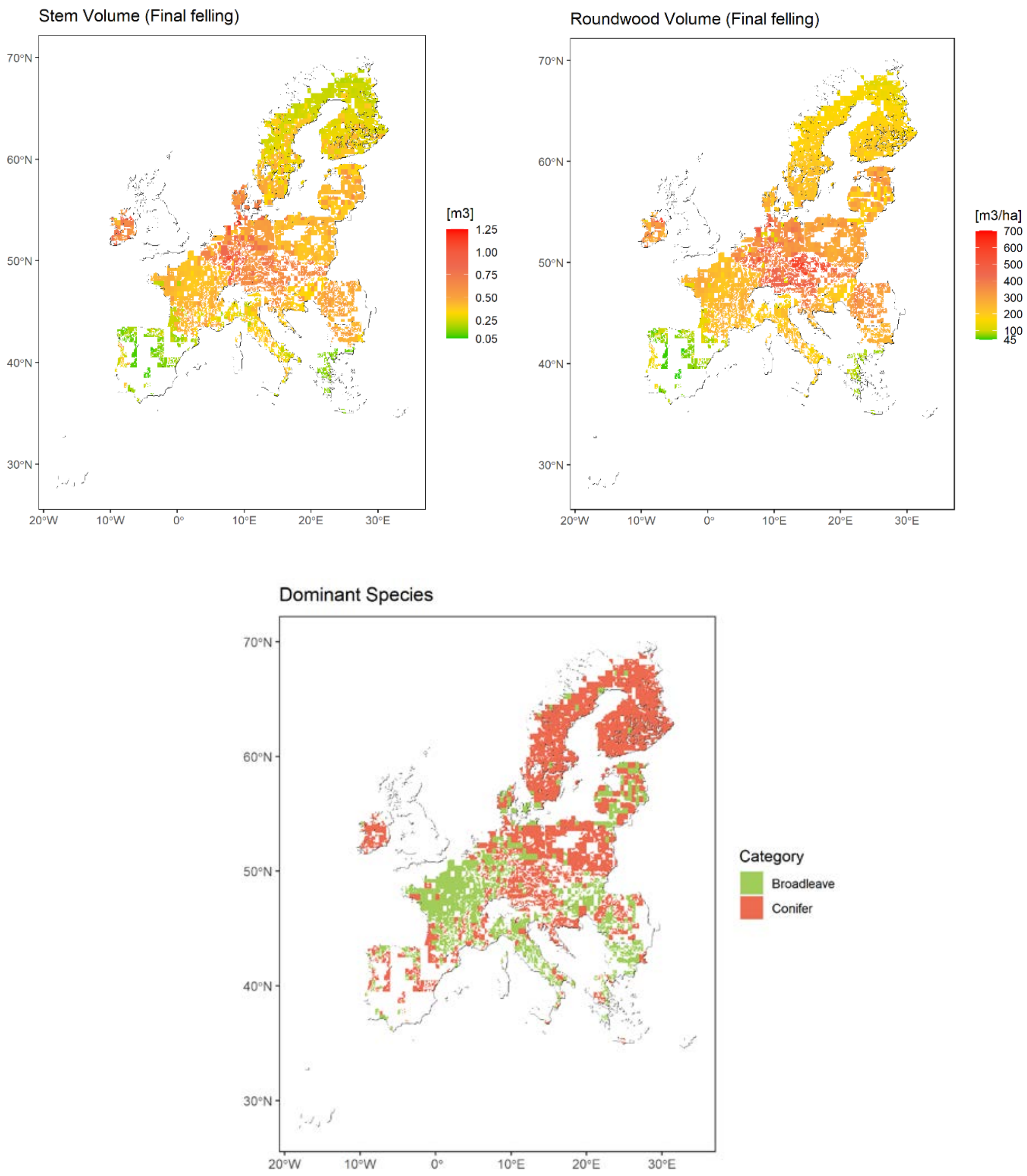


Figure 5. Main forest structure variables used in the forest costing model, average removal stem volume in clear felling (top-left), removal per hectare in clearfelling (top-right), dominant tree species group (bottom)

The overall management cost ranged between 26 EUR/ha/year and 712 EUR/ha/year. In most regions of the EU, cost per hectare ranged between 100-300 EUR/ha/year, the highest costs are observed in mountain regions, similarly to the cost per m^3 (in these regions costs could exceed 400 EUR/ha/year) (Figure 6). The cost per hectare per year is a function of rotation length. Accordingly, in the Nordic region the costs are relatively lower (same overall costs spread over a longer rotation period) when compared to Germany (relatively shorter rotations due to the higher growth).

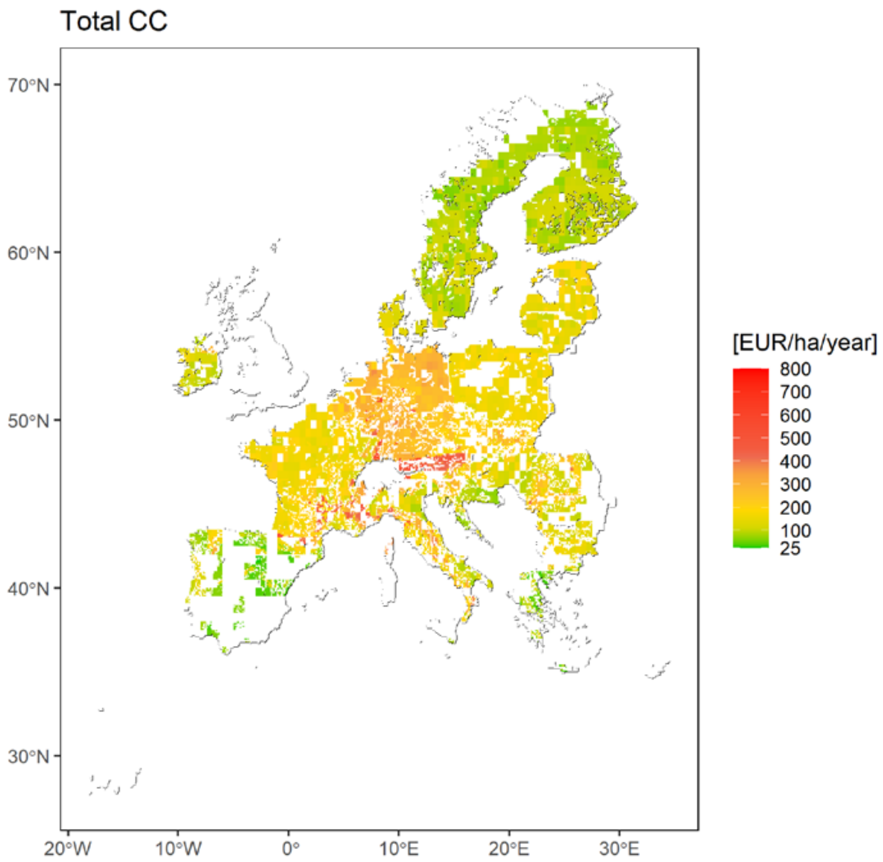


Figure 6. Spatial distribution of total management costs for RF/CC per hectare per year.

In CCF, the total management costs varied between 27 and 245 EUR/m^3, showing an overall slight increase at the EU level compared to the CC system (+2%). A major increase is observed for harvesting costs, representing 83% of total costs and varying between 22 and 235 EUR/m^3, hence, showing an average increase of 44% compared to CC (Figure 7). The costs for PCT and road maintenance remained the same as CC, while the cost for regeneration is not present in CCF, due to assumptions of natural regeneration in this system. The absence of regeneration costs compensates for the strong increase in harvesting costs, leading overall to similar total cost levels in CCF and CC.

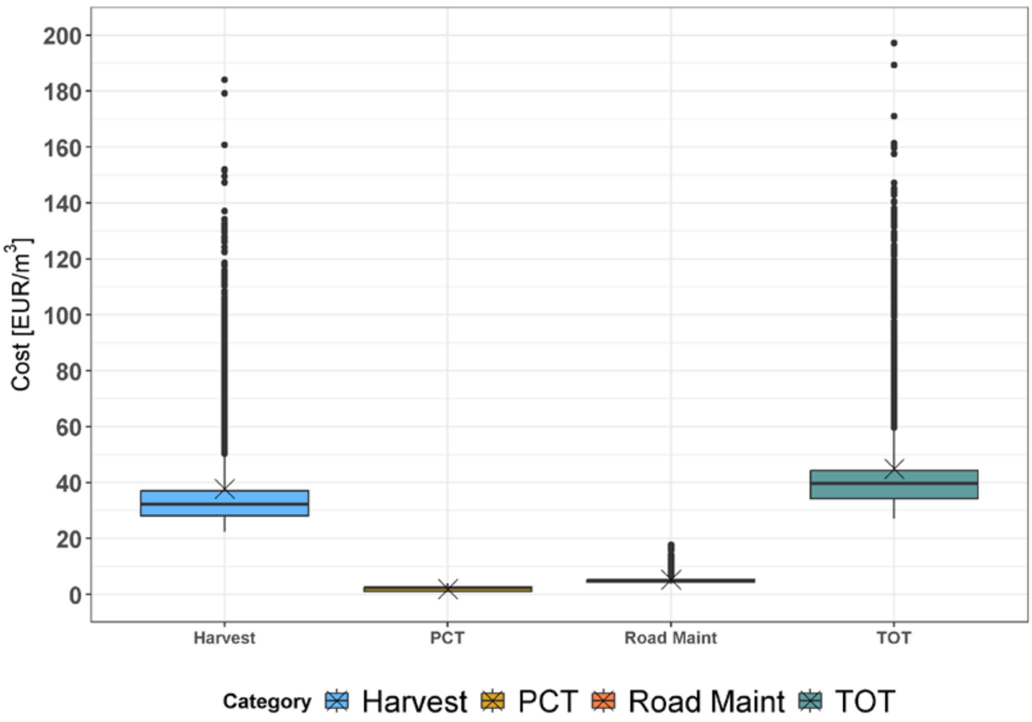


Figure 7. Management cost per m^3 breakdown for CCF by cost component across the EU: grid cell variability. Box representing 25%(Q1) and 75% (Q3) percentiles, central line represents the median and "X" the average. Whiskers extend Q1 − 1.5×IQR and Q3 + 1.5×IQR (IQR= Q3-Q1).

A comparison of the total cost for CCF to CC at the SIMU level shows that in 60% of the simulation grid cells, there is an increase in costs, whereas in 40% of SIMUs, we observe a cost decrease (Figure 8). The cost increase is modest; in 2% of SIMUs, the cost increase exceeds 20% and in 12% it exceeds 10%.

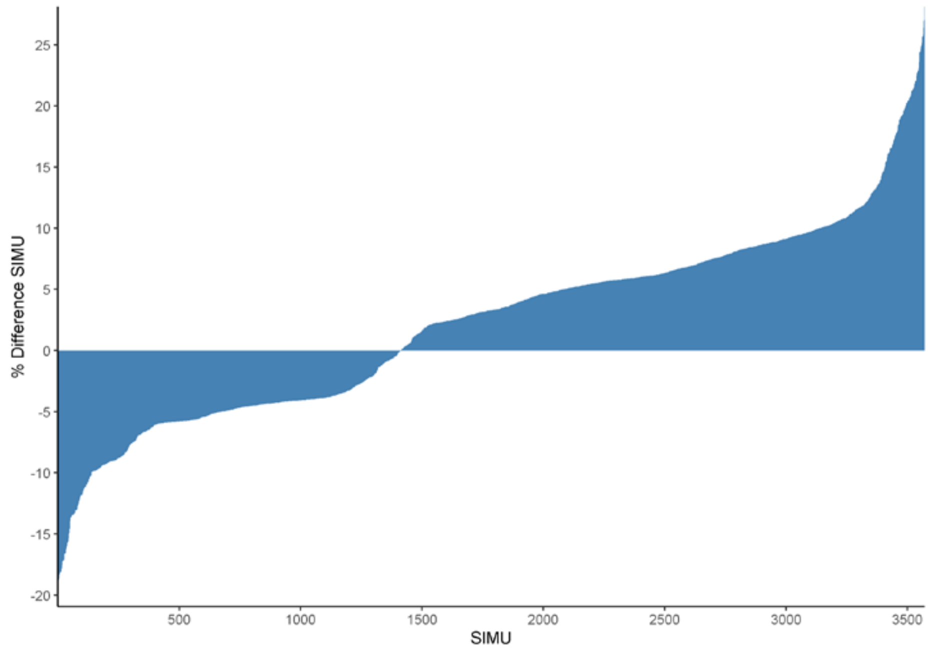


Figure 8. Percentage change in CCF cost compared to CC/RF in each simulation grid cell (the x-axis represents the progressive number of grid cells simulated)

Generally, we observe that management costs increase in regions where wood removal volumes per forest operation are relatively low and characterized by trees of relatively small sizes (e.g. Scandinavia). This is an effect of harvesting costs that increase exponentially when reducing removal per hectare (affecting wood extraction) and stem size (affecting felling and processing operations) at parity of other conditions (see Figure 5 and Figure 9).

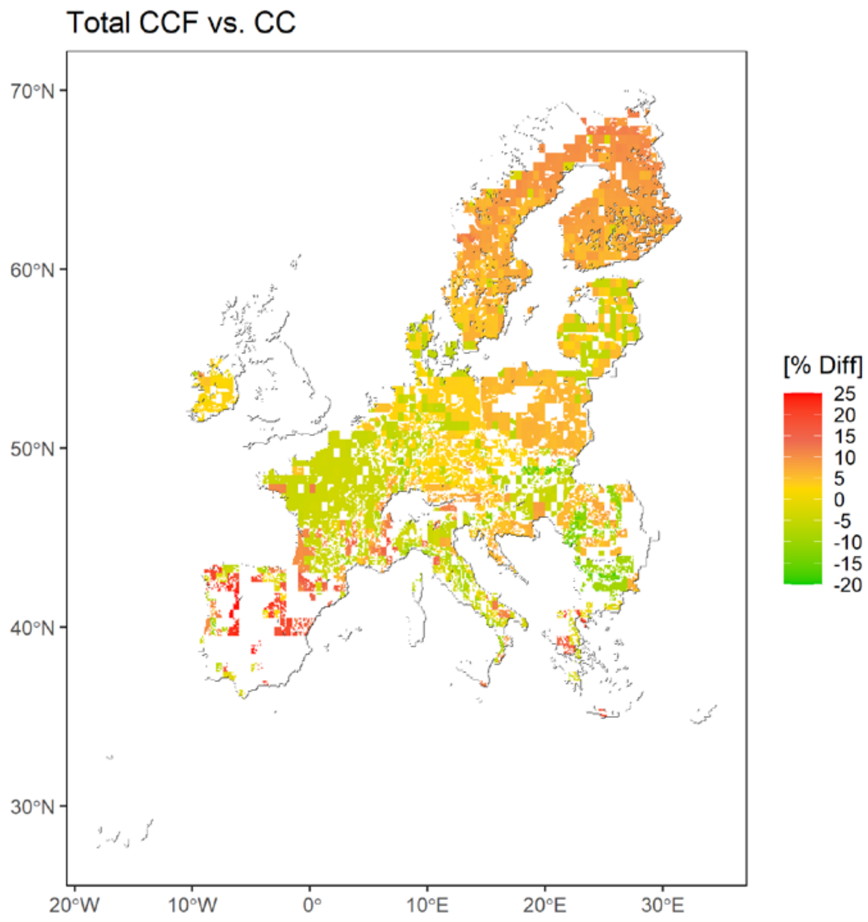


Figure 9. Spatial explicit cost difference between CCF and CC/RF at the simulation grid cell level in the EU (based on cost per m^3)

3.2. Afforestation costs

The total afforestation costs varied between 3,100 EUR/ha and 10,500 EUR/ha (Figure 10). The largest cost component was represented by the tree planting costs (including planting materials and operations) that accounted on average for 46% of the total costs (min. 1,790 EUR/ha, max. 4,820 EUR/ha). Costs for establishment, including plant protection and irrigation, account for 22% of the total afforestation costs (min. 1,000 EUR/ha and max. 2,100 EUR/ha). PCT costs represent 9% of the total (min. 219 EUR/ha to max. 1260 EUR/ha). Similarly, land preparation costs represent, on average, 9% of total costs (min. 329 EUR/ha and max. 1,256 EUR/ha). Finally, overhead costs represent 13% of the total costs (min. 520 EUR/ha to max. 1,378 EUR/ha).

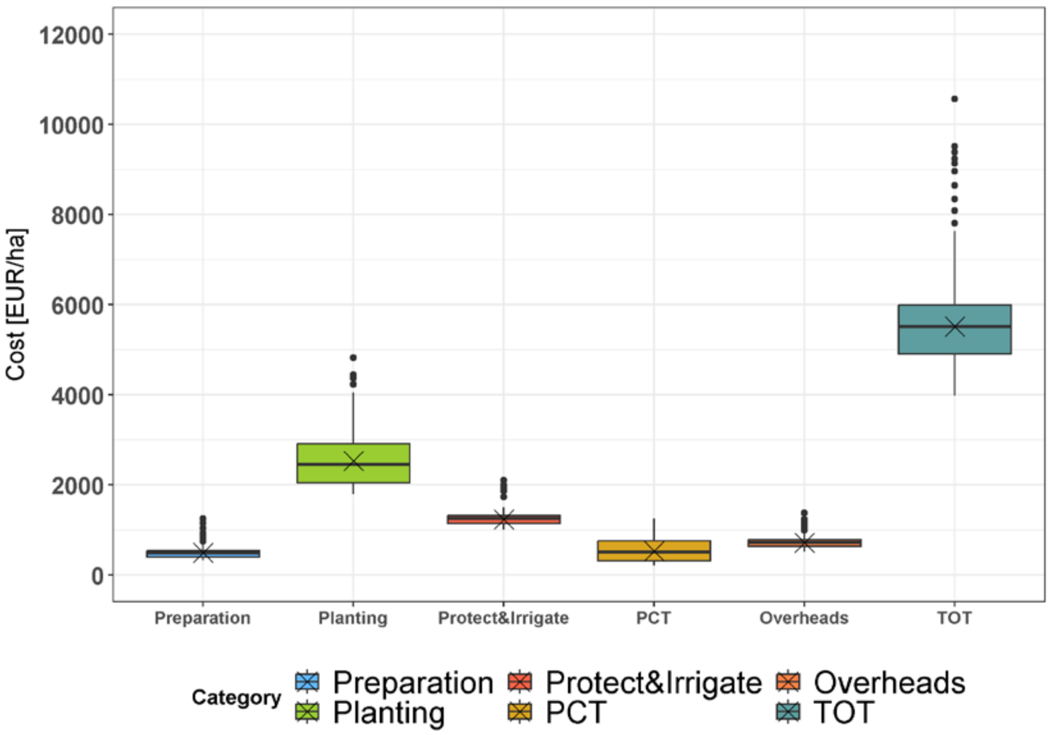


Figure 10. Afforestation cost per hectare by main cost components across the EU: grid cell variability. Box representing 25%(Q1) and 75% (Q3) percentiles, central line represents the median and "X" the average. Whiskers extend Q1 − 1.5×IQR and Q3 + 1.5×IQR (IQR= Q3-Q1).

Afforestation costs under 3,500 EUR/ha can be observed in Eastern EU, in the Baltic states, on flat terrains, and where conifers are planted. The highest costs are incurred in Central EU and where broadleaves are planted (e.g. in France). Scandinavia experiences relatively lower costs than Central EU, because conifers are mostly regenerated on flat terrains at parity of cost drivers (fuel, labor) (Figure 11).

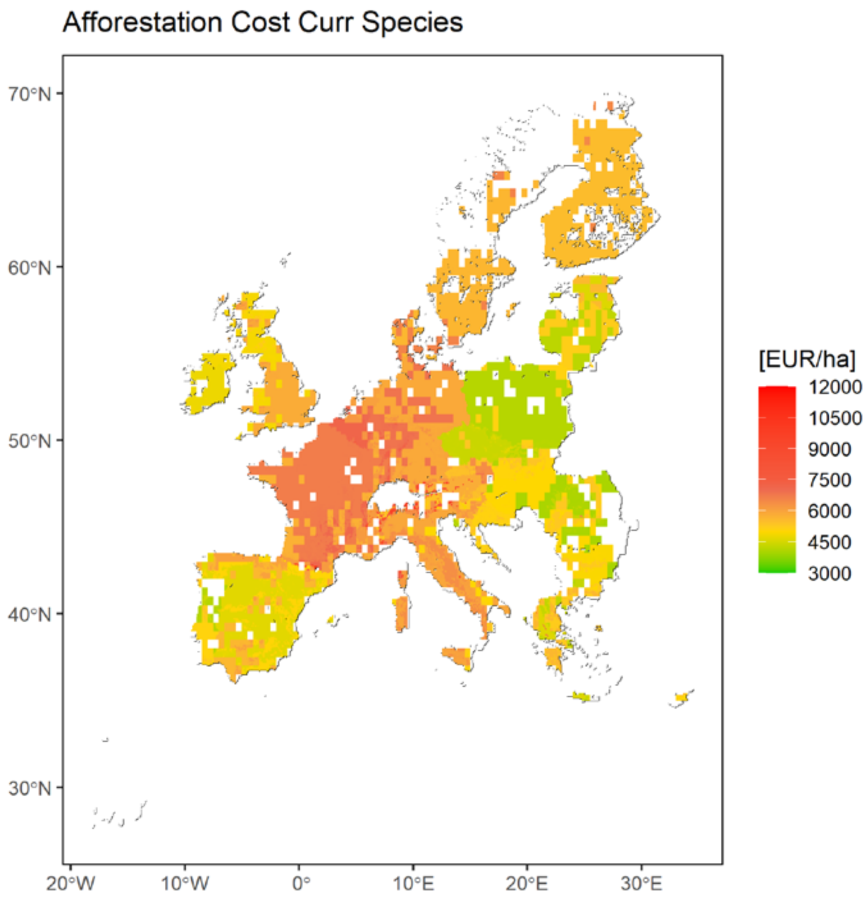
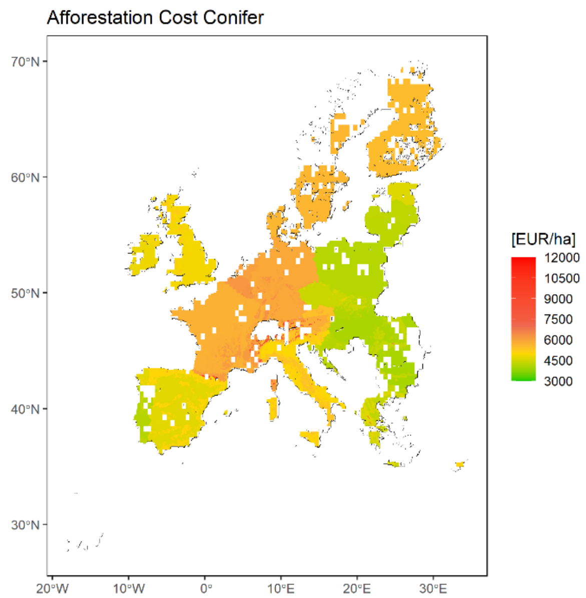


Figure 11. Afforestation cost per hectare by current tree species distribution and suitability area from the G4M model

The afforestation costs were also computed by comparing two species conditions, one generating conifers in all EU grid cells and the second regenerating only broadleaves (Figure 12), as an illustration of potential areas. Afforesting with broadleaves increased costs on average by 19%, relative to conifers, as a result of the higher cost for broadleaf seedlings.



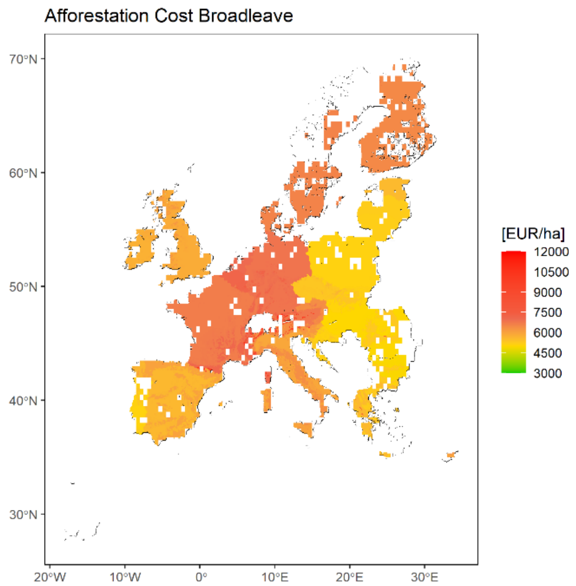


Figure 12. Spatial explicit comparison of afforestation costs for conifers (left) and broadleaves (right).

3.3. Employment in Forestry

Building on previous modelling runs, we have also computed employment figures as output: employment in forest management (for already established forests) from the forest management module, and employment in afforestation (for new forests) from the afforestation module.

The main labor demand component in forestry is represented by harvesting operations, which represent between 47% and 96% of total labor demand per m^3 of harvested wood. Labor is captured through wood harvesting, regenerating activities, and road maintenance. Wood harvesting requires between 0.12 and 4.15 hours/m^3. This very large range is an effect of the adaptation to terrain and forest characteristics of harvesting systems and work efficiency. Regeneration requires between 0.05 and 0.08 hours/m^3, PCT requires 0.05 hours/m^3, and road maintenance requires between 0.02 and 0.13 hours/m^3. The corresponding total labor demand ranges between 0.25 to 4.32 hours/m^3 (Figure 13).

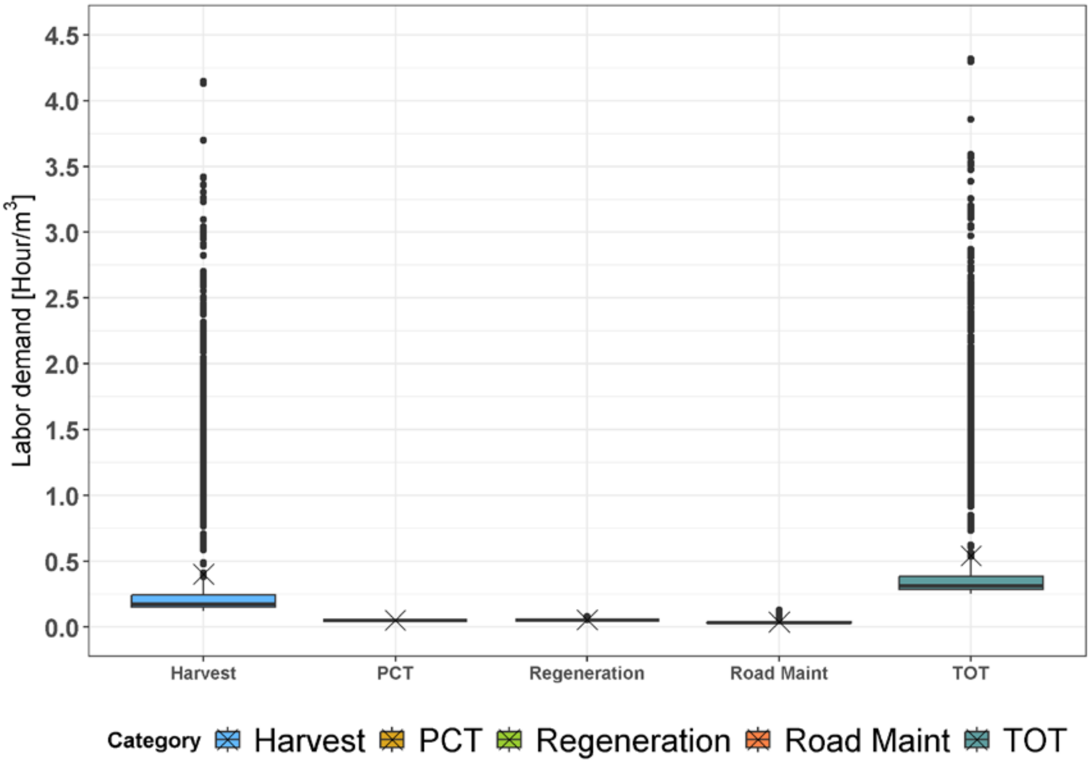


Figure 13. Labor demand in forest management per m^3 of wood harvested (CC/RF management system) according to the main cost components when considering the variability in all grid cells simulated in the EU. Box representing 25%(Q1) and 75% (Q3) percentiles, central line represents the median and "X" the average. Whiskers extend Q1 − 1.5×IQR and Q3 + 1.5×IQR (IQR= Q3-Q1).

In case of CCF, total labor demand varies between 0.27 and 5.05 hours/m^3, showing generally an increase compared to CC (Figure 14 and Figure 15). This effect is driven by the increased time demanded by harvesting operations. The absence of a regeneration labor demand for CCF is unable to compensate for the increase in wood harvesting labor demand (differently from what has been observed for costs), if compared to CC. The labor demand increase is observed in most grid cells (87%), and the increase is generally in the range of 20% increase compared to CC (Figure 15).

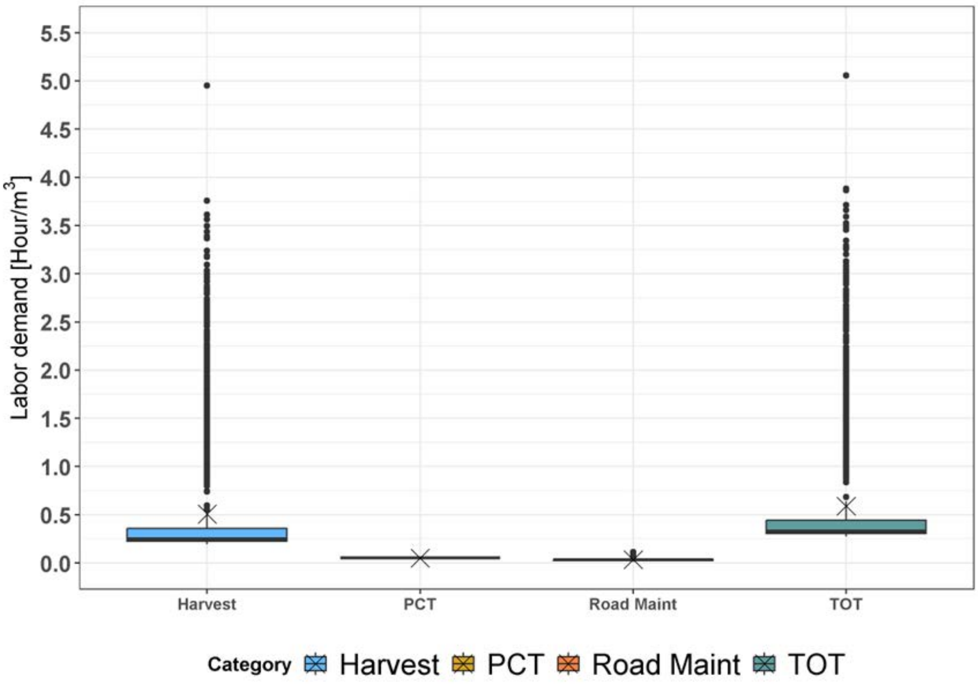


Figure 14. Labor demand in forest management per m³ of wood harvested (CCF management system) according to the main cost components when considering the variability in all grid cells simulated in the EU. Box representing 25%(Q1) and 75% (Q3) percentiles, central line represents the median and "X" the average. Whiskers extend Q1 − 1.5×IQR and Q3 + 1.5×IQR (IQR= Q3-Q1).

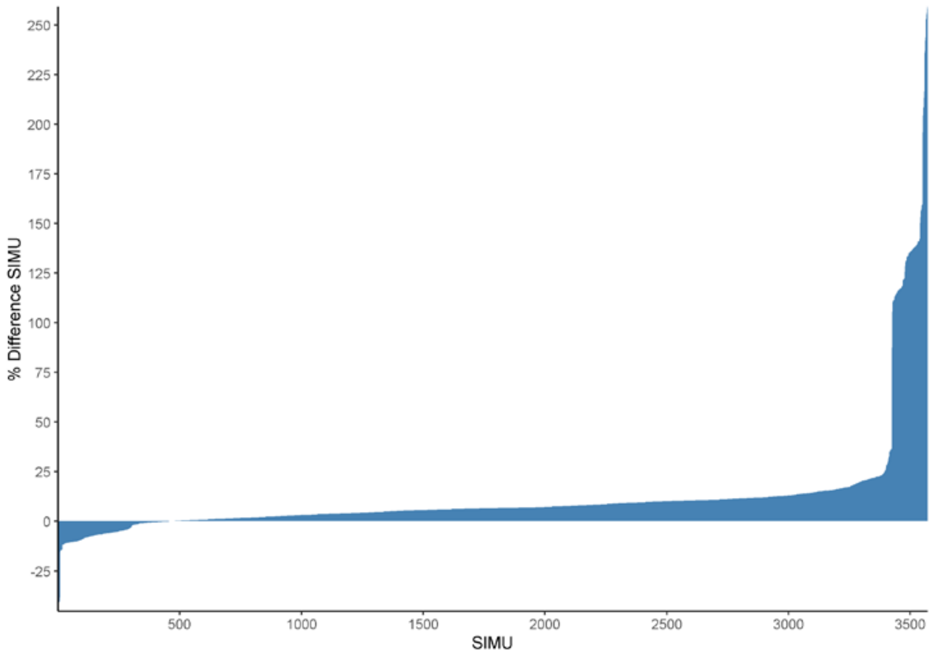


Figure 15. Percentage change of labor demand in CCF compared to CC/RF in each simulation grid cell/SIMU (the x-axis represents the progressive number of grid cell simulated).

In terms of FTE, employment varied between 0.14 and 2.75 FTE x 1000 m^{-3} at the EU scale. The spatial differentiation for labor demand in forestry is associated with the level of mechanization that can be applied in each SIMU and the working efficiency of each single operation. These aspects are mostly influenced by terrain and forest characteristics. Generally, we observe a lower input of labor per hectare in forest areas where the operations are fully mechanized (flat terrains) and an increase of labor demand in regions that are more difficult to mechanize (mountainous regions) (Figure 16).

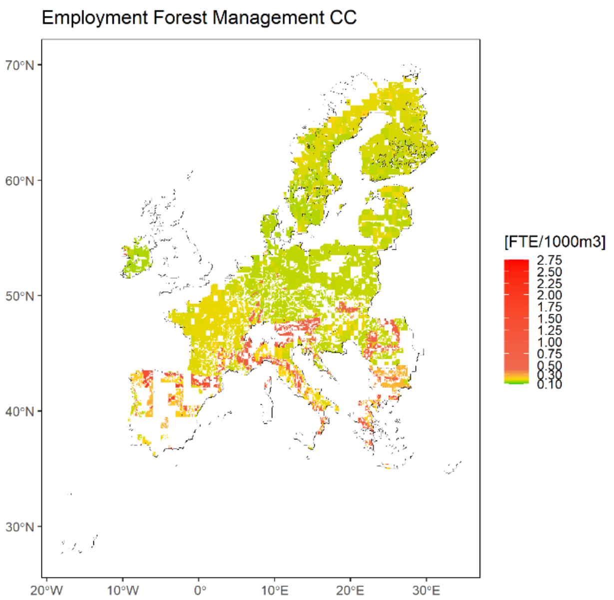


Figure 16. Employment in Forest management (Full Time Equivalent employees x 1000 $^{-}$m^{3} of wood harvested) when considering CC/RF (on the left) and comparing the difference between CCF and CC/RF (on the right).

Afforestation employment per hectare for establishing new forests varies between 35 and 55 FTE x 1000 ha^{-1}. As for forest management, the spatial variation in FTE is mostly influenced by terrain characteristics: mountain areas increase the labor demand (Figure 17).

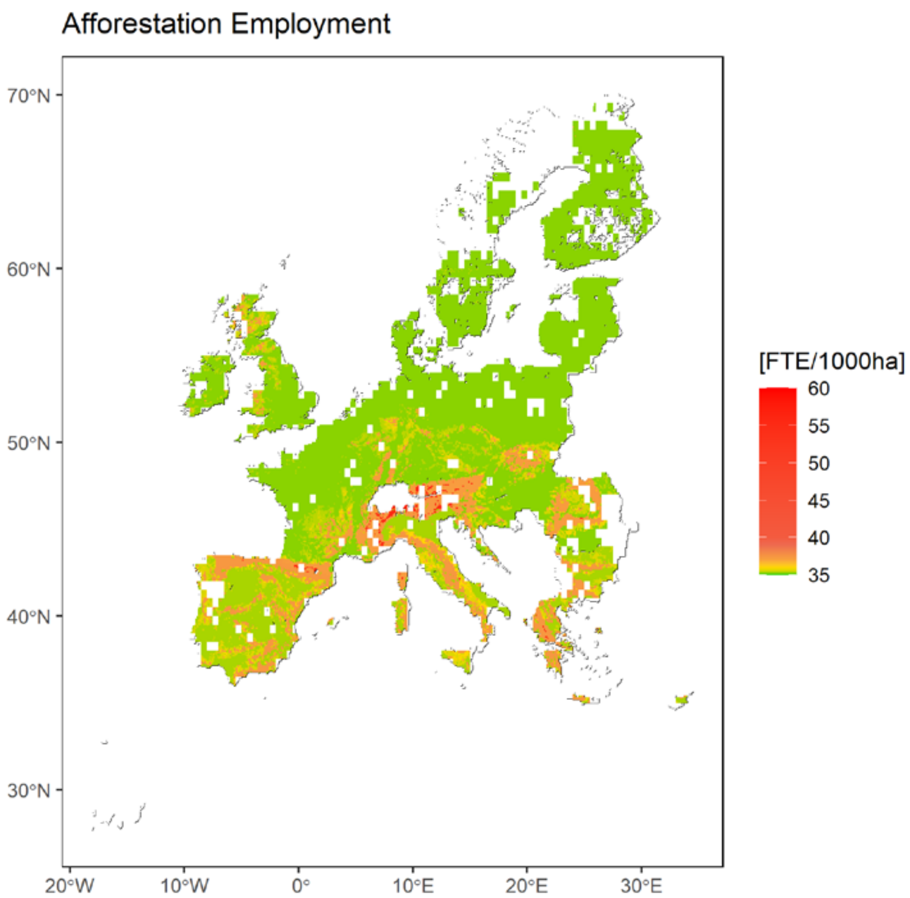


Figure 17. Spatial explicit afforestation employment (Full Time Equivalents x 1000 ha^{-1}).

3.4. Validation

As a validation of our modelling, we compared the output of the costing module with published costing information. Specifically, we compared country-level harvesting costs obtained from recent literature to our model output.

The range of forest harvesting costs output aligns with the costs reported in recent literature for the ten countries (*Table 7*). In Finland and Sweden, it appears that costs for final felling could be slightly overestimated by the model, while in Eastern EU, in some instances, the output of the model could underestimate costs compared to the literature. An overestimate is also possible in the case of cable yarding operations.

The maximum observed in the cost model range is usually larger than the one observed in the literature. In this respect, we should consider that the cost model simulated harvest over the "potential" forest area under management, while the literature costs are usually based on "real" operations that are taking place in forests where there is economic convenience to operate.

Table 7: Comparison of forest harvesting costs from the cost model to reference cost ranges for selected EU countries.

Country	Type of cost	Reference cost range (EUR/m³)	Cost model output range EUR/m³)
Austria[a]	Country average	28	13-97
Bulgaria[b]	Expert average for the country	18	12-56
Czech R.[b]	Expert average for the country	30	11-37
Germany[c]	Harvester & forwarder operations in the region	15-27	14-40
Germany[c]	Skidder-based operations in the region	25-30	32-81
Finland[d]	Final felling operations in the country	11-14	15-22
Italy[e]	Harvester & Forwarder operations in the country	15-33	14-53
Italy[e]	Chainsaw & Skidder operations in the country	21-69	39-85
Italy[e]	Chainsaw & Cable yarder operations in the country	38-78	66-122
Latvia[b]	Expert average for the country	20	12-32
Poland[b]	Expert average for the country	15	12-46
Sweden[f]	Final felling operations in the country	11-13	15-23
Slovakia[b]	Expert average for the country	25	11-54
Slovenia[g]	Mechanized felling operations in the country	18-42	13-68
Slovenia[g]	Motormanual felling operations in the country	26-48	16-85

Sources: [a]Forstbericht 2022. Bericht über die Ertragslage der österreichischen Forstbetriebe> 500 Hektar Land&Forst and BOKU; [b]Moskalik, T., Borz, S. A., Dvořák, J., Ferencík, M., Glushkov, S., Muiste, P., Lazdiņš, A., & Styranivsky, O. (2017). *Timber harvesting methods in Eastern European countries: A review* [Review of timber harvesting methods]. *Croatian Journal of Forest Engineering, 38*(2), 231–241 [c]Thuringen Forst Durchschnittliche Preise für die Grobkalkulation https://www.waldbesitzerportal.de/fileadmin/user_upload/Bilder/Preise-Handout.pdf [d] Statistical Database Luke 2021 https://statdb.luke.fi/PxWeb/pxweb/en/LUKE/ [e]Sperandio, G., Ortenzi, L., Spinelli, R., Magagnotti, N., Figorilli, S., Acampora, A., & Costa, C. (2023). A multi-step modelling approach to evaluate the fuel consumption, emissions, and costs in forest operations. *European Journal of Forest Research*. [f]Skogsstyrelsen 2023 https://pxweb.skogsstyrelsen.se [g]Triplat, M., & Krajnc, N. (2020). Assessment of costs in harvesting systems using WoodChainManager web-based tool. Croatian Journal of Forest Engineering, 41(1), 48–57. https://doi.org/10.5552/crojfe.2020.583

This comparison helps us to understand the need for further model improvements. One potential improvement could be to further adapt the annual utilization of forest machinery by region. Another aspect that requires information for improvement is to take into accounting the scale of operations.

The updated estimates for afforestation costs were compared to the previous estimates from the same model presented in EC (2021b). The comparison shows that costs are significantly higher in the new model version (29% to 117% higher). The main reason for this difference is the inclusion of species differentiation in the new version, as well as additional expenses for tree protection during the plantation establishment (not included in the previous version).

Table 8: Comparison of the afforestation costs as model output to the 2021 version (in 2024 prices)

Country	A) Average Costs Max 2021 version updated[a]	B) Average model output	Diff. % Column (B-A/A)	Min. Model output	Max. Model output
Austria	4,568	5,932	30%	5,431	8,651
Belgium	3,607	6,977	93%	6,216	7,635
Bulgaria	2,252	4,897	117%	3,986	5,296
Croatia	2,707	5,125	89%	4,140	5,406
Cyprus	3,577	5,114	43%	5,059	5,480
CzechRep	2,646	4,460	69%	4,369	5,429
Denmark	3,393	6,158	81%	5,622	6,572
Estonia	2,550	5,036	97%	4,606	5,557
Finland	3,614	5,539	53%	5,519	6,470
France	4,468	6,544	46%	5,732	10,566
Germany	4,205	6,211	48%	5,892	9,385
Greece	3,625	5,104	41%	4,263	8,343
Hungary	2,453	4,879	99%	4,032	5,306
Ireland	3,191	4,791	50%	4,783	5,117
Italy	4,171	6,074	46%	4,977	9,513
Latvia	2,544	4,809	89%	4,260	5,211
Lithuania	2,416	4,601	90%	4,223	5,173
Luxembourg	3,625	6,623	83%	6,217	7,632
Netherlands	3,372	6,383	89%	6,059	7,010
Poland	2,389	4,257	78%	4,155	5,432
Portugal	2,720	4,784	76%	4,130	5,450
Romania	2,678	4,541	70%	4,026	6,440
Slovakia	2,655	4,944	86%	4,111	5,376
Slovenia	3,571	5,852	64%	4,906	9,236
Spain	3,628	5,033	39%	4,650	8,959
Sweden	4,568	5,690	43%	5,630	6,615

[a]According to EC 2021b and updated for inflation (CPI) between 2020 and 2024

For employment, we have compared the FTE/m^3 in two countries with reliable country-level statistics for employment “forestry and logging NACE2”, i.e., Finland (LUKE Database, year 2023) and Sweden (Skogstyrelsen Database, year 2023), after dividing total employment by 2023 FAOSTAT roundwood production data. In these two countries, the employment/m^3 varied between 0.17 and 0.34 FTE x 1000 m^{-3} roundwood, which is comparable to our results (Figure 16) and to EUROSTAT (year 2023). Using EUROSTAT data, we observe that in East and South-EU there is relatively large employment relative to the wood production amount (Annex I, Table 8), and the FTE x m^3 increases by a factor of 10 compared to Finland/Sweden. This employment increase is not observed in our model output (Figure 16). Therefore, the employment share in forestry and logging covered in our costing model varies according to country border and additional activities not related to wood production become relevant in some EU regions, but are not captured well in the costing model (such as forest monitoring, fire suppression, water management).

4. Discussions and next steps

The updated cost model sheds light on how alternative management and afforestation options may change management costs. This study discloses opportunities for employment in forestry and afforestation activities. These advancements will be deployed fully in the upcoming policy pathways in ForestNavigator.

Compared to Di Fulvio et al. (2016), we disclose that cost competitiveness for forest management is not fully aligned with the total supply cost per m^3, where wood transportation is taken into account. The total supply cost considered in Di Fulvio et al. (2016) pointed out the competitiveness of Center-West EU (e.g. Germany), where wood transport costs are relatively lower than in other regions (East EU) due to a denser road infrastructure development. When considering the forest management costs alone and ignoring wood transportation, we can observe that costs are more driven by forest structural attributes, terrain topography and economic conditions, hence other regions emerge as cost-competitive (e.g. East EU). Therefore, the costs presented in this report are informative for management but need to be coupled with the ones related to forest logistics for fully assessing the supply cost to the industry gate.

The change of management from rotational forestry (RF/CC) to CCF has shown that, from a cost competitiveness perspective, impacts are very much dependent on the assumptions regarding the efficiencies in forest harvesting operations and forest regeneration. In most cases, under our assumptions, we have observed an increase in management costs for CCF. However, the reduction in work efficiencies for a single grip harvester in CCF cuttings could be less pronounced than the ones assumed in our cost model. As an example, these could be in the order of 10%, depending on the type of selective cutting (group/patch cuttings, single tree harvesting), according to recent large data collection in Sweden (Häggström, 2024). In the opposite direction, even if we have assumed natural regeneration for CCF, there may be some residual costs for assisted regeneration also under CCF that we did not include in our modelling. Currently, we do not assume an increase/decrease in road maintenance costs when applying different management systems. Under CCF, there is a need to enlarge the supply area to achieve the same volumes of procurement as rotational forest, due to the lower wood removal per hectare. At the same time, the traffic on each forest road per operation could diminish, and these contrasting effects could compensate for each other. At the same time, CCF could entail more complex planning for forest operations which could increase overhead costs.

From an employment perspective, CCF could potentially offer more job opportunities. However, this could potentially come at higher wood provisioning costs. This trade-off needs to be further analyzed together with other ecosystem services that could be potentially generated. Mechanization of forest operations could lower the use of manual work and reduce generally the traditional employment in forest operations in the future; on the other hand it may generate new form of employment for planning and execution of more automatized operations. In general, we can expect that the future costs will be more dependent from the price of energy (fuels and electricity) and costs for new technologies (capital investments) compared to the current situation where many operations are still based on intense use of labor. The current structure of the costing model maintains a separate accounting for capital investments, fuels and labor costs which could enable to explore sensitivity of management/supply costs to changes of these drivers.

We had a simplified consideration of overheads, these would vary depending on the size of business/scale of operations and this aspect would need further analyses. At the same time, further validation of the costing and employment modules is needed for better ascertaining the alignment of the model to national statistics.

5. Conclusions

The updated forestry costing model, which includes forestry and afforestation and a broader range of activities, enabled us to analyze the competitiveness of alternative managements at the EU scale and assess the general level of costs and employment in forestry. This type of information can be fundamental for decision makers needing to evaluate trade-offs across multiple forest services. The combination of the modelled forest management costs together with complementary supply-chain costs (i.e. wood transportation) can also inform forest industries of the economic convenience in wood mobilization. Additionally, the modelling of employment can complement other socioeconomic indicators of welfare associated with ForestNavigator pathways for a more holistic evaluation of the forest sector contribution to the EU forest-based bioeconomy, where comparing bottom-up approaches like the one from this cost model with top-down ones from macroeconomic models.

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Annex I

Table 9: Input, process, and output for each sub-module of the costing model

Operation	Manual/Motor manual operation	Mechanized operation
Cleaning of vegetation		Farm tractor + Mulcher
Soil preparation		Farm tractor + Plougher
Forest planting	Operator + Planting device	Excavator-based
Forest PCT	Operator+ Cleaning saw	
Tree felling & processing	Operator + Chainsaw	Single-grip harvester
Wood extraction		Forwarder Skidder Cable yarder Farm tractor with trailer
Road maintenance		Excavator-based

Table 21. Machinery and operators reference cost factors sourced in Austria

Machine	Purchase price [EUR]	Other Fixed costs [EUR/h]	Fuel consumption [l/hour]	Fuel Price [EUR/l]	Lubricant Cost {% Fuel Cost]	Maintenance [% Purchase]	Operator net wage [EUR/hour]
Chainsaw	2,000	1.3	1.3	1.295	20	120	23.00
Cleaningsaw	1,500	1.0	1.0	1.295	20	120	23.00
Skidder	250,000	8.3	10.5	1.295	10	80	28.00
Yarder	350,000	10.0	8.0	1.295	15	100	51.00*
FarmTractor	200,000	5.8	10.0	1.295	10	100	23.00
Harvester	480,000	23.5	15.5	1.295	27	100	28.00
Forwarder	380,000	23.5	12.4	1.295	10	80	28.00
Excavator	320,000	10.8	10.0	1.295	12	100	28.00

Source: Austria, BFW *Team of two operators (one specialized)

Table 3. Machinery reference cost factors sourced in Germany

Machine	Purchase price [EUR]	Fuel consumption [l/hour]	Fuel Price [EUR/l]	Lubricant Cost {% Fuel Cost]	Maintenance [% Purchase]
Large farm tractor	208000	9.7	1.465	10	100
Mulcher	18800	0.0	0.0	0.0	65
Plough	22000	0.0	0.0	0.0	110
Trailer	15000	0.0	0.0	0.0	30

Water pump	24000	0.0	0.0	0.0	200

Source: KTBL

Table 4. Econometric indicators applied for cross-border adaptation of unitary costs according to EU27 countries

	Base wage [EUR/Hour]	Wage Inflator for social charges	Diesel price [EUR/liter]	Interest Rate	Water price [EUR/m³]
Austria	17.88	1.490	1.295	2.8	0.08
Belgium	23.33	1.572	1.377	2.9	0.11
Bulgaria	4.46	1.316	1.07	3.9	0.04
Croatia	6.75	1.481	1.178	3.3	0.04
Cyprus	16.72	1.156	1.235	3.1	0.03
CzechRep	9.31	1.380	1.164	4.0	0.07
Denmark	24.31	1.201	1.295	2.3	0.16
Estonia	12.37	1.284	1.258	3.5	0.07
Finland	19.49	1.417	1.403	2.9	0.1
France	20.56	1.477	1.395	3.0	0.1
Germany	22.25	1.465	1.366	2.3	0.06
Greece	7.05	1.305	1.262	3.4	0.03
Hungary	5.79	1.386	1.163	6.5	0.06
Ireland	15.2	1.202	1.296	2.7	0.07
Italy	12.82	1.401	1.368	3.7	0.03
Latvia	8.47	1.351	1.259	3.3	0.03
Lithuania	8.19	1.361	1.17	2.9	0.03
Luxembourg	25.62	1.439	1.252	2.8	0.12
Malta	14.39	1.190	0.992	3.4	0.07
Netherlands	23.54	1.475	1.36	2.6	0.05
Poland	7.62	1.291	1.136	5.5	0.05
Portugal	6.24	1.217	1.222	3.0	0.05
Romania	6.09	1.307	1.181	6.3	0.03
Slovakia	7.06	1.358	1.176	3.5	0.05
Slovenia	14.34	1.389	1.198	3.1	0.05
Spain	10.75	1.315	1.196	3.2	0.05
Sweden	19.29	1.517	1.343	2.2	0.07

Source: AUSTROFOMA (2023), ILOSTAT, The World Bank, EC Energy Policy, EUROSTAT, Giannakis et al. (2016), IBNET-ALICE (2018).

Table 5. Machinery/operational technical factors standardized across countries

Machine	Salvage Value [% Purchase]	Economic life [Year]	Annual use [hr]	Techical utilization	Labor inflator	Number of operators
Harvester	20	5.950	2000	79	1.3	1
Chainsaw	10	1.100	1500	50	1.1	1
Cleaningsaw	10	1.100	1500	50	1.1	1
Forwarder	20	5.600	2000	84	1.3	1
Skidder	20	6.000	1500	70	1.2	1
Yarder	20	8.100	1500	66	2.5	2
Chipper	20	5.000	2000	75	1.2	1
Processor	20	5.400	1500	67	1.2	1
FarmTractor	15	5.000	1500	79	1.2	1
Excavator	20	5.400	1500	67	1.2	1

Table 6. Specialized forest machinery (harvester, forwarder, skidder, cable yarder) annual use and economic life adaptation to country borders. For other machinery, Table 2 values were applied.

Country	Annual use [Hour]	Economic life [Year]
Austria	2000	7.00
Belgium	2000	7.00
Bulgaria	1800	7.80
Croatia	1800	7.80
Cyprus	1800	7.80
CzechRep	2000	7.00
Denmark	2500	5.60
Estonia	2500	5.60
Finland	2500	5.60
France	2000	7.00
Germany	2000	7.00
Greece	1800	7.80
Hungary	2000	7.00
Ireland	2000	7.00
Italy	1800	7.80
Latvia	2500	5.60
Lithuania	2500	5.60
Luxembourg	2000	7.00
Malta	1800	7.80
Netherlands	2000	7.00
Poland	2000	7.00
Portugal	1800	7.80
Romania	1800	7.80
Slovakia	2000	6.00
Slovenia	1800	7.80
Spain	1800	7.80
Sweden	2500	5.60
UK	2000	6.00

Table 7. Unitary prices in regeneration/afforestation materials (not adapted to borders)

Item [EUR/unit]	Price	Source
Seedling conifers	1.1	BFZ Catalogue, 2024
Seedling broadleaves	1.6	BFZ Catalogue, 2024
Shelter tube	0.6	Regione Veneto 2022

Table 8. Statistics of employment (EUROSTAT) and wood production (FAOSTAT) for the year 2023

Country	Employment [1,000 FTE]	Roundwood production [m3]	Employment per unit of wood production [FTE x 1,000 m^3]
Austria	14.5	18,049,085	0.80
Belgium	NA	5,212,140	NA
Bulgaria	24.6	4,861,185	5.06
Croatia	11.7	5,200,000	2.25
Cyprus	1.3	8,117	160.16
Czechia	31.3	18,493,000	1.69
Denmark	3.8	3,842,100	0.99
Estonia	5.8	10,446,666	0.56
Finland	21.1	63,430,367	0.33
France	33.5	49,770,000	0.67
Germany	46.6	73,104,568	0.64
Greece	7.8	1,359,105	5.74
Hungary	18.6	4,972,420	3.74
Ireland	NA	3,912,000	NA
Italy	29	13,317,449	2.18
Latvia	13.8	17,400,000	0.79
Lithuania	8.9	7,366,000	1.21
Luxembourg	NA	279,222	NA
Malta	NA	0	NA
Netherlands	2.6	2,976,322	0.87
Poland	45.1	42,785,407	1.05
Portugal	12.8	13,694,733	0.93
Romania	46.7	17,476,457	2.67
Slovakia	18.9	7,101,058	2.66
Slovenia	2.3	4,383,318	0.52
Spain	38.5	19,702,129	1.95
Sweden	21.3	72,200,000	0.30