Database of economic costs of LUM transitions

REPORT ACCOMPANYING THE DATABASE

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Abstract

This deliverable under Work Package 5 of the LAMASUS project presents a harmonised, spatially explicit database of economic costs for land use management (LUM) transitions across Europe, covering cropland, grassland, forest, and wetland systems. The aim is to support robust policy evaluation and scenario analysis in large-scale ex-ante models such as CAPRI and GLOBIOM by quantifying LUM- and region-specific production costs. Methodologies were tailored to data availability and sectoral characteristics. Cropland costs were estimated using a multi-step micro-econometric approach based on a translog cost function, allocating input use across major crops at the NUTS2 level. Grassland costs were derived from FarmDyn simulations, distinguishing eight pasture and managed grassland systems, and parameterised with country-specific input prices. Forest costs were computed using an engineering-based model from the ForestNavigator project, integrating harvesting, regeneration, thinning, and road infrastructure, with differentiation by management type, terrain, and tree species. Wetland costs focused on peatland rewetting, applying a uniform EU-wide value derived from a literature review. Across land use categories, costs are reported under a consistent scheme (fertiliser nitrogen (N), phosphorus (P), and potassium (K), machinery, diesel, seed, labour), enabling comparison within their land use category and allowing for cross-system comparison as a basis for LUM transitions.

Results reveal substantial cost variation across LUMs and countries, driven by labour rates, mechanisation, fertiliser use, and terrain. Intensive systems often show lower unit costs per product due to higher yields, while extensive systems incur higher costs per unit but lower per-hectare inputs. The database will be directly linked to the WP7 model integrations, replacing the cost values of previously aggregated intensity classes with refined, LUM-specific data. This refinement will enhance the accuracy of economic simulations of policy-driven land-use transitions in the EU.

Keywords

Economic costs, land use management, micro-econometric estimations, data modelling

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Nature of the deliverable *DATA*

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Abbreviations

3 - PGmix	Physiological Principles in Predicting Growth for mixed stands
AEZ	Agro-ecological zone
CAPRI	Common Agricultural Policy Regionalised Impact Modelling System
CCF	Continuous Cover Forestry
CLC	CORINE Land Cover
COP	Cereals, Oilseeds, and Protein
CPI	Consumer Price Index
EPIC	Environmental Policy Integrated Climate Model
EU	European Union
Eurostat	European Statistical Office
FADN	Farm Accountancy Data Network
fertCost_N	LUM-specific nitrogen fertiliser cost
fertCost_P	LUM-specific phosphorus fertiliser cost
fertCost_K	LUM-specific potassium fertiliser cost
fuelCost	LUM diesel cost
G4M	Global Forest Model
GAMS	General Algebraic Modelling System
GHG	Greenhouse gas emissions
GLOBIOM	Global Biosphere Management Model
HI	High-input grassland
HILDA+	Historic Land Dynamics Assessment
ILO	International Labour Organisation
ILOSTAT	ILO Statistics
K	Potassium
labourCost	LUM-specific labour cost
LI	Low-input grassland
LU	Livestock Units
LUCAS	Land Use and Coverage Area frame Survey

LUM	Land Use Management
machCost	LUM-specific machinery cost (depreciation and variable costs such as lubricants, insurance)
MS	Member State
NUTS	Nomenclature des unités territoriales statistiques
N	Nitrogen
P	Phosphorus
PCT	Pre-commercial Thinning
PltProtCost	LUM-specific plant protection cost
PWT/PPP	Penn World Table/Purchasing Power Parity
seedCost	LUM-specific (re-)seed cost
SIMU	Simulation Unit
SUR	Seemingly Unrelated Regressions
TF	Type of farming classification
totalCost	Aggregate of all cost positions
WP	Work Package

Executive summary

This deliverable under Work Package 5 of the LAMASUS project provides a comprehensive database of economic costs associated with land use management (LUM) across Europe. The database spans cropland, grassland, forest, and wetland systems, and is designed to enable robust cost comparisons and facilitate integration into large-scale ex-ante models such as CAPRI and GLOBIOM. The overarching objective is to support policy evaluation and scenario analysis by quantifying the economic implications of diverse land use practices.

The methodology for deriving cost data differs by land use category, reflecting the diversity in available data, model structures, and expertise. Cropland costs are estimated using a micro-econometric approach based on a translog cost function; grassland costs are simulated via the bio-economic farm model FarmDyn; forest management costs are derived using an engineering-based model adapted from the ForestNavigator project; and wetland rewetting costs are based on a literature review. The database is structured using a harmonised cost scheme – covering fertiliser, machinery, diesel, seed, and labour costs – for cropland, grassland, and forest.

Cropland systems are represented by LUM-specific cost estimates derived from a multi-step micro-econometric approach using a translog cost function framework. Based on harmonised FADN (Farm Accountancy Data Network) data for specialised crop farms, the method estimates input demand (fertiliser nitrogen - N, phosphorus - P, and potassium - K, fuel, labour, machinery, pesticides) and allocates it across ten major crops at the NUTS2 level. Integration with yields from the EPIC (Environmental Policy Integrated Climate) model enables cost estimations for LUM classes, ensuring consistency with agronomic performance. Results, expressed in EUR (2015) per hectare, reveal substantial variation across crops, LUMs, and regions, primarily driven by differences in fertiliser and labour costs, as well as machinery use. This approach bridges the gap of limited availability of crop-specific physical input data, by using cost data and estimated behavioural relationships to derive consistent input demand estimates. This enables a more robust, spatially explicit cost database for cropland costs to be incorporated into large-scale ex-ante models, such as GLOBIOM.

Grassland systems are characterised by eight LUM types, ranging from very high to low intensity, and reflecting the differences between pasture and managed grassland. FarmDyn simulations, using CAPRI-derived 2015 price data, provide detailed cost components (fertiliser, machinery, diesel, seed, and labour) tailored to country-level input prices. Results in EUR (2015) per hectare show significant cost variation across LUMs and countries, mainly driven by differences in labour and machinery depreciation. Notably, synthetic fertiliser is not applied in lower-intensity systems where manure application fulfils the N requirements, and machinery investments significantly affect per-hectare costs even in low-input systems.

Forest cost data are developed using a spatially explicit engineering-based approach covering harvesting, regeneration, thinning, and road infrastructure, with cost differentiation by management type, terrain, and tree species. Five forest LUM types are considered, ranging from primary (unmanaged) to very intensive management, with primary forest incurring no costs. Costs are reported both per cubic metre of roundwood and hectare. Intensive and very intensive systems exhibit the lowest per-unit product costs due to high yields, while closer-to-nature and combined objective LUMs incur higher costs due to lower operational efficiency and reduced yield. Country-level variations are significant, influenced by terrain, the level of mechanisation, and input prices.

Wetland management focuses exclusively on peatland rewetting. Due to limited site-specific data, a uniform annualised cost, based on a detailed literature review, of 205 EUR ha^{-1} and yr^{1} (based on a literature-derived EUR 3,262 ha^{-1} investment) is applied EU-wide. This simplification is acknowledged as a significant limitation, with implications for the accuracy of regional policy assessments.

A central contribution of this deliverable is its direct linkage to the improvement of ex-ante macro-level models in WP (work package) 7. Section 3 outlines how the new cost database is envisioned to be integrated into CAPRI and GLOBIOM. In CAPRI, grassland costs will transition from a coarse, binary classification (intensive/extensive) to a more refined typology aligned with the LUM definitions, enabled by the newly created LUM geodatabase[1]. Similarly, in GLOBIOM, the grassland costs will be used to populate the new grassland systems, differentiating between high and low-input grassland systems. This will improve the representation of input use, cost heterogeneity, and regional specificity in policy simulations in both GLOBIOM and CAPRI. The LUM-specific costs developed in this task will be aggregated and fed into these models, improving the economic costs for simulating the envisioned scenario work in LAMASUS.

[1] https://www.lamasus.eu/resources/lum-geodatabase/

1. Introduction

In the LAMASUS project, a comprehensive set of land-use management (LUM) systems was defined to produce a LUM geodatabase to represent the spatial and managerial diversity of land use across Europe. These systems — spanning forest, cropland, grassland, wetland, and urban systems — serve as essential inputs to the LAMASUS modelling toolbox, enabling robust assessments of EU land-use policies and change dynamics. The design of these LUM classes incorporated technical modelling requirements of the LAMASUS toolbox and stakeholder feedback gathered during LAMASUS workshops, resulting in a spatially explicit LUM geodatabase (see Deliverable 2.1).

Each LUM system is characterised by distinct management practices, involving differences in farm and forest equipment, operational procedures, specific inputs—such as labour and fertiliser — and their respective intensities. These variations lead to differing environmental effects (as detailed in Tasks 5.1 and 5.2) and production costs, which can vary significantly across regions and countries due to spatial differences in input prices and other agronomic factors. At the same time, production costs are key in shaping landowners' LUM change decisions under various policy settings. In Task 5.3, we quantify region- and LUM-specific production costs, which can be used in combination with the existing LUM geodatabase. The costing database will serve both as a reference for understanding cost structures across Europe and as an input to the large-scale ex-ante models in work package (WP) 7, enabling more accurate assessments of policy impacts using the newly developed LUMs.

This document provides cost information for the land use categories cropland, grassland, forest, and wetlands. For cropland, we have five different LUM systems, each with ten different crops. For grassland, we provide cost information for eight different LUM systems typically found in cattle farms across Europe. These LUMs range from extensive to intensive management systems; however, some grassland systems that are less common, such as rough grazing or silvo-pastoral systems, are not covered in the cost database. The coverage of the forest land use category is quite comprehensive, covering almost all forest LUMs in the LAMASUS geodatabase, including closer-to-nature, combined objective, intensive, and very intensive forest. The LUM "primary forest" is not covered solely because it is considered unmanaged. The final land use category covered is wetlands, which reports only one (rewetting) cost position for all types of wetlands.

This broad coverage translates into a diverse set of LUM systems, each characterised by distinct management practices, input requirements, and operational procedures. For instance, fertiliser application, harvesting methods, and labour needs can vary substantially not only between land use categories but also within them, depending on the intensity and purpose of management. Such variation necessitates tailored cost estimations to accurately reflect the economic realities of each system. To enable comparability across these heterogeneous systems, we applied a harmonised cost structure throughout the database. This ensures that cost components — such as labour, machinery, diesel, seed, and fertiliser — are consistently defined and reported, while still capturing the specificities inherent to each land use management type. The result is a comprehensive and coherent cost database that supports cross-system analysis within the LAMASUS framework.

While the cost components are harmonised for comparability, the methodological approaches used to generate cost estimates differ across land use categories, given the different expertise and data availability of the respective land use category groups. For cropland, a multi-step micro-econometric approach was employed, drawing on a translog cost function framework and observed data. Grassland systems were analysed using a simulation-based approach, employing the FarmDyn bio-economic model to isolate LUM-specific costs. In the case of forest systems, an engineering-based method was used to provide detailed operational information and assign cost factors for standard forestry operations. Wetland costs, by contrast, are based on a literature review, given the limited availability of real-world observations and data.

The purpose of this report is to describe the methodological approaches used to produce the cost database, to highlight the relevant datasets, and to introduce the proposed linkages to the ex-ante large-scale models in WP7. The next section starts with the introduction of each land use category with information on the methodological approaches, exemplary results, as well as a short discussion on the strengths and limitations of the approaches. Finally, this report provides a preliminary outlook for the implementation of the developed cost information and the required LUM aggregation for the large-scale ex-ante models in WP7.

2. Economic cost by land use category

In this section, the methodology and exemplary results for each of the four land use categories – crop, grass, forest, and wetland – are presented. The construction of the costs for each land use category was undertaken by an expert group. Given the broad spectrum of LUMs in this task, each expert group had to use different methodological approaches based on the available data, given their varying levels of detail. Moreover, this work draws on expertise developed in previous research projects and was conducted in close cooperation with other HORIZON projects focused on land use specific cost estimation. Two notable examples of this cross-project cooperation are the forest and wetland costs. For costs associated with forestry we coordinated with researchers from the ForestNavigator project, and their specific cost estimates closely inform the LAMASUS database, while still being tailored to the LAMASUS specific LUM categories and the ex-ante model requirements. In a similar vein the ALFAWetlands project has in-depth work on assessing the cost of rewetting across Europe. The literature review presented in this deliverable was conducted in close cooperation with the ALFAWetlands consortium and considers state of the art rewetting cost estimates, which are adopted to LAMASUS specific requirements.

To provide an overview, Table 1 shows the cost positions used in the database, their definitions, reporting units, and the available spatial resolution for each land use category. For the land use categories cropland, grassland, the cost database has eight harmonised cost positions as seen in Table 1, whereas forest provides five cost positions, and wetland one total aggregate cost position Each cost position is reported in EUR per hectare with the reference year 2015, with the forest sector additionally reporting in per cubic metre and per hectare. Regional coverage differs between the land use categories: cropland and forest provide information at the NUTS2 (2016) level, while grassland only reports at the Member State (MS) level. Grassland values on MS level are mapped to the NUTS2 level to ensure consistent representation across categories. The database is provided through the LAMASUS Zenodo Community and can be downloaded DOI:10.5281/zenodo.16919730.

Table 1: Description of cost positions and available spatial resolution per land use category

COST	DESCRIPTION	UNIT	CROPLAND (spatial resolution)	GRASSLAND (spatial resolution)	FOREST (spatial resolution)	WETLAND (spatial resolution)
fertCost_N	LUM-specific nitrogen fertilizer cost	EUR ha^{-1}	NUTS2	MS	-	-
fertCost_P	LUM-specific phosphorus fertiliser cost	EUR ha^{-1}	NUTS2	MS	-	-
fertCost_K	LUM-specific potassium fertiliser cost	EUR ha^{-1}	NUTS2	MS	-	-
PltProtCost	LUM-specific plant protection cost	EUR ha^{-1}	NUTS2	-	-	-
machCost	LUM-specific machinery cost (depreciation and variable cost such as lubricants, insurance)	EUR ha^{-1} EUR m^{-3} (forest)	NUTS2	MS	NUTS2	-
seedCost	LUM-specific (re-)seed cost	EUR ha^{-1} EUR m^{-3} (forest)	-	MS	NUTS2	-
labourCost	LUM-specific labour cost	EUR ha^{-1} EUR m^{-3} (forest)	NUTS2	MS	NUTS2	-
fuelCost	LUM diesel cost	EUR ha^{-1} EUR m^{-3} (forest)	NUTS2	MS	NUTS2	-
totalCost	Aggregate of all cost positions	EUR ha^{-1} EUR m^{-3} (forest)	NUTS2	MS	NUTS2	EU

fertCost_N, fertCost_P, fertCost_K = nitrogen (N), phosphorus (P), and potassium (K) fertilizer cost respectively, fuelCost = diesel cost, labourCost = labour cost, machCost = machinery cost (depreciation and variable cost such as lubricants, insurance), PltProtCost = plant protection cost, seedCost = (re-)seed cost, totalCost = aggregate of all cost positions

2.1. CROPLAND MANAGEMENT

The following subsections presents the methodological approaches of each land use category and provides exemplary results, while highlighting the limitations of the approaches.

2.1.1. Introduction

To understand production costs associated with cropland and crop production, we estimate NUTS2 level input use across European crop farm systems using a multi-step micro-econometric approach based on a translog cost function framework. By integrating observed cost shares and prices, the analysis estimates input demand and allocates it across ten major crops, both at the farm and NUTS2 levels.

Empirical analysis of agricultural input use is often constrained by the limited availability of crop-specific physical input data. This research addresses that gap by leveraging cost data and estimated behavioural relationships to derive consistent input demand estimates, even in the absence of direct observations.

The methodology combines econometric estimation of cost functions with simulation scenarios from Task 5.1 derived from the EPIC (Environmental Policy Integrated Climate) model. This enables the analysis of input demand under varying farm management practices and yield outcomes across NUTS2 regions.

2.1.2. Methodology

This analysis employs a flexible translog cost function to model the input demand behaviour and cost structures of crop production. The translog framework allows for non-linear substitution among inputs without imposing restrictive assumptions. The system of equations includes a total cost function and a set of input cost share equations, derived via Shephard's Lemma. These are jointly estimated using Seemingly Unrelated Regressions (SUR) to account for cross-equation correlation and improve modelling efficiency. This approach provides key advantages. First, physical input use can be readily derived from cost and price data. Second, substitution effects are data-driven and not fixed a priori. Figure 1 outlines the main steps involved in modelling crop input demand and associated costs and linking them to LUM yield data from the LUM Geodatabase.

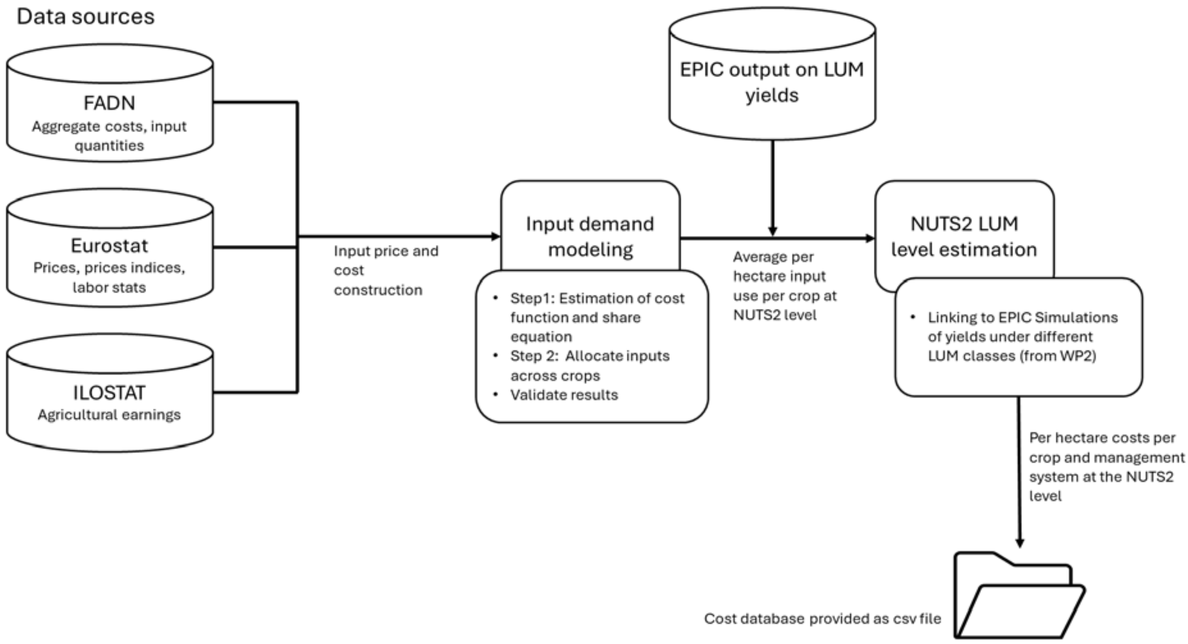

Figure 1: Overview of workflow for estimating crop-level input use across EU crop systems

Data

The empirical analysis utilises harmonised micro-level data from specialised cereals, oilseeds, and protein crops (COP) farms (EU type of farming (TF14), class 15) and specialised general field crop farms (class 16) from FADN (Farm Accountancy Data Network) from 2014 to 2020. The model focuses on ten major EU crops: wheat, barley, maize, rye, rice, potato, sugar beet, rapeseed, sunflower, and soybean. The inputs analysed are fertilisers (N/P/K), fuel, labour, machinery, and pesticides. Table 2 describes the variables and data sources used in the estimation process.

Key data components

Output

Crop-specific production quantities are used directly from FADN. Other outputs (e.g., minor crops) are grouped as a residual category, measured as total farm output minus total outputs of the ten focal crops in EUR 2015.

Input prices and costs

As farm-level input prices are not directly available, national-level input price data from Eurostat and ILOSTAT are used to construct harmonised prices in basic units (e.g., EUR kg^{-1}, EUR $litre^{-1}$). Aggregate farm-level costs for some inputs (e.g., pesticides, machinery, and fuel) are taken directly from FADN, while physical quantities for others (e.g., labour and fertilisers) are multiplied by constructed prices to derive cost variables. Missing or inconsistent data are imputed using EU-wide averages. All continuous variables are log-transformed, with a small constant ($1e^{-4}$) added to avoid undefined logarithms. The input-specific constructions are described in the following subsections.

Input-specific price construction

Fertilisers

Fertiliser price data are obtained from Eurostat's database on purchase prices of the means of agricultural production[2]. This includes both single-nutrient and compound N/P/K fertilisers. The nutrient-specific prices per kg of N, P, and K are based on nutrient contents as outlined in Eurostat's 2020 handbook. The cost per nutrient is calculated as farm-level use multiplied by the nutrient-specific price.

Fuel

Diesel prices are sourced from the same Eurostat dataset. All values are converted to EUR per litre. Diesel oil is used as a proxy for all motor fuel prices. Total fuel costs are taken directly from the FADN.

Labor

Agricultural hourly wage rates in EUR per hour are constructed using Eurostat data on average hours worked per week in agriculture, forestry, and fisheries, and ILOSTAT data on monthly agricultural earnings by sex and economic activity, adjusted for exchange rates. Labour costs are obtained by multiplying the wage rates by labour units (in hours) from the FADN.

Pesticides

Due to the lack of direct price data, changes in pesticide costs are approximated using Eurostat's price indices for plant protection products. The indices were rebased to 2015 and adjusted for consistency over time[3]. The resulting price index captures relative trends in pesticide costs.

Machinery

Total machinery cost combines the costs for machinery upkeep and depreciation of machinery and equipment. Eurostat price index for materials is used to account for price changes, similarly, rebased to 2015.

Empirical strategy

Step 1: Estimation of cost function and share equations

The cost function $C(p, y)$ defines the minimum cost of producing outputs, y, at input prices p, assuming cost-minimising behaviour. Using a translog cost function to capture non-linear interactions between input prices and output, we model the total farm-level production cost as a function of input prices and output quantities:

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[2] Annual prices of 2000 agricultural inputs were used with the inline data code: apri_ap_ina

[3] To ensure comparability over time, we rescaled Eurostat indices from reference years (2010, 2015, 2020) to 2015 (=100).

$$\ln C = \alpha_0 + \sum_{j=1}^{J} \alpha_j \ln p_j + \sum_{m=1}^{M} \beta_m \ln y_m + \frac{1}{2}\sum_{j=1}^{J}\sum_{k=1}^{J} \alpha_{jk} \ln p_j \ln p_k + \frac{1}{2}\sum_{m=1}^{M}\sum_{n=1}^{M} \beta_{mn} \ln y_m \ln y_m + \frac{1}{2}\sum_{j=1}^{J}\sum_{m=1}^{M} \gamma_{jm} \ln p_j \ln y_m + \varepsilon$$

where C denotes total farm-level cost, p_j is a vector of prices of input j, y_m denotes a vector of output quantity m produced by the farm, and ε is the error term. The corresponding cost share equations derived from Shephard's Lemma:

$$s_j = \frac{p_j x_j}{C} = \alpha_i + \sum_{j=1}^{J} \alpha_{ij} \ln p_j + \sum_{k=1}^{M} \beta_{ik} \ln y_k + \tau_i$$

This system of equations is estimated jointly using SUR, thus allowing for the consistent recovery of input cost shares and their responses to prices and output changes (elasticities). To ensure theoretical coherence, the following regularity conditions are imposed: i) linear homogeneity in input prices, symmetry of second-order interactions (i.e., $\alpha_{ij} = \alpha_{ji}$) and the adding-up constraint on cost shares, such that $\sum_j a_j = 1$, requiring the estimation of only $N - 1$ share equations. Once estimated, physical input use, x_i is derived using estimated cost shares, $\hat{s}_i$ as:

$$x_j = \frac{\hat{s}_j \cdot C}{p_j}$$

Step 2: Allocation of inputs across crops

The estimated farm-level input x_i is allocated across crops using observed area shares:

$$x_{jm} = x_j \cdot \frac{a_m}{\sum_m a_m}$$

where m is the area planted with crop m. This proportional allocation assumes uniform input application per hectare across crops, a simplification given the lack of crop-specific input use data.

Step 3: Linking to EPIC simulations from WP2

EPIC model outputs are used to simulate costs under alternative cropland LUMs using yields. For each scenario, output levels are adjusted based on EPIC-simulated yields and the total cost per hectare is recalculated using the estimated translog function coefficients. The predicted input shares are applied to simulate input demand per hectare for input j for different LUM classes:

$$x_j = \frac{\tilde{s}_j \cdot \tilde{C}}{p_j}$$

where $\tilde{C}$ is the predicted total cost under each simulated EPIC yield scenario and $\tilde{s}_j$ is the corresponding simulated cost share.

Table 2: Description of variables and data used in the land use category cropland

ITEM	DESCRIPTION	CODE	UNIT	RESOLUTION	SOURCE
Output					
Wheat	Production quantity	CWHTC_PRQ	Tonnes	Farm-level /annual	Farm level FADN
Barley		CBRL_PRQ			
Maize		CMZ_PRQ			
Rye		CRYE_PRQ			
Rice		CRICE_PRQ			
Potato		CPOT_PRQ			
Sugar beet		CSUGBT_PRQ			
Rapeseed		CRAPE_PRQ			
Sunflower		CSNFL_PRQ			
Soya beans		CSOYA_PRQ			
Other products	Total output for other activities		EUR		
Prices					
Nitrogen prices	Prices are calculated based on the nutritive substance, and for compound fertiliser, the price is based on the N ratio.		EUR kg-1	National average/annual	Eurostat: purchase prices of the means of agricultural production (absolute prices) - annual price (from 2000 onwards) [apri_ap_ina]
Phosphorus prices	Prices are calculated based on the nutritive substance, and for compound fertiliser, the price is based on the P ratio.		EUR kg-1		
Potassium prices	Prices are calculated based on the nutritive substance, and for compound fertiliser, the price is based on the K ratio.		EUR kg-1		

Diesel price	Diesel price is used as a proxy for all fuel prices.		EURL-1		
Wage rate	Wage rate is calculated using monthly agricultural earnings from ILOSTAT and average weekly hours from Eurostat.		EUR hour-1		ILOSTAT: Average monthly earnings for agriculture. code: EAR_4MTH_SEX_ECO_CUR_NB_A
Price index of crop protection	-	-	Index		Eurostat: price indices
Price index of materials	-	-	Index		Eurostat: price indices
Input costs					
N fertiliser	Quantities of N used multiplied by N prices	INUSE_Q	EUR	Farm level/annual	Calculated
P fertiliser	Quantities of P2O5 used multiplied by P prices	IPUSE_Q	EUR		Calculated
K fertiliser	Quantities of K2O used multiplied by K prices	IKUSE_Q	EUR		Calculated
Motor fuels	Motor fuels and lubricants	IFULS_V	EUR		FADN
Wages	Wages of farm labour are calculated as hours multiplied by wage rates	SE011	EUR		Calculated
Crop protection	Crop protection costs	SE300	EUR		FADN
Machinery	Machinery upkeep + machinery depreciation	IUPKP_V + AMCHQP_DY	EUR		FADN

2.1.3. Exemplary results

Input use intensity across the EU

The analysis of input intensity in crop production, measured as average per-hectare input demand, reveals clear differences among EU member states and across major crops. These values are derived from the estimated farm-level cost functions (Step 1) and allocated proportional to crops by area (Step 2). They represent the cost-minimising input requirements conditional on the observed outputs and input prices and thus provide a consistent measure of input intensity across countries, though they are not direct observations of input use.

Nutrients such as N, P, and K are consistently among the most heavily used, but their intensity varies significantly. Figure 2 and Figure 3 present the average demand for N and labour inputs by member states in 2015, compared to the EU-wide average, indicated by the red dashed line. Large regional disparities emerge. Malta is an outlier due to limited data observations and its exclusive focus on potato production. For N, Portugal records the highest average demand per hectare, followed by Bulgaria and Czechia, all well above the EU average, while Finland has the lowest demand. Malta's per-hectare labour demand exceeds all others by far. Excluding this outlier, Portugal, Greece, and Cyprus show the highest labour intensity, with most countries below the EU average. Finland records the lowest demand.

A similar pattern emerges for P, with Portugal leading by a wide margin, while Luxembourg and Bulgaria also exceed the average (see *Figure A1*). Luxembourg records the highest motor fuel demand, followed by Portugal and Italy; Finland again had the lowest use *Figure A2*. Across all inputs, a small group of countries, often the same few, show exceptionally high input demand, while the majority cluster below the EU average line. This pattern suggests a concentration of input-intensive farming in specific regions.

Nitrogen and fuel demand for cereals

Figure 4 examines N demand for three major cereal crops (i.e., barley, corn, and wheat) and reveals substantial variation both between crops and among EU member states. On average, corn requires the most N, followed by wheat and barley, though exceptions exist. In Portugal and Bulgaria, for instance, barley demand surpasses that of corn. The highest N use is estimated in Bulgaria, Czechia, and the United Kingdom, where corn applications often exceed 175 kg N ha^{-1} and peak near 195 kg N ha^{-1} in the UK. Portugal's barley demand is also unusually high at around 185 kg N ha^{-1}. At the other end of the spectrum, Finland and Estonia record the lowest nitrogen use, sometimes as low as 20 kg N ha^{-1}, with Sweden and Latvia also on the lower side.

Figure 5 illustrates the average motor fuel demand per hectare for barley, corn, and wheat across EU countries, highlighting considerable variation. Luxembourg exhibits the highest demand for both barley and wheat, surpassing 600 liters ha^{-1}. On average, motor fuel demand is higher for corn than barley or wheat, notably in Cyprus, Portugal, and the United Kingdom. Finland consistently has the lowest motor fuel demand across all three crops, reflecting less intensive fuel requirements, while Belgium, Bulgaria, and Ireland have relatively demand.

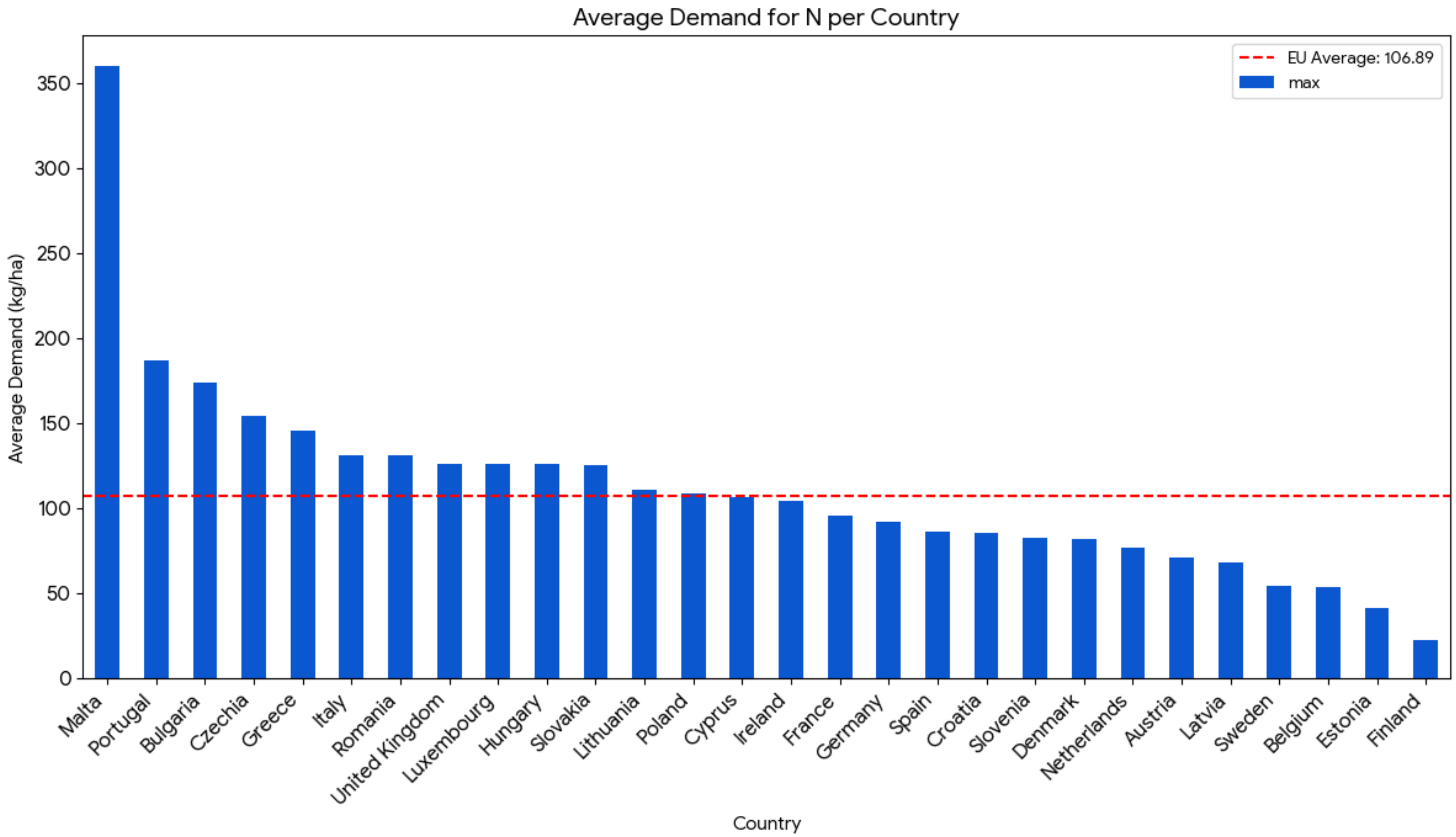

Figure 2: Average nitrogen (N) input demand (kg/ha) across the EU for cropland

Note: *The red dashed line indicates the EU average. Values are derived from cost-minimizing behaviour using the translog cost function, not directly observed input use.*

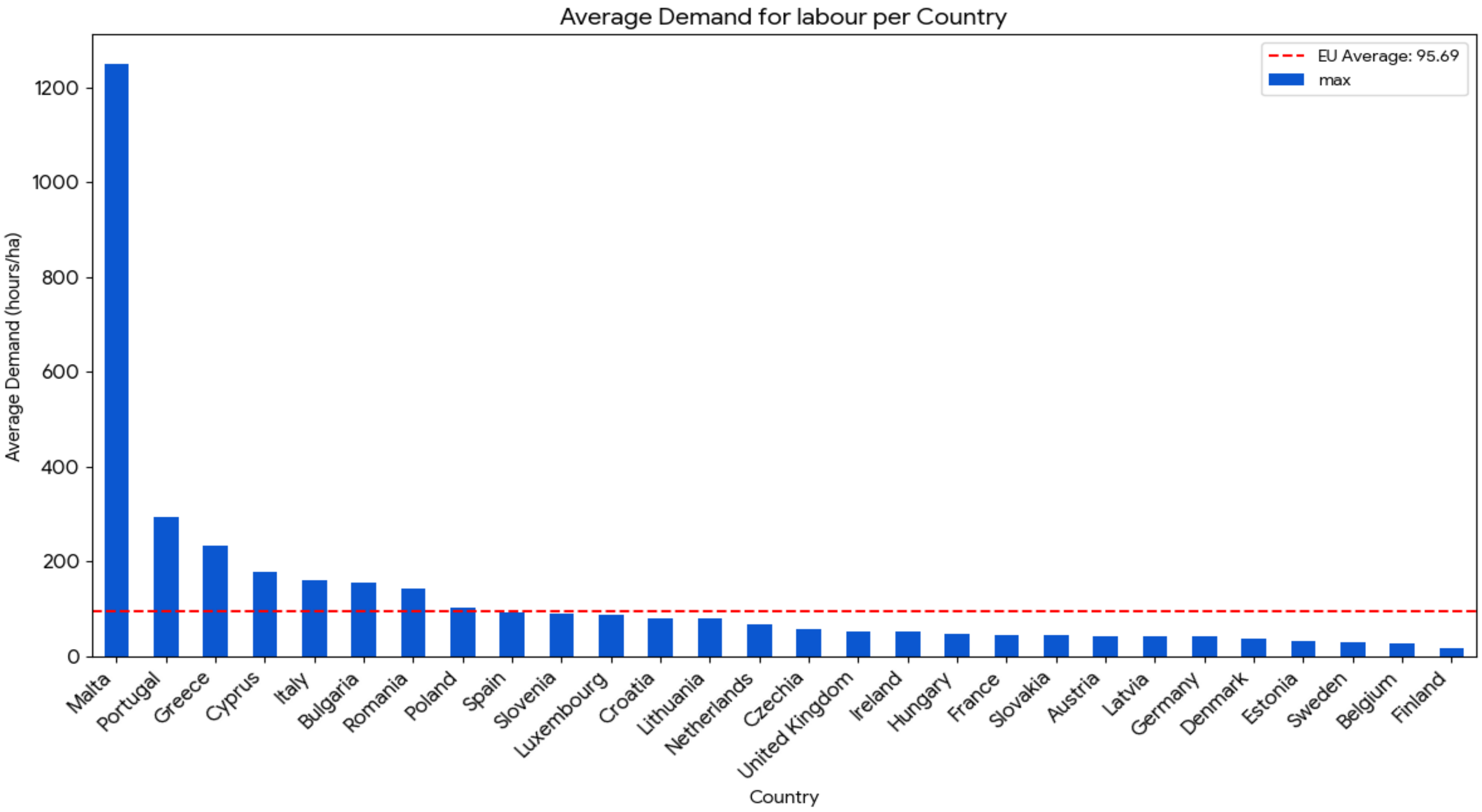

Figure 3: Average labour input demand (hours/ha) across the EU for cropland.

Note: *The red dashed line indicates the EU average. Values are derived from cost-minimizing behaviour using the translog cost function, not directly observed input use.*

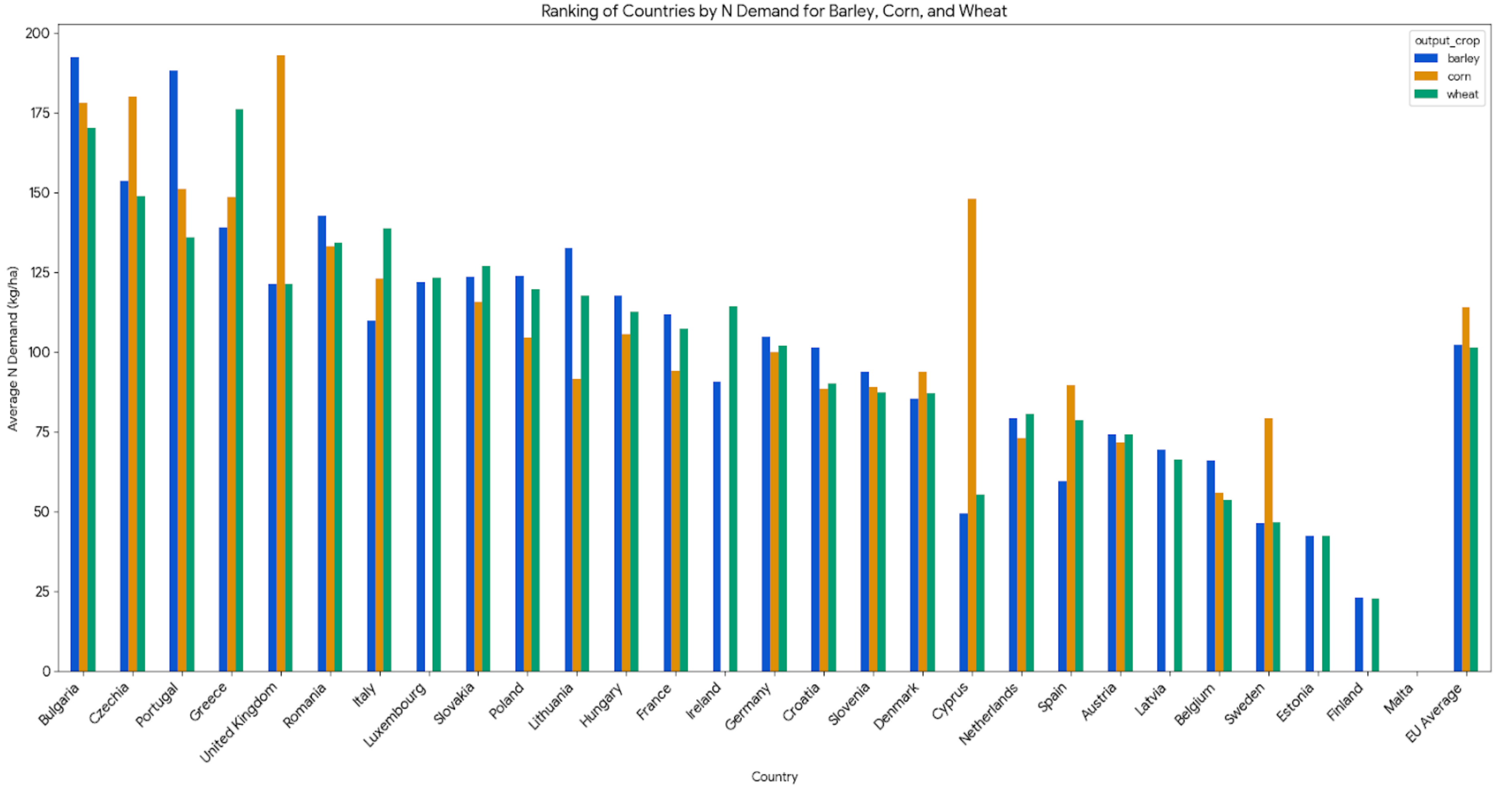

Figure 4: Average nitrogen (N) use for main cereals in the land use category cropland.

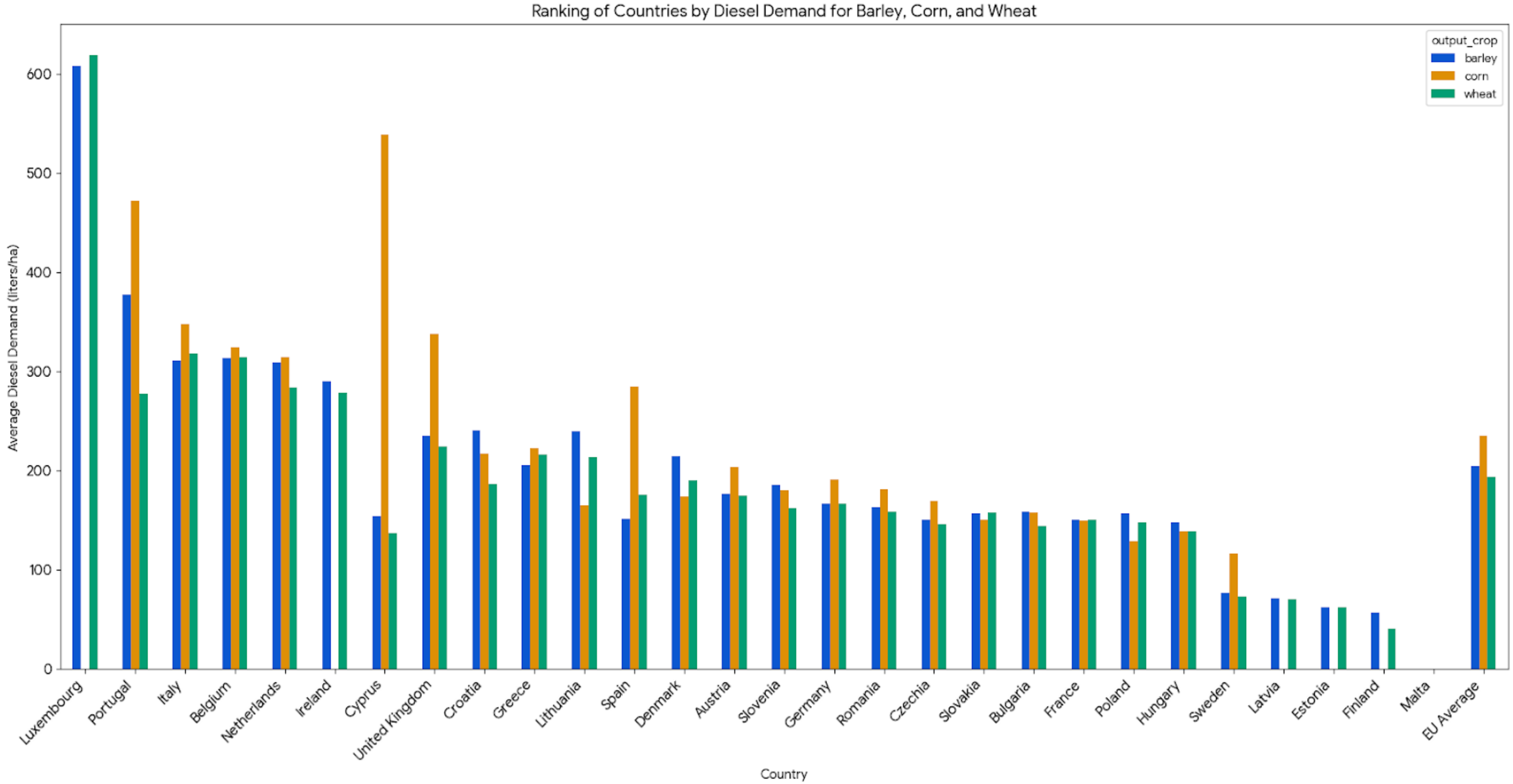

Figure 5: Average motor fuel use for main cereals in the land use category cropland.

These differences reflect variation in production conditions and farming intensity across crops and countries. High input demands, particularly for crops such as corn in the UK, Bulgaria and Luxembourg, are indicative of more intensive cereal production systems. whereas lower demands, observed in Finland and Estonia, reflect less intensive systems and may also be influenced by regional factors such as climate and soil conditions.

Total cost of production across the EU

Figure 6 presents the average costs of different inputs per crop. Results indicate that wages constitute the largest share across all crops. Potatoes incur the highest total cost by a wide margin, driven mainly by high wages and motor fuel expenses, while sunflower seeds have the lowest total cost. Corn, rice, and sugar beet also show relatively high total costs, whereas soy, rye, and rapeseed remain on the lower end. Overall, wages dominate the cost structure, followed by motor fuel and N, with other inputs contributing much smaller shares. In the EU, the majority of farms are family-run and family labour is typically not directly remunerated. As a result, implicit labour costs, often excluded from standard cost analyses, are typically undervalued but once accounted for, labour becomes a central component of the cost composition across crops. We also present results excluding labour, which allows underlying cost patterns to emerge more clearly. When labour is excluded, crops such as rice, potatoes, and sugar beets stand out as the costliest per hectare.

Figure 7 illustrates the cost composition of wheat across EU member states and Figure A3: Cost composition of corn production across the EUFigure A5Figure A3 Figure A5in the Appendix present the results for other major crops. Cost variations across countries are pronounced, likely reflecting differences in management practices and input-use intensity. For instance, Luxembourg, the Netherlands, and Greece tend to have the highest per-hectare costs for cereals, whereas Finland, Estonia, and Latvia consistently report the lowest. Corn production is generally the most expensive with total costs exceeding the EU average of 1,000 EUR ha^{-1} in several member states, followed by wheat production. In oilseeds, rapeseed production is exceptionally costly in Luxembourg, reaching approximately 2,000 EUR ha^{-1}, with the Netherlands and Greece following. Sunflower seed costs are highest in Greece, Portugal, and Italy. Although less widespread, the highest soybean costs are recorded in the Netherlands, Greece, and Italy, while Estonia and Romania have the lowest.

Root crops prove to be the most expensive to produce, with some extreme outliers. For example, Malta's potato production costs exceed 10,000 EUR ha^{-1}. Excluding this outlier, countries such as Italy, Cyprus, and Portugal still report very high root crop costs, often above 3,000 EUR ha^{-1}, driven primarily by labour. Motor fuel also represents a significant expense once labour is excluded. Sugar beet production follows a similar trend, with Portugal and the Netherlands showing especially high costs; Portugal's averages reach around 5,000 EUR ha^{-1}, with labour accounting for over half of the total cost. When labour costs are excluded, most countries fall well below EU averages, highlighting the substantial impact of labour costs on overall production costs.

Analysing the relationship between input demand and costs, Figure A6 reveals a strong positive correlation between a country's average input demand and its total production costs, with most observations clustering close to the trend line. This suggests that higher input demand generally translates into higher production costs. However, potatoes in certain countries appear far above the trend, indicating disproportionately high costs relative to their input demand. Variation around the line also highlights differences in cost structures between countries and crops, suggesting that factors beyond input demand—such as input prices or efficiency—play a role in determining final costs.

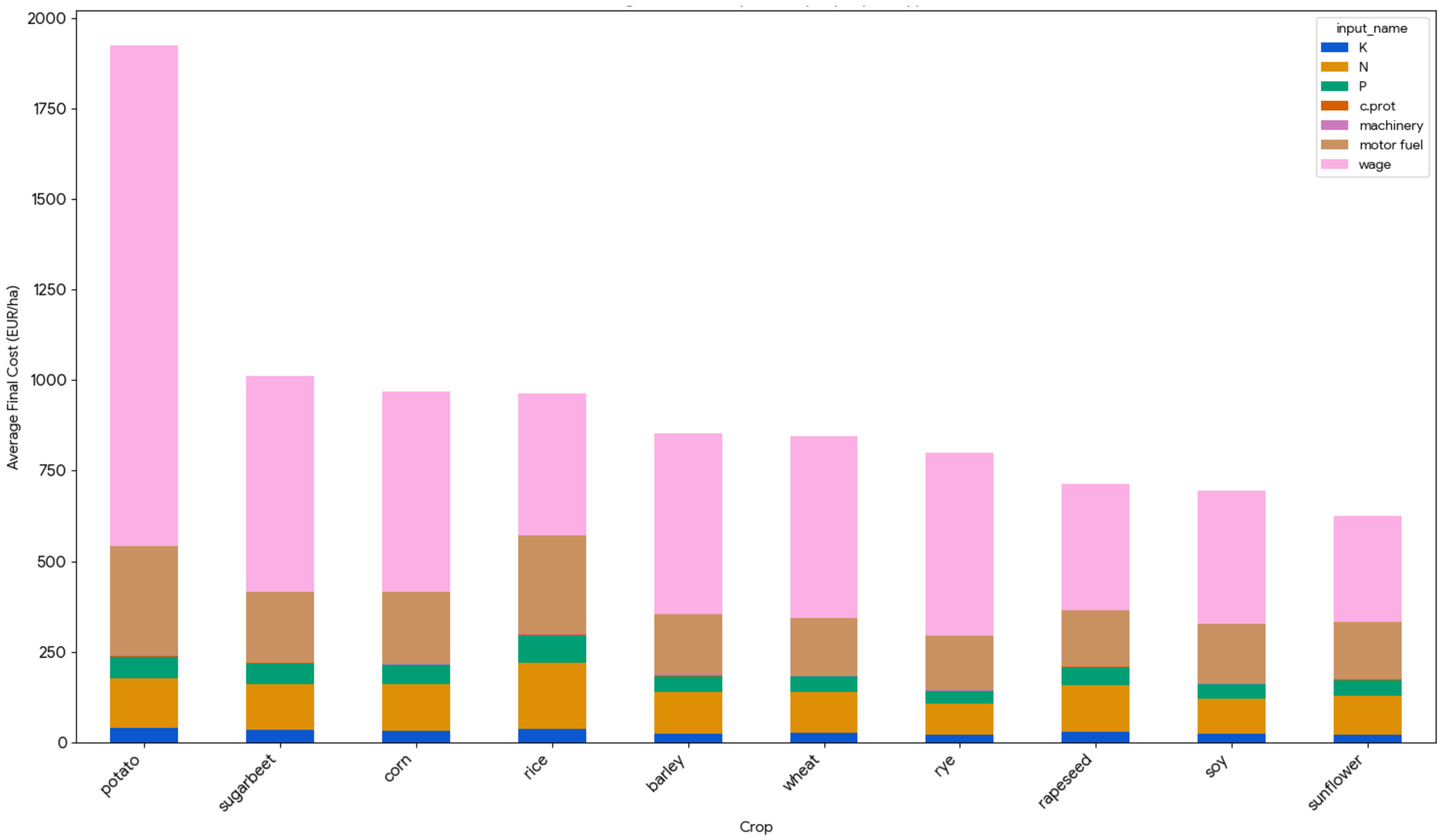

Figure 6: Average total costs EUR ha^{-1} of major crops in the land use category cropland

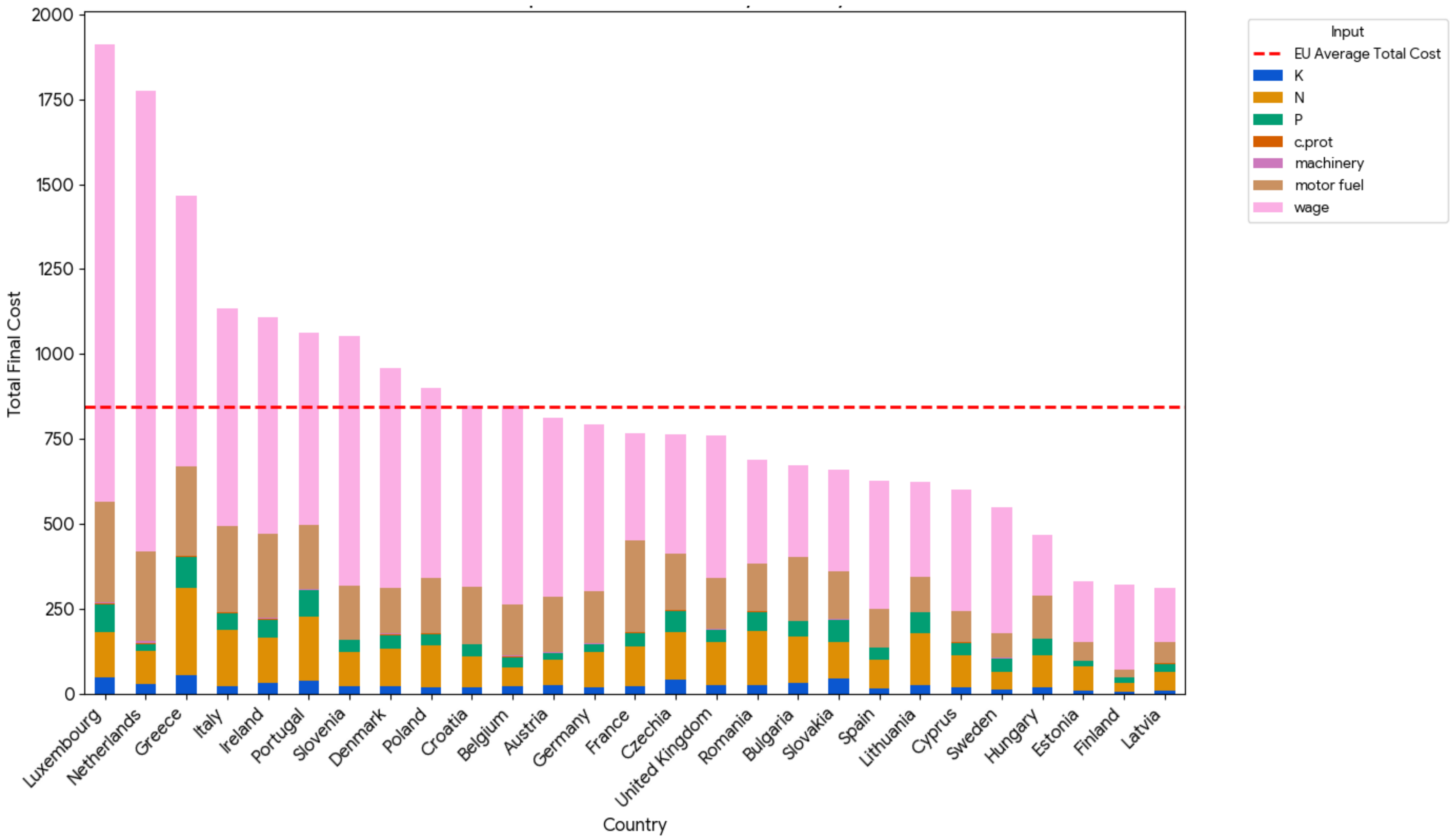

Figure 7: Cost composition of wheat production across the EU .

2.1.4. *Linking input use to EPIC simulated yields*

Figure 8 presents the total cost per hectare of major crops under EPIC land use management systems M1–M5 at the EU level, differentiated by rainfed and irrigated (see Table 3). Across most crops, consistently irrigated systems exhibit higher median costs per hectare, although the magnitude and variability of these differences vary by crop type.

Statistically distinct patterns are apparent for cereals such as wheat, barley, corn, and rapeseed, where cost distributions differ notably between management systems. For root crops, including potatoes and sugar beet, the interquartile range (IQR) is narrower, indicating lower variability and more homogeneous cost structures.

For rapeseed, sugar beet, and wheat, the boxplots show relatively tight clustering of values around the median in the extensive systems (M1 and M2), suggesting lower dispersion and fewer extreme values. Conversely, in more intensive systems (M3–M5), the IQR widens and the whiskers extend further, indicating greater heterogeneity in production costs.

This wider dispersion is particularly pronounced for spring barley (SBAR), corn, winter wheat (WWHT), and rapeseed (RAPE), which may reflect variability in input application rates, management intensity, and technological adoption. In these systems, factors such as efficiency differences and economies of scale likely play a more significant role in shaping cost distributions.

Table 3: EPIC land use management scenarios for cropland category

LUM CODE	LAND USE MANAGEMENT	EPIC LUM SCENARIO CODE	DEFINITION OF EPIC LUM
8	Rainfed extensive arable cropland	M1.rf	Very low intensity, rainfed
		M2.rf	Low intensity, rainfed
7	Rainfed intensive arable cropland	M3.rf	Medium-high intensity, rainfed
		M4.rf	High intensity, rainfed
		M5.rf	Very high intensity, rainfed
6	Irrigated arable cropland	M5.ir	Very high intensity, irrigated

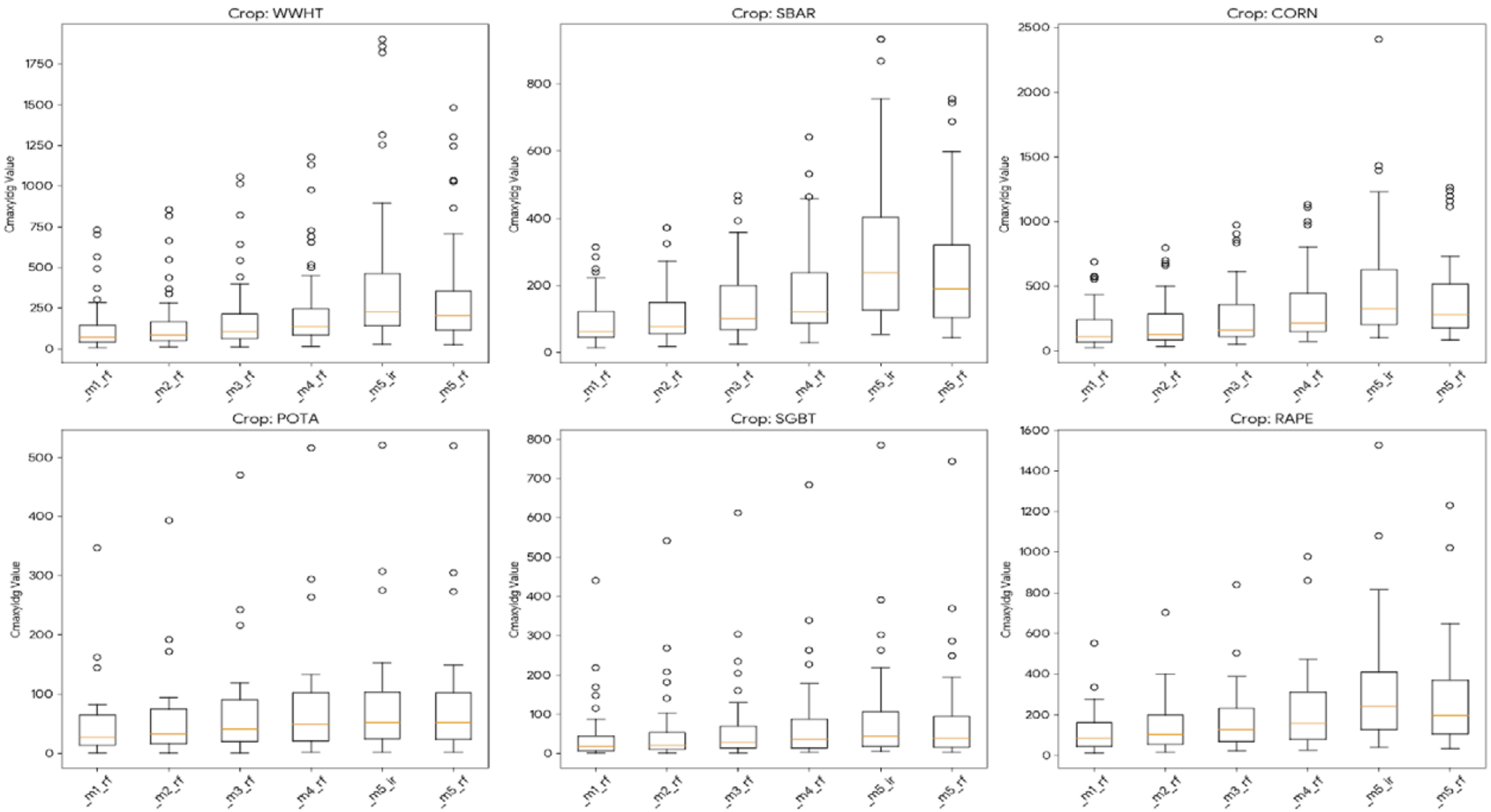

*Figure 8: T*otal costs ha^{-1} of major crops under EPIC land use management systems M1–M5 at the EU level.

Note: Costs are shown separately for rainfed (r) and irrigated (i) systems. Boxplots represent the distribution of costs across the EU, with the box indicating the interquartile range, the line showing the median, and circles representing outliers. Crops included are winter wheat (WWHT), spring barley (SBAR), corn (CORN), potatoes (POTA), sugar beet (SGBT), rapeseed (RAPE), and sunflower (SUNF) (see Table 3 for system details).

2.1.5. Limitation/Discussion

This analysis reveals significant variation in crop input demand and production costs across EU member states. While the EU as a exhibits a high average input use, patterns differ markedly between countries, reflecting the diverse agricultural practices and production conditions. Notably, a strong positive correlation exists between input intensity and total production costs, with wages and motor fuel consistently driving major cost components across crops.

A critical caveat highlighted in this analysis is the frequent underestimation of labour costs in family-run farms, where unpaid family labour often goes unrecorded. This paints an incomplete picture of true production expenses, potentially inflating profitability estimates and masking vulnerabilities, especially in labour-intensive crops like potatoes. Ignoring real labour costs may also weaken incentives for adopting labour-saving technologies and pose challenges for successor generations when they must pay for hired labour at market rates, making farms less viable without family labour input.

One key limitation of this approach lies in the assumption of structural stability—that is, the estimated cost function is presumed to remain valid under the alternative agro-environmental conditions simulated by EPIC. This may not fully capture the behavioural adaptations, technological changes, or shifts in production practices that farmers could undertake in response to new conditions. Additionally, the method treats EPIC-generated yields and input prices as exogenous and unaffected by economic behaviour, which may overlook potential feedback between farm-level decisions and broader market or environmental systems. Lastly, the simulation does not account for estimation uncertainty or adjustment costs, providing point predictions without confidence intervals and assuming smooth, optimal adjustments in input use.

2.2. GRASSLAND MANAGEMENT

2.2.1. Introduction

The specific management of grassland largely influences the costs of forage production. Such costs are highly relevant for the economic performance of grassland-based production systems such as dairy and beef farms. The LUMs developed within the LAMASUS project provide a systematic categorisation of grassland management, including pasture systems, managed grassland, rough grazing, or silvo-pastoral agroforestry. The latter two are not part of the cost database. The detailed reflection of grassland in the large-scale economic models of the LAMASUS modelling toolbox such as CAPRI or GLOBIOM also requires providing costs that capture differences between the LUMs for the EU27.

2.2.2. Methodology

To derive LUM-specific costs for the pasture and managed grassland systems, the single-farm model FarmDyn is used. FarmDyn is a detailed bio-economic model based on mixed-integer programming, which captures both economic and biophysical processes at the farm level. It optimises the selection of production activities to maximise farm profit, providing a highly detailed depiction of input use, outputs, and management decisions. The model has been widely applied in policy and technology assessments, particularly those examining the environmental and economic implications for dairy and beef systems, with a strong emphasis on grassland management (Mertens et al., 2023; Kokemohr et al., 2022; Pahmeyer et al., 2020).

Workflow for isolating grassland-specific costs in FarmDyn

In the LAMASUS framework, land use management within FarmDyn is expressed through detailed farming activities and their interrelated components — such as input levels, technology choices, and management practices, including fertiliser application, mowing frequency, and labour use. A key strength of FarmDyn lies in its capacity to represent these activities and their interlinkages in detail. However, this interlinkage also presents challenges when isolating LUM-specific costs, as disentangling the cost components attributable solely to distinct LUM practices requires a specifically tailored simulation approach.

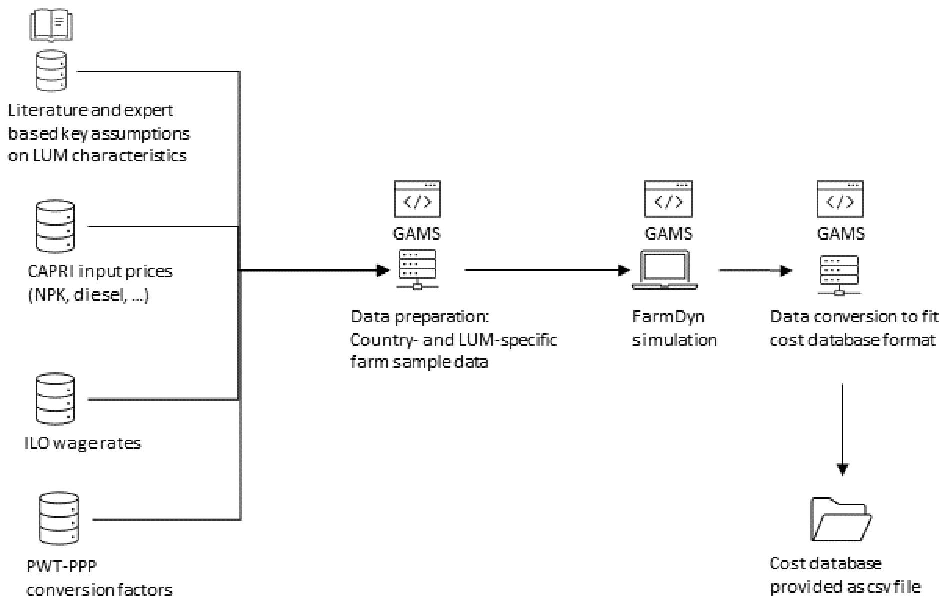

Figure 9: Overview of workflow from data to finished cost database for the land use category grassland.

Note: ILO – International Labour Organisation, PWT-PPP – Penn World Table – Purchasing Power Parity

To isolate the LUM-specific costs, we followed these steps (see Figure 9):

1. For each LUM type, the corresponding stocking density, grassland yield, and — in the case of mown grasslands — the number of mowing events are specified, as detailed in Table

44. The table references the LUM_Code definitions established in the LUM Geodatabase. Stocking density is set to the midpoint of the defined range for each LUM; for example, a range of 1 to 2 livestock units per hectare (LU ha^{-1}) is represented by an average of 1.5 LU ha^{-1}. Grassland yields are estimated using planning data from FarmDyn and calibrated to match the specified stocking densities and assumed 8,500 kg milk cow^{-1}, ensuring that forage production or pasture growth aligns with the requirements of the modelled animal herd. Mowing frequencies are derived from literature sources and reflect varying intensities, based on studies such as Reinemann et al. (2022) and Schwieder et al. (2022). For the land use category grassland, we are focusing solely on those grassland LUMs, which are economically viable grassland management systems for dairy farms within FarmDyn.

2. Input price data is extracted from multiple sources, including the CAPRI data base (primarily EUROSTAT-based), International Labour Organization (ILO) data on Member State-specific wage rates, and data on PPP exchange rates for country-specific adjustments of FarmDyn cost results, where no other information could be obtained. The chosen input data is tailored to the requirements of FarmDyn to provide the agreed-upon cost position within this task, i.e., fertiliser-(N/P/K), diesel-, machinery-, seed-, and labour-cost for grassland.
3. Data is prepared by developing a farm sample file in which each country–LUM combination is represented by a distinct farm, characterised by land use management-specific attributes and country-specific input prices.
4. Each farm in the sample file was simulated using a FarmDyn version adapted to isolate grassland-related costs from other farm activities.
5. Harmonising the FarmDyn results file to the LAMASUS cost database structure and providing the results as a .csv file.

Table 4: Land use management in the grassland land use category with FarmDyn specific assumptions for stocking density, mowing events, and yields

LUM_CODE	LAND USE MANAGEMENT	STOCKING DENSITY (LU HA^{-1})	MOWING EVENTS	YIELD (T DM HA^{-1})
15	Very high-density managed pasture system	2.5	-	5.5
16	High-density managed pasture system	1.5	-	4
17	Moderate-density managed pasture system	0.75	-	2.15
18	Low-density managed pasture system	0.25	-	0.65
19	Very high-density managed grassland	2.5	4	10

20	High-density managed grassland	1.5	3	8
21	Moderate-density managed grassland	0.75	2	6
22	Low-density managed grassland	0.25	2	4
23	Rough grazing	-	-	-
24	Silvo-pastoral agroforestry	-	-	-
25	Managed semi-natural and natural grassland	-	-	-
26	Unmanaged semi-natural and natural grassland	-	-	-

Specification of grassland cost components in FarmDyn

In the next section, the exact cost positions for grassland, their estimation in FarmDyn, and the data used are described.

Machinery costs

In FarmDyn, machinery costs comprise several components. The primary element is investment costs, which are induced either from the direct acquisition of machinery or from the use of flexible machinery services, depending on the equipment type. The investment is an integer variable in FarmDyn, reflecting the indivisibility of machinery investments, meaning that such investments must be made in whole units rather than fractions (e.g., 0.35 of a tractor). We specify the threshold under which farms can buy machinery flexibly instead of investing at 3 EUR ha^{-1}. The sum of both needs to provide the machinery necessary to realise grassland production as the farming activity of interest. The required grassland operations are based on data from the Kuratorium für Technik und Bauwesen in der Landwirtschaft (KTBL) 2014/15 data (KTBL 2014) and are determined by the number of mowing events. For pasture, operations are taken from Bayrische Landesanstalt für Landwirtschaft (LfL) (2025). In addition, variable costs for machinery use are provided, covering, amongst others, lubricants, repair, and maintenance. Diesel costs, however, are accounted for in a separate cost position. The year 2015 was chosen to align with the KTBL 2014/15 cost data, which served as the basis for the analysis. Accordingly, input prices from CAPRI were extracted for the year 2015 to ensure consistency.

Diesel costs

Diesel costs are calculated based on the hours of tractor use required for grassland activities. Since all other machinery — such as fertiliser spreaders, mowers, and loader wagons — is either mounted on or towed by the tractor, only the tractor itself directly consumes diesel. The total amount of diesel used by the tractor is multiplied by the diesel prices provided by the CAPRI database for the year 2015 for each EU Member State.

Seed costs

Seeds are inputs in FarmDyn, required for grassland, silage, and pasture. Seed costs needed for reseeding are not part of the data provided by CAPRI. Therefore, FarmDyn uses KTBL 2014/15 prices for seeds for permanent grassland. These seed prices are adjusted for PPP in each EU Member State using the German costs as the baseline.

Fertiliser costs

FarmDyn uses price data for synthetic fertilisers containing N (urea ammonium nitrate, ammonium sulphate nitrate), P (phosphorus potassium 18/10), and K (calcium ammonium nitrate, potassium magnesium). The model calculates fertiliser costs based on the physical quantities applied, which are multiplied by the corresponding prices and nutrient contents. Input prices for the elemental nutrients (N, P, and K) are sourced from CAPRI and converted into the specific fertiliser types used in FarmDyn. This pricing data refers to the year 2015 and covers all EU Member States. The nutrient requirements of grassland are determined by the targeted yield level and can be met through synthetic fertilisers and/or manure. In some LUM types, due to the relationship between stocking density and yield, manure alone is sufficient to meet nutrient demands, resulting in no synthetic fertiliser costs for those systems.

Labour costs

In FarmDyn, the model can either use household labour or hire labour. In general, outside labour fais only employed if the available working hours of the household exceed the required labour hours from the on-farm activities. In general, the farm owner is not remunerated in FarmDyn per hour but is assumed to use the optimised profit to retrieve a household income. Hence, to determine a labour cost position for each of the LUMs, we post-model multiply the EU Member State specific wage rates (ILO-based) times the labour used regardless of the person, which can be specifically associated with grassland activities.

2.2.3. Exemplary results

The main result of this work is the provision of a cost database for the different grassland LUMs in the EU. Due to the large spatial coverage, the result cannot be described at a disaggregated level. Therefore, we aggregate the results for LUM 15 (very high-density managed pasture) to LUM 22 (low-density managed grassland) across the Member States to explain differences between the LUMs. In addition, we provide selected results at the EU Member State level.

The machinery costs consist of fixed machinery costs, from depreciation of investments, and variable machinery costs. Mown grassland has higher machinery costs than pasture due to the machinery needed for mowing and preparing silage. Their average over all countries is around 110 EUR ha^{-1} for LUM 15 to 18 and 120 EUR ha^{-1} for LUM 19 to 22 (Figure 10).

However, the relatively high machinery costs for pasture are caused by the depreciation years, independent of actual usage. Variable machinery costs vary for mown grassland as costs increase when grassland is cut more often and more manure and synthetic fertiliser are applied. Variable costs, covering, amongst other lubricants and repair costs, are higher for mowed grassland than pasture due to the higher machinery use. The variable machinery costs increase with increasing intensity of LUM 19 to 22 due to more cuts, fertiliser application, and, consequently, more machinery use.

Diesel costs are accounted for separately from the variable machinery costs. Still, they are strongly and positively correlated to the variable machinery costs, as they are also a direct and use-dependent result of machinery operations. Diesel costs on pasture are around 20 EUR ha^{-1} for all LUMs, as only a few machinery operations require tractors (Figure 10). They do not differ between LUMs, as these operations are independent of the pasture intensity in FarmDyn. For mown grassland, the average diesel costs range from 100 EUR ha^{-1} in LUM 19 to 50 EUR ha^{-1} in LUM 22. Again, they increase with increasing intensity due to having more cuts and fertiliser applications, corresponding to higher machinery use and diesel costs.

The reseeding of permanent grassland incurs seed costs. In FarmDyn, reseeding is not linked to grassland intensity; therefore, seed costs are identical for land-use management types (LUM) 15 to 18 (approximately 10 EUR ha^{-1}) and LUM 19 to 22 (approximately 20 EUR ha^{-1}). These relatively low values result from the fact that reseeding does not occur annually; instead, the costs are proportionally allocated in the annual cost estimates for each LUM.

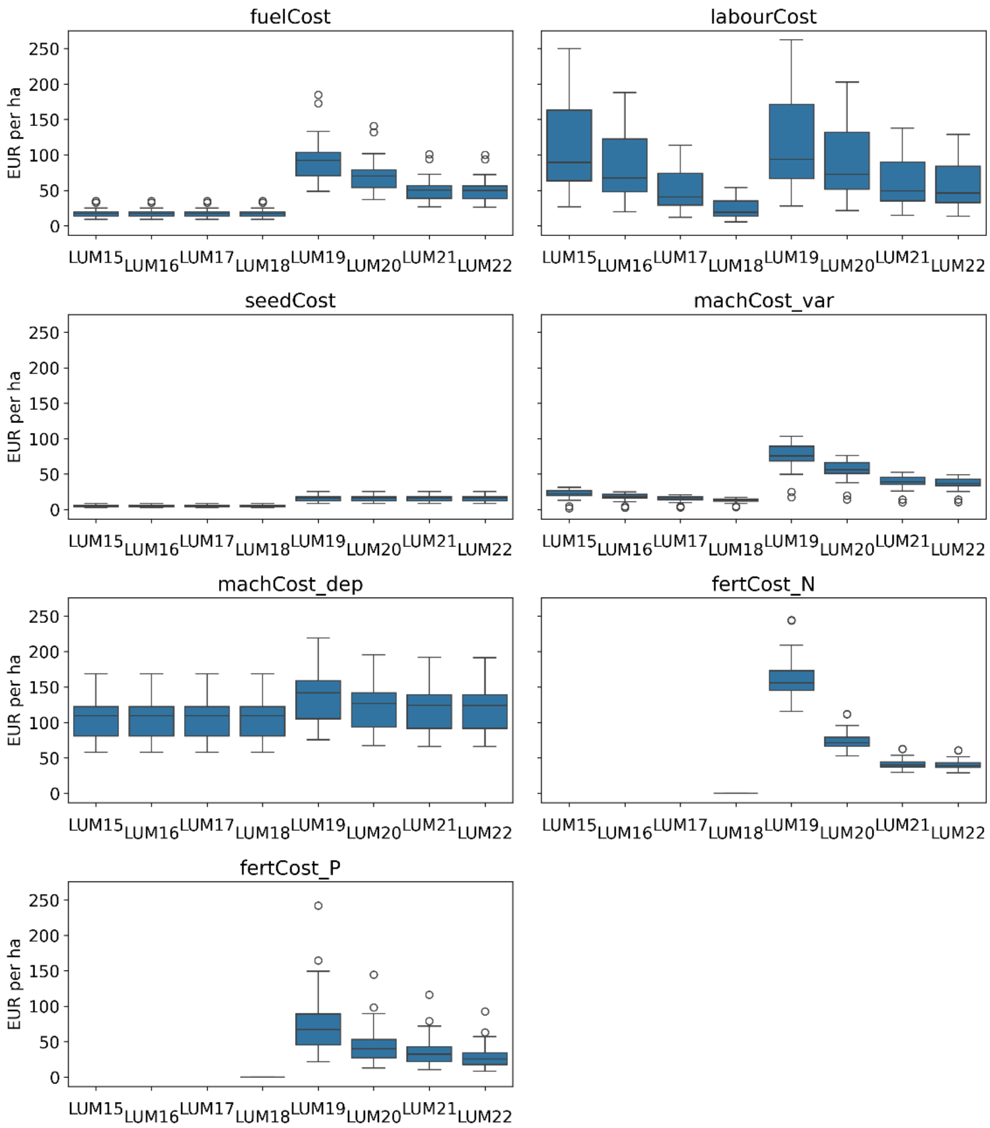

Figure 10: Different costs of LUM 15 to 22, averaged across EU27 Member States, the United Kingdom, and Norway

Note: machCost_var – variable machinery cost, machCost_dep – depreciation machinery cost, fuelCost – diesel cost, labourCost – labour cost, seedCost – seed cost, fertCost_N- cost of nitrogen in fertiliser, fertCost_P - cost of phosphorus in fertiliser

Fertiliser costs strongly differ between mown grassland and pasture. In FarmDyn, crops need yield-dependent nutrients that can be provided by manure and synthetic fertiliser. Nutrients from the grazing herd are sufficient for the roughage-derived yield level of pasture, and no additional synthetic fertiliser is applied, causing no costs to occur. For mown grassland, chemical fertiliser is applied to LUM 19 to LUM 22, causing average costs from 150 to 40 EUR ha^{-1} for N and 65 to 35 EUR ha^{-1} for P. Differences between LUM 19 to LUM 22 are caused by the different yield levels and yield-livestock relations that cause an increasing need for synthetic fertiliser with increasing LUM intensity.

Labour costs show a large variation between LUMs and within LUM, the latter mainly caused by large wage differences between countries. For pasture, labour need is caused by a yield-dependent factor to account for the fact that more time is needed for pasture management, herd change, fencing, and watering places are required when more animals are on the pasture for longer. This results in labour costs ranging from 100 EUR ha^{-1} for LUM 15 to 30 EUR ha^{-1} for LUM 18. For mown grassland, labour costs increase with increasing intensity due to more cuts and fertiliser application. This causes a range of average labour costs from 100 EUR ha^{-1} for LUM 19 to 50 EUR ha^{-1} for LUM 22.

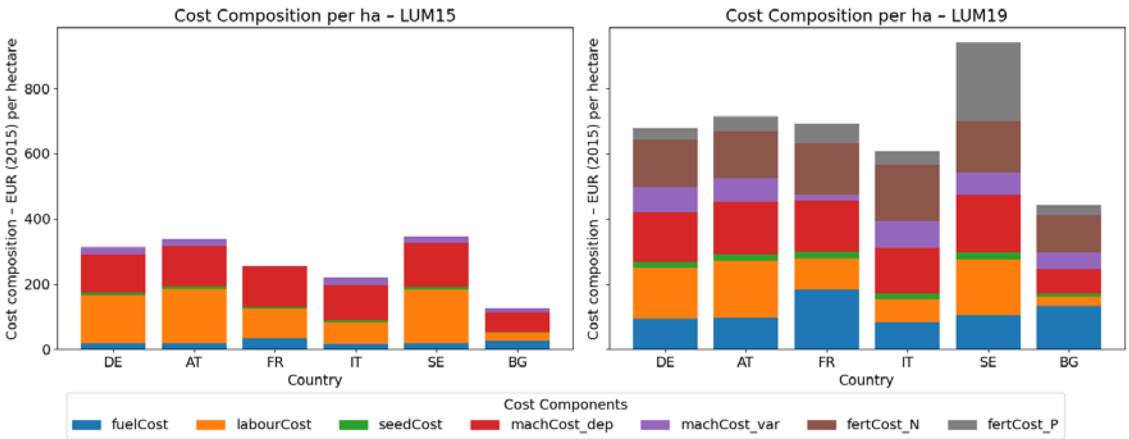

Figure 11: Cost composition for LUM 15 and LUM 19 for selected countries

The overall costs of the LUMs vary strongly, as depicted for some exemplary countries in Figure 11. For example, in the case of LUM 15, costs in Germany are around 300 EUR ha^{-1}, whereas in Bulgaria they are approximately 120 EUR ha^{-1}. In general, labour costs and machinery depreciation represent the largest share of total costs. However, the relative importance of labour costs is lower in countries with very low wage levels, such as Bulgaria. Diesel, seeds, and variable machinery costs contribute only a small portion to the overall costs of LUM 15. For LUM 19, costs again differ considerably between countries. In Sweden, for instance, costs are around 900 EUR ha^{-1}, compared to roughly 400 EUR ha^{-1} in Bulgaria. These differences are largely driven by variations in labour costs, machinery depreciation, and the high cost of P fertiliser in Sweden. Across the countries, we observe consistent patterns in the main cost components — namely labour, machinery depreciation, and nitrogen fertiliser. Compared to pasture, diesel plays a more prominent role in the cost structure of mown grassland.

The results provide LUM 15 to 22 cost estimates for all EU countries, as well as Norway and the United Kingdom. For LUM 15, 18, 19, and 22, Figure 12 illustrates exemplary cost differences between countries. For LUM 15, costs range from over 400 EUR ha^{-1} in the Netherlands to 120 EUR ha^{-1} in Bulgaria. For LUM 18, they range from 250 EUR ha^{-1} in Luxembourg to 100 EUR ha^{-1} in Romania. LUM 19 shows a cost range from around 900 EUR ha^{-1} in Sweden to approximately 400 EUR ha^{-1} in Bulgaria. For LUM 22, Sweden again has the highest costs at 500 EUR ha^{-1}, while Bulgaria reports the lowest, at around 250 EUR ha^{-1}. These variations highlight the importance of considering country-specific costs for LUMs rather than relying on EU-wide average values.

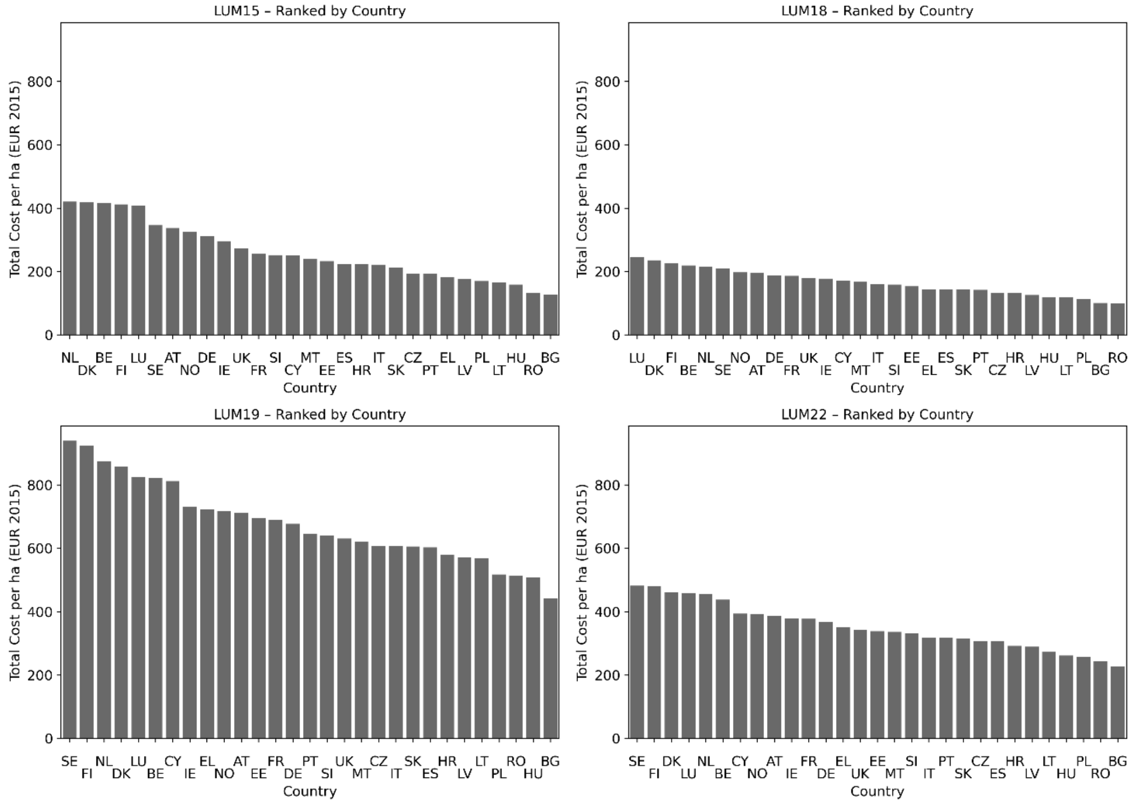

Figure 12: Ranking of total costs for LUM 15, LUM 18, LUM 19, LUM 22 over EU member states, the United Kingdom, and Norway.

2.2.4. Limitation/Discussion

Estimating costs using the FarmDyn model has several limitations. First, only input prices differ between countries, but grassland technology coefficients are the same for all countries. However, production systems between member states differ due to, amongst other things, differences in climatic conditions, machinery operations, herd characteristics, and policies. However, farming systems within member states can also be highly heterogeneous, and grassland management on a single farm can vary in intensity and management. This heterogeneity causes cost differences between and within member states, which are currently not covered by the model. Future model development should include the regionalisation of the coefficient of grassland activities to further improve the representation of regional cost differences in grassland management.

FarmDyn currently relies on data from 2015 to have a consistent base year with CAPRI, which provided the prices for the member states. Future work should update the data to a more recent year, facilitating the validation of the results.

The yield level is a core driver of costs and is related to high uncertainty. The LUM definition lacks a definition of yield levels or ranges that correspond to the stocking density. FarmDyn selects yields consistent with the present herd and its forage needs. This returns relatively low yield levels for pasture compared to the literature. However, large-scale, cross-country, consistent data with a high resolution for grassland yields are not available. A crop growth model to capture the LUMs under different pedo-climatic conditions could overcome this data gap. However, preliminary data from the EPIC model assessed within the LAMASUS project were insufficient.

Machinery investments are a strong driver of the costs for different LUMs. In FarmDyn, they are caused by the depreciation of the machinery costs over its lifetime, mainly related to a fixed number of years and independent of its usage. This can increase the costs for LUM 1 to LUM 4 with pastures with relatively low machinery use, but they still require investment. In reality, farms have different grassland intensities and partly arable land, resulting in different machinery utilisation capacities. We tackle this problem by allowing machinery, which is rarely needed, to be realised as a continuous investment. However, by always representing only one LUM per farm, FarmDyn tends to overestimate the investment costs for machinery.

2.3. FOREST MANAGEMENT

2.3.1. Introduction

Forest management costs are related to a series of operations from tree regeneration, thinning (i.e., reducing forest density) and final harvesting, these are all incurred during the lifetime of a forest. As part of the forest management costs, harvesting costs are typically the dominant part and well-documented, but other cost components related to regeneration and infrastructure are non-negligible in assessing overall forest management profitability. In Sweden, for example, regeneration and road maintenance make up roughly a third of forest management costs (Skogsstyrelsen, 2023). Hence, realistic modelling of forest management costs must reflect the full cost structure for informing silvicultural decisions.

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. Closer to nature management can impact on yields and cost of forest operations, e.g. through implementing management practices like selective logging in Continuous Cover Forestry (CCF) systems (Rautio et al., 2025).

A more advanced forest management costing model has been developed by using an engineering-based costing approach, which integrates: 1) all the main forest operations (harvesting, regeneration, and road infrastructure maintenance), 2) forest management system-specific differentiation of costs, and 3) division of cost structures in labor, fuel, depreciations and other machinery costs and seedlings. The presented cost database uses the updated version of the forestry costing model, further described in Di Fulvio and Lessay (2025) from the Forest Navigator project.

2.3.2. Methodology

In this report, we applied an updated EU-scale forestry cost model developed initially as part of the ForestNavigator Horizon Europe project. This forestry cost model uses an engineering-based costing approach to estimate financial costs and assesses machinery, fuels, and labour demand for various forest management systems. This model covers the EU27 region at a fine spatial resolution (5-arcmin-0.5 degree) and is compatible with the G4M-X forest model variable input. The model comprises three main sub-modules, including engineering, logistics, and cost adaptation described in detail in [Report on EU forest management costing module](#).

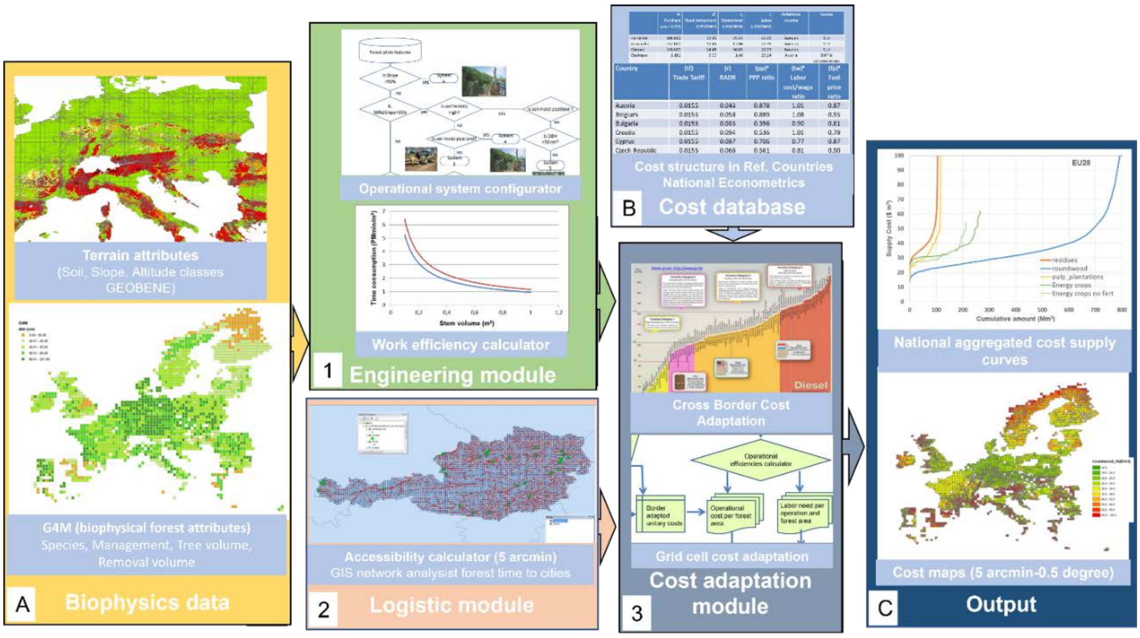

Figure 13: Structure of the forestry costing model: databases (A, B), sub-modules (1,2,3), and output (C)

Source: Di Fulvio and Lessay (2025)

The Engineering Module (Figure 13, 1): This module is responsible for computing the operational efficiency for each forest operation. It selects forest machinery systems based on terrain topography and forest structural attributes derived from the forest model G4M-X. Based on the input, it assesses operational time consumption and efficiency using empirical equations from the literature (Di Fulvio et al. 2016). Key inputs include terrain variables (soil, slope, and altitude classes) and forest structural variables (tree species group, management operation type, average removed tree volume, and removal volume per hectare). Operational efficiency is assumed to be independent of country borders and computed in each simulation unit using literature equations (Supplement of Di Fulvio et al., 2016), using as input the terrain and forest variables listed above, according to each simulation unit (SIMU).

The Logistics Module (Figure 13, 2): This module calculates wood transportation distances and travel time from forest simulation units (SIMUs) to the nearest cities, serving as proxies for forest product markets. It is used when computing overall supply costs from forests to forest industries.

The Cost Adaptation Module (Figure 13, 3): This module combines the outputs from the engineering and logistics modules with economic information from a cost database. It adapts unitary operational costs (for machinery, fuel, and labour) to country borders using econometric relations. Unitary costs for capital, labour, and fuels are collected from reference countries and standardised for calculation. Specifically, the adaptation is performed to the country border according to the econometric indicators listed in Table 5.

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

INDICATOR	DATA SOURCE
Fuel price (EUR/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
Labour cost (EUR/hour)	Labour 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: Di Fulvio and Lessay (2025)

The costing model is written in the General Algebraic Modelling System (GAMS), which allows it to combine heterogeneous inputs and perform rapid simulations and aggregations across scales.

Total forest management costs are summed up based on the costs for regeneration, pre-commercial thinning (PCT), thinning, final felling, and road maintenance incurred in each SIMU. In addition, a 15% cost inflator is included in all SIMUs to reflect a standard overhead level across the EU in the cost calculation. The model can differentiate costs by tree species groups (conifers vs. broadleaves) and management regimes (very intensive, intensive, combined objective, close to nature). Chapter 2 of D4.4 of the ForestNavigator project details the methods of the whole forestry cost module (Di Fulvio and Lessay, 2025).

For the scope of the LAMASUS cost database, we have further refined costs to link them to different management classes (LUMs), each representing a different way of managing forests.

For each LUM, we have adapted the forest structural variables and the efficiency of forest operations to reflect its characteristics, according to Table 6.

Table 6: Forest management cost modelling assumptions for each LUM.

LUM (#)	ASSUMPTIONS
Primary Forest (1)	Negligible management costs
Closer-to-nature (2)	Simulated as a selective harvest system (CCF). Efficiencies in felling/processing operations are simulated according to thinning (24-29% less efficiency compared to clearcutting). Efficiencies in wood extraction are adjusted according to the wood removal volume per hectare (accumulated roundwood volume in 20 years). Regeneration costs are assumed to be negligible as they rely on natural regeneration. Total roundwood production per hectare over a rotation period is assumed to be 25% lower than roundwood production under intensive management.
Combined objective (3)	Simulated as a shelterwood harvesting system. Efficiencies in felling/processing operations are reduced by 10-15% compared to clearcutting. Removal per hectare, considered in wood extraction efficiency computation, is reduced by 20% compared to clearcutting to account for stepwise extraction from the harvest area. Regeneration costs per hectare are 50% of the costs incurred in intensive systems, considering assisted natural regeneration. Total roundwood production per hectare over a rotation period is assumed to be 15% lower than in intensive management.
Intensive (4)	Assumed business-as-usual operational efficiencies and forest structural input for clearcut operations according to tree species composition, rotations, tree volume, and removal per hectare from the Global Forest Model (G4M). Artificially regenerating by planting seedlings.
Very intensive (5)	Assumed for all operations the most efficient systems (corresponding to conifer harvesting operations). Artificially regenerated by planting seedlings.

Forest management costs were computed for the potential supply area of the EU27 forests. Costs were modelled in two stages. First, at the level of each simulation unit, modelling output generated costs for the four categories: labour (direct and indirect labour-related costs), fuels (cost for fuel and lubricants), seedling (seedling material used for forest regeneration), and depreciation and other costs (machinery-related depreciation costs and variable other costs). The SIMU forest structures and yields were based on the forest management potential area and harvest volumes derived from G4M (0.5 x 0.5 degree resolution), where wood demand was set to infinity to activate all potentially manageable forest areas in the future (i.e., forests available for wood supply). Under this assumption, all such areas were placed under optimal rotational forest management. Alternative management scenarios were simulated over the same potential area, assuming variations in roundwood yields as shown in Table 6.

Second, the cost for each category (labour, fuel, depreciation, seedling) and their sum per SIMU were averaged by weighing them according to harvest volume contribution to the NUTS2 (2016) mapping used for LAMASUS. All costs were computed using 2023-2024 prices and deflated to the year 2015 using country-specific Consumer Price Index (CPI).

Forest management costs are reported in two units: a) EUR per cubic metre of roundwood extracted, b) EUR per hectare and year. For the first measure, overall costs were divided by the overall roundwood production (yield) in a hectare of forest for each SIMU during a rotation cycle. For the second measure, at the SIMU level, overall costs were divided by the rotation period (years). The cost for a unit of product can be applied for modelling the supply competitiveness under the alternative managements, and it accounts implicitly for the wood yield change across managements. The cost per hectare and year can be used for evaluating the landowner's costs when implementing different management alternatives. However, the cost per hectare and year needs to account also for changes in yields and, accordingly, revenues for each management option.

2.3.3. Results

Costs per unit of product

The cost for forest management at the EU27 level varied generally between 30 and 50 EUR m^{-3} roundwood; however, in some cases, costs could exceed this level and be more than 80 EUR m^{-3}. The highest average cost per unit of product is reached under LUM3 (combined objective), where costs increased by 10% on average compared to LUM4 (intensive) and 14% compared to LUM5 (very intensive). The lowest cost per unit of product is achieved under LUM5 (very intensive). The cost differential between LUM2 (closer-to-nature) and LUM4 is only 2% (Figure 14).

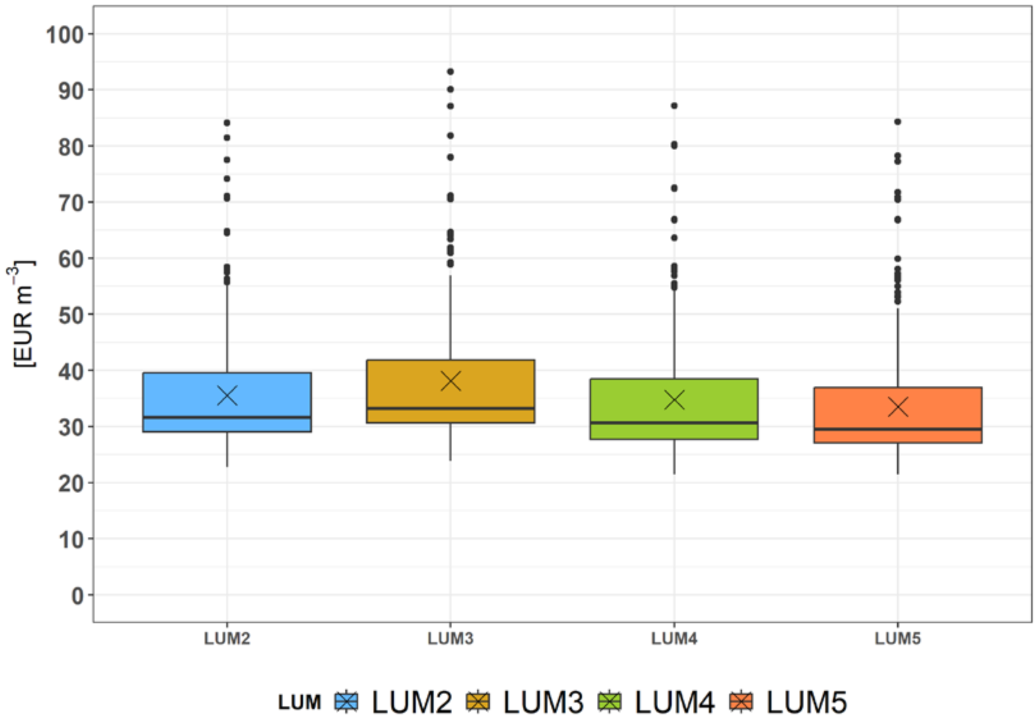

Figure 14: Forest management costs per unit of product by land use management at the EU27 level (based on the NUTS2 variability).

Note: 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).

Among the components of the forest management costs, depreciations (fixed costs) and other variable costs related to machinery make up the largest share of overall costs for all LUMs: these represent 46-49% of total costs, and their average across LUMs is 17 EUR m^{-3}. Labour-related costs are 31-35% of the total cost, for an average across LUMs of 12 EUR m^{-3}. Fuels represent 10-15% of the total costs, and their average across LUMs is 5.4 EUR m^3. Finally, seedling costs are the lowest in terms of cost incidence, with an average of 0-8% across the LUMs, an average of 2 EUR m^{-3}.

Figure 15 (below) shows that by adopting less intensive management systems (LUM2 or 3) there is a relative increase in labour, depreciation, and fuel costs compared to the more intensive systems (LUM4 or 5). These cost increases are due to the reduction of operational efficiencies in closer-to-nature and combined objective management systems, compared to more intensive management. In contrast, we can observe a reduction of seedling costs when transitioning from LUM4-5 to LUM2-3. This reduction of seedling costs is associated with a reduction of artificial regeneration and increased reliance on natural regeneration.

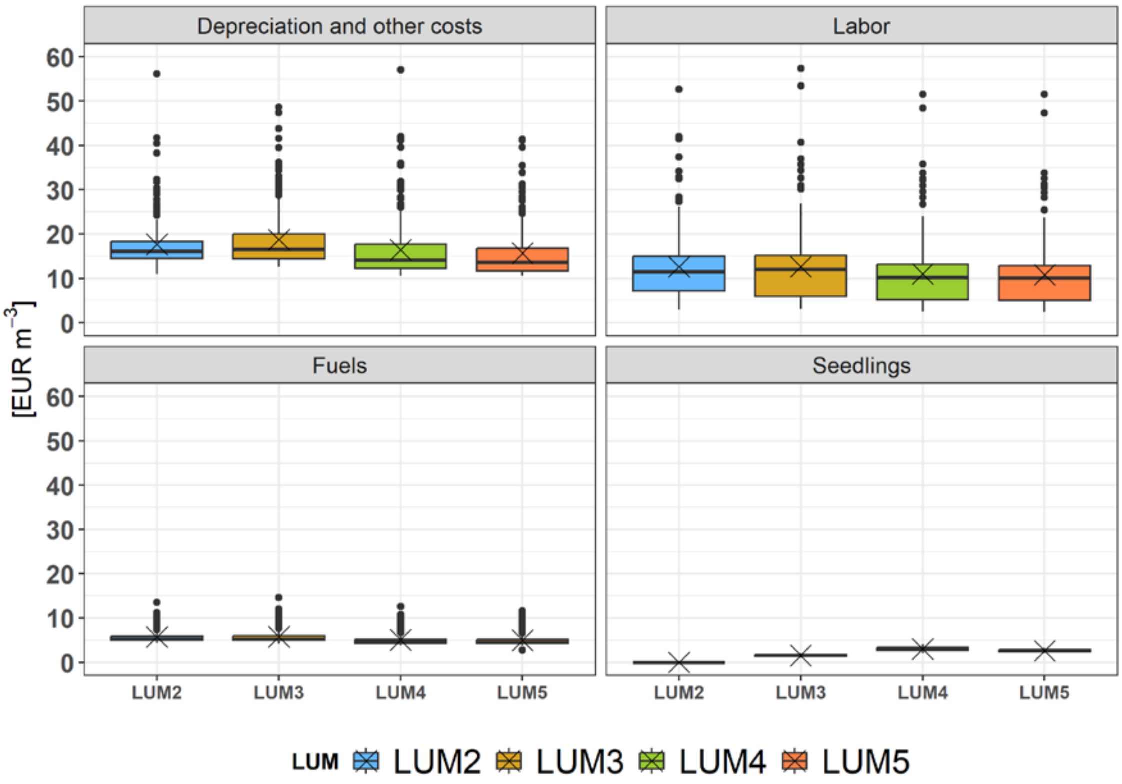

Figure 15: Cost per unit of product according to LUMs and cost category at EU27 aggregated level (based on the NUTS2 variability).

Note: 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).

The relation between the various cost categories is not fixed but varies substantially across NUTS2 and depends on the level of mechanisation and operational efficiency applied according to the topography and forest structural attributes. As an example, in the Austrian mountains (e.g., AT33-Tirol), where logging operations apply chainsaw felling/processing and cable yarder extraction, the incidence of labour costs reached 49% and the fuel-related costs were 11%. In contrast, in Sweden, where highly mechanised systems based on harvester and forwarder are commonly applied to conifer forests on flat terrains (e.g., SE33-Norrland), the incidence was 33% for labour costs and 13% for fuels.

At the country level, we observe that countries with the largest variability in costs across NUTS2 regions are also the ones with the highest average costs per unit of product: Austria (AT), Greece (EL), Italy (IT), and Spain (ES). In these countries, mountains (IT, AT) and low-stocked forests (ES, EL) (i.e., low removal of roundwood per hectare, small, harvested stem volumes, and broadleaves) increase management costs over 40 EUR m^{-3} compared to the rest of the EU27 countries.

The lowest costs are observed in countries with highly productive forests on flat terrains and/or low prices for the inputs used in forest operations (i.e., Bulgaria (BG), Czechia (CZ), Estonia (EE), Lithuania (LT), Latvia (LV), and Poland (PL)). In these countries, management costs are generally lower than 30 EUR m⁻³. Similarly, low unitary costs are also observed in Ireland (IE), hosting very productive conifer plantations that are easy to mechanise.

The effect of transitioning from one LUM to another is visible if comparing LUM5 and LUM3 (the largest relative difference), where LUM3 (combined objective) increases the average costs by ca. 5 EUR m^{-3} compared to LUM5 (intensive) in most countries.

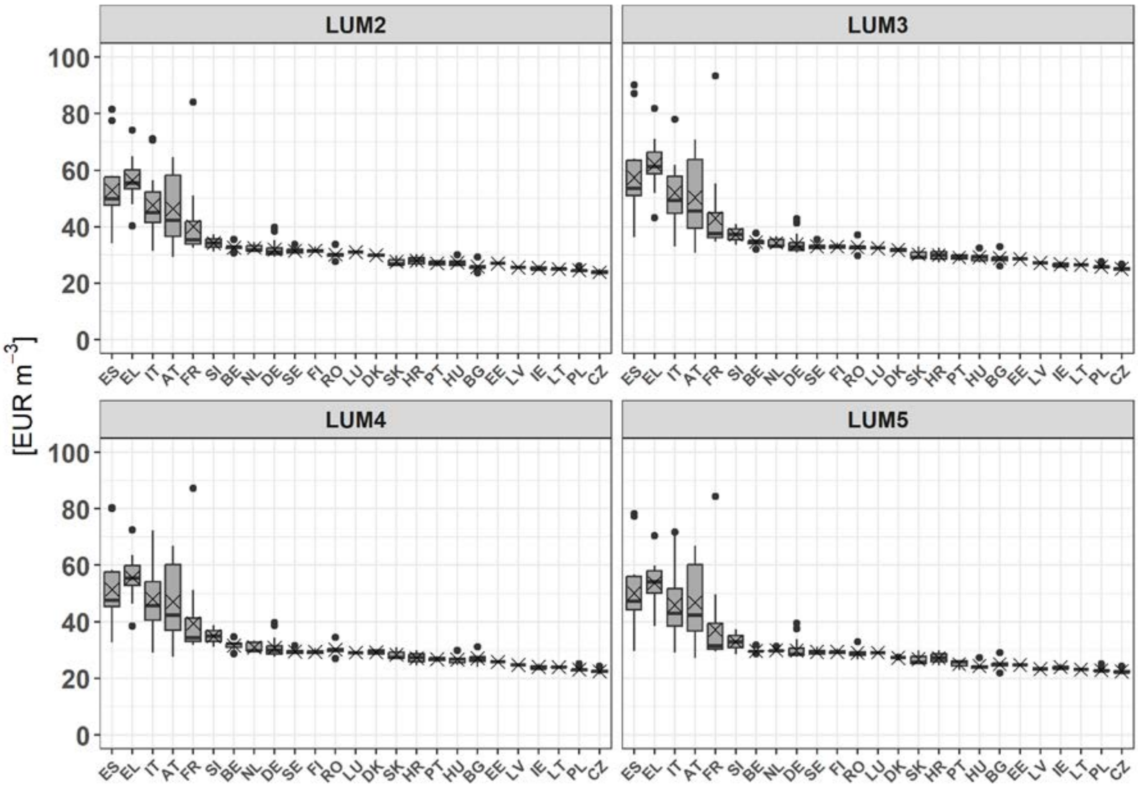

Figure 16: Forest management costs per unit of product for LUM2-LUM5 by EU27 country (ranked by overall forest management costs across categories). (based on the NUTS2 variability).

Note: 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).

Costs per unit of land

The forest management costs per unit of land and year at the EU27 level generally varied between 80 and 230 EUR ha^{-1} yr^{-1} (Figure 17). However, in some cases, management costs could exceed this level and be over 300 EUR ha^{-1} $year^{-1}$.

Observing differences in costs across LUMs, the highest average cost per unit of land (177 EUR ha^{-1} $year^{-1}$) is observed under the LUM4 (intensive management). Under LUM4, the costs increase by 21 EUR ha^{-1} yr^{-1} compared to LUM3 (combined objective) and 55 EUR ha^{-1} yr^{-1} compared to LUM2 (close to nature). The costs for LUM5 (very intensive) are slightly lower (-7 EUR) compared to LUM4. The higher costs for the two most intensive managements are due to the higher wood removals per hectare (yields) during the rotation period, which requires higher costs for wood harvesting operations compared to less intensive management systems.

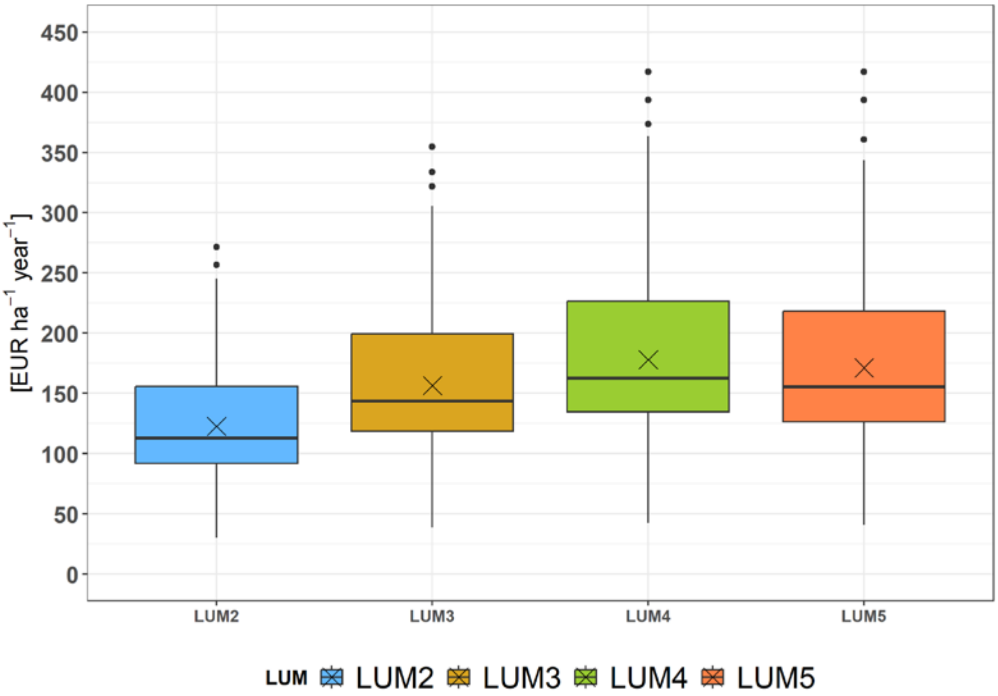

Figure 17: Forest management costs per hectare and year according to LUMs at EU27 aggregated level (based on the NUTS2 variability).

Note: 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).

Similar to costs per unit of product, forest management costs per hectare are driven by the two cost categories: labour and depreciation and other variable costs (Figure 18). Depreciation and other variable costs account for 39% and 46% of the total cost, respectively, while labour represents between 31% and 36% of the total costs. Fuel accounts for 16% to 18% of costs, and the seedling cost represents between 0 and 16% of costs.

In contrast to the costs per unit of product, we observe an increase in all cost categories when transitioning from closer-to-nature management (LUM2) to the other managements (Figure 14). The differences in costs are less pronounced among the other three LUMs (LUM3, 4, 5).

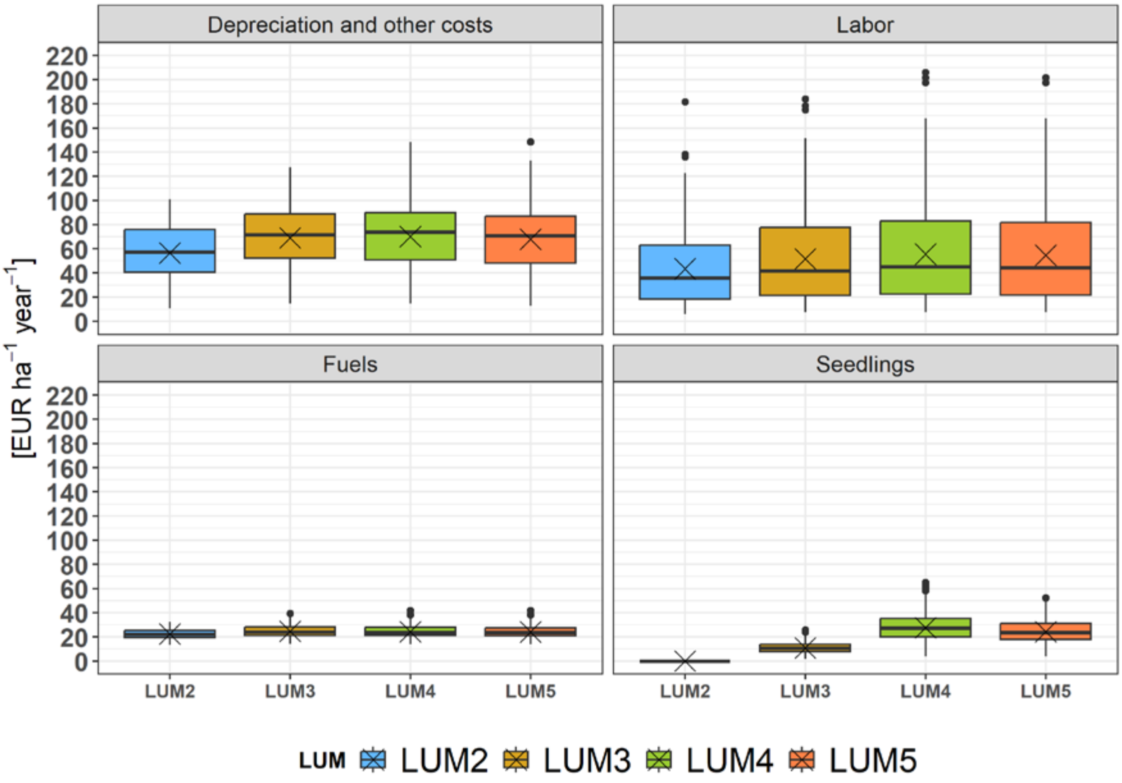

Figure 18: Cost per hectare and year by LUM and cost category at the EU27 aggregated level (based on NUTS2 variability).

Note: 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).

After ranking countries by cost per hectare, we observe that countries characterised by high unitary input prices and relatively high yields have the highest costs (Austria - AT, Germany - DE) and exceed an average cost of 200 EUR ha^{-1} year^{-1} under LUM2 (i.e. the most cost-efficient LUM) (Figure 19). In contrast, countries with the lowest costs per hectare at less than 100 EUR ha^{-1}year^{-1} include those with low yields (e.g., Greece (EL) and Spain (ES)) and countries with homogenous conifer forests and highly mechanised operations in Northern Europe (e.g., Finland (FI) and Sweden (SE)).

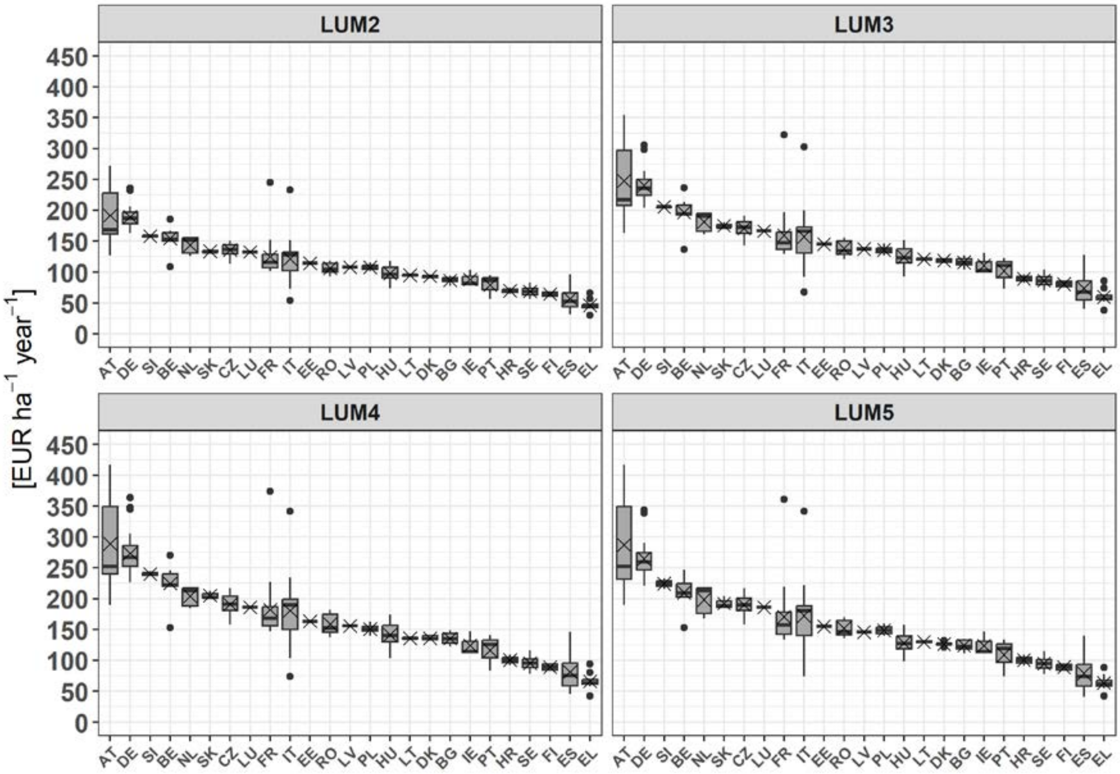

Figure 19: Ranking of total costs per hectare and year for LUM 2, LUM3, LUM4, LUM 5 over EU27 member states (based on the NUTS2 variability).

Note: 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).

2.3.4. Limitation/Discussion

In this section, we have analysed the costs for alternative forest management types. However, profitability for forest management depends on costs and revenues. Our results need to be complemented by a modelling approach that includes an analysis of the financial revenues associated with each LUM. These analyses are performed in economic models like GLOBIOM, which rely on market equilibrium by combining spatial cost-supply curves with demand functions.

In the GLOBIOM analysis, to obtain supply costs for wood products at the industry gate, the management costs presented here are combined with wood transportation costs according to Di Fulvio et al. (2016). For this reason, we have reported management costs per unit of product, which can easily be combined with transportation costs during an economic evaluation of supply costs.

The representation of closer-to-nature and combined objective LUMs was based on the reduction of operational efficiencies and forest yields, as observed in the literature. We did not modify some of the key structural forest parameters (i.e., harvested stem sizes) when transitioning from one management to another, given the uncertainty in these parameters.

As part of the ForestNavigator project, additional process-based modelling of forest structures under these managements is currently being performed by combining G4M and 3PGMIX forest models, which will also better inform the future cost modelling.

For the modelling of costs in this report, we focused on wood production. However, additional ecosystem services influence management operations according to forest characteristics, such as management related to forest fire prevention, creation of infrastructure for recreational activities, or forest monitoring. These costs are not currently included in the model. We have included a 15% percentage share as an inflator for overheads on the costs obtained from the model, which partially addresses these extra non-accounted costs.

The costs presented in the cost database are computed according to the potential areas under alternative management (LUM), according to the entire forest area available for wood supply in the EU27. We did not consider the current areas effectively managed according to each of the specific LUMs. This can be obtained by combining the cost database with the LUM map created in the LAMASUS LUM Geodatabase. This approach will allow the computation of costs for current management from GLOBIOM and implement the transition to alternative management according to scenarios. In this regard, the costs reported for each LUM are the ones incurred at a steady state (when each management is fully implemented). We did not account for the additional transitioning costs that could be incurred when transitioning from one steady state to the next one.

2.4. WETLAND MANAGEMENT

2.4.1. Introduction

Draining peatlands for agricultural use accelerates the oxidation of soil organic matter, leading to carbon losses. Rewetting these drained peatlands – specifically referring to raising the water table level to restore them to their natural wetland state – can substantially reduce such carbon losses. While a higher water table would significantly reduce carbon dioxide (CO_2) and nitrous oxide (N_2O) emissions by limiting aerobic decomposition and nitrification processes, rewetting could result in more methane (CH_4) release under anaerobic conditions; yet, the overall long-term carbon balance of rewetted peatland remains positive. However, rewetting often results in a loss of agricultural productivity and requires investment in infrastructure to raise the soil water table. As a result, rewetting causes important economic trade-offs between agricultural use and ecosystem restoration, which in turn influences the optimal land-use decisions within the GLOBIOM model.

2.4.2. Methodology

In GLOBIOM, two main categories of costs are associated with peatland rewetting: opportunity costs and construction costs. Opportunity costs represent the value of foregone agricultural production, including land rents and agricultural revenues, and are endogenously determined within the model's optimisation framework. Construction costs are based on the analysis by Wichmann et al. (2022), which reviewed 17 rewetting projects in Germany. The study estimated an average cost of approximately 3,262 EUR ha^{-1}, including both planning and implementation expenses. This value is consistent with the cost range reported by the European Commission (2022), which estimated average investment costs for rewetting between 955 and 4,735 EUR ha^{-1}, and annual maintenance costs ranging from 29 to 470 EUR ha^{-1}. To incorporate these construction costs into GLOBIOM, the average investment of 3,262 EUR ha^{-1} is converted into an annualised cost in 2000 USD ha^{-1}, using a 3% interest rate over 30 years. This yields an equivalent cost of approximately 205 USD ha^{-1} yr^{-1}, which is applied across all EU27 countries within a quadratic cost function.

2.4.3. Limitation/Discussion

Although rewetting is a local process, which is strongly influenced by site-specific factors such as soil characteristics, hydrological feasibility, agricultural market conditions, and public perception, GLOBIOM currently applies a single average cost value across all EU regions. In practice, rewetting costs are expected to vary considerably depending on peatland type, degree of degradation, management practices, and socioeconomic conditions (Agora Agriculture, 2024). Due to limited data availability, this simplification may lead to over- or underestimation of rewetting impacts in certain areas and thus should be interpreted with caution in the context of regional policy development or land-use planning.

3. Envisioned link of cost database to large-scale ex-ante models

One of the key objectives of LAMASUS is to improve the quantification of recent or future land-use management changes in the ex-ante models. More specifically, Task 7.1 aims to improve the representation of cropland, grassland, forest, and wetland management in the large-scale ex-ante models CAPRI, GLOBIOM, IMAGE and MAGNET. A key factor of this improved management representation is a more accurate representation of management costs. This section describes how such an implementation of the cost structure would look like, based on the example of grassland costs and the ex-ante models CAPRI and GLOBIOM. The implementation for cropland, grassland, and wetland follows a similar design. All the cost implementations will be described in detail in D7.1.

3.1 IMPLEMENTATION OF GRASSLAND COST IN CAPRI

The current implementation in CAPRI is based on the estimation of yields, area, and production at the Member State level for one aggregate grassland category (GRAS), using multiple data sources on land use (CLC, LUCAS, HILDA+) and Eurostat crop statistics (see Figure 20). In a rather simplistic approach, GRAS is further split into intensive (GRAI) and extensive (GRAE) grassland, assuming a 50%/50% split in acreage. Yield is increased by 40% for GRAI and decreased by 40% for GRAE, compared to the average MS GRAS yield. The associated costs are derived from the distribution of sector-specific input costs and their allocation to each crop group, such as GRAS. In a second step, the estimated costs for GRAS are then split between GRAI and GRAE based on their respective yield levels.

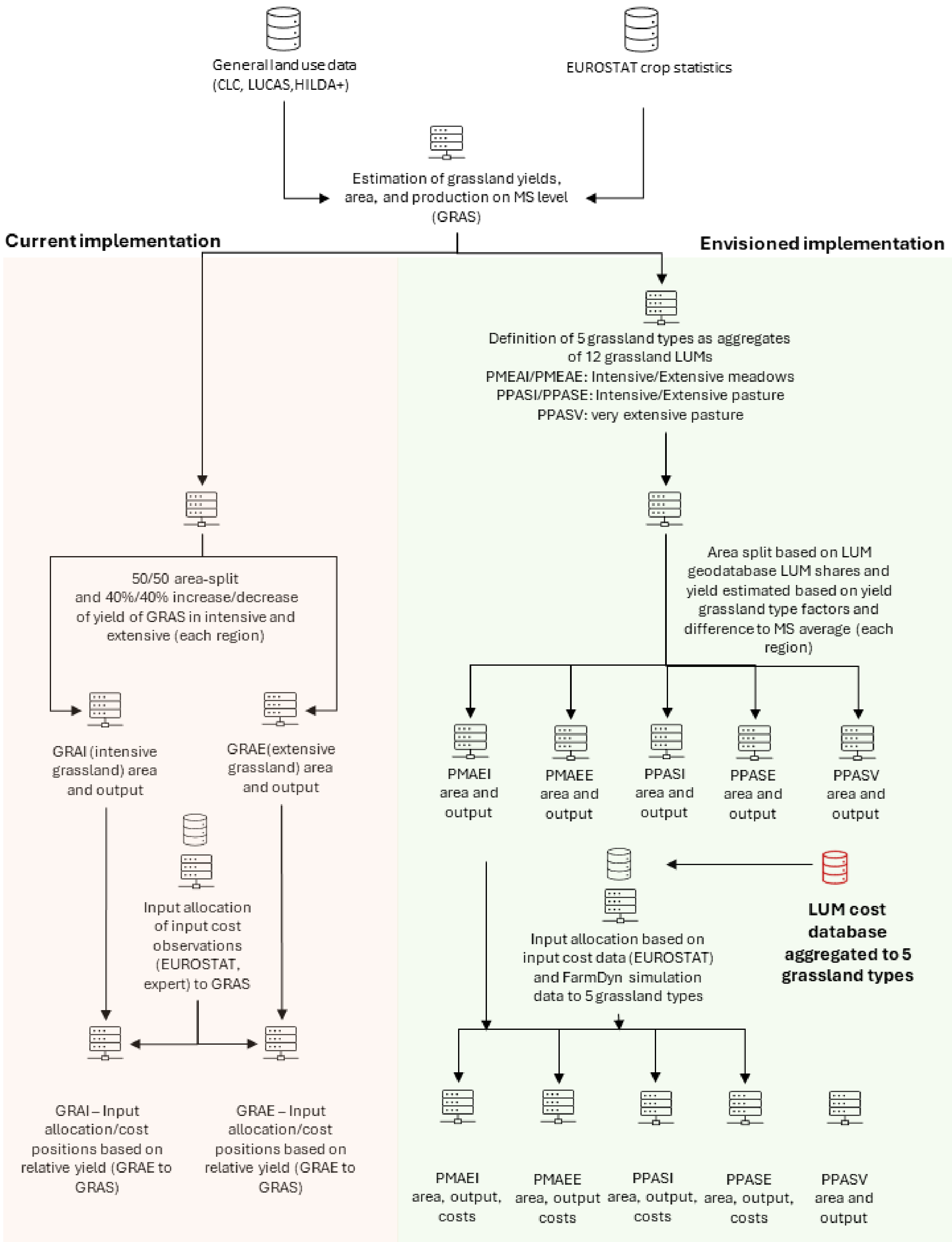

Figure 20: Current and envisioned implementation of grassland costs in the new grassland representation in CAPRI based on new LUM structure.

The envisioned implementation in CAPRI is also illustrated in Figure 20. Building on the same GRAS estimation used in the model's first step, the second step incorporates the developments in LUM definitions from the geodatabase and the cost structures developed in this task. Since the LUM geodatabase is highly detailed, the proposed LUMs must be aggregated for computational reasons. The corresponding mapping is presented in Table 7, where each grassland type (meadow or pasture) is subdivided into intensive and extensive categories. An additional grassland type—very extensive pasture—covers LUM classes 23 to 26, which are not included in the cost database.

Table 7: Mapping of LUMs to proposed CAPRI grassland types.

LUM_CODE	LAND USE MANAGEMENT CLASS	... MAPPED TO
15	Very high-density managed pasture system	PPASI
16	High density managed pasture system	
17	Moderate density managed pasture system	PPASE
18	Low density managed pasture system	
19	Very high-density managed grassland	PMAEI
20	High density managed grassland	
21	Moderate density managed grassland	PMAEE
22	Low density managed grassland	
23	Rough grazing	PPASV
24	Silvo-pastoral agroforestry	
25	Managed semi-natural and natural grassland	
26	Unmanaged semi-natural and natural grassland	

Note: PPASI – intensive pasture, PPASE – extensive pasture, PMAEI – intensive maedow, PMAEE – extensive maedow, PPASV – very extensive pasture

The regional area of each grassland type aggregate is derived from the regional share of these grassland types, based on the total grassland area and grassland-type-specific area in the LUM geodatabase. Yields are estimated using the national average grassland yield, adjusted by expert-based yield correction factors, and must be consistent with the total grassland production (GRAS) from the first step. Input cost allocation to each grassland type is based on the cost positions developed in this task, which are used as priors in an estimation approach. This approach distributes EUROSTAT input cost data across grassland types, resulting in a consistent cost structure as well as area and production levels per grassland type.

3.2 IMPLEMENTATION OF GRASSLAND COST IN GLOBIOM

In GLOBIOM, previously, grassland areas were not distinguished according to management intensity. As part of the LAMASUS project, we introduced a classification system that distinguishes between High Input (HI) and Low Input (LI) systems for grasslands in the EU. This classification of areas is based on information from the LUM Geodatabase and yield and fertilizer use data developed in the EPIC Model, described in (D5.1) and publicly accessible in the LAMASUS Zenodo community, which also utilizes the Geodatabase as a core input parameter.

To create the HI and LI classification, we developed a mapping between the LUM classes and the GLOBIOM grassland classes. Table 8 shows the link between the LUM classes and the associated GLOBIOM grassland management class.

Table 8: Mapping the LUM land classes to GLOBIOM land classes

CODE	LABEL	GLOBIOM LAND CLASSES
15	Very high-density managed pasture	High Input Grassland
16	High density managed pasture system	
19	Very high-density managed grassland	
20	High-density managed grassland	
4012	Intensive heterogeneous grassland classes	
14	Agroforestry	Low Input Grassland
17	Moderate-density managed pasture system	
18	Low-density managed pasture system	
21	Moderate-density managed grassland	
22	Low-density managed grassland	
23	Rough grazing	
24	Silvo-pastoral agroforestry	
25	Managed semi-natural and natural grassland	
26	Unmanaged semi-natural and natural grassland	
4013	Extensive heterogeneous grassland classes	

Using the databases above, GLOBIOM calculates the following:

1. Area and yields based on Simulation Units, which are thereafter aggregated to country, soil, slope, altitude, and agro-economical zone (AEZ) classifications at the HI and LI systems for the base-year.
2. Fertilizer use at the Simulation Units, which is then aggregated to country, soil, slope, altitude, and AEZ classifications at the HI and LI systems.
3. Grassland technologies, including silvo-pasture, are aggregated at the regional level for HI and LI systems.

The cost calculations for the HI and LI grassland systems use the FarmDyn model, as outlined in the Methodology section (Section 2.2.2). GLOBIOM will calculate the per-hectare costs for HI and LI grassland systems based on the LUM classifications, accounting for the limitations highlighted in section 2.2.4. These LUM classifications will serve as the basis for assigning these costs for machinery, seed, and labour costs per hectare. In contrast, fertilizer costs will be applied to the per-unit fertilizer used from the EPIC data. As mentioned in the exemplary results (Section 2.2.3), the different cost databases are available for EU Member state level, but aggregated differently for different LUM classes. GLOBIOM will adopt a similar costing strategy to aggregate the different LUM classes and the different costs available to generate a per-hectare cost for HI and LI grassland systems.

4. Conclusion

The results presented in this deliverable provide a harmonised, spatially explicit cost database for cropland, grassland, forest, and wetland land use management (LUM) systems in the EU. By integrating sector-specific methodologies—econometric modelling for cropland, bio-economic simulation for grassland, engineering-based costing for forestry, and literature-based estimates for wetlands—this work allows for direct comparison of costs across systems and regions to allow LUM transition assessments. The observed variations in costs by management type, region, and input composition offer valuable insights for understanding the economic drivers behind land use transitions.

For the LAMASUS project, these results form a key input to WP7, where the database will replace highly aggregated cost assumptions in CAPRI and GLOBIOM with detailed, LUM-specific estimates. This will significantly improve the capacity to simulate the economic impacts of policy measures at high spatial resolution. The data will be implemented and tested in forthcoming model runs by the WP7 teams, enabling refined scenario analysis for EU land use policy evaluation.

Future updates for a more spatially refined cost database for grassland are envisioned if more accurate data from the EPIC crop growth model are available for grassland LUMs.

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6. Appendix

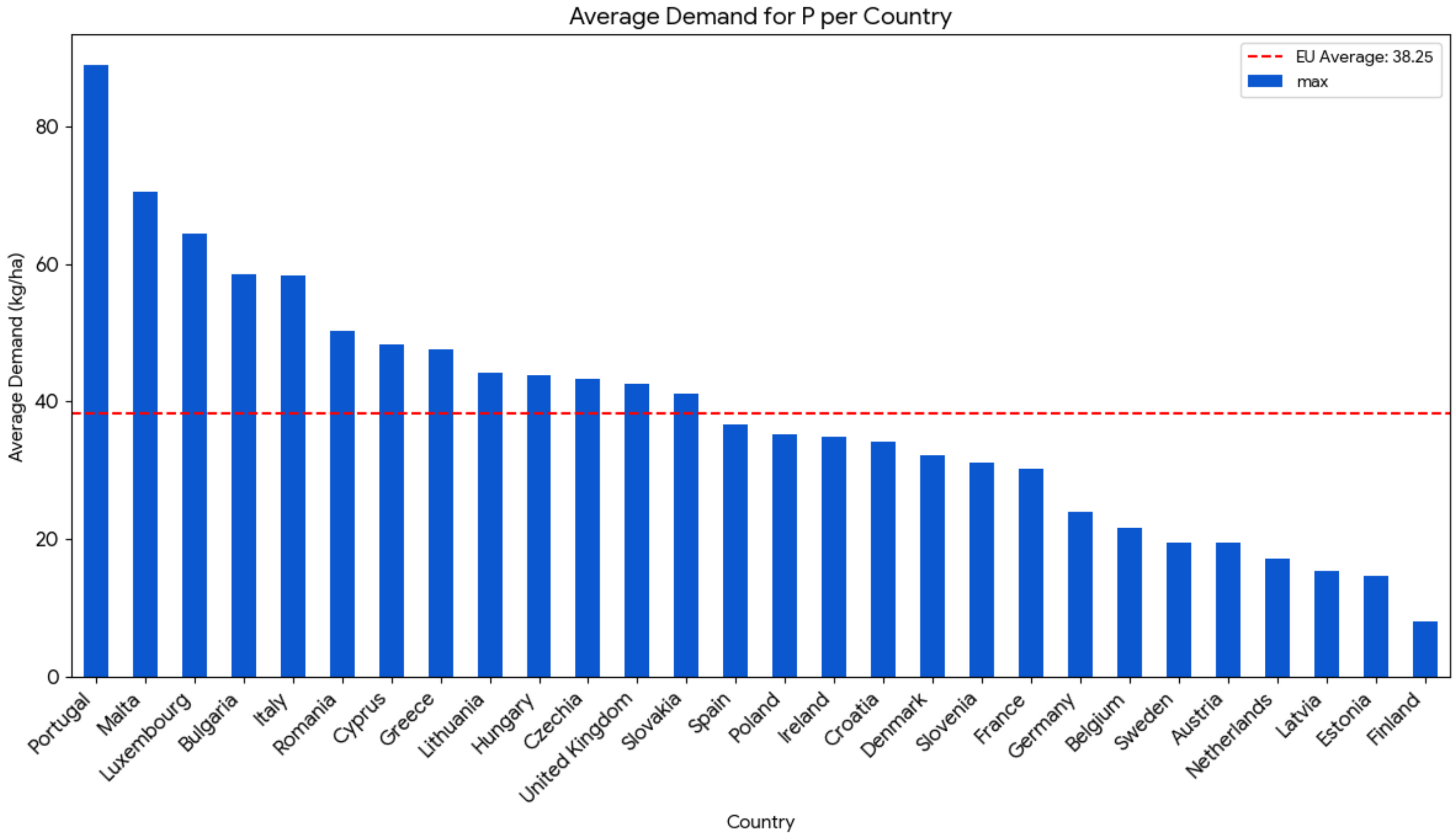

Figure A1: Average P input demand (kg/ha) across the EU for cropland with the red dash line indicating the EU average indicated with a red. Values are under cost-minimising behaviour using the translog cost function, not directly observed input use.

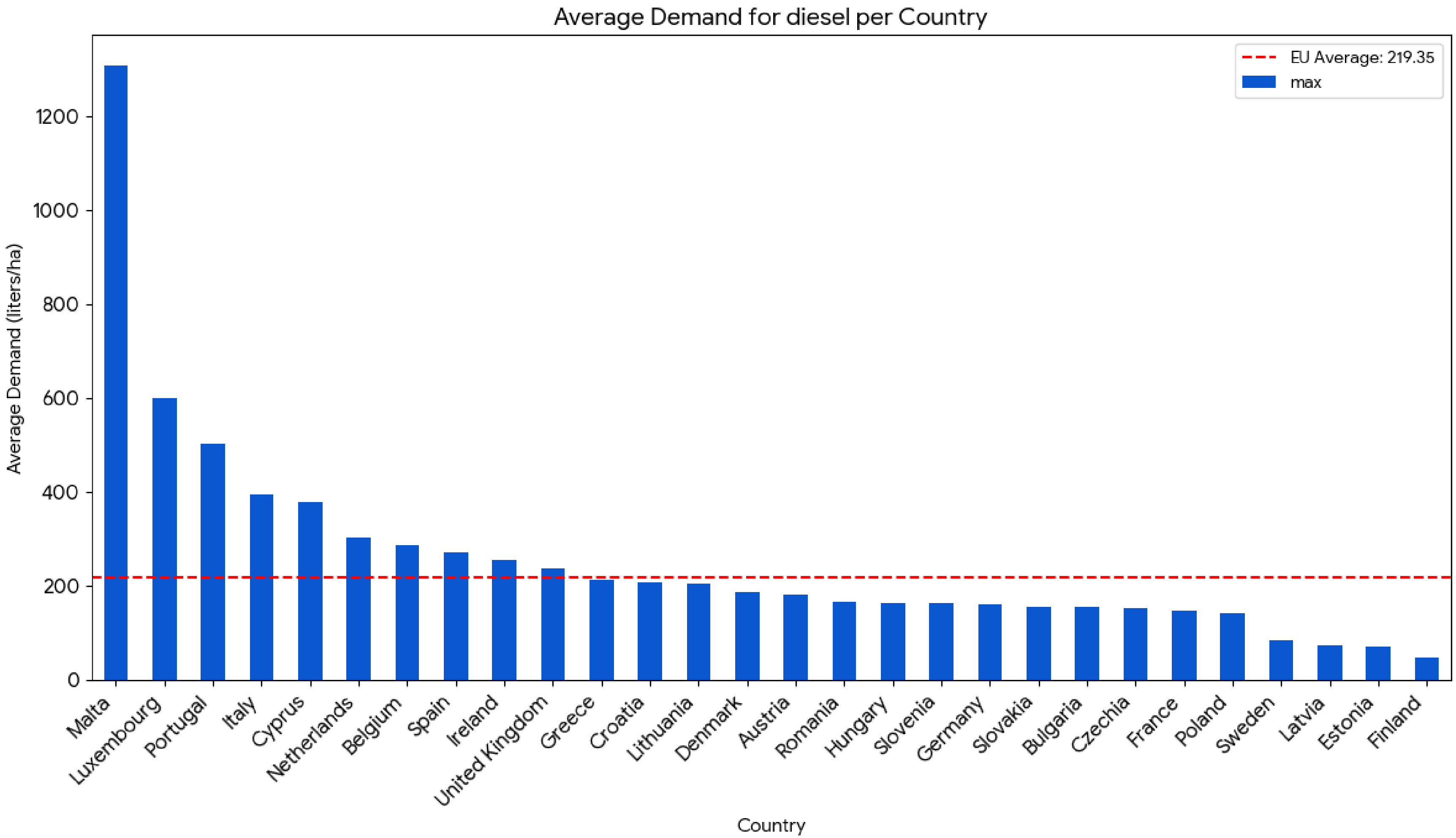

Figure A2: Average diesel input demand (liter/ha) across the EU for cropland with the red dash line indicating the EU average indicated with a red. Values are under cost-minimising behaviour using the translog cost function, not directly observed input use.

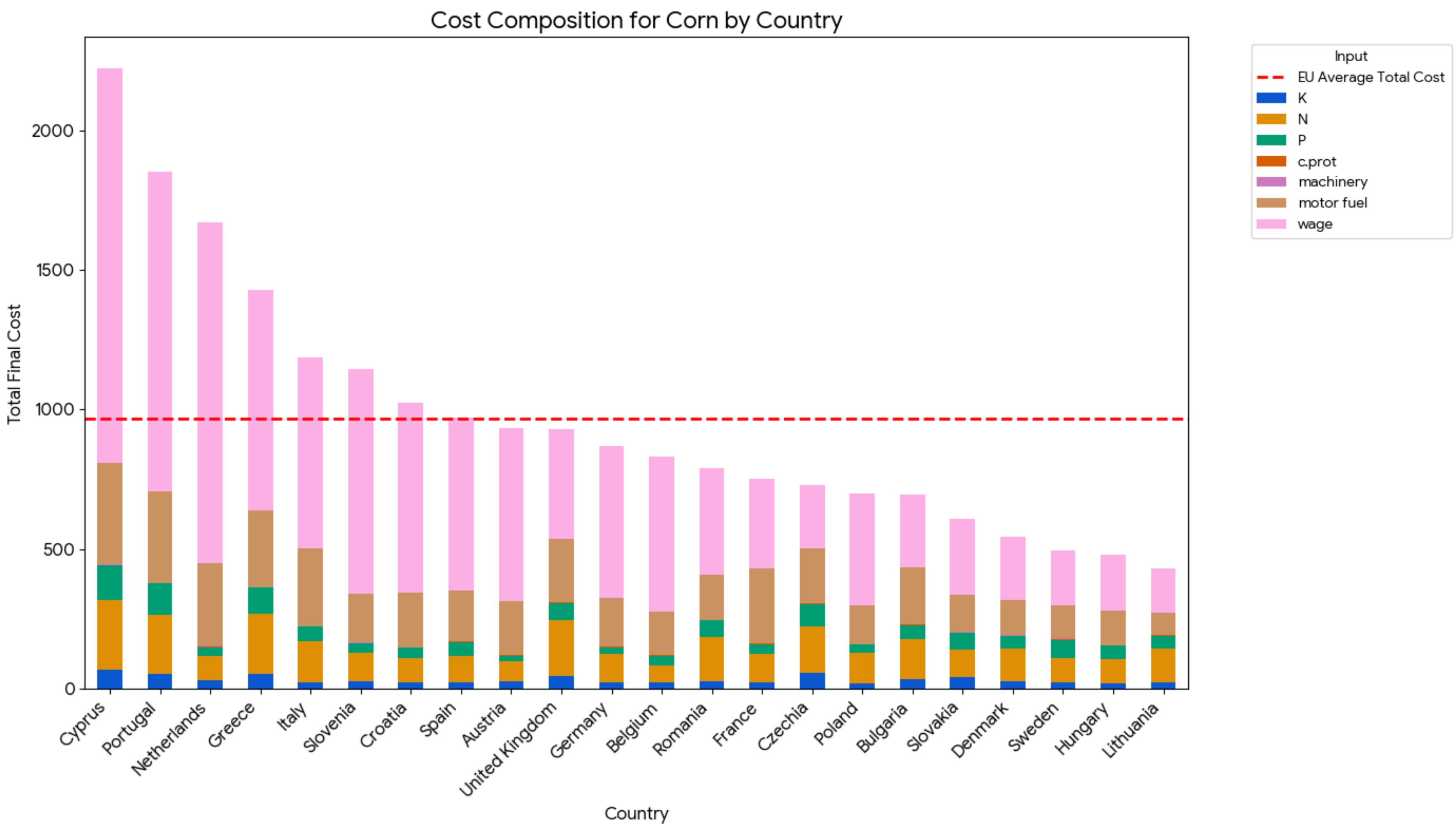

Figure A3: Cost composition of corn production across the EU

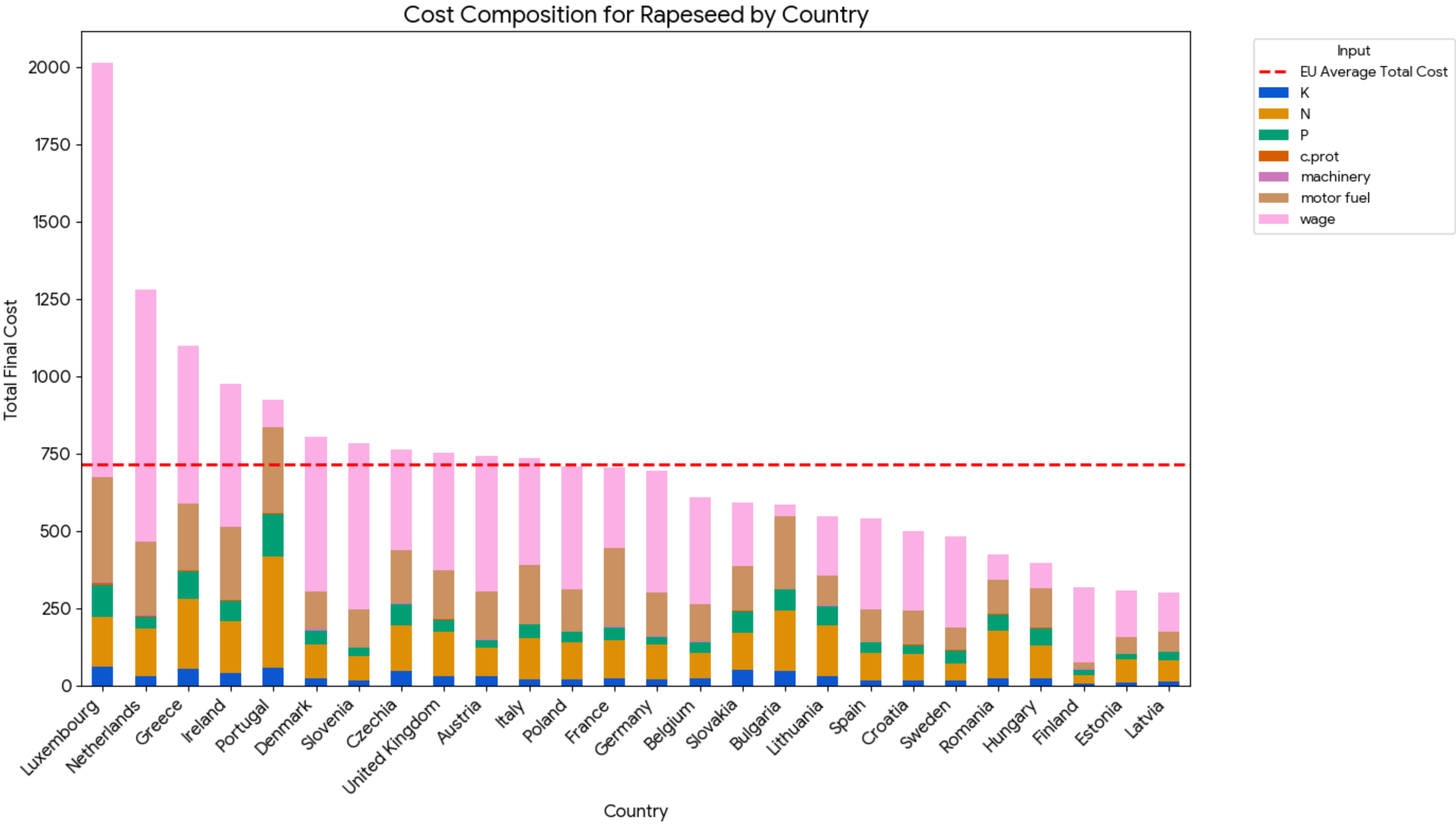

Figure A4: Cost composition of rapeseed production across the EU

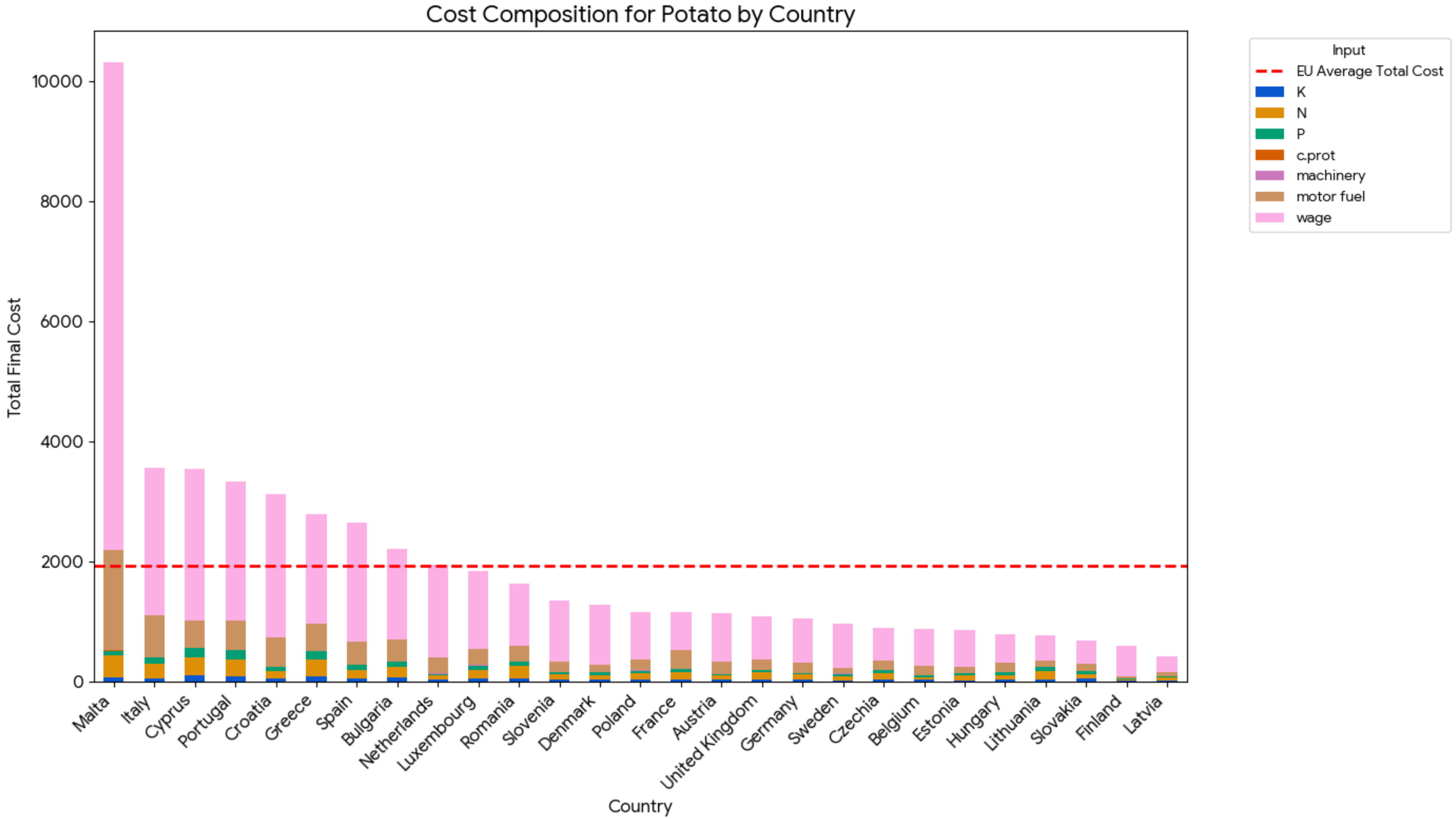

Figure A5: Cost composition of potato production across the EU

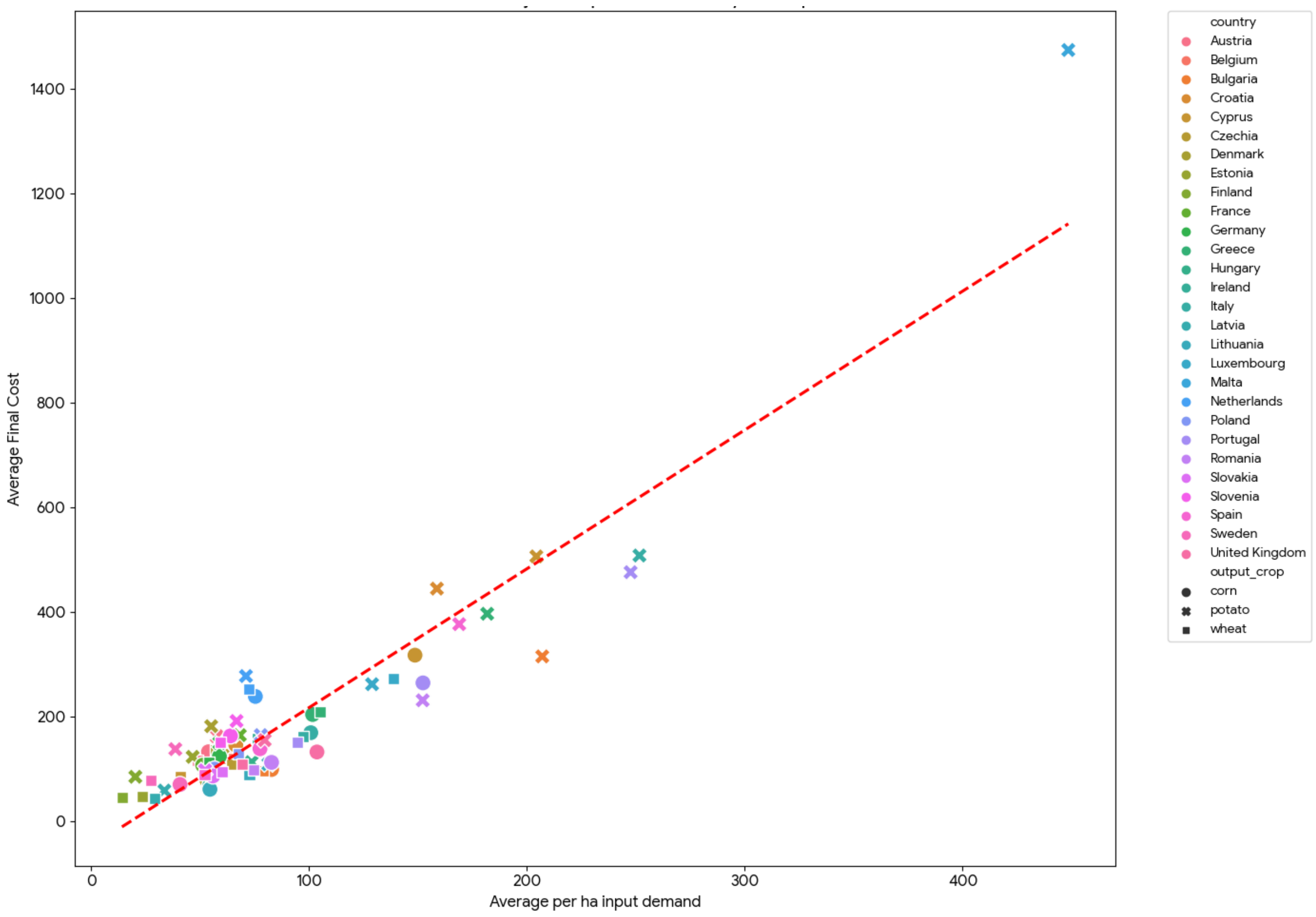

Figure A6: Plotting correlation between costs and input demand across countries for corn, wheat, and potato