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Land Use and Production Practices Shape Unequal Labour Demand in Agriculture and Forestry

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Abstract

Agriculture and forestry remain vital sources of rural employment; yet both sectors face challenges of low labour productivity, demographic change, and structural inefficiencies. Modernisation improves productivity but often reduces labour demand, creating a policy dilemma between innovation and job preservation. Therefore, this study aims to quantify labour input across different land use types related to agriculture and forestry in Latvia. This study develops a multi-stage framework to quantify labour inputs across agricultural and forestry land uses in Latvia. The research results indicate that labour intensity decreases with farm size but varies more strongly by production type. Perennial plantations, vegetable and potato cultivation, and dairy and pig farming show the highest labour demands, whereas energy crops and grass-based systems require the least. In forestry, establishment and tending dominate labour needs, while mechanised harvesting reduces input requirements. These findings highlight the strategic role of labour-intensive, high-value activities in sustaining rural employment. Policy should prioritise targeted support for labour-intensive, high-value farming and forestry activities to maximise rural jobs and income growth.

Keywords: labour input; labour demand; land use; agriculture; forestry

1. Introduction

Employment in agriculture and forestry remains a vital contributor to sustaining rural livelihoods. Agriculture remains a cornerstone of rural economies, serving as a primary source of income and employment through a wide range of activities along the agri-food value chain. Labour-intensive and sustainable agricultural practices are essential for enhancing household incomes and generating stable employment opportunities [1,2]. Employment diversification within agriculture further strengthens economic resilience, particularly among poorer households, by increasing productivity and wages [3]. The reallocation of labour to diversified agricultural activities and the adoption of cooperative farming structures foster community cohesion, social participation, and institutional collaboration [4,5].

However, the agricultural sector continues to face persistent structural challenges. These include low labour productivity, rising wage costs, and recurrent seasonal or long-term labour shortages [6,7]. These issues are exacerbated by demographic pressures such as an ageing rural population and youth outmigration, as well as by inefficiencies in labour organisation and allocation [8,9]. Additionally, climate change poses a significant threat to rural labour capacity, with rising temperatures projected to reduce agricultural labour productivity by up to a half in some vulnerable regions by the end of the century [10].

Forestry also provides essential, though often overlooked, employment opportunities in rural regions, particularly where reforestation and ecosystem restoration projects are active. The sustainable use of forest resources contributes to poverty reduction, enhances household income generation, and reinforces rural socio-economic structures [11]. Agroforestry systems have been shown in some cases to require less labour than input-intensive farming systems [12]. Despite a general decline in the forestry workforce and substantial regional disparities, the sector remains a key contributor to rural development [13]. Labour migration undermines the efficiency of forest management and local income generation [14], underscoring the need for a sufficiently skilled and locally available workforce to ensure both ecological sustainability and rural well-being.

Addressing these rural employment challenges requires a clear understanding of structural constraints such as low labour productivity and demographic shifts. Sustainable intensification, improved resource management, and selective mechanisation can reduce labour input without undermining productivity or economic viability [15,16]. Policies must prioritise the qualification, allocation, and long-term sustainability of the rural workforce to enhance the resilience of agricultural systems and promote inclusive rural development grounded in structural insight.

Policymakers in rural labour policy face a fundamental dilemma between promoting innovation and preserving employment. On one side, public support for innovation, technological advancements, and enhanced competitiveness is expected to improve farm productivity and resilience, contributing to long-term sustainability. However, these same innovations often reduce the demand for manual labour and thus reduce employment opportunities [15,17]. Even sustainable intensification and conservation-oriented practices may lower labour requirements [16]. As a result, modernisation may unintentionally displace workers, unless it is accompanied by proactive measures to ensure inclusive employment, workforce adaptation, and the long-term sustainability of rural labour markets.

The European Union (EU) Common Agricultural Policy (CAP) 2023–2027 provides a flexible framework to support sustainable rural development. This is attained primarily by maintaining rural employment [18]. Simultaneously, broader EU policy initiatives such as the European Green Deal [19], the Circular Economy Action Plan [20], and the Bioeconomy Strategy [21] all emphasise the potential for rural job creation through transitions to greener, more circular economies. These frameworks involve employment gains, provided workers possess appropriate green skills. However, quantitative evidence on the labour impacts of bioeconomy in rural areas has remained limited [22]. Thus, these developments underscore the growing importance of anticipating and quantifying workforce needs across agriculture and forestry, aligning policy ambitions with labour market realities.

This study aims to quantify the labour input across different land-use types related to agriculture and forestry in Latvia. To achieve this, a novel approach to quantifying labour input across various land uses in rural areas of Latvia is introduced. This involves a detailed and multi-stage framework that enables precise calculation of labour-hour consumption per hectare or per animal by systematically accounting for variations in enterprise size, production specialisation, and levels of technological equipment.

By addressing the current lack of quantitative data, particularly concerning the bio-economy, the study contributes to a better understanding of structural labour dynamics. It supports the formulation of policies that align economic, environmental, and social objectives in the context of sustainable rural development. The results provide an evidence base for policy decisions that seek to balance technological innovation and productivity growth with the preservation and promotion of rural employment.

2. Background of the Study

2.1. Task- and Sector-Specific Approaches to Quantifying Labour Input

In the literature on agriculture and forestry, measurement of labour input varies mainly according to sectoral focus. A common approach in crop production involves expressing labour input per unit of land, most often as labour time per hectare. Many studies adopt this land-based metric, using terms such as effective working hours per hectare, labour days per hectare, or man-hours per hectare [17,23–25]. Measurement approaches further diverge based on farming operations, such as sowing, weeding, fertilising, and irrigation [15,26–29].

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Livestock and dairy systems apply distinct labour input metrics, often defined per animal or herd task. Studies quantify the time spent per cow on activities such as feeding or milking, typically using weekly or daily timeframes [30,31]. In forestry contexts, labour input is recorded as worker days per hectare for tasks like felling, reflecting episodic but labour-intensive activities [32].

Additionally, several sources quantify labour input using standardised constructs such as annual work units or productive work hours [33,34], enhancing comparability across farm types and labour regimes. When labour inputs are expressed relative to other inputs, such as land area or the number of animals, the concept of labour intensity is appropriate [35].

A notable research gap is the absence of standardised labour input metrics, which hinders cross-study comparisons. Diverse units such as days, hours, or annual work equivalents introduce inconsistencies. Measuring labour input in terms of hours per hectare or per animal provides a consistent, scalable, and task-insensitive unit that aligns with land use intensity and livestock management, thereby enabling more accurate benchmarking across various farming systems and operational contexts.

2.2. Mechanisation as a Driver of Labour Reduction in Large-Scale and Specialised Production

Mechanisation plays a central role in reducing labour requirements in arable crop systems. Mechanical planters and dibble bars significantly reduce the time and physical effort associated with sowing operations compared to manual planting techniques [25,36]. Similarly, mechanised weeding and cultivation enhance worker productivity by lowering both the number of labourers needed and the physical burden of field tasks [37,38]. Mechanised irrigation systems, particularly sprinkler and drip systems, are likewise associated with significant labour savings per hectare when compared to furrow-based irrigation [26,39].

In contrast to annual systems, where sowing and weeding dominate labour use, mechanisation is most impactful during pruning and thinning operations in permanent cropping systems. Devices such as blossom thinners and automated thinning machines improve labour productivity by decreasing the time and labour intensity of manual thinning while enhancing crop uniformity [40,41]. Although complete replacement of manual labour is not feasible in many contexts, mechanical thinning substantially reduces the need for intensive follow-up labour and facilitates improved marketability of fruits [42,43]. Mechanical harvesters substantially reduce labour input by performing harvesting tasks more efficiently and with fewer operators [17,23].

Grassland-based production systems, including meadows and pastures, introduce yet another set of labour challenges, which are solved by mechanisation, particularly during short harvesting times. Tools such as chippers and pickup headers expedite formerly manual alignment tasks, contributing to time savings, although these technologies do not eliminate the need for manual adjustment [44]. Mechanisation of these systems allows for quicker completion of seasonal tasks, reducing dependence on large seasonal labour forces and improving time-sensitive harvesting logistics.

Mechanisation is also transformative in livestock systems, where feeding and milking are the most labour-intensive tasks. Mechanised feeding systems distribute feed while maintaining consistency in ration delivery [45]. Automated milking systems reduce the labour required for routine milking and offer consistent labour demands across varying herd sizes, contributing to scalability and management flexibility [31,46]. More broadly, the integration of digital technologies and mechanised equipment into dairy operations has led to considerable gains in labour efficiency and productivity [47].

As this evidence suggests, larger farms often benefit more from the economies of scale of mechanisation, reducing labour input per unit area or animal. Specialisation in production increases task complexity, usually resulting in higher labour efficiency gains from mechanisation. Accurate labour input estimation must thus consider both scale and specialisation of production to reflect realistic workload differences and help optimise resource allocation in diverse agricultural and forestry settings.

2.3. Scale and Technology Boost Labour Efficiency on Larger Farms

Larger operations tend to exhibit greater labour efficiency and increased reliance on hired hands relative to their smaller counterparts. In crop systems, evidence from plantation contexts shows that large estates employing mechanised harvesting cover substantially more area per hour than those relying on manual tools [17]. Mechanised grain farms similarly report improvements in yields, profitability, and food self-sufficiency. Interestingly, the most significant benefits are often observed among the smallest holdings, which face acute labour shortages. At the same time, the largest farms show more modest reductions in wage labour demand following mechanisation [48,49].

A similar pattern emerges in livestock production, where labour productivity rises with herd size. Herds beyond the medium threshold required markedly fewer labour hours per animal than their smaller counterparts [46,50]. Beef enterprises of considerable scale achieved higher output per labour unit, reflecting economies of scale in both land and livestock management [8]. Time devoted to calf care per farm increased with herd expansion, while per-calf attention remained greatest on the smallest holdings [51].

Beyond efficiency measures, structural characteristics also influence labour organisation. Larger and more diversified farms are more likely to employ wage workers, and greater tenancy is associated with higher overall labour inputs [33,52].

Despite these insights, comparative studies explicitly contrasting small and large enterprises across production systems remain limited. Most research focuses either on highly mechanised large-scale operations or on smallholder farms in isolation. Moreover, existing work typically measures labour efficiency in terms of output value rather than relative to land area or animal numbers. These gaps constrain a comprehensive understanding of how scale shapes labour input as a dimension of resource demand.

2.4. Labour Needs Differ by Production Specialisation and Crop Type

Labour requirements in agriculture vary significantly across different production systems and management practices. Specialised, high-value systems, such as cherry and vegetable cultivation, are notably labour-intensive [2,53]. Similarly, organic farming, although it demands more labour per hectare, tends to provide more stable employment compared to conventional methods [1]. Conversely, some less intensive systems, like oil palm cultivation, can lead to a decrease in overall family labour [54].

The adoption of certain agricultural practices also influences labour dynamics. Conservation agriculture, for instance, presents a mixed picture. Some studies indicate an increase in labour input requirements, particularly for women, with instances of child labour observed in Sub-Saharan Africa [55]. However, other findings suggest that conservation agriculture-based sustainable intensification practices can substantially decrease labour use [16,56]. Agroforestry practices have also been shown to require less labour than fertilised maize fields, though more than non-fertilised continuous maize [12].

Furthermore, specific tasks within agricultural systems contribute to varying labour demands. For example, early cleaning activities can require varying labour inputs depending on the season, spanning several productive work hours per hectare [34]. In livestock systems, calf care and milk feeding illustrate how certain stages require disproportionately high labour inputs despite overall efficiency gains from scale [51,57].

Overall, comparative studies examining labour inputs across different agricultural domains remain scarce. Most research tends to focus on specific animals or crops, resulting in fragmented insights that hinder a comprehensive understanding of labour dynamics across farming types. This gap restricts the ability to generalise findings or develop integrated labour efficiency strategies applicable across varied agricultural contexts.

2.5. Forestry Integrates Labour Costs for Operational Planning

Labour costs are a central component of forestry planning models, often included to assess economic feasibility and conduct sensitivity analyses. For instance, models developed in Latvia have included labour expenses to facilitate sensitivity analyses of key cost drivers, such as timber volume and transport distance [58].

Beyond modelling exercises, empirical studies emphasise that labour efficiency in forestry depends on both environmental and operational factors. In North America, challenging terrain and dense vegetation have been shown to reduce worker productivity [59]. Stand type and silvicultural operation likewise influence the time and effort required.

Work-time studies reveal that production activities such as felling, processing, stacking, and extraction typically account for the majority of labour input. At the same time, worksite preparation and equipment maintenance make up the remainder [32]. The duration of these tasks varies considerably depending on stand conditions and harvesting methods.

Aside from these studies, research explicitly quantifying labour requirements in forestry is limited. Most studies address labour costs indirectly through operational models, while comprehensive empirical assessments across diverse forest conditions and management practices are sparse. Closing this gap is essential for improving the accuracy and applicability of forestry planning tools.

3. Materials and Methods

3.1. Agriculture

In this study, labour input in agricultural land use is defined as the number of labour hours per hectare of land or per grazing animal. Labour input is quantified for the main crop groups (cereals, oilseeds and pulses; vegetables and potatoes; perennial crops; energy crops; other crops; fallow land; grassland in arable land; meadows and pastures) and main grazing animal groups (dairy cows; other grazing animals; pigs; poultry) in 2021, because this year was typical year for agricultural activities in Latvia. The calculation process incorporates a farm size-based classification system, as summarised in Appendix A (Table A1). The classification was undertaken to examine the effects stemming from the assumption that smaller farms require more intensive labour input than larger farms, primarily due to their reliance on outdated machinery and equipment.

The assessment of labour input across agricultural sectors and farm size groups in this study applies multiple methods as follows: 1) the ordinary least squares regression method was performed on the Latvian Farm Accountancy Data Network (FADN) farm-level data [60], 2) calculation of average labour hours for specialised farms in FADN data [60], and 3) adjustments were made using the Latvian Rural Consulting and Education Centre (LLKC) Gross Margins calculations [61].

The analytical framework applies the ordinary least squares regression method, where the dependent variable is total labour input (hours) comprising both paid and unpaid labour within farm operations, and the independent variables are land area allocated to different production types and average livestock population per farm. To address the FADN data limitations, a composite grazing animal group, "other grazing animals", was created, applying standardised weighting coefficients of 1 for non-dairy cattle and horses, and 0.3 for sheep and goats. The regression outputs are presented in Table 1.

Table 1. Average labour input (hours) per hectare or per grazing animal, and statistical output parameter estimates and significance levels in different agricultural sectors in Latvia in 2021*.

Parameter	Estimate	Std. Error	t-value	Probability (>|t|)	Significance
Intercept	1 128	103.1	10.938	< 2e-16	***
Cereals, oilseeds, pulses	12.42	0.3791	32.763	< 2e-16	***
Vegetables and potatoes	215.4	14.06	15.325	< 2e-16	***
Perennial plantations	234.2	19.10	12.258	< 2e-16	***

Other crops	54.89	6.51	8.431	< 2e-16	***
Dairy cows	87.04	3.079	28.265	< 2e-16	***
Other grazing animals	12.19	1.849	6.590	7,51e-11	***
Pigs	3.46	0.07882	43.895	< 2e-16	***
Poultry	0.8394	0.0889	9.443	< 2e-16	***

* Significance codes: 0 '' 0.001 '' 0.01 '' 0.05 '.' 0.1 '' 1. Residual standard error: 2 407 on 889 degrees of freedom. Multiple R-squared: 0.8676, adjusted R-squared: 0.8664. F-statistic: 728.1 on 8 and 889 DF, p-value: < 2.2e-16.

Table 1 presents the mean labour input in terms of hours per hectare or per grazing animal across various agricultural sectors in Latvia in 2021, along with regression parameter estimates and p-values.

The results indicate a significant disparity in labour requirements among industries. Vegetable/potato cultivation and plantations of perennials recorded the highest average labour per hectare (234.2 and 215.4 hours, respectively), while dairy cow husbandry had the highest average labour input per animal (87.04 hours). Poultry and pig sectors, however, required significantly lower amounts of labour (0.84 and 3.46 hours, respectively), while other grazing animals had an average of 12.19 hours.

To quantitatively assess labour input for various types of agricultural land use, anonymised farm-level data from the FADN for the year 2021 were utilised [60]. FADN is a harmonised European system for collecting microeconomic data on farms, providing detailed information on farm incomes, production activities, and structural characteristics for policy analysis and research. From the 1,000 farms in the FADN data, a subset of 898 farms (90% of the total) was used for calculations, excluding:

- rabbit farms (results are not statistically significant);
- beekeeping farms (very large differences in labour input between medium and large farms);
- farms where the number of calves exceeds the total number of dairy cows and other cattle by 2 times or more (rapidly expanding);
- farms with only areas of meadows and pastures;
- cereal, oilseed, and pulse farms with relatively high outsourcing (exceeding 5 EUR per hour);
- farms where the difference between observed values and those predicted by the statistical model (residual) exceeds a magnitude of 10,000 (extreme values that interfere with accurate calculation results).

Although the FADN provides detailed data on approximately 1,000 Latvian farms, most of them are mixed-specialisation enterprises that produce several products at the same time. In such a situation, it is not possible to accurately determine the labour input into the production of each product.

To overcome this challenge, the calculations are performed by selecting FADN farms with the narrowest possible specialisation. However, even within this group, significant differences in results are observed between farms. Therefore, the obtained data are adjusted using the LLKC Gross Margins data for 2021, which defines standard activities for different crop groups and grazing animal groups.

The total land area and number of grazing animals for each crop and grazing animal group, categorised by farm size groups, were calculated using FADN data [60]. Due to frequent underreporting of land areas for micro farms in FADN records, calibration was performed for this farm size category using national statistics [62], which reports a total agricultural land use area of 1.97 million hectares (in Appendix A, Table A2).

Our calculation results are cross-validated using Eurostat statistics on agricultural labour input [63]. This comparison ensures the methodological accuracy of our conclusions. According to these data, in 2021, the total labour input from agricultural land use was 61.15 thousand Annual work units (AWU), where 1 AWU = 1,840 hours per year, of which 21.78 thousand AWUs correspond to salaried employees, while 39.37 thousand AWUs to employees working without direct remuneration, benefiting instead from profits or production outputs.

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3.2. Forestry

For calculations of labour input from forestry land use, a different approach is applied, although the outcome is the same – labour hours per hectare of land use. In forestry, labour input is dependent on the dominant tree species as well as the silvicultural activity or timber extraction done in the forest area. The latest available data for 2024 was used for calculations. Due to the purpose of different forestry activities, the labour input calculations have been classified into silvicultural and logging activities. In the estimation of labour inputs in forestry land use, such silvicultural activities as soil preparation, planting, forest protection, forest replenishment, tending, young stand tending, underbrush tending, and maintenance of amelioration systems are included. The labour inputs for each silvicultural operation, depending on the dominant tree species, have been determined based on evaluations by industry practitioners.

As for logging activities, the labour input was assessed by determining the capacity of each piece of equipment per hour, depending on the logging activity, cubic meters per hour (m^3/h), as reported in the Latvian State Forest's 2024 efficiency indicators of logging service providers [64]. Logging activities employ techniques such as a harvester and chainsaw (for cutting trees), a forwarder (for timber delivery), and transport (for timber transportation). In addition to capacity, the proportion of chainsaw use in percentage (%) was determined, depending on the dominant tree species and logging activity (see Appendix A, Table A3).

The total land area for silvicultural and logging activities, depending on the dominant tree species, was calculated using data from national statistics in 2022 as follows:

- Soil preparation is employed in natural forest regeneration to enhance the success rate of regeneration through natural processes. However, soil preparation is not universally applied in all instances of natural regeneration. For this analysis, it is assumed that soil preparation, specifically topsoil mineralisation achieved by creating furrows with a disc plough or ridges using an excavator, is implemented in approximately 50% of naturally regenerating forest areas. Consequently, the total area subjected to soil preparation was estimated by summing the total area of forest regeneration achieved through sowing and planting with half of the naturally regenerating forest area, based on national statistical data on forest regeneration [65];
- The total area of forest planting was calculated by combining the total area of forest regeneration (by sowing and planting) with the total area of planted forests as reported in the national statistical data on afforestation [66];
- The total area of forest requiring protection (except for dominant tree species – black alder, aspen, and white alder) and tending was determined by aggregating the total area of forest regeneration conducted over the preceding four years;
- It is posited that the area requiring young stand tending is approximately 30% smaller than the total area requiring tending, reflecting the less frequent and prolonged tending needs of young stands;
- The total area subjected to forest replenishment was estimated as half of the total area of regenerated forest;
- Data on the total forest area where logging activities – including main felling, maintenance felling, and other types of felling – were conducted, along with corresponding timber stock, were obtained from national statistical records on inventoried forest felling areas and stock volume [67];
- It is assumed that the total area subjected to underbrush tending corresponds to 90% of the total area of logging activities;
- The total area where maintenance of amelioration systems has been performed was obtained from national statistical data on forest land area [68].

The total areas of silvicultural activities are summarised in Appendix A (Table A4). The total areas of logging activities and their total stock volumes are reported in Appendix A (Table A5).

The validation of the determined labour input was conducted using national statistical data on employment by activity type [69], which reported a total workforce of 13,200 full-time equivalent

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employees in 2022. By comparing our results with this official statistic, we ensure the methodological robustness of our approach.

3.3. Spatial Analysis

Several data sources are used for spatial identification. For field-level crop production, Rural Support Service data for 2021 are used (upon request, not publicly available). For the spatial location of grazing animal holdings, the Agricultural Data Centre produces data for 2021, which is available upon request (not publicly available). For spatial information on all forest parcels and their dominant tree species, data from the State Register of Forests for 2024 is used (upon request, publicly not available).

Based on this information, we calculated the labour input at the individual parcel level, taking into account the characteristics of each plot and management practices (the overall size of the farm managing each specific land parcel). To ensure data protection for individual fields and to make spatial visualisation more straightforward, the parcel-level results were summarised in a grid of 100-hectare square cells [70]. By standardising the data in 100-hectare cells, greater consistency and comparability in the spatial representation of labour intensity across the study area were achieved, and the processing of complex parcel geometries was simplified.

4. Results

4.1. Agriculture

The results reveal substantial variation in labour inputs across different agricultural sectors and farm size groups (Table 2). The highest labour inputs per hectare were observed in perennial plantations and vegetable and potato cultivation. On micro farms, perennial plantations required an average of 726 hours per hectare, followed closely by vegetables and potatoes at 667 hours per hectare. Small farms reported slightly lower labour inputs in these categories, with 647 and 595 hours per hectare, respectively. Thus, labour intensity decreased substantially with farm size – large farms required 234 and 215 hours per hectare in perennial plantations and vegetable production, respectively, while medium farms required 441 and 405 hours.

Labour input differences across farm size groups were also notable for grazing animal categories. For dairy cows with calves, micro farms reported the highest labour requirement at 387 hours per animal, followed by small farms (196 hours), medium farms (106 hours), and large farms (87 hours). A similar pattern emerged across other grazing animal farms. Goats required 203 hours per animal on micro farms, but only 42 on both large and medium farms. Horses required 82 hours per animal on micro farms and 17 hours on large and medium farms. Sheep and other grazing animals followed the same trend, with labour inputs increasing consistently from large to micro farms.

Among arable crops, cereals, oilseeds, and pulses exhibited moderate labour intensity, with micro farms requiring 63 hours per hectare and large farms only 15 hours per hectare. Energy crops consistently required the lowest labour inputs across all farm size categories, ranging from 13 hours per hectare on large and medium farms to 28 hours per hectare on micro farms.

Table 2. Average labour inputs in agricultural land use, categorised by farm size groups and the main crop and grazing animal groups in Latvia in 2021, hours per hectare or grazing animal.

Agricultural sector	Large farms	Medium farms	Small farms	Micro farms	Micro farms differ from large farms, times
Cereals, oilseeds, pulses	15	20	32	63	4.2
Vegetables and potatoes	215	405	595	667	3.1

Perennial plantations	234	441	647	726	3.1
Energy crops	13	13	25	28	2.2
Other crops	55	103	152	301	5.5
Fallow land	7	8	16	28	4.0
Grasslands	16	30	44	88	5.5
Meadows and pastures	3	6	9	18	6.0
Dairy cows (with calves)	87	106	196	387	4.4
Other grazing animals	24	32	55	65	2.7
Sheep	9	9	18	45	5.0
Goats	42	42	72	203	4.8
Horses	17	17	29	82	4.8
Pigs	3.5	20	60	119	34.0
Poultry	0.8	0.8	2.3	4	5.0

For fallow land, grasslands, and meadows/pastures, labour inputs were uniformly very low but still demonstrated a positive association with decreasing farm size. For example, labour input on fallow land ranged from 7 hours per hectare on large farms to 28 hours per hectare on micro farms. Similarly, meadows and pastures required just 3 hours per hectare on large farms compared to 18 on micro farms (Table 2).

In the category of non-ruminant livestock, pigs and poultry showed markedly low labour requirements on large farms, 3.5 and 0.8 hours per animal, respectively. However, these values increased considerably on micro farms to 119 hours for pigs and 4 hours for poultry. Medium farms showed an especially steep increase for pigs, reporting 20 hours per animal (Table 2).

The spatial distribution of agricultural labour intensity across Latvia follows considerable regional variation (Figure 1). The highest continuous levels of labour input intensity are concentrated in the western regions of the country. Central Latvia has high labour input intensity, indicating sustained agricultural activity. In contrast, the areas surrounding the capital, Riga, show very low levels of agricultural labour input. In eastern Latvia, labour intensity also remains high, suggesting that agricultural practices in this region similarly require substantial labour inputs. The northern area of Latvia displays a consistent pattern of medium to low labour intensity, indicating a moderate level of agricultural engagement. In general, the map reveals a structured spatial gradient in agricultural labour input intensity, with the most pronounced activity occurring in western and south-eastern Latvia.

Figure 1. Spatial distribution of agricultural labour intensity in Latvia in 2021, hours per 100 hectares [70].

4.2. Forestry

The average labour input associated with forestry land use shows notable variation across silvicultural operations and dominant tree species (Table 3). The most labour-intensive operations are underbrush tending, young stand tending, and general tending, each consistently requiring 23 to 25 hours per hectare across nearly all tree species. Specifically, underbrush tending exhibits the highest average input, reaching 25 hours per hectare uniformly for all species except aspen and grey alder, which have reduced labour requirements in other categories.

Planting and soil preparation are also prominent labour inputs, with both operations requiring 24 and 20.3 hours per hectare, respectively, for pine, spruce, birch, black alder, and other species. These operations are absent for aspen and grey alder, suggesting a different silvicultural regime for these species. Forest replenishment requires 22 hours per hectare for all species except birch, aspen, and grey alder.

Forest protection labour input is reported at 13.5 hours per hectare for pine, spruce, birch, and other species. Maintenance of amelioration systems is uniform across all species, requiring 13 hours per hectare, indicating standardised management efforts in this domain regardless of species composition.

Overall, tending operations are the most uniformly applied and labour-intensive activities across species. At the same time, soil preparation, planting, forest protection and replenishment vary more substantially and are absent for some species, particularly aspen and grey alder.

Table 3. Average labour inputs in forestry land use categorised by silvicultural operations and the dominant tree species in Latvia in 2024, hours per hectare.

Dominant tree species	Soil preparation	Planting	Forest protection	Forest replenishment	Tending	Young stand tending	Underbrush tending	Maintenance of amelioration systems
Pine	20.3	24	13.5	22	23	23	25	13
Spruce	20.3	24	13.5	22	23	23	25	13
Birch	20.3	24	13.5	0	23	23	25	13

Black alder	20.3	24	0	22	23	23	25	13
Aspen	0	0	0	0	23	23	25	13
Grey alder	0	0	0	0	23	23	25	13
Other	20.3	24	13.5	22	23	23	25	13

The highest equipment capacities are observed in timber transport by lorry, with a consistent output of 18 cubic meters (m^3) per hour across all logging activities. Harvesters also demonstrate a substantial capacity, particularly in main felling and other types of felling, yielding 18.7 m^3/h, more than double the capacity recorded for maintenance felling (7.9 m^3/h) (Table 4).

Table 4. The average capacity of logging equipment, depending on logging activity in Latvia in 2024, m^3 per hour.

Logging activity	Harvester	Chainsaw	Forwarder	Timber lorry
Maintenance felling	7.9	0.9	5.8	18
Main felling	18.7	0.9	12.2	18
Other types of felling	18.7	0.9	12.2	18

Forwarders exhibit moderate variation, with capacities ranging from 5.8 m3/hour during maintenance felling to 12.2 m^3/h during main and other types of felling. This increase parallels the pattern observed for harvesters, indicating higher productivity in non-maintenance operations (Table 4).

Chainsaw productivity remains constant at 0.9 m^3/h across all logging activities, representing the lowest capacity among all equipment types and the only value that does not vary with logging context.

In summary, harvester and forwarder capacities are markedly higher during main and other types of felling than in maintenance felling, while timber lorry and chainsaw outputs remain unchanged across activities.

Unlike agriculture, where output is annual or more frequent, forestry demands continuous labour over a long rotation cycle. Labour intensity fluctuates widely, with alternating periods of low and high demand, which limits direct comparability with agriculture.

The spatial distribution of forestry labour input intensity in Latvia reveals a distinct pattern of clustering, with marked regional variation in labour allocation to forestry activities (Figure 2). In the south-eastern region of Latvia, forestry labour intensity is low relative to most of the territory. This area features several delineated clusters of high-intensity labour input, indicating localised concentrations of forestry operations. Northern Latvia exhibits relatively high levels of forestry labour input. The area comprises several smaller clusters of intense labour inputs, reflecting a dispersed yet notable forestry presence. A contiguous band of elevated labour intensity is observed traversing the central part of the country, extending through parts of Latvia. In the coastal region of Latvia, forestry labour intensity is higher compared to adjacent inland territories. Overall, the data indicate that the most labour-intensive forestry activities in Latvia are concentrated in coastal areas of the west and in the central region, characterised by numerous small spatial clusters with high labour input levels.

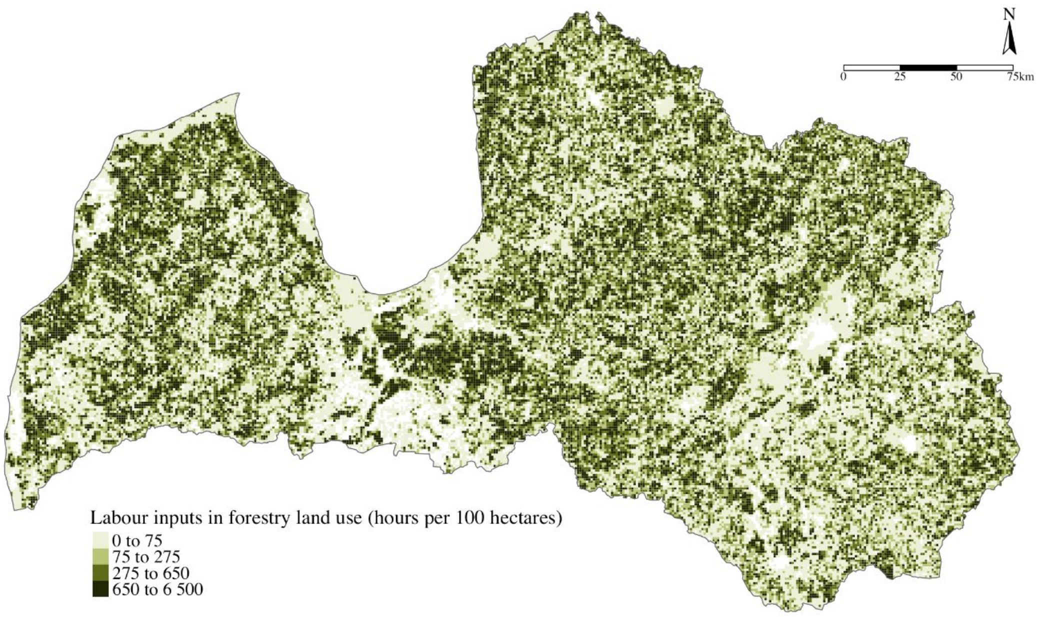

Figure 2. Spatial distribution of forestry labour intensity in Latvia in 2024, hours per 100 hectares [70].

5. Discussion

5.1. Farm Size and Labour Intensity in Agriculture

The research results consistently suggested that larger farms systematically require fewer labour hours per unit of output, whether measured per hectare or animal, than their smaller counterparts. Several interrelated factors contribute to this pattern. Larger farms typically possess greater capacity to invest in mechanisation, automation, and optimised infrastructure, thereby reducing reliance on manual labour [17]. This is particularly evident in labour-intensive sectors such as pig production and grazing livestock, where large farms demonstrated labour input reductions exceeding 80%, and up to 97% in the case of pigs, relative to micro-scale operations. These efficiencies are less accessible to smaller farms due to capital constraints and the indivisibility of specific technologies.

Larger holdings often adopt more streamlined workflows, whereas micro and small farms frequently rely on diverse, low-tech, and labour-intensive methods [51]. As a result, micro farms exhibited labour input levels at least three times higher per unit than large farms, reflecting both technological and organisational limitations.

Fixed labour requirements associated with supervision, maintenance, and animal care do not scale linearly with production size. Larger herds or field areas do not necessarily entail proportional increases in labour demand, as evidenced by markedly lower labour hours per animal on larger livestock farms in the results. This nonlinear scaling of labour inputs aligns with previous empirical findings [46,50], reinforcing the interpretation that increased farm size yields significant labour efficiencies.

The findings also support international evidence suggesting that while land productivity may plateau or decline with increasing size, labour productivity typically rises with larger scales of agricultural production [35]. As scale increases, management and operational efficiencies tend to favour labour productivity gains. In contrast, land productivity may stagnate or even decline due to less intensive land use, diminished attention to marginal plots, or reliance on monocultures.

5.2. Complexity of Production as the Key Driver of Labour Demand

Although labour intensity declines with increasing farm size across all sectors, this effect is more pronounced in labour-intensive systems. The analysis thus challenges the common assumption that small farms are intrinsically labour-intensive due solely to their size. Instead, the results of this study highlight that production complexity is a more accurate determinant of labour demand.

Micro and small farms growing vegetables or managing grazing livestock require disproportionately high labour per hectare or animal, indicating that the labour burden is elevated not because of their small scale, but due to the complexity of the agricultural systems involved. Highly specialised and high-value systems, such as vegetable cultivation and perennial plantations, consistently require greater labour input due to their complex, labour-intensive tasks, as has also been demonstrated by some earlier studies [2,53]. In contrast, extensive systems such as fallow land and grasslands were considerably less labour-intensive, and this was likely not due to scale but due to their low management complexity.

High-value and management-intensive systems involve manual tasks that are difficult to mechanise, yet mechanisation and standardisation play a critical role in reducing labour input. Arable crops benefit from economies of scale and high mechanisation potential, leading to reduced labour requirements on larger farms, as confirmed by the results. Infrastructure and system constraints explain the labour intensity of small-scale livestock operations. For instance, micro farms raising dairy cows or pigs face higher labour requirements, likely due to the lack of automation and limited access to specialised labour-saving equipment.

Substantial variation across production types furthermore reinforces the role of production complexity. Perennial crops, vegetables, and livestock systems exhibited significant disparities in labour inputs across size classes, whereas energy crops, grasslands, and fallow land showed uniformly low labour needs. Thus, variation in labour intensity is explained by activities involved rather than by the size of operations, suggesting that labour requirements are more closely tied to production type than to scale.

These research results align with broader research indicating that the overall structure of land use and the specific mix of activities, rather than farm size alone, are central determinants of employment creation, rural livelihoods, and the trajectory of structural transformation in rural areas [71].

5.3. Silvicultural Regimes Drive Episodic Variation in Forestry Labour Input

The results indicate that labour demand in forestry is more closely associated with the complexity of specific operations than with the category of tree species. Moreover, labour demand in forestry appears to be episodic, with pronounced peaks during establishment and tending phases, and a significant reduction in direct employment needs as mechanisation in logging increases. The most labour-intensive operations, such as underbrush tending, young stand tending, and general tending, required 23 to 25 hours per hectare across nearly all tree species. Their uniformity suggests that labour demand in these phases is governed by the intrinsic complexity of managing early stand development, which is relatively unaffected by species differences. Similarly, planting and soil preparation required high labour input for most species, but were absent for aspen and grey alder, indicating differences in silvicultural regimes rather than species.

The analysis of equipment productivity reveals how operational complexity shapes indirect labour requirements. Harvester and forwarder capacities were significantly higher in main and other types of felling than in maintenance felling, indicating that using equipment to save labour works best in large, less fragmented operations. In contrast, chainsaw productivity remains consistently low across all logging contexts, highlighting both the persistence of manual labour in certain operations and its limited scalability. The high labour intensity associated with timber lorry operations, irrespective of felling method, is supported by study indicating that log transport by truck incurs relatively high labour costs [58].

5.4. Land Use Legacies and Spatial Patterns of Labour Intensity

Historical land use legacies and prevailing biophysical constraints strongly shape labour input patterns. The spatial distribution of labour demand closely mirrors the patterns of forested versus agricultural land cover [72], which continue to structure regional labour allocation. In Latvia, a clear spatial inverse relationship exists between forest and agricultural land use, which is reflected in the opposing labour input intensities across the two sectors. Regions characterised by extensive forest cover show higher forestry labour demand, whereas areas dominated by agricultural land exhibit more labour-intensive farming activities. These patterns suggest that the nature and intensity of land use, determined by both ecological suitability and historical land management regimes, remain key drivers of regional labour demand variation.

In and around the metropolitan region of the capital city, Riga, both agricultural and forestry labour inputs are markedly low. This pattern aligns with the urban character of the area, which is characterised by high population density, a dominant non-agricultural employment sector, and limited land availability for primary production. As a result, labour input patterns in the capital region deviate from those observed elsewhere in the country, further underscoring the influence of land use practices and socio-economic context on labour distribution.

Notably, the findings indicate that peripheral regions, such as the eastern regions of Latvia, can exhibit levels of labour intensity that surpass those of more central economic zones. This contradicts the expectation that labour intensity scales uniformly with production size and suggests instead that diversified farming practices, lower degrees of mechanisation, or specific market and environmental constraints may generate heightened labour demands.

5.5. Limitations, Policy Improvements and Opportunities for Future Research

Several limitations related to data and methodology warrant consideration. Parcel-level data often represent mixed-specialisation farms, hindering the precise attribution of labour inputs to specific products. While the analysis emphasises specialised farms and incorporates LLKC standard activity data for calibration, some heterogeneity persists. The land areas of micro-farms are frequently underreported, although partially corrected using national statistics. In forestry, the long rotation cycle and uneven temporal distribution of labour complicate annual comparisons with agriculture; estimates rely on assumptions about the share of land undergoing particular silvicultural operations.

The research demonstrates how scale, production complexity, land use, and technological interactions impact labour demand in agriculture and forestry. The implication of the results points to policy and research priorities. Future research should focus on addressing the structural and data-related gaps revealed in this study. Long-term evaluation of mechanisation uptake, particularly among smaller farms, is necessary to understand how capital constraints and access to technology shape labour dynamics over time. Comparative analysis across production systems would help identify tasks and activities that remain resistant to technological improvements and thus continue to demand significant manual labour. In parallel, integrating labour efficiency assessments with environmental and social sustainability frameworks could clarify trade-offs between productivity gains, ecological goals, and rural employment opportunities. More advanced spatial analyses that combine information on land use, mechanisation potential, and demographic factors would also enhance understanding of regional disparities in rural labour intensity. For forestry, further research should investigate how silvicultural practices and climate adaptation strategies influence episodic patterns of labour demand. Finally, improving parcel-level labour data and addressing underreporting by micro-farms, together with applying dynamic models to evaluate efficiency drivers across farm size and production types, would substantially refine the evidence base for rural employment and policy design.

Many policymakers are paying substantial attention to facilitating employment in rural areas. Moreover, one of the tools used is differentiating support payments based on the size of the farms [73,74]. The research shows that farm size only partially explains labour demand intensity. Furthermore, specialisation plays an even more critical role in creating employment opportunities than size. From this perspective, for employment facilitation, primary attention of rural employment facilitation policies should not be on size, but specialisation.

6. Conclusions

This study quantified typical labour inputs across agricultural and forestry land uses in Latvia, calculating labour hours per hectare or animal for a wide range of production types, farm sizes, tree species, and tasks. Labour input estimates were derived by calculating average labour hours for specialised farms, further adjusted through LLKC Gross Margins estimates, and complemented by expert evaluations or calculated using equipment productivity indicators. The results demonstrate that labour intensity consistently declines with increasing farm size, yet differences between production types are even more pronounced. Highest labour intensity occurs in perennial plantations, as well as in vegetable and potato cultivation. Among livestock, dairy cows and pigs required exceptionally high labour inputs, with pigs showing one of the most pronounced disparities between micro and large scales of production. Energy crops and grass-based land uses require the lowest labour inputs, though even this shows increased labour demands on smaller farms. In forestry, tending and establishment operations (planting, soil preparation) dominate labour demand, while mechanised harvesting shows pronounced productivity advantages for felling. The spatial distribution of labour demand closely reflects the longstanding division between forested and agricultural areas, although labour intensity only partly reflects land use.

The empirical evidence generated by this study has several implications for rural development policy, particularly concerning fostering employment in the agricultural and forestry sectors. While supporting smaller farms can maximise employment per unit, our findings emphasise that prioritising labour-intensive and high-value crops and activities, such as perennial plantations, vegetable and potato cultivation, dairy farming, and pig farming, is equally, if not more, critical for driving rural job creation and rising incomes. These sectors consistently show the highest labour demands, and are thus strategic targets for employment-focused support. Conversely, energy crops and grass-based systems, while extensive, contribute less to labour demand and should not be prioritised solely for job creation. In forestry, labour demand is concentrated in tending and regeneration operations, suggesting that policy attention should shift to silvicultural workforce development for employment generation. International and European experience demonstrates that rural development policies, such as the CAP, can positively influence farm employment. However, the impact depends strongly on the type of subsidy and its targeting. Investments in labour-intensive sectors, value-added activities, and diversification are more likely to sustain and create jobs than broad-based support based solely on farm size.

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Abbreviations

The following abbreviations are used in this manuscript:

AWU	Annual work units
CAP	European Union Common Agricultural Policy

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EU	European Union
FADN	Latvian Farm Accountancy Data Network
h	hours
LLKC	Latvian Rural Consulting and Education Centre
m^3	cubic meter
%	percent

Appendix A

Table A1. Farm size groups in different agricultural sectors in Latvia in 2021.

Agricultural sector	Large farms	Medium farms	Small farms	Micro farms
Cereals, oilseeds, pulses (ha)	>300	>100, ≤300	>20, ≤100	≤20
Potatoes and vegetables (ha)	>30	>10, ≤30	>2, ≤10	≤2
Perennial plantations (ha)	>30	>10, ≤30	>2, ≤10	≤2
Energy crops (ha)	>30	>10, ≤30	>2, ≤10	≤2
Other crops (ha)	>150	>50, ≤150	>10, ≤50	≤10
Fallow land (ha)	>300	>100, ≤300	>20, ≤100	≤20
Grassland (ha)	>300	>100, ≤300	>20, ≤100	≤20
Meadows and pastures (ha)	>300	>100, ≤300	>20, ≤100	≤20
Dairy cows (number)	>200	>30, <=200	>4, <=30	<=4
Other grazing animals (number)	>200	>30, <=200	>4, <=30	<=4
Horses (number)	–	>30	>4, <=30	<=4
Goats (number)	–	>50	>5, <=50	<=5
Sheep (number)	–	>50	>5, <=50	<=5
Pigs (number)	>=1000	>=100, <1000	>=5, <100	<5
Poultry (number)	>=50k	>=1k, <50k	>=20, <1k	<20

Table A2. The total land area (ha) and grazing animal number for each crop and grazing animal group, categorised by farm size groups in Latvia in 2021.

Agricultural sector	Large farms	Medium farms	Small farms	Micro farms	Total
Cereals, oilseeds, pulses (ha)	526 827	217 347	148 684	77 355	970 213
Potatoes and vegetables (ha)	4 459	1 894	2 530	14 916	23 798
Perennial plantations (ha)	2 174	2 509	3 387	1 733	9 803
Energy crops (ha)	881	176	138	15	1 210
Other crops (ha)	682	1 065	2 459	9 612	13 819
Fallow land (ha)	309	6 718	26 564	26 194	59 785
Grassland (ha)	44 568	55 153	75 044	118 223	292 989
Meadows and pastures (ha)	22 100	71 726	173 626	331 180	598 631
Dairy cows (number)	37 049	48 509	34 902	10 783	131 243
Other grazing animals (number)	86 516	131 355	42 255	2 648	262 774
Horses (number)	-	62 290	25 226	2 466	89 982
Goats (number)	-	3 721	5 014	2 355	11 090
Sheep (number)	-	1 857	4 177	2 430	8 464

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Pigs (number)	315 972	8 298	11 020	3 634	338 924
Poultry (number)	4 956 310	609 399	253 395	38 596	5 857 700

Table A3. The proportion of chainsaw usage depending on the dominant tree species and logging activity in Latvia in 2024, %.

Dominant tree species	Maintenance felling	Main felling	Other types of felling
Pine	12	9	9
Spruce	12	9	9
Birch	15	12	12
Black alder	18	15	15
Aspen	25	20	20
Grey alder	28	18	18
Other	12	9	9

Table A4. The total land area of forestry activities, depending on the dominant tree species in Latvia in 2024, ha.

Dominant tree species	Soil preparation	Planting	Forest protection	Forest replenishment	Tending	Young stand tending	Underbrush tending	Maintenance of amelioration systems
Pine	8 337	8 486	31 021	4 316	31 021	21 715	38 272	19 049
Spruce	9 820	9 851	38 935	5 081	38 935	27 255	37 208	14 581
Birch	5 809	2 592	42 669	4 788	42 669	29 868	31 193	20 265
Black alder	1 080	583	0	857	6 693	4 685	2 122	4 726
Aspen	2 918	25	0	2 914	24 712	17 298	5 459	6 078
Grey alder	2 515	168	0	2 511	21 102	14 771	8 682	7 496
Other	63	49	508	54	508	356	374	2 271
Total	30 540	21 754	113 133	20 520	165 640	115 948	123 311	74 466

Table A5. The total land area (ha) and the total stand volume (m^3) of logging activities, depending on the dominant tree species in Latvia in 2024.

Dominant tree species	Maintenance felling		Main felling		Other types of felling	
Indicator	Area	Stand volume	Area	Stand volume	Area	Stand volume
Pine	10 110	447 099	11 229	2 949 161	21 185	453 687
Spruce	8 689	430 924	5 241	1 314 902	27 412	875 109
Birch	11 575	365 271	16 527	3 586 121	6 557	165 630
Black alder	803	26 898	990	220 134	565	19 622
Aspen	1 588	50 072	3 759	924 629	719	24 188
Grey alder	1 122	22 094	7 778	1 148 901	747	29 950
Other	65	1 527	117	12 368	234	7 650

Total	33 952	1 343 885	45 641	10 156 216	57 419	1 575 836

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