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# Evaluating Alternative Transformation Pathways of Wood-Based Bioeconomy: Application of an Input–Output Model

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**Abstract:** The wood-based bioeconomy is one of the main pillars of sustainable transformation and decarbonisation of the economy, as it promotes the use of renewable resources, reduces reliance on fossil fuels, and supports the development of eco-friendly industries. The paper provides quantitative insight into the potential impacts of transformation of the wood-based bioeconomy in Slovenia, a small, export-oriented economy with ample, but sub-optimally used, forest resources. The analysis uses an input–output (I-O) model to estimate I-O multipliers of sectors representing the wood-based bioeconomy and to capture their direct and indirect impacts on the Slovenian economy. The baseline performance of the wood bioeconomy sectors and their potential to induce economic activity (Scenario A) are estimated with an adjusted I-O model (based on the national I-O table for 2015), in which hybrid sectors are divided into conventional and bio-based segments. Alternative transformation pathways are translated into four additional scenarios. While Scenario B foresees progress in efficiency and integration within the existing structure of transactions, Scenario C (increased energy use of wood biomass) and Scenarios D/D+ (technology- and capital-intensive restructuring) represent two extreme restructuring pathways of the sector. The results of scenario analysis with the I-O model show that the changes in the input requirement structure of the Slovenian wood-based bioeconomy could result in up to a 17% increase in total output, up to a 20% increase in the number of employees, and up to a 16% increase in incomes, all of them attributed to the most optimistic scenario (D+). The results of the study provide quantified assessments underpinning strategic planning for the wood-based bioeconomy, both in the industry and public policy spheres.

**Keywords:** wood-based bioeconomy; input–output model; transformation pathways; impact analysis; strategic planning

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## 1. Introduction

The global economic system relies on fossil raw materials, and it is not sustainable in the long term [1]. Global challenges with long-term and irreversible effects, such as demographic growth and climate change, warn us about the planetary boundaries and the need to profoundly change our resource use patterns [2,3]. The recent crises (COVID-19 pandemic, war in Ukraine) that have fundamentally shaken the stability of the economic system give a further boost towards exploring alternative models, accelerating the shift from fossil- to bio-based feedstocks at greatest extent possible [4,5].

The bioeconomy, as an alternative concept of organizing economic activities based on sustainable use and value creation of biomass [1,6], has a strong role in addressing the above challenges. Derived from the widely accepted definition of the bioeconomy by the European

Commission, it includes and integrates terrestrial and marine ecosystems and their services; all primary production that uses and produces biological resources (agriculture, forestry, fisheries, production of aquatic organisms); and all economic resources and industrial sectors involving resources and the processes of production of food, feed, products, energy, and services, which are based on natural resources of biological origin [7]. The role that the bioeconomy can play in the transition towards more sustainable (renewable, circular) resource use therefore spans well beyond the conventional bioeconomy sectors concerned with agri-food and wood-processing value chains. Rapid technology growth constantly increases the possibilities for replacing fossil-based technologies and materials with bio-based ones in a growing number of manufacturing sectors. Optimization of key enabling technologies, such as biorefining [8,9], and increasingly favourable price-cost ratios further accelerate this transition [1,3].

Wood represents one of the major sources of world biomass and creates an economical frame for the so-called wood-based bioeconomy [1,10,11]. At the European level, the wood-based bioeconomy appears to be developing in two parallel ways: (1) the increased use of wood as a renewable resource within existing production chains and (2) the use of wood as an input in cascading resource use and biorefinery processes [12,13]. The first strain of applications is characterized by reducing $CO_2$ emissions by using wood as the main building material. The use of wood and wood products enables both production with a lower carbon footprint and long-term storage of carbon in buildings or parts of buildings [14]. The second strain of wood-based bioeconomy development is based on the enhancement of the conventional forestry and wood-processing industries where lignocellulosic side streams enter various biorefining processes, while the outputs are valorised through industrial innovations in several sectors [15].

This paper is examining different scenarios of wood-based bioeconomy transition in Slovenia. In relative terms (measured in tonnes per hectare per year), Slovenia is one of the countries with the highest availability of woody biomass in Europe [11]. Despite the good availability of wood, Slovenia lags behind the leading European countries with similar natural endowments in the efficiency of deployment of forestry and wood resources in the overall national wood-based bioeconomy [16,17]. The Slovenian wood-based bioeconomy today consists mainly of (1) forestry; (2) the wood-processing and furniture industry; (3) the paper industry; and (4) the use of wood for heat and electricity, a growing sector of (5) wood construction, whereas wood use in (6) the manufacturing of chemicals is very limited [18,19]. The bottleneck of the value chain is mainly a technologically outdated wood-processing industry that is poorly integrated along the value chain, both upwards and downwards [20]. Adding to this, the current scale of processing facilities does not allow for the development of biorefinery facilities at an industrial scale. As a result of these circumstances, most roundwood is exported in case of regular management [21]. Following a chain in natural disasters and a consequent increase in timber due to sanitary felling since 2014 [22], the poor efficiency of forest wood biomass utilization was further exposed. Ample room for improvement is thus available for the wood-based bioeconomy in Slovenia, with different possible pathways of future development. In addition to this, the pathways of the restructuring of the wood-based bioeconomy in Slovenia also need to take into account the long-term impacts of climate change, which are likely to result in an irreversible change in the tree species composition and changes in the technological properties of wood [23–25].

The current study employs the input–output modelling framework to address the above challenge. The input–output model (I-O model) provides an analytical environment to analyse the interdependence of industries in the economy [26]. One of the most important useful features of the input–output model, which, furthermore, enables the evaluation of different scenarios of economic development (impact analysis), is the assessment of the multiplicative effects of exogenous changes on the economy through the I-O multipliers [26].

The concept of I-O modelling has also been widely used recently in the field of bioeconomy development. For example, Budzinski et al. [27] used the above-mentioned methods to assess the progress of the German forest bioeconomy. Lehtonen and Okkonen [28] used input–output methodology to assess the economic impact of establishing new settlements based on the bioeconomy. Loizou et al. [29] and Jurga et al. [30] used the input–output model to assess the employment and income potentials of the Polish bioeconomy at the national and regional levels, respectively. Analyses of different scenarios for bioeconomy development, including the wood value chain, were also conducted [31–33]. On the other hand, I-O modelling has also proven to be a very useful tool to run different agricultural policy scenarios and assess the impact of public interventions, such as through the mechanisms of the EU Rural Development policy [34].

In contrast to the input–output method widely used for evaluating the potentials of various bioeconomy sectors to the overall (macro-)economic performance, studies examining different scenarios of restructuring wood value chains are rare, especially when it comes to evaluating scenarios with significant and underutilized resource bases as a baseline in a small export-oriented economy like Slovenia. In the future development of the Slovenian wood-based bioeconomy, the availability [11] and technological properties of wood and the ability to develop its capacities for cascading use will determine wood flows and, consequently, intersectoral transactions in the future. The future performance of the wood-based bioeconomy will largely depend on the number of nodes within the network of value creation, income, and employment in the Slovenian wood-based bioeconomy [27,35]. Therefore, it is crucial to know the multiplicative effects of different wood-processing options in Slovenia and thus assess the potential for upgrading the wood-processing sectors in the Slovenian bioeconomy.

The regression of the wood-processing industry in Slovenia is illustrated by the fact that about 91% of the harvested industrial roundwood was processed in the period from 2000 to 2003, while this share collapsed to 54% in the period before 2014, when the chain of natural disturbances (glazing and consequential bark beetle gradation) temporarily increased the harvesting of roundwood [16]. Over the last two decades, Slovenia missed many opportunities to efficiently add value of forest wood biomass within its national economy, as well as opportunities to contribute to the added value of the bioeconomy within the production chains of the forestry and wood-processing sector. With the closure of some major processing facilities in the country (most prominently chemical pulp production in 2007 and veneer production in 2016), combined with the outdated wood-processing technologies, the baseline situation of the Slovenian wood-based bioeconomy is low and offers ample room for improvement [36]. In the last decade, Slovenia has made strong policy commitments towards the deployment of circular economy and bioeconomy. In the Slovenian Development Strategy 2030 [37], two bioeconomic principles are among the most important goals: (1) a low-carbon circular economy and (2) sustainable management of natural resources. Given the biomass resource base, the slowly recovering conventional wood-processing sectors, the demand-driven transition to bio-based technology in some of the country's leading export sectors (chemical industry, automotive), as well as the growing demand for bioenergy, there is potential for the wood-based bioeconomy in Slovenia to better utilize its potential [38,39].

Apart from some partial, sector-specific evaluations on the economic aspects of the development of wood processing in future [20,40], a comprehensive economic evaluation of the future pathways for the wood-based bioeconomy have not yet been addressed. This study has the ambition to fill the gap. Its aim is to evaluate the potential of the wood value chain in the Slovenian bioeconomy using an I-O model. Five distinct scenarios have been identified, reflecting different pathways towards deployment of the potential for the growth of the wood-based bioeconomy in Slovenia, differing in sectoral mix, as well as in technological and capital complexity. Their performances were evaluated in terms of total output, employment, and income growth. In line with this aim, the paper starts with the presentation of the modelling tool and data requirements and describes the process of scenario building and its contents. The Results section presents the results concerning the state of the wood-based bioeconomy in Slovenia, including impact analyses. Next, the different pathways of the Slovenian wood-based bioeconomy are discussed, followed by the conclusions and the policy implications of the study.

## 2. Materials and Methods

Input–output analysis was used in our study to assess the potential for overall economic growth of the wood-based bioeconomy in Slovenia. Despite their known limitations deriving from their static character (see [26]), input–output models remain a valuable economic decision support tool, in particular for assessing the wider economic impacts of exogenous changes occurring in one or a limited number of sectors (e.g., changes in final demand, public interventions). Based on our aims to assess the direct and indirect effects of different pathways of wood-based bioeconomy development, we implemented the input–output approach using publicly available statistical data, supplemented by expert panels in scenario formation and related assumptions (sectoral input requirement vectors). The results were discussed in relation with existing similar studies for other countries and regions.

The input–output model is a static model based on data presented in the input–output table, compiled through surveys at regular intervals (every 5 to 10 years). The positive features of the methodology are: (1) the so-called top-down approach, a posterior econometric tool that offers the possibility to assess the impact on the whole economy and not only on the sectors of interest; (2) due to the highly aggregated level, e.g., the national level, the model is not so data-intensive; and (3) it offers the possibility to assess direct and indirect impacts [41]. By using specific data manipulations, the input–output model also provides the ability to measure economic impacts at the regional level, which was not applied in our case due to the relatively small economy and lack of disaggregated data for sectors at both the national and regional levels. For more information on the assumptions and limitations of the I-O model, see Miller and Blair [26].

### *2.1. Theoretical Background of Input Output Model*

Input–output modelling, in the form of a general equilibrium analysis, provides a convenient analytical setup to analyse the interdependencies among sectors in an economy. Roughly speaking, it consists of systems of linear equations that represent the distribution of industrial products in the economy, their production, and their consumption [24]. The basic input–output model generally consists of macroeconomic economic data for a given geographic area (country, region). It deals with the activity of a group of industries that produce goods (output) and use goods from other industries (input) in the course of final production. One of the main features of the I-O system is its ability to evaluate the intersectoral relationships among all sectors of the economy under examination. These intersectoral relationships, i.e., the flows of goods between different sectors and their interdependencies, are represented in the transaction matrix of the I-O table [34,42].

The underlying theoretical framework of the model consists of a system of linear equations, one for each economic sector. From a methodological point of view, row transactions determine the total gross output of each sector ($X_i$), which consists of the intermediate consumption of the national economy ($\sum_j^n X_{ij}$) and the final demand ($Y_i$) (Equation (1)). The final demand represents the sum of consumption ($C_i$), exports ($E_i$), and other final demand variables ($OF_i$) (Equation (2)).

$$X_i = \sum_j^n X_{ij} + Y_i \tag{1}$$

$$Y_i = C_i + E_i + OF_i \tag{2}$$

On the other hand, column transactions determine the total inputs ($X_j$) of individual sectors and consist of intermediate inputs ($\sum_i^n X_{ij}$) and other primary inputs (compensation of employees—$CE_j$, imports—$IMP_j$, and other primary input variables—$OPI_j$).

$$X_j = \sum_i^n CE_j + IMP_j + OPI_j \tag{3}$$

From the basic transaction matrix, two other important matrices are derived in order to provide a base for the estimation of the direct and total requirements of the sectors of an economy: (1) direct requirements matrix and (2) Leontief inverse matrix.

The columns of the direct requirements matrix represent the structure of the production process of each sector and each technical coefficient ($a_{ij}$), illustrating the input requirements for the production per unit of the final product. The direct coefficients are computed by dividing the expenditure for input a that the sector $j$ purchases from the selling sector $I$ $(X_{ij})$ by the total output of sector $j$ $\left(X_j\right)$.

$$a_{ij} = \frac{X_{ij}}{X_j} \tag{4}$$

In matrix form, the direct requirements matrix is the $A$ matrix, and $X$ and $Y$ are the vectors of total output and final demand, respectively. The direct requirements matrix provides information only on the direct effects of each economic sector, while the most important information comes from the Leontief inverse matrix, in which the total effects, both direct and indirect, are calculated. The I-O system with the relationships between sectors and final demand can also be described by a system of linear equations in matrix form:

$$X = AX + Y \tag{5}$$

where, solving Equation (5) for final demand, $X - AX = Y$, or abbreviated to:

$$(I - A)X = Y \tag{6}$$

It is derived that there is an n × n system of linear equations with n unknowns. Finally, by solving Equation (6) for total output $X$, we obtain:

$$X = (I - A)^{-1}Y \tag{7}$$

The solution of system 6 represents the basic solution of Leontief's I-O system. It represents the quantity of total output $X$ of the economy that is increased due to an exogenous change in the final demand of a sector (e.g., investment, increased national consumption, etc.). The matrix $(I - A)^{-1}$ is the so-called Leontief inverse or total requirements matrix. Each element of this matrix indicates the total (direct and indirect) requirements of sector $i$ per unit of final demand for sector $j$'s output.

The I-O model described above is often referred to as a demand-driven model because it relates the gross output of the sector to changes in the final demand. Using Leontief inverse and exogenous data, the standard I-O multipliers (linkage coefficients) can be estimated. The calculation of these linkage coefficients provides valuable information on the dynamics of individual sectors and their ability to generate knock-on effects in an economy.

The structure of the I-O table allows the researcher to use various techniques to assess the impact of exogenous changes, i.e., the impact that a potential change in final demand has on intersectoral transactions and the total gross output of each sector in the economy. In this context, the I-O methodology was applied to assess and compare the impacts of alternative scenarios of long-term restructuring of the wood-based bioeconomy in Slovenia.

### 2.2. Calculating of I-O Multipliers

The broad and deep introduction of the methodology regarding how the I-O multipliers are calculated can be found elsewhere, in Miller and Blair [26] as well as in Loizou, Chatzitheodoridis, Michailidis, Tsakiri, and Theodossiou [42]. In short, the I-O multipliers represent the most known linkage coefficients that are widely used to assess intersectoral relations within an economy. The current study applies the standard approach by estimating output, income, and employment multipliers.

Output multipliers show the overall increase in the economy's output that is needed to satisfy a unit increase in the final demand of the sector under examination. This shows the degree of interdependence a given sector has with all other local sectors. The output multipliers are estimated by Equation (8):

$$OM_j = \sum_{i=1}^{n} b_{ij} \tag{8}$$

where $(OM_j)$ represents the $j$ sector's output multiplier, which is calculated by the sum of the $j$ sector's elements of the Leontief inverse matrix ($b_{ij}$).

The income multipliers estimate the impacts of a change in the exogenous final demand on the economy's household income. The term income is used for the household income, namely, the compensation of employees. An alternative measure of income effects are the Type I income multipliers that are measuring the overall variation in the economy's household income as a result of a unitary change in a sector's income. For their estimation, the direct income and total income effects should be computed firstly; the direct income effect (Equation (9)) is computed in the same way as the technical coefficients, by dividing the income of a sector $j$ in the household vector by the total output of sector $j$.

$$HDE_j = \frac{H_j}{X_j}, \tag{9}$$

where the direct income effect of sector $j$ (or income coefficient) $(HDE_j)$ is calculated by the ratio between the income of sector $j$ $(H_j)$ and the total inputs of sector $j$ ($X_j$).

The total household income effect (or the simple income multiplier) shows the total change in the economy's income due to a unit change in the final demand of a sector, as presented in Equation (10).

$$HDIE_j = \sum_{i=1}^{n} b_{ij} \times HDE_j, \tag{10}$$

where the total income effect of sector $j$ ($HDIE_j$) is calculated by multiplying the sum of the $j$ sector's elements of the Leontief inverse matrix ($b_{ij}$) by the direct income effect of sector $j$ $(HDE_j)$.

Finally, the sectoral Type I income multipliers are computed by the ratio of the total $(HDIE_j)$ to the direct income effect ($HDE_j$), which is presented in Equation (11).

$$IM_j = \frac{HDIE_j}{HDE_j} \tag{11}$$

Employment multipliers can also be computed following the same procedure as above, measuring the total change in the economy's employment due to a change in employment by sectors for Type I multipliers or the change in the overall employment level due to a change in the final demand of a sector (total employment effects or simple employment multipliers).

The direct, total, and indirect effects have to be computed initially:

The direct employment effect is computed using Equation (12):

$$EDE_j = \frac{E_j}{X_j}, \tag{12}$$

where sector $j$'s direct employment effect (or employment coefficient) $(EDE_j)$, is calculated by the ratio between the number of employers in sector $j$ $(E_j)$ and the total inputs of sector $j$ $(X_j)$.

Equation (13) presents the calculation of the total employment effect:

$$EDIE_j = \sum_{i=1}^{n} b_{ij} \times EDE_j, \tag{13}$$

where sector $j$'s total (direct and indirect) employment effect ($EDIE_j$) is calculated by multiplying the sum of the $j$ sector's elements of the Leontief inverse matrix ($b_{ij}$) by the direct employment effect of sector $j$ $(EDE_j)$.

And finally, the Type I employment multipliers are analogously estimated by the ratio of the total ($EDIE_j$) to the direct employment effect ($EDE_j$) (Equation (14)).

$$EM_j = \frac{EDIE_j}{EDE_j} \tag{14}$$

*2.3. Data Requirements and Determination of Wood Value Chain*

An input–output table is a data matrix that provides the structure of the economy at a given point in time and describes the inter-industry links among the inputs required for production processes and the outputs of the sectors under study, which eventually form the final demand [43]. In the presented study, we used the input–output table of 2015 as a base, which was the latest available fully surveyed national I-O table in Slovenia at the time of the research (2021 and 2022). The baseline I-O table for Slovenia originally consisted of 65 sectors [41]. Aiming to evaluate the performance and inter-sectoral linkages of the wood-based bioeconomy in Slovenia, we first examined the related economic sectors (Table 1). In our study, the wood-based bioeconomy consists of the following sectors: A02—forestry and logging; C16—manufacturing of wood and of products of wood and cork, except furniture, and manufacturing of articles of straw and plaiting materials; C17—manufacturing of paper and paper products; C20.590*—wood-based chemicals; C31+32—manufacturing of furniture and other manufacturing; and D35*—wood-based heat and electricity.

**Table 1.** Wood-based bioeconomy sectors in the Slovenian economy.

| NACE Code | Sector |
|---|---|
| A02 | Forestry and logging |
| C16 | Manufacturing of wood and products of wood and cork, except furniture; manufacturing of articles of straw and plaiting materials |
| C17 | Manufacturing of paper and paper products |
| C31+32 | Manufacturing of furniture and other manufacturing |
| D35* | Electricity and heat from wood |
| C20* | Chemicals from wood |

Among the sectors listed above, two of them (*) are considered as hybrid sectors and were disaggregated from the initial sectors. To disaggregate the wood-based chemicals sector within entire chemicals sector in Slovenia, we performed a detailed analysis of publicly available financial reports [44] of major firms in the sector that currently utilize wood-based inputs. Wood-based chemicals currently make up 0.9% of the entire Slovenian production of chemicals and represent an important share of the production of bio-based chemicals in Slovenia, which was estimated at 3% [45] using the JRC definition of hybrid sectors in the bioeconomy for EU countries [46–48]. A similar disaggregation method was also used for the wood-based heat and electricity sector. Publicly available financial reports of the energy companies engaged in wood biomass [44] were analysed in order to disaggregate them from the aggregate energy sector. Information on corporate wood consumption for energy purposes was additionally used to estimate the scale of the sector at 1.9% of sector D35*, which is the electricity, gas, steam, and air conditioning sector. This is similar to a previous estimation of bio-based shares in line with the JRC definition of hybrid sectors of the bioeconomy for EU countries [46–48], which was estimated at around 2% [45].

*2.4. Scenario Building and Input–Output Impact Assessment*

Over the last three decades, the Slovenian wood-based bioeconomy has witnessed a marked decline in large processing capacities, while vibrant and diversified small and medium enterprises are gaining significance. Regarding the projections of the wood-based bioeconomy, different pathways of future development should be evaluated. To address this issue, an input–output analysis offers a suitable tool for impact assessment. Based on hypothetical exogenous changes to the economy, it has the ability to capture economy-wide effects in the form of a general equilibrium. It captures both direct and indirect impacts, i.e., knock-on impacts arising from a sector under examination. In the current case, this refers to sectors which involve the wood-based bioeconomy in Slovenia and, indirectly, all other sectors of the economy which play an essential role in terms of input requirements [26].

To evaluate different pathways of the Slovenian wood-based bioeconomy, we developed five different input–output impact assessment scenarios, assuming two levels of hypothetical changes: (1) changes in the sector's input requirements and (2) a hypothetical increase in total sector-specific output due to the aforementioned input changes.

In the process of building these scenarios, the structure of input requirements of the wood-based bioeconomy sectors in the 2015 input–output Table were first analysed [49]. We defined the relative shares of (1) intermediate consumption, (2) compensation of employees, (3) imports of goods and services, and (4) other primary inputs in each sector.

Sector-specific focus groups with experts from various domains of the wood-based bioeconomy were organized to critically evaluate the 2015 data and to discuss the relevant pathways of sector development as the basis for the scenarios. The pathways were established to differ from each other in terms of sectoral mix, level of technological sophistication, and the sector's ability to absorb the harvested forestry products within the national economy. By evaluating the 2015 data, a baseline scenario (Scenario A) was defined. Based on the results of the focus group discussions on the relevant development pathways of the wood-based bioeconomy in Slovenia, the following scenarios were formed:

- Scenario A: Baseline scenario;
- Scenario B: Increased efficiency in wood processing;
- Scenario C: Increased energy use of wood biomass;
- Scenario D: Technology- and capital-intensive restructuring;
- Scenario D+: Technology- and capital-intensive restructuring with increased input requirements.

Finally, to test the upper limits of the wood-based bioeconomy's potential, benchmarking with the leading countries in the European wood-based bioeconomy was carried out. For this purpose, the input–output tables of Austria, Germany, and Sweden were analysed [49]. A comparative analysis of the structure of sector-specific relative input requirements was performed to assess the so-called "development lag" of the Slovenian wood-based bioeconomy. For the benchmark analysis, we decided to apply the values for Austria as a proxy for a well-performing country with comparable resource endowments. Austrian inter-industry linkages were used to define the (very optimistic) benchmark scenario of technology- and capital-intensive restructuring with increased input requirements (Scenario D+). This scenario includes the highest levels of improvement for the wood-processing sector (C16) and the paper industry (C17), while the upper bound performance was assumed in the calculations for the other sectors.

To define the structure of the input requirements of the entire wood-based bioeconomy in Slovenia, we used the shares of sectors in the total output of the whole wood value chain as weights for the weighted average of the input requirements of the whole wood-based bioeconomy. Changes in the total output of the remaining sectors were assumed to take place simultaneously with the hypothetically changed input structure.

For Scenario A, the total output of the sectors in 2015 was applied. For Scenario B, it was assumed that the changed structure of inputs could increase the total output of the wood-processing sector by 25% compared to Scenario A, while the total outputs of other sectors remained at the 2015 level. Scenario C included only forestry and the use of wood for heat and electricity, so excluding the wood-processing sectors, forestry would increase to 45% and heat and electricity to 54%. Scenario D and D+ included optimistic and very optimistic sector upgrades, respectively, so we assumed that, compared to 2015, the total output of the wood-processing sector could increase by 50%, that of the paper and furniture sectors by 25%, and that of wood-based chemicals by 45%, while heat and electricity would remain at the 2015 level.

In order to provide a level playing field for a comparative assessment of the performances of the five scenarios, they were all derived from the same assumption, which was an increase in final demand by EUR 100 million. Accommodating this external shock to the I-O multipliers and the (scenario-specific) allocations of increased final demand within the economy, the potentials of total output, income, and number of employees were assessed.

Finally, to determine the amount of roundwood required in a given scenario, we consulted the input–output table from 2015, which stipulates that 29% of the demand in the forestry sector was for forestry services, while the remaining 71% represented the value of wood. The value of wood in a given scenario was then divided by the average wood market price, which averaged EUR 47.2 per cubic meter in 2015, and the result was the assessed amount of consumed roundwood [50].

## 3. Results

### *3.1. Wood-Based Bioeconomy Potentials in Slovenia*

Table 2 presents the sector-specific input–output multipliers in the national wood-based bioeconomy, revealing their potential to contribute to the Slovenian wood-based bioeconomy (Table 2). Sectors with the highest linkages in the economy (highest I-O multipliers) were considered as key sectors, with the highest potential to induce economic activity.

**Table 2.** Input–output multipliers of wood value chain sectors in Slovenia.

| NACE | Name | OM | R | R (WB) | EM (Type 1) | R | R (WB) | IM (Type 1) | R | R (WB) |
|---|---|---|---|---|---|---|---|---|---|---|
| A02 | Products of forestry | 1.81 | 44 | 6 | 1.62 | 44 | 6 | 2.55 | 25 | 4 |
| C16 | Wood and of products of wood | 2.61 | 14 | 2 | 2.30 | 32 | 4 | 2.69 | 21 | 2 |
| C17 | Paper and paper products | 3.02 | 5 | 1 | 4.39 | 5 | 1 | 4.06 | 6 | 1 |
| C20* | Wood chemicals | 2.33 | 22 | 4 | 3.02 | 17 | 3 | 2.31 | 33 | 6 |
| C31 | Furniture and other manufactured goods | 2.45 | 18 | 3 | 2.29 | 33 | 5 | 2.44 | 29 | 5 |
| D35* | Wood electricity and heat | 2.41 | 20 | 5 | 4.06 | 8 | 2 | 2.61 | 24 | 3 |

Output multiplier (OM), Type 1 employment multiplier (EM) and Type 1 income multiplier (IM). NACE represents the international NACE codes of selected economic sectors. R shows the ranks of specific multipliers in the whole economy, while R (WB) represents the rank of specific multipliers within the Slovenian wood-based bioeconomy.

The linkage analysis revealed that the paper industry ranks fifth in the overall economy and first in the wood-based bioeconomy, with a value of 3.02 in terms of output multipliers. This means that, if the final demand in the paper industry increased by EUR 1 million, the total output of the whole economy would be increased by EUR 3.02 million. Thus, in terms of all sectors directly and indirectly related to the paper industry, an additional EUR 2.02 million could be generated in the economy under examination. The lowest-output multipliers for the wood-based bioeconomy were found for the forestry sector, which ranks 44th in the total economy. In this case, an output multiplier of 1.81 showed that a EUR 1 million increase in final demand in the forestry sector would lead to a EUR 1.8 million increase in total output, of which EUR 0.8 million would be generated by sectors directly and indirectly related to the forestry sector.

A similar result was found for employment, where the paper industry ranks first in the wood-based bioeconomy, with a Type I employment multiplier of 4.39, while forestry ranks last, with 1.62. This suggests that, for every person employed in the paper industry, there is a need for an additional 3.39 employees in directly or indirectly associated sectors. In the case of forestry, on the other hand, for one person employed, 0.6 additional jobs are needed in other directly or indirectly related sectors.

In the Type 1 income multiplier analyses, the paper industry again ranked first (4.06), while wood-based chemicals ranked last (2.31). These results indicate that a EUR 1 million increase in household income in the paper industry would induce an additional EUR 3.06 million in income in directly or indirectly related sectors. In the case of wood-based chemicals, a EUR 1 million increase in income would induce an additional EUR 1.3 million in income in directly or indirectly related sectors.

### *3.2. Wood-Based Bioeconomy Sector Input Requirements*

Table 3 presents the relative economic input requirements of the sectors included in the wood-based bioeconomy. The current status was obtained from the latest available input–output table [49] and was reviewed by expert groups of each sector.

**Table 3.** Current, optimistic, and benchmarked structures of input requirements in selected wood value chain sectors.

| | Forestry | | Wood Processing | | | Paper Industry | | | Furniture | Wood-Based Chemicals | Wood-Based Heat and Electricity | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **NACE** | **Current** | **Optimistic** | **Current** | **Optimistic** | **Very Optimistic** | **Current** | **Optimistic** | **Very Optimistic** | **Current** | **Current** | **Current** | **Optimistic** |
| A02 | 22.6% | 24.0% | 7.6% | 10.0% | 12.7% | 0.9% | 1.5% | 4.7% | 0.0% | 18.1% | 20.0% | 42.6% |
| B | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 2.0% | 2.0% | 0.8% | 0.0% | 0.6% | 0.0% | 0.0% |
| C16 | 0.0% | 0.0% | 13.1% | 18.4% | 23.6% | 0.7% | 0.7% | 0.5% | 10.1% | 0.4% | 22.6% | 0.0% |
| C17 | 0.0% | 0.0% | 0.3% | 0.4% | 1.9% | 20.5% | 20.0% | 14.4% | 0.6% | 0.4% | 0.0% | 0.0% |
| C19–20 | 2.9% | 2.0% | 2.6% | 2.9% | 1.6% | 4.3% | 4.3% | 4.1% | 1.1% | 5.8% | 0.0% | 0.0% |
| C22 | 0.0% | 0.0% | 0.1% | 0.1% | 0.4% | 0.2% | 0.2% | 0.6% | 2.2% | 0.1% | 0.0% | 0.0% |
| C23 | 0.0% | 0.0% | 0.8% | 1.0% | 0.7% | 0.0% | 0.0% | 0.0% | 0.4% | 0.0% | 0.0% | 0.0% |
| C24 | 0.0% | 0.0% | 2.1% | 2.3% | 0.2% | 0.0% | 0.0% | 0.3% | 0.7% | 0.1% | 0.0% | 0.0% |
| C25 | 0.3% | 0.4% | 0.6% | 0.7% | 0.9% | 0.3% | 0.3% | 0.0% | 2.7% | 0.3% | 0.0% | 0.0% |
| C28 | 0.3% | 0.3% | 0.2% | 0.3% | 0.4% | 0.3% | 0.5% | 0.2% | 0.2% | 0.8% | 6.0% | 6.0% |
| C29–30 | 0.2% | 0.2% | 0.6% | 0.7% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.4% | 0.0% | 0.0% |
| C31–32 | 0.0% | 0.0% | 0.2% | 0.3% | 0.0% | 0.0% | 0.0% | 0.0% | 2.0% | 0.1% | 0.0% | 0.0% |
| C33 | 1.3% | 1.0% | 0.3% | 0.4% | 0.4% | 0.8% | 1.0% | 0.9% | 0.3% | 5.2% | 0.0% | 0.0% |
| D35 | 0.2% | 0.2% | 1.4% | 2.0% | 1.9% | 2.9% | 4.1% | 3.6% | 0.9% | 2.5% | 1.2% | 1.2% |
| E37–39 | 0.0% | 0.0% | 0.1% | 0.1% | 1.0% | 0.2% | 1.0% | 3.5% | 0.1% | 0.3% | 0.3% | 0.3% |
| F | 0.5% | 0.5% | 0.6% | 0.8% | 1.7% | 0.1% | 0.1% | 1.0% | 0.1% | 0.9% | 0.5% | 0.5% |
| G46 | 0.5% | 0.4% | 3.8% | 4.3% | 5.7% | 3.4% | 3.4% | 3.5% | 3.4% | 0.3% | 0.0% | 0.0% |
| H49–51 | 4.1% | 6.0% | 1.2% | 1.6% | 4.0% | 2.1% | 2.5% | 4.0% | 1.0% | 3.2% | 0.4% | 0.4% |
| H52 | 0.2% | 0.2% | 0.2% | 0.2% | 1.5% | 0.3% | 0.3% | 1.2% | 0.0% | 0.2% | 0.0% | 0.0% |
| OS | 3.1% | 3.4% | 4.8% | 5.5% | 5.2% | 3.7% | 3.8% | 5.5% | 6.4% | 4.9% | 1.4% | 1.4% |
| Total | 36.3% | 38.6% | 40.5% | 52.0% | 63.5% | 42.9% | 45.9% | 48.8% | 32.3% | 44.3% | 52.4% | 52.4% |
| D1 | 8.1% | 8.5% | 11.4% | 13.0% | 11.7% | 7.6% | 10.0% | 11.0% | 12.6% | 18.4% | 13.6% | 13.6% |
| IMP | 9.8% | 10.0% | 40.7% | 27.7% | 17.3% | 43.8% | 36.1% | 30.6% | 46.7% | 16.9% | 13.8% | 13.8% |
| OPI | 45.8% | 42.9% | 7.3% | 7.3% | 7.4% | 5.7% | 8.0% | 9.6% | 8.4% | 20.4% | 20.2% | 20.2% |
| TSBP | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% |

#### 3.2.1. Forestry

Regarding the structure of intermediate consumption, forestry is the least complex sector, which is logical if we assume that its main task is to provide wood for further processing. In 2015, intermediate consumption reached 36%, compensation of employees reached 8.1%, import of goods and services reached 9.8%, and other primary inputs reached 45.8%. The main sectors from which most intermediate inputs are required are forestry services, transportation services, chemical products (fuels), and machinery and equipment repair and installation services. According to the experts, the optimistic structure of forestry input would not change much. Due to the changed structure of forestry organizations in the last decade, it is expected that forestry services will be outsourced, which will lead to a higher share of forestry services and transportation services (Table 3).

#### 3.2.2. Wood-Processing Sector

The structure of the input requirements of the wood-processing sector in 2015 consisted of 40.5% intermediate consumption, 11.4% compensation of employees, 40.7% import of goods and services, and 7.3% other primary inputs. Within intermediate consumption, the most important sectors were wood processing itself, forestry, wholesale trade in services, metal production and processing, the chemical industry, the energy sector, and the transport sector. A desirable optimistic structure of intermediate input demand, based on interviews with experts, would increase the share of intermediate inputs from 40.5% to 52% and reduce the dependence on imports from 40.7% to 27.7%. Due to the higher dependence on domestic inputs, the share of employee compensation would also increase, while the other primary inputs would remain the same (Table 3). With a very optimistic structure of input requirements in the wood-processing sector (Table 3), which mimics the 2015 Austrian input–output table [49] as a benchmark, total intermediate inputs would increase from 40.5% to 63.5%, imports of goods and services could decrease from 40.7% to 17.3%, compensation of employees could reach 11.7%, and other primary inputs could reach 7.4% (Table 3).

#### 3.2.3. Paper Industry

Since the complete shutdown of domestic industrial cellulose production in 2007, the Slovenian paper industry has been largely dependent on imports of goods (in particularly pulp) and corresponding services, which in 2015 accounted for 43.8% of the total input requirements of the Slovenian paper industry. On the other hand, 42.9% intermediate inputs, 7.6% compensation of employees, and 5.7% other primary inputs were consumed. The optimistic structure of input demand in the paper industry may slightly alter the structure of the paper industry. In this case, intermediate inputs reach 45.9%, compensation of employees reaches 10%, imports of goods and services reach 36.1%, and other inputs reach 8%. With a very optimistic structure of input demand (Table 3) in the paper industry, taken from the 2015 Austrian input–output table [49], the total input consumption could increase from 42.5% to 48.8%, imports of goods and services could decrease from 43.8.7% to 30.6%, compensation of employees could reach 11.0%, and other primary inputs could reach 9.6% (Table 3).

#### 3.2.4. Furniture

The structure of the Slovenian furniture sector in 2015 consisted of 32.3% intermediate inputs, 13.6% compensation of employees, 46.7% import of goods and services, and 8.4% other primary inputs. The main sectors in the structure of intermediate inputs were wood processing, wholesale trade in services, metal processing, manufacturing of rubber and plastic products, and the furniture sector itself. A comparative analysis of the structure of intermediate input demand in this sector in other countries revealed that the Slovenian furniture industry's wood products have the highest share in terms of intermediate inputs (Table 3). It is for this reason that—in contrast with some previous cases (wood processing, paper industry)—no benchmark values were set for the input demand of the sector, and in further analyses, it was assumed that this structure would not change.

#### 3.2.5. Wood-Based Chemicals

The wood-based chemicals sector is a hybrid sector, with products and outputs originally attributed to the chemicals sector. Therefore, for the purposes of our study, the wood-based chemicals sector was disaggregated from the chemicals sector based on JRC coefficients for bio-based production in European Union countries [45,47] and publicly available annual reports of companies producing chemicals from wood [44]. Based on detailed analyses, we assumed that intermediate inputs could account for 44.3%, compensation of employees for 18.4%, import of goods and services for 16.9%, and other primary inputs for 20.4% in the structure of input demand for wood-based chemicals (Table 3). The current total supply was estimated to be EUR 17 million in 2015, which is 0.5% of the total supply at basic prices in the Slovenian chemical industry.

#### 3.2.6. Wood-Based Heat and Electricity

The sector that generates electricity and heat from wood is also considered as a so-called "hybrid sector" [47]. In the case of Slovenia, this poses another methodological problem, as data are collected in different ways in national surveys. For example, only energy (heat or electricity) generated in enterprises from wood and wood waste is recorded as a product of the electricity, gas, steam, and air conditioning sector, while the use of wood for energy by households is considered as consumption of forestry products. Therefore, only products for industrial use are reported as wood energy in our analyses.

In addition, wood-based heat and electricity were also disaggregated from the original electricity, gas, steam, and air conditioning sector. To achieve this, we first analysed the data provided by the National Statistics Office on the amount of wood used for renewable energy production [51]. Based on the collected information and additional expert interviews, we assumed that the structure of wood-based heat and electricity demand in 2015 was composed of 52.4% intermediate inputs, 13.6% compensation of employees, 13.8% imports of goods and services, and 20.2% other primary inputs (Table 3). The total supply of the wood-based heat and energy sector was, thus, estimated at EUR 35.5 million, representing 1.8% of the total original electricity, gas, steam, and air conditioning sector.

### *3.3. Impact Assessment Scenarios*

To evaluate the potential of the wood-based bioeconomy in Slovenia in line with the scenarios briefly presented in Section 2.4, we applied the following assumptions about the structure of the wood-based bioeconomy (Table 4).

**Table 4.** Determination of wood value chain structure based on total outputs of the sectors for 5 different scenarios of the Slovenian wood-based bioeconomy.

| | | Forestry | Wood Processing | Paper Industry | Furniture | Wood-Based Chemicals | Heat and Electricity | Wood Value Chain |
|---|---|---|---|---|---|---|---|---|
| Scenario A | TO (mio EUR) | 358.2 | 577.1 | 783.2 | 743.4 | 14.3 | 30.5 | 2506.7 |
| | Weight | 14.3% | 23.0% | 31.2% | 29.7% | 0.6% | 1.2% | 100.0% |
| Scenario B | TO (mio EUR) | 358.2 | 721.3 | 783.2 | 743.4 | 14.3 | 30.5 | 2651.0 |
| | Weight | 13.5% | 27.2% | 29.5% | 28.0% | 0.5% | 1.2% | 100.0% |
| Scenario C | TO (mio EUR) | 358.2 | 0.0 | 0.0 | 0.0 | 0.0 | 432.0 | 790.2 |
| | Weight | 45.3% | 0.0% | 0.0% | 0.0% | 0.0% | 54.7% | 100.0% |
| Scenario D | TO (mio EUR) | 358.2 | 865.6 | 979.0 | 929.3 | 20.8 | 30.5 | 3183.3 |
| | Weight | 11.3% | 27.2% | 30.8% | 29.2% | 0.7% | 1.0% | 100.0% |
| Scenario D+ | TO (mio EUR) | 358.2 | 865.6 | 979.0 | 929.3 | 20.8 | 30.5 | 3183.3 |
| | Weight | 11.3% | 27.2% | 30.8% | 29.2% | 0.7% | 1.0% | 100.0% |

#### 3.3.1. Baseline Scenario (Scenario A)

The baseline scenario does not consider any differences in the structure of wood processing in 2015 and represents the so-called "business as usual" approach. In 2015, forestry accounted for 14.3%, wood processing for 23.0%, the paper industry for 31.2%, wood-based chemicals for 0.6%, and wood-based heat and electricity for 1.2% of the total output of the entire wood value chain (Table 4).

#### 3.3.2. Scenario with Increased Efficiency in Wood Processing (Scenario B)

The second scenario assumes that progress in the wood-based bioeconomy is primarily sought in the conventional wood-processing sector (C.16). Here, we assume that the total output of the wood-processing sector would increase by 25%, which would result in a changed structure of the Slovenian wood value chain as follows: forestry, 13.5%; wood-processing sector, 27.2%; paper industry, 29.5%; wood-based chemicals, 0.5%; and wood-based heat and electricity, 1.2% (Table 4). In this case, an optimistic input requirement structure was used for the wood-processing sector, while the intermediate input demand of the other sectors in the wood value chain may have remained at the level of the baseline scenario (Table 3).

#### 3.3.3. Increased Energy Use of Wood Biomass (Scenario C)

The third scenario tests the rather extreme assumption that the wood biomass use largely shifts down the value-added pyramid to the energy sector. In this case, the wood value chain would consist only of the forestry sector (45.3%) and the wood-based heat and electricity sector (54.7%) (Table 4).

#### 3.3.4. Technology- and Capital-Intensive Restructuring (Scenario D)

The fourth scenario takes an optimistic, high-value-added approach and assumes that all wood-processing sectors would increase in terms of total output. It is assumed that the total output of the wood-processing sector may increase by 50%, the total output of the paper and furniture industry by 25%, and the total output of wood-based chemicals by 45%. The structure of the wood value chain would, in this case, be as follows: forestry, 11.3%; wood processing, 27.2%; the paper industry, 30.8%; furniture, 29.2%; wood-based chemicals, 0.6%; and wood-based heat and electricity, 1% (Table 4).

Together with the assumed increase in production and the hypothetical modernization of forestry, wood processing, paper production, and wood-based energy production, this scenario involves increased input requirements, as defined in the optimistic projections (Table 3). For the remaining sectors, such as furniture and wood-based chemicals, it is assumed that the demand for inputs does not change, so only an increase in total output is considered.

#### 3.3.5. Technology- and Capital-Intensive Restructuring with Increased Input Requirements (Scenario D+)

The D+ scenario is very optimistic and represents the theoretical boundaries of the system in terms of aggregate value added of the forest-based bioeconomy. In considering this scenario, we assumed that the increase in the total output of the wood-processing sector would be similar to scenario D (Table 4), while the sectoral input requirements would be changed to optimistic (forestry and wood-based heat and electricity sector) and very optimistic structures (wood-processing and paper industry sectors). However, for furniture and wood-based chemical production, it was assumed that the input requirements would not change, so only an increase in total output was considered in the analysis (Table 3).

### *3.4. Impact Assessment*

A comparison of "business as usual" (scenario A) with different hypothetical scenarios (B–D+) gave us the opportunity to evaluate the potential of the Slovenian wood-based bioeconomy in terms of total output, number of employees, and income.

According to the results of the analyses, the changes in the input requirement structure of the Slovenian wood-based bioeconomy could result in a 17% increase in total output, a 20% increase in the number of employees, and a 16% increased income when comparing the most optimistic scenario (D+) with the baseline scenario (A). In terms of roundwood consumption, the highest potential for consumption was found in the use of wood just for the production of heat and electricity (an increase of 82%), which would involve a 27% decrease in income and a changed structure of the direct and indirect effects of employment. Decreasing indirect effects can be related to lower added value in the whole wood value chain. However, between scenarios that included industrial wood processing, the potential for increased wood consumption was found to be between 12% and 31% compared to the business-as-usual scenario.

Exogenous changes in final demand for 100 mio EUR in the Slovenian wood-based bioeconomy in 2015 would result in 92.8 mio EUR of produced total output, which is consistent with 56% direct effects and 44% indirect effects. In this case, 1037 new jobs and 19.2 mio EUR of household income would be created (Table 5). The wood-processing upgrade scenario (Scenario B), including the optimistic upgrade of the wood-processing sector (NACE C.16), represents favourable results in terms of a projected improvement in economic performance. In these terms, an exogenous increase in final demand of 100 mio EUR in the Slovenian wood-based bioeconomy would result in 103 mio EUR of produced total output, consistent with 55% direct effects and 45% indirect effects. In this case, 1134 new jobs and 20.7 mio EUR of household income would be created (Table 5). Scenario C consists of the use of wood for electricity and heat production, and thus, the exogenous changes in final demand for 100 mio EUR were allocated through the economy based on the forestry and heat and electricity sectors. The scenario would bring an 89.4 mio EUR increase in the total output, consistent with 67% direct effects and 33% indirect effects, 1230 new jobs, and 14.1 mio EUR of household income (Table 5). Scenario D includes an optimistic upgrade of the wood-based bioeconomy, and thus, the exogenous changes in the final demand for 100 mio EUR were allocated through optimistically changed input requirement structures. In these terms, a total output of 103.1 mio EUR would be created, consistent with 55% direct effects and 45% indirect effects, 1162 new jobs, and 21.3 mio EUR of household income (Table 5). Scenario D+ includes a very optimistic upgrade of the wood-based bioeconomy, and, thus, the exogenous changes in final demand for 100 mio EUR were allocated through very optimistically changed input requirement structures. In these terms, 111.6 mio EUR of total output would be created, consistent with 56% direct effects and 44% indirect effects, and 1295 new jobs and 22.9 mio EUR of household income would be created, respectively (Table 5).

**Table 5.** Total national effects of 100 mio EUR total final demand changes in five different scenarios (A–D+) of input–output impact assessments.

| S | Δ FD (mio EUR) | Δ FD Forestry (mio EUR) | Δ FD Forestry ($m^3$ EUR) | Effect | Output | | | | Employment | | | | Income | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | mil EUR | (%) [a] | (%) [b] | (%) [c] | N | (%) [a] | (%) [b] | (%) [c] | mil EUR | (%) [a] | (%) [b] | (%) [c] |
| A | 100 | 5.62 | 84,538 | TE | 92.8 | | 3.7% | 0.13% | 1037 | | 3.5% | 0.11% | 19.2 | | 4.5% | 0.10% |
| | | | | DE | 51.5 | 56% | | | 448 | 43% | | | 7.7 | 40% | | |
| | | | | IE | 41.3 | 44% | | | 590 | 57% | | | 11.5 | 60% | | |
| B | 100 | 6.38 | 95,970 | TE | 100.3 | | 4.0% | 0.14% | 1134 | | 3.8% | 0.12% | 20.7 | | 4.8% | 0.11% |
| | | | | DE | 55.6 | 55% | | | 492 | 43% | | | 8.3 | 40% | | |
| | | | | IE | 44.7 | 45% | | | 641 | 57% | | | 12.4 | 60% | | |
| C | 100 | 33.54 | 504,521 | TE | 89.4 | | 3.6% | 0.12% | 1230 | | 4.2% | 0.13% | 14.1 | | 3.3% | 0.07% |
| | | | | DE | 59.7 | 67% | | | 690 | 56% | | | 5.6 | 40% | | |
| | | | | IE | 29.7 | 33% | | | 540 | 44% | | | 8.5 | 60% | | |
| D | 100 | 6.41 | 96,422 | TE | 103.1 | | 4.1% | 0.14% | 1162 | | 3.9% | 0.12% | 21.3 | | 4.9% | 0.11% |
| | | | | DE | 57.1 | 55% | | | 502 | 43% | | | 8.5 | 40% | | |
| | | | | IE | 46.0 | 45% | | | 659 | 57% | | | 12.8 | 60% | | |
| D+ | 100 | 8.19 | 123,197 | TE | 111.0 | | 4.4% | 0.15% | 1289 | | 4.4% | 0.14% | 22.8 | | 5.3% | 0.12% |
| | | | | DE | 62.4 | 56% | | | 572 | 44% | | | 9.2 | 40% | | |
| | | | | IE | 48.6 | 44% | | | 717 | 56% | | | 13.6 | 60% | | |

S—scenario; FD—final demand; TE—total effect; DE—direct effect; IE—indirect effect; N—number of employees; [a]—shares of direct and indirect effects; [b]—share of national economy in 2015; [c]—share of Slovenian wood-based bioeconomy in 2015.

From the broader national economy perspective, a 100 mio EUR growth in final demand would not have significant impacts on the national economy scale, but it would represent a significant change to the wood-based bioeconomy (Table 5). In 2015, the whole Slovenian economy created 73.1 billion EUR of total output, employed 944 thousand people, and created 18.9 billion EUR of household income. The wood-based bioeconomy at that time represented 3.4% of the total output (2.5 billion EUR), 3.1% of employed people (29,591 people), and 2.3% of the created household income in Slovenia [41]. In these terms, an exogenous change of 100 mio EUR in final demand would result in between 0.12% and 0.15% of output, 0.11% and 0.14% of the number of employees, and 0.07 and 0.12% of household income in the Slovenian economy. In the case of a wood-based bioeconomy, the represented impacts may result in changes of 3.6%–4.5% in terms of total output, 3.5%–4.4% in terms of the number of employees, and 3.3%–5.3% in terms of newly created household income (Table 5).

## 4. Discussion

This study presents the status of the wood-based bioeconomy in the Slovenian economy, shows its detailed structure, and assesses its inter-industry linkages at the current stage (year 2015, latest available data), addressing possible paths for further development. Input–output analyses, with a special focus on the sectors of the wood-based bioeconomy (forestry, wood-processing industry, paper industry, wood-based chemical industry, furniture industry, and wood-based heat and electricity industry), were performed through calculations of input–output multipliers and impact assessments in terms of total output, number of employees, and household income.

*4.1. Wood-Based Bioeconomy Potentials*

In general, input–output multipliers indicate the potential of each sector in the model regarding their contribution to the overall economy in terms of output, employment, and household income. Among the 65 sectors of the Slovenian economy, the wood-based bioeconomy sectors, which include processing of raw materials, rank high, so it can be assumed that they have the potential to induce knock-on effects in the Slovenian economy. Of the bioeconomy sectors examined in our study, the paper industry and the wood-processing and furniture industries have the highest multipliers in terms of output and employment. The lowest multipliers in this regard were found in the forestry sector, which is logical considering its status in the value chain—provision of raw materials (e.g., roundwood) for further processing—where little value is added. Similar results can also be found in Loizou, Jurga, Rozakis, and Faber [29] and Jurga, Loizou, and Rozakis [30], where the overall potential of the bioeconomy for Poland was analysed. In their case, primary sectors such as forestry ranked low, while manufacturing sectors such as wood-processing and furniture ranked high. Thus, the input–output analyses in this study assume that the processing industries will be strengthened and achieve better vertical connectivity, i.e., greater utilization of the domestic raw material base. In this case, the wood-based bioeconomy can become not only the leading branch of the bioeconomy in the country, but also one of the key engines of growth for the national economy.

Our analysis provides some additional insight into previous studies on material balance [3,52] that has strong implications for the development of the future Slovenian wood-based bioeconomy. Material balance studies, which focus on wood availability, describe Slovenia as one of the countries with the highest wood availability per hectare and correspondingly place the country among the so-called "net exporters" of wood [53,54]. On the other hand, as the input–output table data for the wood-based bioeconomy reveals the opposite. The sector is highly import-dependent, with the majority of imports representing already-manufactured primary or secondary processed wood products [49]. The additional insight applies to the fact that, in national economy terms, the Slovenian wood-based bioeconomy loses much primary production and value-added potential in the processing of raw roundwood. Analyses of input requirement structures of the wood-based bioeconomy sectors have shown that imports of goods and services accounted for 39% of the production inputs in the whole value chain in 2015, with several possible ways to reduce the share of imports and replace it with domestic primary production in the future.

To address this issue, our study tested five different scenarios, mimicking the projected future structure of the Slovenian wood-based bioeconomy. The baseline scenario (current structure and performance of the sector) was confronted with one low-value-added scenario and three high-value-added scenarios. The impact analysis assumed a fixed exogenous change in final demand of EUR 100 million (around 4% of total output of wood-based bioeconomy sectors), specifically allocated to the whole economy for each scenario. In this way, we assessed differences in output, employment, and household income multipliers. A similar approach to exogenous shocks in the economy was also explored by Loizou, Karelakis, Galanopoulos, and Mattas [34].

The analyses showed that the exogenous increase in final demand of EUR 100 million in the current (2015) Slovenian wood-based bioeconomy (Scenario A) would lead to EUR 92.8 million of new output created, 1037 new employees, and EUR 19.2 million of new household income. Scenarios B, D, and D+ show that an expansion of the wood-based bioeconomy could lead to at least 10% higher output, 9% more employees, and 8% higher household income. These values refer to Scenario B, in which only some of the wood-processing sectors were expanded. Scenarios D and D+, on the other hand, considered an optimistic and very optimistic expansion of the entire wood-based bioeconomy. Compared to the baseline scenario, the EUR 100 million increase in final demand under scenarios D and D+ would lead to an increase in total output of between 11% (scenario D) and 20% (scenario D+), an increase in employment of between 12% and 24%, and an increase in household income of between 11% and 19%. The only scenario that had a lower overall economic impact compared to the baseline scenario was Scenario C, which tested the use of wood only for heat and electricity generation (low value added). Scenario C resulted in a 3% decrease in total output and a 27% decrease in household income, while employment could increase by 19%.

### *4.2. Methodological and Data Constrains*

Due to objective circumstances (unavailability of the newer 2020 table at the time of the analysis), a modelling tool—the disaggregated national I-O model—was developed on the basis of the 2015 national I-O table. Although this is a shortcoming, it should be noted that updating the analysis with the more recent2020 I-O table would not have affected the main findings of the paper. The reason for this lies in the underlying I-O theory [26], according to which the technological coefficients, which represent the (Leontief) production function of each sector, remained constant for most sectors. Sizeable impacts on the performance of bioeconomy sectors were induced by the changes in the sector's input requirements in the scenario analysis. In interpreting the results of this study, the reader should be aware of the change that has occurred in the wood-based bioeconomy sectors since 2015. A major change has taken place in the primary forestry sector with the centralization of the management of state-owned forests, which account for 20% of the forest area and around 50% of the industrial roundwood consumption within a single, state-owned business entity, State Forestry Company [22,55]. This, together with the state political commitments [56] and corresponding State Forestry Company company's regulations [57], is aimed at making more harvested roundwood available for domestic primary processing, thus reducing the export of roundwood, which renders the assumptions of the three scenarios (increased consumption of domestic roundwood) close to reality. Regarding the wood manufacturing sector, a notable change is the closure of a large plywood operation in 2016, which somewhat diminishes the feasibility of scenario B (expansion of the wood-processing sector).

Another word of caution applies to sectoral aggregation. This applies particularly to the sectors that include many different sub-activities (groups and classes), such as the wood-processing sector (C16). The results of the impact analysis apply only to the sector aggregate C16. The results fail to address the projected impacts of several sub-activities, such as sawmilling and planing of wood (C16.10), the manufacturing of veneer sheets and wood-based panels (C16.21), the manufacturing of assembled parquet floors (C16.22), the manufacturing of other builder**s'** carpentry and joinery (C16.23), the manufacturing of wooden containers (C16.24), and the manufacturing of other wood products.

Thirdly, the scenarios applied in the impact assessment anticipated hypothetical changes within the wood-based bioeconomy in terms of the share of sectors within the wood value chain, and the structure of input requirements was implemented differently to apply the hypothetical exogenous change in final demand. Scenarios D and D+ were motivated by the projected mid- to long-term changes in the species composition of forest stands in Slovenia, and consequently, the changing structure of timber assortments and the technological characteristics of wood [58,59]. One of the most pronounced projected changes is faster growth and a higher proportion of hard-wood (beech) in the wood sector's structure. Changes in the raw material base dictate a greater focus on (more technologically and capital-intensive) industries, such as wood-based chemicals. With regard to the static character of the input–output model (based on 2015 figures), and taking into the account the intensive modernization of the wood value chain (digitalization, robotization, etc.) that we are currently witnessing, the output and household income multiplier may be underestimated, and the employment multiplier may be overestimated to some extent.

### *4.3. Policy Implications and Future Perspectives*

In the last decade, the forest-based bioeconomy in Slovenia has not fallen short of government initiatives and strategies. It started with the action plan for improving and increasing the competitiveness of the forest wood chain in Slovenia by 2020 [60]. The wood value chain was also included in the national Smart Specialization Strategy [39], where different aspects of the forest-based bioeconomy (novel materials, intersectoral collaboration, circular economy) were integrated into three (out of nine) strategic priorities. Next, the wood value chain was also included among the key objectives of Slovenia's 2030 strategy for development [37], with two bioeconomic principles outlined: (1) a low-carbon circular economy and (2) sustainable management of natural resources. Wood biomass was recognized as the key resource base in the transition of Slovenia to a circular economy [38]. Finally, in 2022, the Ministry of Economic Development and Technology published the document implementing measures for the development of the wood-processing industry by 2030.

The strategies listed above are characterized by a top-down narrative and ambitious goals, which are not met by binding financial commitments. The second feature, symptomatic of development policies not just in Slovenia, but also across the EU (e.g., cohesion policy, rural development policy), is the sectoral focus and weak coordination between the policies. This situation is particularly unfavourable for horizontal sectors such as the bioeconomy, where coordinated action is essential. The results of this study, revealing the knock-on economic effects of alternative approaches (scenarios) towards the organization of the forest-based bioeconomy, provide guidance for policy planning. By using input–output models, it is possible to measure not only the direct impacts of exogenous changes, but also the indirect impacts on the economy. This gives decision makers the opportunity to assess not only primary demand (i.e., raw materials), but also secondary demand, as inputs from related sectors (construction, energy, new labour, etc.) can increase the likelihood of achieving the strategic goals. Moreover, by illustrating the interdependence between economic sectors, the results provide a clear signal for policy planners and decision makers that a more coordinated policy action with clear financial commitments is needed.

## 5. Conclusions

The evidence of the leading EU countries and regions in the bioeconomy reveal the importance of strong, consolidated value chains with large-scale industrial processing units in their core. They find it easier to provide leverage for value-adding throughout the whole value chain [61]. While the scale and the level of integration of industrial operations in the wood value chain in Slovenia significantly dropped in recent decades [62], the sector adapted inter alia by increasing the exports of roundwood [63] (in particular, lower-quality roundwood) to large-scale processing facilities in the vicinity, most notably in Austria and Slovenia. Integration into wider, cross-border value chains by supplying roundwood to and supplying intermediate outputs from these large-scale processing facilities for processing into finished products appears to be a feasible scenario [17] for leveraging wood-based bioeconomy potential [64]. In terms of future research, it would be worthwhile to delve into such a scenario to make a quantified assessment of the impacts of such restructuring for particular sectors, as well as for the national wood-based bioeconomy as a whole. Methodologically, a multi-regional input–output model seems to be an appropriate approach, as it would allow for a quantified insight into the interdependence of the different regions in terms of structure and transactions between sectors. A similar impact analysis as that carried out in this paper, but in this case from a multi-regional and cross-border perspective, would provide valuable information and, thus, help with strategic planning of the (extended) wood-based value chain at the macro-regional level. In this context, strengthening of trans-regional and cross-border cooperation would also provide a basis for technological breakthroughs in the wood-based bioeconomy sectors and, consequently, would aid in the economic performance of the wood-based bioeconomy sectors, both individually and as a whole.

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## References

1. Winkel, G. (Ed.) *Towards a Sustainable European Forest-Based Bioeconomy*; European Forest Institut: Joensuu, Finland, 2017; Volume 8, p. 162.
2. Carus, M.; Dammer, L. The circular bioeconomy—Concepts, opportunities, and limitations. *Ind. Biotechnol.* **2018**, *14*, 83–91. [CrossRef]
3. Verkerk, P.J.; Hassegawa, M.; Van Brusselen, J.; Cramm, M.; Chen, X.; Maximo, Y.I.; Koç, M.; Lovrić, M.; Tegegne, Y.T. *The Role of Forest Products in the Global Bioeconomy—Enabling Substitution by Wood-Based Products and Contributing to the Sustainable Development Goals*; FAO: Rim, Italy, 2022; p. 168.
4. Galanakis, C.M.; Brunori, G.; Chiaramonti, D.; Matthews, R.; Panoutsou, C.; Fritsche, U.R. Bioeconomy and green recovery in a post-COVID-19 era. *Sci. Total Environ.* **2022**, *808*, 152180. [CrossRef] [PubMed]
5. Woźniak, E.; Tyczewska, A. Bioeconomy during the COVID-19 and perspectives for the post-pandemic world: Example from EU. *EFB Bioecon. J.* **2021**, *1*, 100013. [CrossRef]
6. Keegan, D.; Kretschmer, B.; Elbersen, B.; Panoutsou, C. Cascading use: A systematic approach to biomass beyond the energy sector. *Biofuels Bioprod. Biorefin.* **2013**, *7*, 193–206. [CrossRef]
7. European Commission. *A Sustainable Bioeconomy for Europe: Strengthening the Connection Between Economy, Society, and the Environment*; Publications Office of the European Union: Luxembourg, 2018; p. 107. Available online: https://knowledge4policy.ec.europa.eu/publication/sustainable-bioeconomy-europe-strengthening-connection-between-economy-society_en (accessed on 23 November 2024).
8. Kangas, H.-L.; Lintunen, J.; Pohjola, J.; Hetemäki, L.; Uusivuori, J. Investments into forest biorefineries under different price and policy structures. *Energy Econ.* **2011**, *33*, 1165–1176. [CrossRef]
9. Carus, M.; Dammer, L.; Puente, Á.; Raschka, A.; Arendt, O. *Bio-Based Drop-In, Smart Drop-In and Dedicated Chemicals*; Nova-Institut: Huerth, Germany, 2017; p. 3.
10. Balat, M.; Ayar, G. Biomass energy in the world, use of biomass and potential trends. *Energy Sources* **2005**, *27*, 931–940. [CrossRef]
11. Verkerk, P.J.; Fitzgerald, J.B.; Datta, P.; Dees, M.; Hengeveld, G.M.; Lindner, M.; Zudin, S. Spatial distribution of the potential forest biomass availability in Europe. *For. Ecosyst.* **2019**, *6*, 5. [CrossRef]
12. Hurmekoski, E.; Jonsson, R.; Korhonen, J.; Jänis, J.; Mäkinen, M.; Leskinen, P.; Hetemäki, L. Diversification of the forest industries: Role of new wood-based products. *Can. J. For. Res.* **2018**, *48*, 1417–1432. [CrossRef]
13. Hurmekoski, E.; Smyth, C.E.; Stern, T.; Verkerk, P.J.; Asada, R. Substitution impacts of wood use at the market level: A systematic review. *Environ. Res. Lett.* **2021**, *16*, 123004. [CrossRef]
14. Hildebrandt, J.; Hagemann, N.; Thrän, D. The contribution of wood-based construction materials for leveraging a low carbon building sector in europe. *Sustain. Cities Soc.* **2017**, *34*, 405–418. [CrossRef]
15. Huang, H.-J.; Ramaswamy, S.; Tschirner, U.W.; Ramarao, B.V. A review of separation technologies in current and future biorefineries. *Sep. Purif. Technol.* **2008**, *62*, 1–21. [CrossRef]
16. Arnič, D.; Prislan, P.; Juvančič, L. Raba lesa v slovenskem biogospodarstvu. *Gozdarski Vestn.* **2019**, *77*, 375–393.
17. Juvančič, L.; Berne, S.; Oven, P.; Osojnik Črnivec, I. Strategic concept paper for Bioeconomy in Slovenia: From a patchwork of good practices to an integrated, sustainable and robust bioeconomy system. *Open Res. Eur.* **2023**, *3*, 167. [CrossRef] [PubMed]

18. Krajnc, N.; Piškur, M. Tokovi okroglega lesa in lesnih ostankov v Sloveniji = Roundwood and wood waste flow analysis for slovenia. *Zb. Gozdarstva Lesar.* **2006**, *80*, 31–54.
19. Kropivšek, J.; Straže, A.; Bučar, D.G. Analysis of primary value chains in Slovenian forest and wood bioeconomy. *Drv. Ind. Znan. Stručni Čas. Pitanja Drv. Tehnol.* **2024**, *75*, 359–369. [CrossRef]
20. Pirjevec, T. *Ponovni Zagon Slovenske Lesnopredelovalne Industrije: Magistrsko Delo*; Univerza v Ljubljani: Ljubljana, Slovenia, 2015.
21. UNECE. Country Market Statments. Available online: https://unece.org/forests/market-statements-2020 (accessed on 3 June 2022).
22. Čater, M.; Železnik, P. (Eds.) *Forests and Forestry in Slovenia*; Slovenian Forestry Institute: Ljubljana, Slovenia; The Silva Slovenica Publishing Centre: Ljubljana, Slovenia, 2021; p. 120.
23. Arnič, D.; Gričar, J.; Jevšenak, J.; Božič, G.; von Arx, G.; Prislan, P. Different wood anatomical and growth responses in european beech (*Fagus sylvatica* L.) at three forest sites in Slovenia. *Front. Plant Sci.* **2021**, *12*, 669229. [CrossRef]
24. Arnič, D.; Krajnc, L.; Gričar, J.; Prislan, P. Relationships between wood-anatomical features and resistance drilling density in norway spruce and european beech. *Front. Plant Sci.* **2022**, *13*, 872950. [CrossRef]
25. Jevsenak, J.; Tychkov, I.; Gricar, J.; Levanic, T.; Tumajer, J.; Prislan, P.; Arnic, D.; Popkova, M.; Shishov, V.V. Growth-limiting factors and climate response variability in Norway spruce (*Picea abies* L.) along an elevation and precipitation gradients in Slovenia. *Int. J. Biometeorol.* **2021**, *65*, 311–324. [CrossRef] [PubMed]
26. Miller, R.E.; Blair, P.D. *Input-Output Analysis: Foundations and Extensions*, 2nd ed.; Cambridge University Press: New York, NY, 2009; p. 737.
27. Budzinski, M.; Bezama, A.; Thrän, D. Monitoring the progress towards bioeconomy using multi-regional input-output analysis: The example of wood use in Germany. *J. Clean. Prod.* **2017**, *161*, 1–11. [CrossRef]
28. Lehtonen, O.; Okkonen, L. Regional socio-economic impacts of decentralised bioeconomy: A case of Suutela wooden village, Finland. *Environ. Dev. Sustain.* **2013**, *15*, 245–256. [CrossRef]
29. Loizou, E.; Jurga, P.; Rozakis, S.; Faber, A. Assessing the potentials of bioeconomy sectors in poland employing input-output modeling. *Sustainability* **2019**, *11*, 594. [CrossRef]
30. Jurga, P.; Loizou, E.; Rozakis, S. Comparing bioeconomy potential at national vs. regional level employing input-output modeling. *Energies* **2021**, *14*, 1714. [CrossRef]
31. Rimmler, T.; Kurttila, M.; Pesonen, M.; Koljonen, K. Economic impacts of alternative timber-cutting scenarios in Finland: An input–output analysis. *For. Policy Econ.* **2000**, *1*, 301–313. [CrossRef]
32. Thomson, K.J.; Psaltopoulos, D. Incorporating Output Projections into a Regional Input-Output Model: The Case of Forestry in Rural Scotland. *J. Appl. Input-Output Anal.* **2000**, *6*, 15.
33. Bösch, M.; Weimar, H.; Dieter, M. Input–output evaluation of Germany's national cluster of forest-based industries. *Eur. J. For. Res.* **2015**, *134*, 899–910. [CrossRef]
34. Loizou, E.; Karelakis, C.; Galanopoulos, K.; Mattas, K. The role of agriculture as a development tool for a regional economy. *Agric. Syst.* **2019**, *173*, 482–490. [CrossRef]
35. Giurca, A. Unpacking the network discourse: Actors and storylines in Germany's wood-based bioeconomy. *For. Policy Econ.* **2018**, *110*, 101754. [CrossRef]
36. Straže, A.; Gornik Bučar, D.; Kropivšek, J. Identification of value chains in the Slovenian forest and wood bioeconomy. *Les/Wood* **2024**, *72*, 21–34. [CrossRef]
37. Soos, T.; Lautar, K.; Urbancic, H.; Kobe Logonder, N.; Kmet Zupancic, R.; Fajic, L.; Cokl, A.; Gantar, J.; Lenarcic, M.; Culpa, N. *Strategija Razvoja Slovenije 2030*; Sluzba Vlade Republike Slovenije za Razvoj in Evropsko Kohezijsko Politiko: Ljubljana, Slovenia, 2017; p. 72.
38. MOPRS. *Kažipot Prehoda v Krozno Gospodarstvo*; Ministrstvo za Okolje in Prostor Republike Slovenije: Ljubljana, Slovenia, 2018; p. 59.
39. Služba Vlade Republike Slovenije za razvoj in evropsko kohezijsko politiko. Slovenska Strategija Pametne Specializacije S4; Služba Vlade Republike Slovenije za razvoj in evropsko kohezijsko politiko: Ljubljana, Slovenija. 2017. Available online: https://www.gov.si/assets/ministrstva/MKRR/S4-Slovenska-strategija-pametne-specializacije/Slovenska-strategija-pametne-specializacije.pdf (accessed on 23 November 2024).
40. Tavzes, Č.; Biloslavo, R.; Grdović Gnip, A.; Schau, E.; DeVallance, D.; David, B.; Šušteršič, I.; Gavrić, I.; Mikuljan, M.; Prelovšek Niemelä, E.; et al. *Ekonomski Vidiki Prestrukturiranja Lesno-Predelovalne Panoge v Republiki Sloveniji*; Wood Industry Directorate, Ministry of Economic Development and Technology: Ljubljana, Slovenia, 2020.
41. Kahouli, S.; Martin, J.C. Can offshore wind energy be a lever for job creation in France? Some insights from a local case study. *Environ. Model. Assess.* **2018**, *23*, 203–227. [CrossRef]
42. Loizou, E.; Chatzitheodoridis, F.; Michailidis, A.; Tsakiri, M.; Theodossiou, G. Linkages of the energy sector in the Greek economy: An input-output approach. *Int. J. Energy Sect. Manag.* **2015**, *9*, 393–411. [CrossRef]
43. Ní Dhubháin, Á.; Fléchard, M.-C.; Moloney, R.; O'Connor, D. Assessing the value of forestry to the Irish economy—An input–output approach. *For. Policy Econ.* **2009**, *11*, 50–55. [CrossRef]
44. AJPES. AJPES-Agencija Republike Slovenije za Javnopravne Evidence in Storitve. Available online: https://www.ajpes.si/?language=english (accessed on 5 May 2022).

45. Kocjančič, T.; Rac, I.; Novak, A.; Arnič, D.; Juvančič, L. *Premostitev Vrzeli v Biogospodarstvu od Gozdne in Kmetijske Biomase do Inovativnih Tehnoloških Rešitev: Inventarizacija Dejavnosti, Ovrednotenje Stanja in Ažuriranje Kazalnikov in Orodij za Oceno Pripravljenosti Prehoda v Biogospodarstvo v Sloveniji*; Biotehniška Fakulteta: Ljubljana, Slovenia, 2021; p. 52.
46. Ronzon, T.; Piotrowski, S.; Tamosiunas, S.; Dammer, L.; Carus, M.; M'barek, R. Developments of economic growth and employment in bioeconomy sectors across the EU. *Sustainability* **2020**, *12*, 4507. [CrossRef]
47. Ronzon, T.; Piotrowski, S.; M'Barek, R.; Carus, M. A systematic approach to understanding and quantifying the EU's bioeconomy. *Bio-Based Appl. Econ.* **2017**, *6*, 1–17. [CrossRef]
48. Ronzon, T.; M'Barek, R. Socioeconomic Indicators to Monitor the EU's Bioeconomy in Transition. *Sustainability* **2018**, *10*, 1745. [CrossRef]
49. Eurostat. *Symmetric Input-Output Table at Basic Prices (Product by Product)*; Eurostat: Luxembourg, 2022. Available online: https://ec.europa.eu/eurostat/web/esa-supply-use-input-tables/information-data (accessed on 23 November 2024).
50. Statistical Office of the Republic of Slovenia. *Odkup Lesa*; Statistical Office of the Republic of Slovenia: Ljubljana, Slovenia, 2022. Available online: https://www.stat.si/StatWeb/en/News/Index/11422 (accessed on 23 November 2024).
51. Statistical Office of the Republic of Slovenia. *Poraba Lesa in Lesnih Odpadkov za Proizvodnjo Elektrike in Toplote*; Statistical Office of the Republic of Slovenia: Ljubljana, Slovenia, 2022. Available online: https://www.stat.si/StatWeb/en/News/Index/11422 (accessed on 23 November 2024).
52. Verkerk, P.J.; Anttila, P.; Eggers, J.; Lindner, M.; Asikainen, A. The realisable potential supply of woody biomass from forests in the European Union. *For. Ecol. Manag.* **2011**, *261*, 2007–2015. [CrossRef]
53. Kastner, T.; Erb, K.-H.; Nonhebel, S. International wood trade and forest change: A global analysis. *Glob. Environ. Chang.* **2011**, *21*, 947–956. [CrossRef]
54. Lamers, P.; Junginger, M.; Hamelinck, C.; Faaij, A. Developments in international solid biofuel trade—An analysis of volumes, policies, and market factors. *Renew. Sustain. Energy Rev.* **2012**, *16*, 3176–3199. [CrossRef]
55. Ščap, Š.; Arnič, D. Povezovanje v verigo vrednosti za višjo dodano vrednost. In *Trajnostna Raba Lesa: Priročnik*; Volfand, J., Ed.; Fit Media: Celje, Slovenia, 2021; pp. 28–32.
56. MGRTRS. *Izvedbeni Dokument Ukrepov Razvoja Lesnopredelovalne Industrije do Leta 2030*; Ministrstvo za Gospodarski Razvoj in Tehnologijo, Direktorat za Lesarstvo: Ljubljana, Slovenia, 2022.
57. SIDG. *Pravila Družbe Slovenski Državni Gozdovi, d. o. o., o Načinu in Merilih za Prodajo Gozdnih Lesnih Sortimentov*; SIDG: Kočevje, Slovenia, 2023.
58. Poljanec, A.; Bončina, A. Structure and composition of forest stands at regional and national levels in the last five decades. *For. For. Slov.* **2020**, 24–35.
59. Prislan, P.; Gričar, J.; Čufar, K.; de Luis, M.; Merela, M.; Rossi, S. Growing season and radial growth predicted for Fagus sylvatica under climate change. *Clim. Chang.* **2019**, *153*, 181–197. [CrossRef]
60. Miklič, J. *Les je lep: Akcijski Načrt za Povečanje Konkurenčnosti Gozdno-Lesne Verige v Sloveniji do Leta 2020*; Ministrstvo za kmetijstvo in okolje RS: Ljubljana, Slovenia, 2012.
61. Morone, P.; D'Adamo, I.; Cianfroni, M. Inter-connected challenges: An overview of bioeconomy in Europe. *Environ. Res. Lett.* **2022**, *17*, 114031. [CrossRef]
62. Polanec, S. Firm Dynamics in Transition. In Proceedings of the 34th annual European Finance Association (EFA), Ljubljana, Slovenia, 24–27 August 2007; University of Ljubljana: Ljubljana, Slovenia, 2007. Available online: https://ssrn.com/abstract=967663 (accessed on 23 November 2024).
63. Ščap, Š. Značilnosti zunanje trgovine z okroglim lesom v letu 2023. *InfoGozd Skrbno Gozdom* **2024**, *5*, 21–26. [CrossRef]
64. Kropivšek, J.; Straže, A.; Gornik Bučar, D. Kvalitativna/strateška analiza izbranih verig vrednosti v slovenskem gozdno-lesnem biogospodarstvu. *Les/Wood* **2023**, *72*, 35–48. [CrossRef]