energies

Article

The Development of a Model of Economic and Ecological Evaluation of Wooden Biomass Supply Chains

Bohdan Hrechyn [1,*], Yevhen Krykavskyy [2] and Jacek Binda [2]

[1] Department of Marketing and Logistics, Lviv Polytechnic National University, 79000 Lviv Oblast, Ukraine
[2] Department of Finance and Information Technologies, Bielsko-Biala School of Finance and Law, 43-382 Bielsko-Biała, Poland; yevhen.v.krykavskyi@lpnu.ua (Y.K.); jbinda@wsfip.edu.pl (J.B.)
* Correspondence: bohdan.d.hrechyn@lpnu.ua; Tel.: +48-604-775-216

Abstract: This scientific publication is dedicated to the development of scientific methodological and practical recommendations about the formation of ecologistics approaches towards usage of the energetical potential of wooden biomass as a promising trend of economic activity subject development. The hierarchy of ecological chain build-up is established, which will allow one to effectively organize the logistics of supply of biomass to the place of energy production. The methodological approaches to modeling of economic and ecological evaluation of wooden mass supply chain were improved. It is aimed to the calculation of expanses and harmful emissions that depend on specific logistics processes in implementation of perspective actions of collection and recycling of wooden biomass and substitution of non-renewable energy sources by it, which, on the one hand, analyzes the actual state of affairs of knowledge in the field of ecological processes evaluation, and on the other hand, however, identifies restrictions on the amounts of potential provision of biomass. Due to the proposed model of economic and ecological evaluation of the supply chain of wooden biomass and the development of software with a database that covers information on specific logistics processes, it will be possible to conduct economic and ecological evaluation on each step of the logistics chain, present specific processes in cash equivalents, depict ecological effectiveness, and identify the most vulnerable points of the logistics system, opening vast opportunities for improvement of other supply systems.

Keywords: ecologistics; supply chains; ecological evaluation; economic evaluation; energetic potential; wooden biomass; environment; logistics processes

check for updates

Citation: Hrechyn, B.; Krykavskyy, Y.; Binda, J. The Development of a Model of Economic and Ecological Evaluation of Wooden Biomass Supply Chains. *Energies* **2021**, *14*, 8574. https://doi.org/10.3390/en14248574

Academic Editor: Idiano D'Adamo

Received: 28 June 2021
Accepted: 19 August 2021
Published: 20 December 2021

1. Introduction

The actualization of ecological problems in the global environment stimulates the scientific and practical research of social phenomenon and processes that affect the quality of natural and production environments in different fields of life activities. Economical, logistical, organizational, and managerial processes and analytical technologies to realize the energetical potential of wooden biomass must become the means to reach the aim of energy independence of Ukraine, on the one hand, and the strategic vector of state politics development in the sphere of environmental protection and production environment on the other. Ecologization is one of the main innovative competitive advantages of logistics activity and has to cohere with it. According to global practice, it is quite important to combine logistics and ecologizational processes, as the logistics part itself is a key alternative for economic activities of manufacturers and their agents, while ecological is an innovative part, both for subjects of economic activity and socioeconomical systems of higher levels of management.

2. Scientific Novelty of the Obtained Results

From an ecological point of view, Forsberg analyzed an optimum of production processes and electrical energy distribution in a country supplied with biomass by another country [1]. In terms of energy and money expenditure, Suurs explored this topic in his study and evaluated general strategies for the importing of biomass as an energy carrier for Europe and Latin America [2].

Studies of logistics starting from biomass collection to biofuel, heat, or electrical energy recycling and production were carried out by Pfohl [3], Weber [4], and Gudehus [5]. Their approaches were based on classical logistics planning and optimization; however, analysis and evaluation of environmental impacts caused by shipping and other logistics processes have not been sufficiently studied.

This article includes references to works written by researchers who focused on economic and/or ecological biomass evaluation and supply and provision processes and who also took changes and tendencies in energy industry into account. Pistorius [6] and Plöchl [7] conducted energy estimation of different biomass types. A considerable number of works is dedicated to estimating the whole life cycle of biomass, from cultivation production of energy (Jungbluth [8], Krotschek [9], Spath [10], Marheineke [11], Scholwin [12]) to biofuel (Mardon [13], Soimakallio [14], Zah [15]). However, logistics and provision processes are not described in detail in their works, and only central tendencies are measured; hence, there is a high level of abstraction.

Scientists such as Kanzian et al. [16], Neff et al. [17], Scholz et al. [18], and Suurs [2] described models that enabled the analysis of one or a few processes of biomass provision, taking into account needs for personnel, time, and materials, and that also enabled estimation of costs and waste levels. They believed that the figures estimated in the analyses would serve as reference points for future economic and ecological evaluations.

Eberhardinger evaluated ecological balance of production processes of electrical energy obtained from wood waste. His analysis emphasized the impact of the whole supply chain and wood biomass provision on the biofuel energy balance. They reached the conclusion that a logistical component of biomass supply and provision have the potential for improvement in terms of expenditure, energy usage, and quality [19].

Given the extent of pollution caused by fossil fuels and human concerns about health and environmental protection, it is necessary to focus on strategies, practices, and actions that allow for the implementation of a sustainable energy system based on bioenergy production. It is known that the COVID-19 pandemic period has led to a socioeconomic crisis, which will have serious consequences for international logistics systems. Given that the transport sector is responsible for a significant share of CO_2 emissions, special emphasis should be placed on biofuels and sustainable development at the global level. This is particularly true in the case of Ukraine, as an agricultural country, where a concentrated large part of biomass is obliged to act as an active participant in this process in the following ways:

- Use raw materials that meet the criteria of sustainability;
- Analyze the supply chain for the actual sustainability of the product;
- Use industrial symbiosis and energy communities as an effective element of cooperation among energy consumers;
- Implement a policy that supports the development of bioenergy and biofuels;
- Popularize the tendency of the willingness to pay for green or circular products among business and individual consumers;
- Support those business models that implement eco-initiatives in comparison with business models that include the consumption of conventional products based on fossil materials [20,21].

This research is related to the improvement of methodical approaches to making a model of economic and ecological evaluation of the wood biomass supply chain, which is oriented towards providing a high level of business entity competitiveness based on ecologistics. In the research were used such methods as the methods of observation, factor analysis, and economic and mathematical modeling. In contrast to existing studies [1–19,22,23], it allows one to secure a steady pace of wood biomass provision and consumption growth and to apply a diversified approach to the attraction of investment resources and employment of new technologies. Further developments have occurred in essential components of the supply chain in the process of wood biomass provision and consumption. They, in addition to the existing ones [1–19,22,23], take ecological standards and energy usage efficiency level into account and make it possible to minimize negative impacts on ecology and to secure resource saving, stable development of business entities, and increases Ukrainian business effectiveness. Comparative calculations, e.g., on the use of coal, briquettes, peat, and gas as a fuel, are usually based on the estimation of direct costs without taking into account associated costs (for example, costs aimed at minimizing the negative impact on the environment, etc.) in the supply chain.

This research and the proposed model are cross-applicable and relevant for all countries with a significant wood stock.

3. Statement of Basic Materials

Protection of natural and industrial environments, regulatory and logistics processes, balance of greenhouse waste emissions, and also bioenergy industry development are closely interconnected. These mutual relations form the basis for future projects, research, and elaboration of a database in the sphere of economic and/or ecological evaluation applied to forestry, the energy industry, and biomass logistics. In term of raw material reserves, central and western regions of Ukraine are the most promising for production organization (Figure 1).

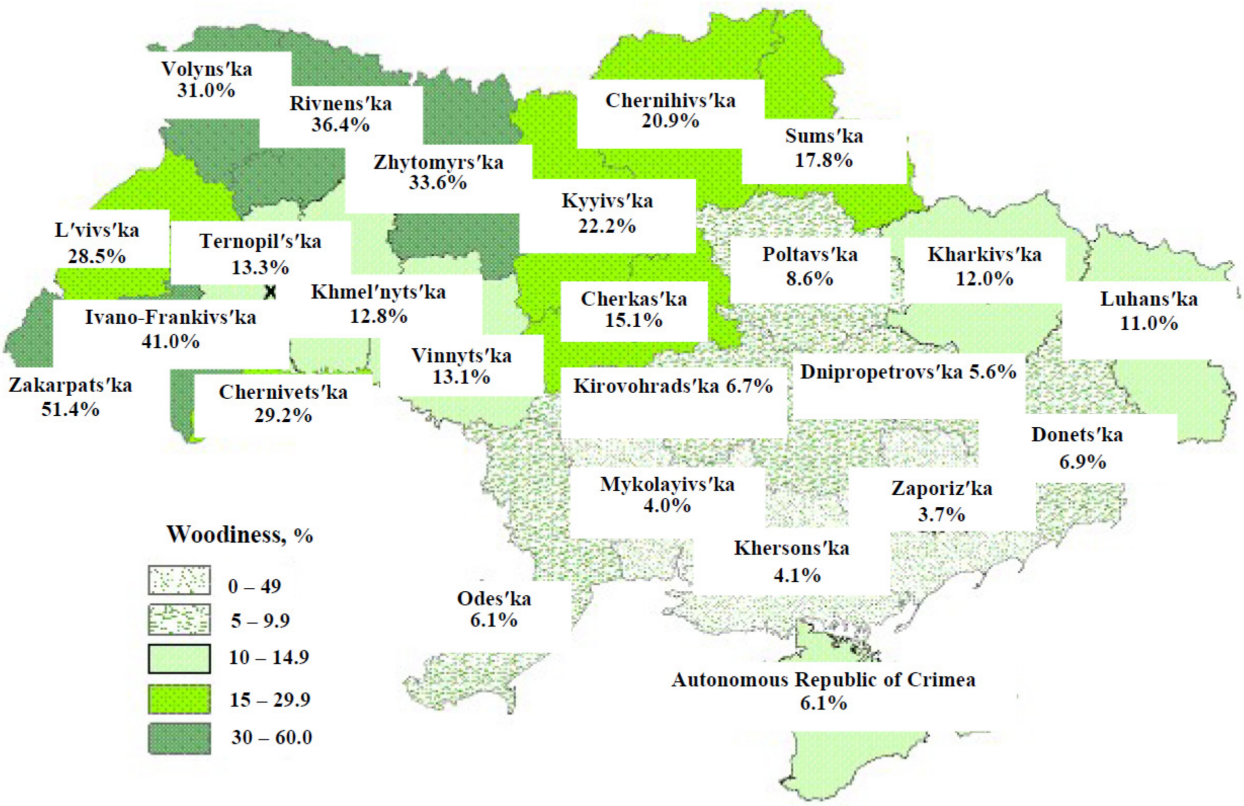


Figure 1. Raw material base for wood biomass provision in the territory of Ukraine [24].

The research suggests a typical wood biomass supply chain including gathering of wood raw materials (fallen trees, cutting standing trees) → loading raw material into a vehicle → transshipment of raw material (the biomass can be overloaded) → transporting of raw material to terminals (warehouses) → unloading of raw material → warehousing and storage of raw material → chopping raw material into woodchips → transporting of woodchips to a production department → production of biofuel (pellet) and delivery after production. With regard to internal and external technical and technological, infrastructural, financial, and organizational conditions, this chain transforms into an individual wood biomass supply chain of a business entity (Figure 2).

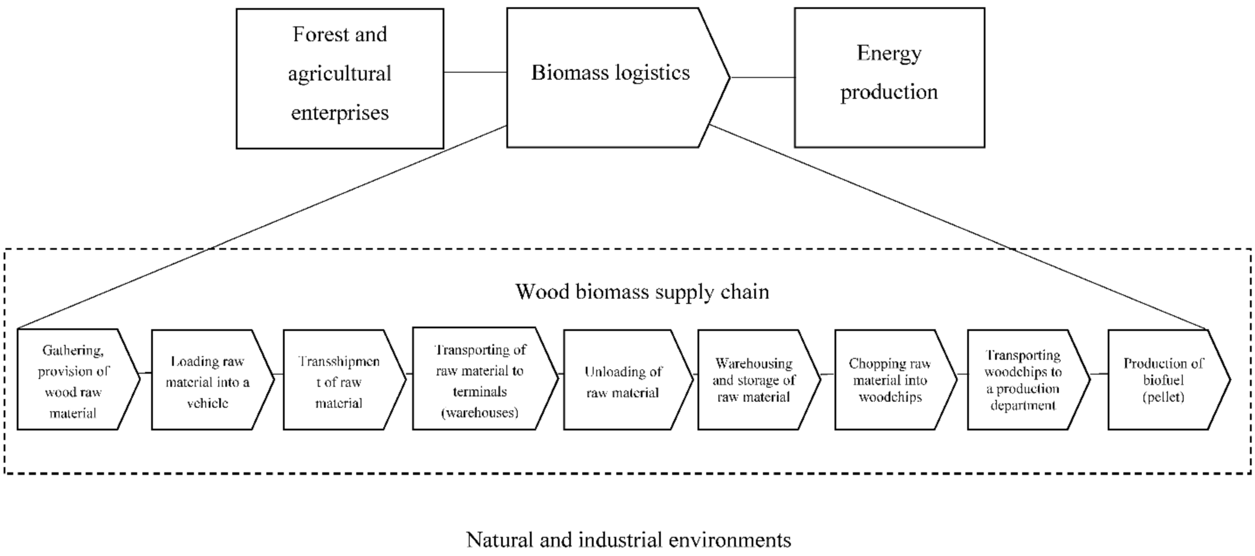


Figure 2. Biomass logistics: wood biomass supply chain.

According to the Ukrainian biofuel portal, woodchips production volumes are gradually increasing, although it is not a large-scale phenomenon. Woodchips are mainly produced by recycling waste obtained from industrial wood sawing; not more than 10% of logging waste is recycled [24,25]. In general, the situation with economic management by regions in Ukraine is stable. From year to year, economic processes become more efficient, wood stocks increase, log harvest decreases, and the amount of processing increases, leading to an increase in the amount of waste for energy fuel.

Miscanthus and willow are still underused, due to the alternative use of land for agricultural purposes being more profitable.

The application of methodic approaches, improved and developed in this research, will facilitate identification of "narrow" areas in modelling of wood biomass provision processes as well as economic and ecological evaluation of wood biomass supply chains, which will help to receive the information needed for making practical management solutions.

For example, if the task is to measure the impact of logistics processes on the natural environment during the whole process of biomass provision, then on the one hand, it should be clarified what types of impact on the environment will be analyzed, and, on the other hand, what methods will be used for estimation, to what extent the existing norms should be obeyed, and, finally, how will the outcomes be interpreted and presented [25,26].

Improvement of methodical approaches will be followed by elaboration of a model of economic and ecological evaluation of a wood biomass supply chain. The model will aim to calculate costs and measure the amount of hazardous waste emissions into the environment, which will enable evaluation of economic and ecological effectiveness of the whole process. Applying this model in practice requires a large number of parameters. The more detailed the data calculation description is, the more realistic the economic and ecological evaluation of wood biomass supply system's effectiveness of a business entity can be.

Economic evaluation of each process encompasses all the information on consumer spending and expenses on equipment (cars, vehicles, and other), personnel, and if needed on infrastructure.

Since railway and air transportation are usually considered as services provided by a third party and used according to demand, they will not be included into this calculation model. Types of road transport for freight shipping include common classic freight transport and shipping by agricultural machinery.

Transport costs include vehicle usage costs C_{veh}, personnel costs C_{per}, and vehicle repair and tuning up costs C_{tun}.

Fuel costs have considerable impacts on transportation cost calculations. Hazardous waste emissions into the environment, which are produced by road vehicles, should be taken into consideration. Information on emissions is provided for each type of vehicle (for example, a road train consisting of a semi-trailer truck and a trailer 34–40 t with the norm Euro-3) for a corresponding road category (for example, an agricultural road) in accordance with fuel costs on an empty or fully loaded vehicle, which corresponds to a load factor γ changing from 0% to 100%. Linear relations between fuel costs and a load factor are taken into account for fuel cost calculation. Figure 3 depicts dependency of diesel fuel costs F_{fuel} in grams/km on a vehicle load factor for different types of roads.

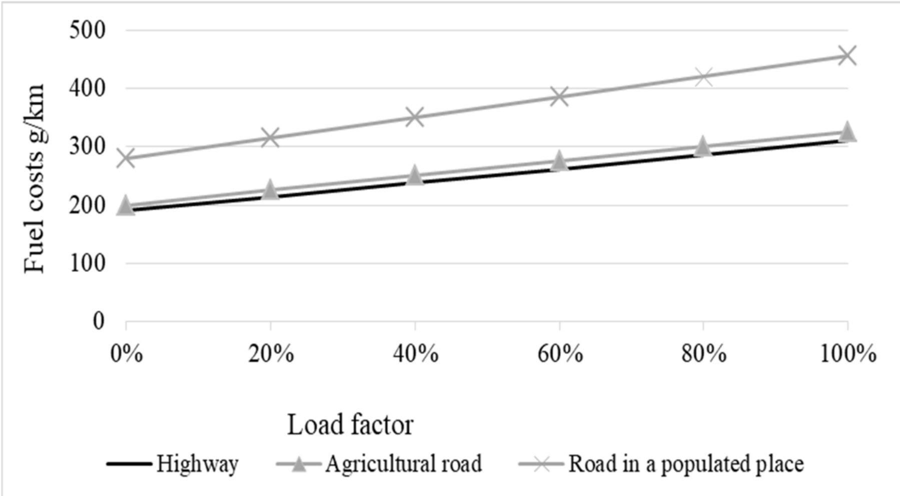


Figure 3. Dependency of fuel costs on a load factor [16].

The formula for calculating fuel costs C_{fuel} on freight transport m_{car}, which is shipped at a distance L, is as follows:

$$C_{fuel} = \frac{L \cdot m_{car}}{1000 \cdot m_{pload} \cdot \gamma} \cdot \left[\left(F_{fuel}^{100} - F_{fuel}^{0} \right) \cdot \gamma + k_{ret} \cdot F_{fuel}^{0} \right] \quad (1)$$

where F_{fuel}^{100} stands for fuel usage with a 100% loaded vehicle, and F_{fuel}^{0} stands for fuel usage with no load vehicle. In order to calculate fuel costs on a return road, a return coefficient is used, namely k_{ret} = 2 if return freight transport takes place and k_{ret} = 1 if a truck returns empty.

In order to calculate fuel costs of a partly loaded vehicle with m_{pload}, it is necessary to know its potential load $\left(m_{pload} \cdot \gamma \right)$. This index is presented to a client for space distribution in a vehicle. For example, a tank truck for dry bulk cargo used for transportation of pellet fuel can have enough room to transport the material for a few clients at a time.

In order to secure a full load for each transport change m_{pload}, it is necessary to calculate the difference between the maximum allowable weight of a vehicle and the weight of an empty vehicle. Simplified data applicable for all, without exception, Euro-standards are used to calculate the weight.

Semi-trailer trucks can be grouped according to engine power: vehicles with engine power P $\leq$ 210 kW, which belong to light semi-trailer trucks; and vehicles with engine power P > 210 kW, which belong to heavy semi-trailer trucks.

If a transport route consists of a few road types, this factor is included in square brackets (see (2)) in accordance with each road type k_r, for example, a controlled-access highway, or roads outside (tracks) or within populated areas. According to this, fuel consumption of one transport shift is calculated as follows:

$$C^{1}_{fuel} = \sum k_r \cdot \left[\left(F^{100}_{fuel} - F^{0}_{fuel} \right) \cdot \gamma + k_{ret} \cdot F^{0}_{fuel} \right] \quad (2)$$

Total fuel consumption is calculated separately for each transport change:

$$C^{\Sigma}_{fuel} = \sum k_{tc} \cdot C^{1}_{fuel} \quad (3)$$

Since 1 January 2016, all the cars imported from abroad have to meet the ecological standard Euro-5. As a result, there is a complete ban on importing cars produced earlier than 2010/2011 (or a compulsory engine redesign in accordance with the eco-standard), since, in fact, the ecological standard Euro-5 came into effect in EU-countries and the USA in 2009 and, consequently, car manufacturers commenced production of cars meeting Euro-5 standards after 2009.

Unfortunately, national business entities do not always monitor vehicles for Euro-5 standards. Thus, the suggestion is to introduce an average index of all Euro-standards Euroave, which are legislatively established (Euro 0–5). This will make it possible to estimate the level of hazardous emissions based on the statistical data of the vehicles' yearly kilometrage (km) and the volume of transported cargo (T-km).

It is recommendable to use the method suggested by a German scientist, Borken [16], for estimating fuel consumption of the vehicles used for wood biomass transportation. His method presupposes differential adjustment of fuel consumption based on five different applications of concentrated load to five different points, namely maximum load, normal load, minimum load, transportation (for example, transportation from a warehouse to a field), and idling (for example, during preparations or waiting), as shown in Figure 4.

Upon timing of concentrated load application points, it is possible to estimate vehicle fuel consumption according to the ratio

$$F_{burnt} = \sum k_{\%} \cdot C_{cons}, \quad (4)$$

where C_{cons} is fuel consumption for a specific application point and is applied in the research in order to estimate fuel consumption of agricultural machinery with the given rated powers for different concentrated load application points.

In addition to the fuel consumption C_{fuel}, there are costs of other materials employed C_{em} and road costs. In contrast to the vehicle usage costs C_{veh}, there are personnel costs C_{per} including vehicle repair C_{rv} and control costs C_{cv}. They are not constants and change with time, for example, lubricant costs.

Special software, "maKost", is applied in European practice. It has a database carefully selected for calculating all constant and changeable costs for each concrete agricultural vehicle model and evaluating its potential negative impacts on the natural environment. The program was elaborated by "KTBL", a German inspection board monitoring agricultural machinery and construction, and it is obviously multifunctional software. All parameters can be set individually, and the database can be used to calculate fuel costs and repair costs, to outline the needs, estimate economic factors, etc. [27–29]. In order to reduce time expenditure and make calculations as accurate as possible, it is recommendable that Ukrainian business entities use the aforementioned software. We also suggest that a national analogue of this program be elaborated, which would allow one to take into account the peculiarities of the vehicles used by our business entities.

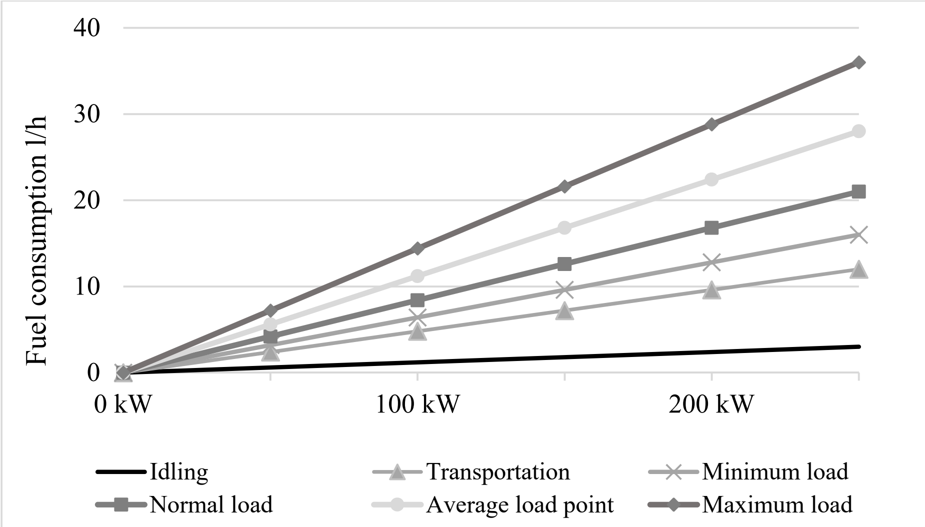


Figure 4. Correlation between fuel consumption and agricultural machinery power for different load application points [28].

In 2006, a Viennese scientist, Kanzian, introduced a model of calculating transportation time of short agricultural connections, in particular, for trucks making 4–12 km (from the forest to wood biomass processing department). The average speed of vehicles was assumed to be 17 km/h [16].

Wood biomass transshipment processes include cargo transshipment costs C_{tsh} where various machines and processes are involved. In general, the expenditure includes specific costs on infrastructure C_{tsh}^{inf}, with the area S_{tsh}^{a}, personnel C_{tsh}^{p}, machines C_{tsh}^{m}, and also energy expenditure C_{tsh}^{e} to get machinery ready for use:

$$C_{tsh} = t_{tsh} \cdot \left(S_{tsh}^{a} \cdot C_{tsh}^{inf} + C_{tsh}^{p} + C_{tsh}^{m} \right) + C_{tsh}^{e}, \quad (5)$$

where t_{tsh} is cargo transshipment time.

The observations of German scientist Dobers have shown that a flatbed truck with a crane can be loaded with branches in 10 min. Branches are aligned and piled up easily, which is quite productive as the time for unloading is one third quicker (while unloading branches are not to be aligned or piled) [30].

Evaluating the time needed for transshipment of woodchips using a pneumatic loader with shovel, it was estimated that loading of a container of 30 m^3 takes 15 min. Thus, the effectiveness of the process will be 120 m^3 per hour, which is 1 shovel lift in 1 min [31].

The process of unloading of woodchips off a vehicle is performed by turning it over; according to preliminary calculations, it is possible to unload 240 m^3 of round timber, firewood, or bales in an hour or 260 m^3 of woodchips or fuel pellets [2].

The storage expenses are divided into infrastructural expenses C_{infs} and extra expenses on container production and storage of cover materials C_{con}, and also the expenses on loading, transshipping, and unloading C_{load} are taken into account. Different types of wooden biomass require different types of storage options: in the warehouses with or without a roof, in silos, reservoirs, containers, bales, or large bags. All in all, for every option, the following formula to calculate the expenses on storage of cargo C_{stor} in a time t_{stor}, could be used:

$$C_{stor} = t_{stor} \cdot \left(C_{infs} + C_{con} \right) + C_{load} \quad (6)$$

Additional expenses C_{con} are estimated on the basis of the number of containers n_{con} or storage structures (wooden framework, hopper for bulk materials) and expenses on their production C_{prod}. In case the biomass is to be covered with waterproof material (area

S_{mat}) to protect from environmental conditions, then these expenses ($S_{mat} \cdot C_{mat}$) are added to the sum:

$$C_{con} = n_{con} \cdot C_{prod} + S_{mat} \cdot C_{mat} \quad (7)$$

If stored outdoors or covered, the expenses of the containers and the required amount of waterproof material required to cover a certain area as well as its assembling and expenses on storage space rental are determined.

Woodchips are loaded, unloaded, and transshipped by means of pneumatic loaders. Transshipment of the woodchips is also performed with ventilation measures and reduction of dry mass loss. If biomass is needed to be transshipped again during the storage, then the additional area S_{tshp} (e.g., larger hopper for bulk materials) is added to the number of times of loadings n_{tshp} in a time t_{tshp}. The loading, unloading, and transshipment expenses are calculated with the formula

$$C_{load} = (t_{load} + t_{unl}) \cdot \left(C^{p}_{load} + C^{m}_{load}\right) + n_{tshp} \cdot t_{tshp} \cdot \left(C^{p}_{sload} + C^{m}_{sload} + S_{tshp} \cdot C^{\inf}_{sload}\right) \quad (8)$$

where t_{load} and t_{unl} are the time indicator of loading and unloading, respectively; C^{p}_{load} and C^{m}_{load} are the expenses of staff and machines for loading, transshipment, and unloading, respectively; C^{p}_{sload} and C^{m}_{sload} are the expenses of staff and machines for second loading, respectively; and C^{inf}_{sload} are specific expenses of infrastructure. The expenses of storage of wooden biomass are calculated with the formula

$$C_{stor} = t_{con} \cdot n_{con} \cdot \left(C^{p}_{load} + C^{m}_{load}\right) + \frac{t_{load} + t_{unl}}{3600} \cdot n_{con} \cdot \left(C^{p}_{stor} + C^{m}_{stor}\right) \quad (9)$$

where n_{con} is the number of containers; t_{con} is the time of the work of loader; and C^{p}_{stor} and C^{m}_{stor} are the staff expenses and machinery for storage, respectively.

Apart from this, we should take into account the loss of wooden biomass weight during the process of drying that is considerable in first weeks of storage. The loss of weight during the drying process happens in first six weeks and reaches from 80% to 100%.

The expenses on preliminary preparation and processing the wooden biomass C_{prep} are calculated similar to the expenses on transshipment of cargo, including the infrastructural expenses, staff and maintenance of technical means and energetic expenses in general.

$$C_{prep} = t_{prep} \cdot \left(S_{prep} \cdot C^{inf}_{prep} + C^{p}_{prep} + C^{m}_{prep}\right) + C^{e}_{prep}. \quad (10)$$

The cut branches are chopped with the wood chopping machine (no infrastructural expenses). The chopping expenses C_{ch} are calculated with the following formula:

$$C_{ch} = t_{ch} \cdot \left(n_{ch} \cdot C^{p}_{ch} + C^{m}_{ch}\right) + C^{e}_{ch}, \quad (11)$$

where n_{ch} is the amount of biomass for chopping.

If wood chips, during the chopping, are immediately blown into a vehicle or a container for storage, then one should take into account the readiness of the vehicle or the container, as well as the personnel, for example a driver, who is waiting at this time. In this case, another item of additional costs arises:

$$C^{ch}_{con} = t^{ch}_{con} \cdot \left(C^{p}_{con} + C^{m}_{con}\right), \quad (12)$$

where C^{ch}_{con} is costs of the servicing of the container during the chopping; t^{ch}_{con} is chopping time; C^{p}_{con} is personnel costs of the servicing of the container; C^{m}_{con} is machine costs of the servicing of the container.

Then the effectiveness of chopping should be verified. Since the readiness of the vehicle or the container, into which the chopped wood is loaded, is not established, redundant time is spent on waiting, and, consequently, redundant financial costs arise. Research has shown that waiting time and the time spent on the tuning of the wood chopping machine reduce the net chopping time to 60–70% [18,32].

During the filtration of wood chips, one should also take into consideration seasonal differences. The quota of small fractions during the usage of waste wood amounts to 50% in summer months and may plunge to 25% after the leaves fall down in winter months.

If the non-filtered wooden chips are loaded by pneumatic wheel loader, then the filtration costs C_{fil} are calculated in the following way:

$$C_{fil} = t_{fil} \cdot \left(S_{fil} \cdot C_{fil}^{\inf} + C_{fil}^{p} + C_{fil}^{m} + C_{sload\ fil}^{p} + C_{sload\ fil}^{m} \right) \tag{13}$$

where C_{fil} is filtration costs; t_{fill} is filtration time; $C_{fil}^{\inf}$ is specific infrastructural costs of filtration; C_{fil}^{p} is personnel costs of filtration; C_{fil}^{m} is machine costs of filtration; $C_{sload\ fil}^{m}$ is personnel costs of transloading; $C_{sload\ fil}^{m}$ is machine costs of transloading.

Natural air drying of wooden biomass is a long-lasting process; however, the drying can be done using machinery, for example, using a drying cylinder or a drying container. In order to calculate drying costs C_{dr} in addition to heating energy costs C_{he}^{e}, we should consider the costs of the servicing of infrastructure, of drying machinery, and of appropriate containers (grate container)—C_{inf}^{teh}. Here one will also add personnel costs C_{dr}^{p} and costs of the servicing of drying equipment C_{de}^{m}, thus obtaining the following drying costs C_{dr}:

$$C_{dr} = t_{dr} \cdot C_{\inf}^{tech} + C_{he}^{e} + \left(t_{dr} + t_{prep\ dr} \right) \cdot \left(C_{dr}^{p} + C_{dr}^{m} + C_{\inf}^{tech} \right) \tag{14}$$

where t_{dr} is time for the preparation to drying; $t_{prep\ dr}$ is post-drying treatment time.

According to the research [2], having taken into account the heat and electricity consumption of the drying cylinder and the drier, we must calculate total costs of the drying of wood chips with water content from 40% to 10%. In case of six-month drying, financial costs that are needed to obtain dry mass amount from 6 Euro/t to more than 40 Euro/t, and in case of twelve-month drying, from 4 Euro/t to more than 24 Euro/t.

Ecological evaluation is carried out in the way analogous to the economical evaluation. For every process, data are calculated to define the level of harmful emissions into the environment during the usage of fuel, the preparation of equipment (machinery, means of transport, etc.), and the work of personnel, while ensuring the functioning of infrastructure.

In order to calculate the influence of any means of transport on the environment, one takes as a basis the factors of influence of greenhouse gases, such as carbon dioxide, methane, and nitrogen oxide emissions. The algorithm of their calculation is analogous to the calculation of fuel costs for every shift of transportation, type of road, and cargo type for an empty or fully loaded truck.

We take into consideration every separate type of road in the same way as in the process of economical evaluation:

$$V_{veh} = \frac{L \cdot m_{car}}{m_{pload} \cdot \gamma} \cdot \left[\left(F_{CO_2}^{100} - F_{CO_2}^{0} \right) \cdot \gamma + k_{ret} \cdot F_{CO_2}^{0} \right], \tag{15}$$

where V_{veh} is harmful emissions of a vehicle; $F_{CO_2}^{100}$ is emissions factor if the vehicle is loaded 100%; $F_{CO_2}^{0}$ is emissions factor if the vehicle is not loaded.

$$F_{CO_2} = \sum k_r \cdot \left[\left(F_{CO_2}^{100} - F_{CO_2}^{0} \right)^{veh} \cdot \gamma + \left(F_{CO_2}^{0} \right)^{veh} \cdot k_{ret} \right]. \tag{16}$$

We suggest that domestic enterprises calculate the decrease of the level of harmful emissions in a way that, when the biofuel burnt by the vehicles is estimated, the emissions of CO_2 and SO_x caused by it should be equal to 0. This means that, depending on the increase of the quota of biofuel in traditional fuel, the CO_2 and SO_x emissions will decrease in percentage, Table 1 is given as an example. The fact that the level of harmful emissions from 2011 till 2013 remained at 9% means that the quota content of biofuel in the vehicles of the enterprise remained unchanged during this period.

Table 1. Decrease of CO_2 emissions in percent in cases of year-to-year increases of biofuel quota in the vehicles of enterprises.

Years	Quota of CO_2 Emissions Decrease in Contrast to 2005 on Condition that Biofuel Quota Increases, %
2006	2
2006	4
2010	6
2012	8
2014	10
2016	12
2018	14
2020	16

[self-elaborated].

In order to calculate the direct emissions of road transport, with respect to CO_2-equivalent, we should use the derivatives of the emissions factors:

$$F_{CO_2} = F_{CO_2bio} + F_{CH_4} \cdot Q_{gg}^{CH_4} + F_{N_2O} \cdot Q_{gg}^{N_2O}, \tag{17}$$

where F_{CO_2bio} is emissions factor of a vehicle that uses biofuel; F_{CH4} is greenhouse gases emissions factor; Q_{gg}^{CH4} is greenhouse gases emissions quota.

When we evaluate fuel consumption of the entire supply chain, during the ecological evaluation, we obtain the factors of the emissions of side mixtures (oils, etc.) F_{veh}^{sm}, infrastructure F_{veh}^{inf}, machinery F_{veh}^{m}, and other fuel consumption F_{veh}^{fuel} in the chain. This is why CO_2 emissions into the environment are added to direct F_{veh}^{de} and indirect emissions, and the harmful emissions of a vehicle are calculated as follows:

$$V_{veh} = F_{veh}^{de} + F_{veh}^{fuel} + F_{veh}^{sm} + F_{veh}^{m} + F_{veh}^{inf}, \tag{18}$$

In order to transship the biomass, trucks with crane bodies, pneumatic wheel loaders, and fork loaders are used. Since during the loading and unloading of the vehicles the emissions of harmful substances into the environment take place, then

$$V_{trs} = V^{de} + V_{trs}^{ee} + V_{trs}^{sm} + V_{trs}^{m} + F_{veh}^{m} + V_{trs}^{inf}, \tag{19}$$

where V_{trs} is emissions during the transshipment; V^{de} is direct emissions; V_{trs}^{ee} is engine emissions during the transshipment; V_{trs}^{sm} is emissions of side mixtures during the transshipment; V_{trs}^{m} is machinery emissions during the transshipment; V_{trs}^{inf} is infrastructure emissions during the transshipment.

Direct emissions of harmful substances are influenced by the usage of fuel during the transshipment of cargo V_{trs}^{de}, as well as while waiting, and by the idling of vehicles F_{veh}^{de}

$$V^{de} = V_{trs}^{de} + F_{veh}^{de}. \tag{20}$$

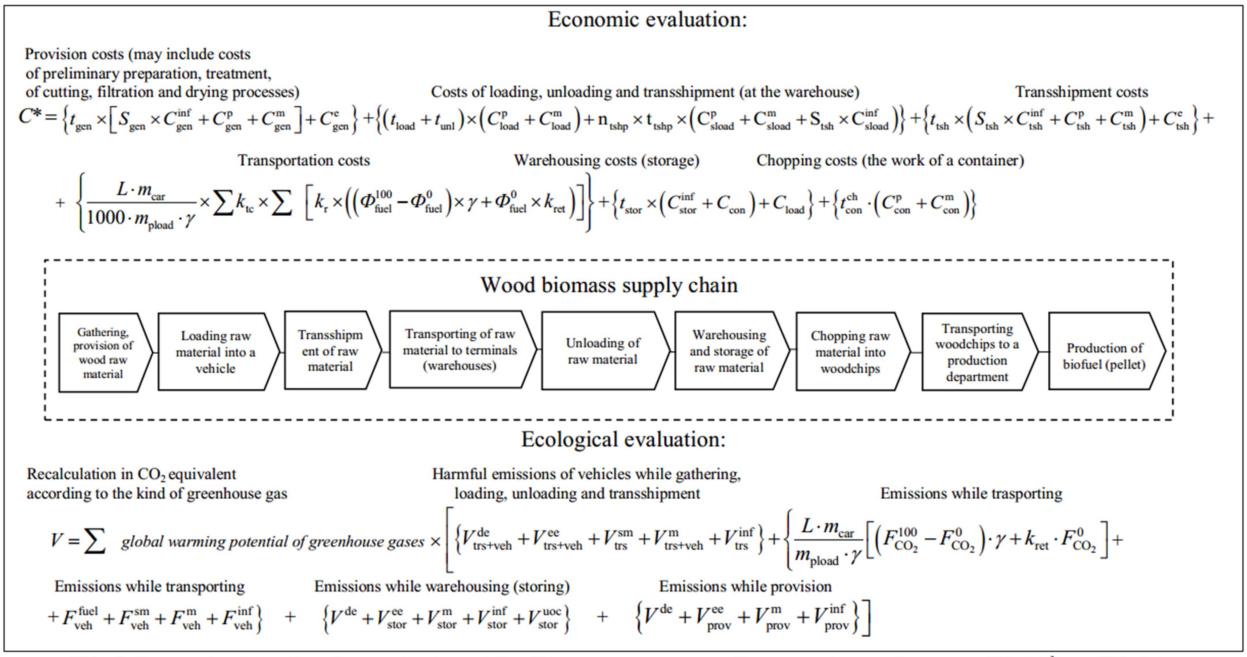
The first ones are influenced by the consumption of fuel and electric energy by the machinery (pneumatic wheel loaders and fork autoloaders), and the evaluation of indirect emissions (costs of infrastructure and consumables) are already included in the economic model.

The emissions of harmful substances during provision include chopping, filtration, and drying processes.

$$V_{prov} = V^{de} + V^{ee}_{prov} + V^{m}_{prov} + V^{\inf}_{prov}. \quad (21)$$

At this time, we obtain direct emissions caused by the usage of fuel for corresponding machines. We take into consideration the usage of fuel and electric energy, as well as machines (equipment) and corresponding infrastructure (maintenance of the place) during the entire logistics chain.

The composition of the model of the economic and ecological evaluation of a wooden biomass supply chain (Figure 5) is based on the evaluation of specific logistic processes of "provision–loading–transporting–transshipment–unloading–chopping–warehousing–storage", which depend on the functioning sequence, the evaluation of costs and harmful substances emission, as well as on the identification of the volumes of the potential wooden biomass provision.



Note: * C – general costs; t – time; S – area; L – transportation distance; m – mass; n – quantity; γ – carrying capacity usage coefficient; k – coefficient: tc – transportation shift; ret – fuel costs of the way back; r – road type. $F^{100}_{fuel}, F^{0}_{fuel}, \Phi^{100}_{CO_2}, \Phi^{0}_{CO_2}$ – factors of fuel consumption and emissions if the truck is 100% loaded and without load; upper indices of consumption and emissions: p – personnel; m – machinery (equipment); inf – infrastructure; e – energy consumption; sm – side mixtures; ee – engine; de – direct emissions; fuel – other fuel consumption in the chain; uoc – consumables; V – general harmful emissions.

Figure 5. The model of the economic and ecologic evaluation of a wooden biomass supply chain. Source [self-elaborated].

A typical chain of chopped wood supply includes the processes of loading raw material (branches, trunks) by a mobile crane; road transportation by different trucks; unloading by turning over, emptying, or cutting; chopping and storing of wood chips at a rented warehouse, for example; as well as biofuel production.

However, not only physical processes (transportation, transshipment, warehousing, provision of raw material, etc.) are important in biomass supply, but it is also important to have a modern software product with a corresponding database, which encompasses information about the specific character of logistic processes (vehicle type, its carrying capacity, the level of the development of transportation and warehousing infrastructure, and its peculiarities in mountain regions, etc.). The following software products are used in global practice: the database "ecoinvent"; the library "Umberto"; the directory of emissions factors for traffic "HBEFA"; software for calculations "EcoTransiT World" and "MaKost"; the global model of emissions for integrated systems "GEMIS"; and basic data for environment management "PROBAS". The usage of the appropriate software products is possible on condition of their adaptation to the domestic databases.

Practical usage of the model of the economic and ecological evaluation of a wooden biomass supply chain will enable business entities not only to promote the increase of the quota of the usage of alternative energy sources in the general energy consumption of the country, but also to decrease general costs of gathering, transporting, warehousing, and processing wooden biomass and at the same time to decrease significantly the volumes of greenhouse gases emissions into the natural and industrial environment. A possible real application of the model can be divided into three areas:

- Business (formation of the business model of enterprises in the field of renewable energy sources);
- Fuel (the rationale for the choice of fuel for heating homes, infrastructure, hotels, recreation centers, and local authorities);
- Recycling (substantiation of directions of use of woodworking waste: chipboard, chemical processing, cardboard, paper, fuel) [33].

By using the elaborated model and on the basis of expert estimates of the scientists of Dortmund Technical University, it was established that business entities will be able to decrease the cargo turnover by about 15%, which will lead to the decrease of costs and harmful substance emissions by about 10% and will give possibility to analyze systematically their costs and the negative impacts on the natural and industrial environments in separate logistics processes or logistics chains [30]. The literature sources listed in the article testify to the significant potential of wood biomass in Ukraine. As well as for solar and wind energy there are state preferences for biomass, so a certain system of benefits can be offered to consumers themselves, including exemptions from VAT, export duties, etc.

It is necessary to conduct economic and ecological evaluations of wooden biomass supply chain at every stage with the help of analytical models, defining certain indices. Thanks to the suggested model of the economic and ecological evaluation of wooden biomass supply chains, concrete processes of business entities can be presented in monetary equivalents and can be evaluated in terms of greenhouse gases emissions, and the combination of these results will give possibility to reflect the ecological effectiveness of a logistics system. Moreover, the elaborated economic and ecological model enables the identification of the most "vulnerable spots" in the wooden biomass supply chain, which will become the basis for further optimization of the entire chain and will provide broad opportunities to improve the analogous evaluation of other supply systems with consideration of different types of transport. The proposed approach could be suitable for the supply chain of coal, briquettes, peat, and gas.

4. Conclusions

The first step towards a "green economy" in Ukraine (which is one of the key aims of energetic policy of the EU) will be a change to renewable sources of energy, considering that the main directions of energetical potential of biomass and biogas realization in Ukraine is the production of heat energy and electricity, along with the understanding that modern methods of energy production are environmentally harmful. Bioenergetics is one of the chief aims of renewable sources of energy sector development for Ukraine, taking the country's strong reliance on imported energy carriers into account, mainly natural gas, and the high biomass potential available for energy production. Modern technologies allow different types of biomass to be manufactured; as a result, even those economic entities are effective for which biofuel business is supplementary, based on their own raw materials and those that have active heat supply reorientation, for instance, using solid biofuel boilers that have proven their effectiveness and fast payoff.

Systematization of the results of scientific applied research afford grounds for the following conclusions:

Logistics research should be focused on new models and new solutions that will allow the manufacturers of ecological types of energy out of biomass to see concrete practical steps of the state and investors in encouraging new ideas, technologies, and investing solutions support.

The mechanism of constructing and structuring of logistics chains is provided with a description. The chains are oriented on ecologistics development and stable rates of wooden biomass provision and consumption growth, which will allow a high level of competitiveness of the subject economic activity and business efficiency to be ensured by raising investment resources and new technologies in Ukraine.

During the research on the interaction of elements in logistics in the resources supply sphere, the topical problems of formation and storage of necessary bio raw materials for their further recycling into biomass as one of the energy alternatives in regional industry that considers the specific activity of the subjects, market infrastructure, and other factors. The proposed model covers the sequence of functioning of such logistics processes as provision, loading, transporting, transshipment, unloading, grinding, warehousing, storage, and indexes, showing consumer spending and expenses on equipment (machinery, vehicles, etc.), staff, infrastructure and so on.

The method's approaches were improved to construct a model of economic ecological evaluation of supply chains of wooden biomass that will allow the toolkit of logistic management in supply processes management to be enriched, particularly when using biomass for production purposes, and to broaden the sphere of business interaction with biomass supplier and business entity that ensure its effective recycling. This will also allow concrete processes of business entities to be presented in monetary equivalents and evaluate them from the perspective of greenhouse gases emissions, and the resulting combination will allow one to show ecologistic effectiveness of the whole logistics system.

The paper presents and improves the core components of supply chains in the process of provision and consumption of wooden biomass, which will allow the negative impacts on the natural and production environment to be minimized in practice and the usage of non-renewable energy sources to be reduced, to ensure resource economy and to support the development of sustainable business entities.

The model of economic and ecological evaluation of logistics chains constructed by the authors indicates the perspective direction of further implementation of the ideas of integrated management of resources, expenses calculation, and harmful emissions in whole logistics chains and also channels further research to search for mechanisms of energy and resource consumption volume reduction due to the all-in-one vision of production and logistics processes.

Author Contributions: Conceptualization, Y.K. and B.H.; methodology, B.H.; software, J.B.; validation, Y.K., J.B., and B.H.; formal analysis, B.H.; investigation, B.H.; resources, B.H.; data curation, Y.K.; writing—original draft preparation, B.H.; writing—review and editing, B.H.; visualization, B.H.; supervision, Y.K.; project administration, J.B. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Exclude this statement, did not report any data.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Forsberg, G. Biomasse energz transport. Analysis of bioenergy transport chains using life cycle inventory method. *Biomass Bioenergy* **2000**, *19*, 17–30. [CrossRef]
2. Suurs, R. Long Distance Bioenergy Logistics. An Assessment of Costs and Energy Consumption for Various Biomass Energy Transport Chains. Master's Thesis, Universiteit Utrecht, Copernicus Institute, Department of Science, Technology and Society, Utrecht, The Netherlands, 2002; p. 78.
3. Pfohl, H.-C. *Ökologische Herausforderungen an Die Logistik in den 90er Jahren. Umweltschutz in der Logistikkette bei Ver-und Entsorgung*; Schmidt: Berlin, Germany, 1993; p. 10.

4. Weber, J. Logistik-Controlling–Konzept und empirischer Stand. *Kostenrechn. Z. Für Control. Account. Syst.-Anwend.* **2001**, *45*, 275–282. [CrossRef]
5. Gudehus, T. *Logistik. Bd 1: Grundlagen, Verfahren und Strategien*; Springer: Berlin, Germany, 2000; p. 660.
6. Pistorius, T.; Zell, J.; Hartebrodt, C. *Untersuchungen zur Rolle des Waldes und der Forstwirtschaft im Kohlenstoffhaushalt des Landes Baden-Württemberg*. Forschungsbericht FZKA-BWPLUS.; Forstliche Versuchs-und Forschungsanstalt BadenWürttemberg, Institut für Forstökonomie: 2006. p. 224. Available online: https://www.irb.fraunhofer.de/bauforschung/baufolit/projekt/Untersuchungen-zur-Rolle-des-Waldes-und-der-Forstwirtschaft-im-Kohlenstoffhaushalt-des-Landes-Baden-W%C3%BCrttemberg/20100282/ (accessed on 23 August 2021).
7. Plöchl, M.; Heiermann, M. *Ökologische Bewertung der Bereistellung Landwirtschaftlicher Kosubstrate zur Biogaserzeugung*. Bornimer Agrartechnischer Benchte. p. 32. Available online: https://opus4.kobv.de/opus4-slbp/files/4030/1_BAB_32_2.pdf (accessed on 23 August 2021).
8. Jungbluth, N.; Frischknecht, R.; Faist, M. *Ökobilanz für die Stromerzeugung aus Holzbrennstoffen und Altholz*; Projekt 41458 Vertrag 81427; Herausgegeben von Bundesamt für Energie: Bern, Switzerland, 2002; p. 77.
9. Krotschek, C.; König, F.; Obernberger, I. Ecological assessment of integrated bioenergy systems using the Sustainable Process Index. *Biomass Bioenergy* **2000**, *18*, 341–368. [CrossRef]
10. Mann, M.K.; Spath, P.L. A life cyde assessment of biomasscofiring in a coal-fired power plant. *Clean Prod. Process.* **2001**, *3*, 81–91. [CrossRef]
11. Marheineke, T.; Krewitt, W.; Neubarth, J.; Friedrich, R.; Voß, A. *Ganzheitliche Bilanzierung der Energie-und Stoffströme von Energieversorgungstechniken*; Forschungsbericht; Universität Stuttgart. Institut für Energiewirtschaft und rationelle Energieanwendung: Stuttgart, Germany, 2000; Volume 74, p. 107.
12. Scholwin, F. Ökologische Bewertung der Nutzung nachwachsender Rohstoffe zur Biogasgewinnung und-nutzung. Umwelteffekte und ihre Berücksichtigung im Anlagenbetrieb. In *Biogas. Energieträger der Zukunft; Tagung Osnabrück, 12. und 13. April 2005*; Gesellschaft Energietechnik, Hg.: Düsseldorf, Germany, 2005; pp. 77–87. Available online: https://www.ifeu.de/fileadmin/uploads/landwirtschaft/pdf/IFEU-TAB-Nawaro-stofflich.pdf (accessed on 23 August 2021).
13. Mardon, C. The feasibility of producing alcohol fuels from biomass in Australia. *Int. J. Glob. Energy Iss.* **2007**, *27*, 138–159. [CrossRef]
14. Soimakallio, S.; Mäkinen, T.; Ekholm, T.; Pahkala, K.; Mikkola, H.; Paappanen, T. Greenhouse gas balances of transportation biofuels, electricity and heat generation in Finland–Dealing with uncertainties. *Energy Policy* **2009**, *37*, 80–90. [CrossRef]
15. Zah, R. Umweltbilanz von Biotreibstoffen. *GWA* **2007**, *12*, 953–959.
16. Kanzian, C.; Fenz, B.; Holzleitner, F.; Stampfer, K. Waldhackguterzeugung aus Schlagrücklass. Fallbeispiele im Laub-und Nadelholz: Project Universität für Bodenkultur Wien. Department für Wald-und Bodenwissenschaften: Wien, Austria, 2006; p. 17.
17. Neff, A.; Nelles, M.; Loewen, A.; Hapla, F. Perspektiven für die energetische Verwertung von Landschaftspflegeholz. In *Jahrbuch der Baumpflege*; Dujesiefken, D., Kockerbeck, P., Eds.; Haymarket Media: Hamburg, Germany, 2006.
18. Scholz, V.; Idler, C.; Daries, W.; Egert, J. Lagerung von Feldholzhackgut. Verluste und Schimmelpilze. *Agrartech. Forsch.* **2005**, *11*, 100–113.
19. Eberhardinger, A.W.W.; Zormaier, F.; Schardt, M.; Huber, T.; Zimmer, B. *Prozessanalyse und Ökobilanzierung der Bereitstellug von Waldhackgut*; Schlussbericht for Lehrstuhl für Forstliche Arbeitswissenschaften und Angewandte Informatik; Technische Universität München: Freising, Germany, 2009; p. 166.
20. D'Adamo, I.; Falcone, P.M.; Huisingh, D.; Morone, P. A circular economy model based on biomethane: What are the opportunities for the municipality of Rome and beyond? *Renew. Energy* **2021**, *163*, 1660–1672. [CrossRef]
21. D'Adamo, I.; Falcone, P.M.; Morone, P. A new socio-economic indicator to measure the performance of bioeconomy sectors in Europe. *Ecol. Econ.* **2020**, *176*, 106724. [CrossRef]
22. Bretzke, W.R. *Nachhaltige Logistiksysteme–Anpassungsbedarfe in Einer Welt Steigend Energiekosten, Überlasteter Verkehrswege und Rigide Bekämpfter Schadstoffemissionen*; Tagungsband Magdeburger Logistiktagung: Magdeburg, Germany, 2009; p. 95.
23. Bringezu, S. Nutzungskonkurrenzen bei Biomasse–Auswirkungen der Verstärkten Nutzung von Biomasse im Energiebereich auf Die Stoffliche Nutzung in der Biomasse Verarbeitenden Industrie und Deren Wettbewerbsfähigkeit Durch Staatlich Induzierte Förderprogramme [Electronic Resourse]. 2008. Available online: http://www.rwiessen.de/media/content/pages/publikationen/rwi-projektberichte/PB_BiomasseNutzungskonkurrenz_Kurzfassung.pdf (accessed on 14 October 2013).
24. Orhanizatsiya Pererobky Lisosichnykh Vidkhodiv: Proekt/[L′vivs′ke Oblasne Upravlinnya Lisovoho ta Myslyvs′koho Hospodarstva]—L′viv, Ukraine 2016. p. 40. Available online: https://lvivlis.gov.ua/ (accessed on 23 August 2021).
25. Hrechyn, B.D. *Approaches of Ecologistics to the Usage of Wood Biomass Power Potential: Dys. kand. ek. Nauk: 08.00.06 Hrechyn Bohdan Dmytrovych*; University of Water Management and Environmental Engineering: Rivne, Ukraine, 2018; p. 265.
26. Hrechyn, B.D. Substantial Characterization of the Methods for Evaluating Negative Impact of Production and Logistics Activities of Enterprises in the Context of the Strategic Development of Eco-Logistics in Ukraine. *Business Inform.* **2016**, *4*, 169–176.
27. Borken, J. *Basisdaten für ökologische Bilanzierungen. Einsatz von Nutzfahrzeugen in Transport, Landwirtschaft und Bergbau*; Springer: Braunschweig, Germany, 1999; p. 223.
28. Eckel, H. *Energiepflanzen. Daten für die Planung des Energiepflanzenanbaus*; KTBL: Darmstadt, Germany, 2006; p. 372.
29. MaKost 2009b: Kuratorium für Technik und Bauwesen in der Landwirtschaft e. V. (KTBL) (Hg.): MaKost -Maschinenkosten und Reparaturkosten. [Electronic Resourse]. Available online: https://www.ktbl.de/ (accessed on 24 August 2021).

30. Dobers, K.; Clausen, U. *Bewertung der Ökoeffizienz von Logistiksystemen am Beispiel der Biomassebereitstellung (Logistik, Verkehr und Umwelt)*; Auflage: 1; Taschenbuch. Praxiswissen Service: Dortmund, Germany, 2011; p. 212.
31. Spickermann, C. *Hackschnitzellagerung und–Handling*; Westphalian University of Applied Sciences: Dorsten, Germany, 2007.
32. Wittkopf, S. Bereitstellung von Hackgut zur Thermischen Verwertung durch Forstbetriebe in Bayern. Ph.D. Thesis, Technische Universität München, Wissenschaftszentrum Weihenstephan für Ernährung, Landnutzung und Umwelt, Munich, Germany, 2005; p. 209.
33. Krykavskyy, Y. *Lohistyka Dlya Ekonomistiv: Pidruchnyk. Druhe Vydannya, Vypravlene ta Dopovnene*; Vydavnytstvo L'vivs'koyi Politekhniky: L'viv, Ukraine, 2014; p. 476.