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Cost–Benefit Analysis for Supply Chain of Renewable Gases from Perennial Energy Crops: The Case of Lithuania

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Abstract: The increasing production of renewable gases has been driving attention to perennial energy crop production, particularly the problem of choosing an attractive and effective way to produce the supply chain from the farmer to the biogas plant. The production of perennial energy crops for renewable gases may provide an excellent chance for a sustained bioeconomy and help to minimize the total environmental effect of the section. This study aims to demonstrate the scenarios associated with the production of five perennial energy crops, namely, Miscanthus, Switchgrass, Perennial Ryegrass, Common Sainfoin, and Lucerne, for renewable gases in the supply chain. The investigation was carried out utilizing cost–benefit methodology, during which a net benefit identification was executed by comparing the internal rate of return (IRR), payback period (PBT), and net present value (NPV), in addition to the benefit-cost ratio (RBC). According to the results, the best and most attractive perennial energy crops for biogas production include Miscanthus and Switchgrass. Perennial Ryegrass, Common Sainfoin, and Lucerne are not attractive crops for the supply chain of renewable gases. The earned revenue is too small to cover the costs of cultivation.

Keywords: cost–benefit assessment; perennial crops; biogas; supply chain flow

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1. Introduction

The world is talking about the implementation of climate change mitigation measures and about new technologies that reduce the concentration of pollutants in the environment. Effective measures to reduce greenhouse gas emissions are needed to halt the increase in global average temperatures. The European Green Deal seeks to transform the EU economy by 2050 into one that is contemporary, energy-efficient, and innovative, so that there are no carbon or greenhouse gas emissions, and the economic growth is decoupled from resource use. For all this to actually be achieved over the transition period of 2030–2050, the reliance of the energy system on fossil fuels must be reduced. Countries of the European Union decide independently on their energy production types, so it is important to ensure a responsible and socially justified transition to a Green Economy [1].

Renewable gases, including biogas and biomethane, will be central to achieving carbon-neutrality by 2050, and will help the EU become less dependent on external energy supplies. By-products of the breakdown of organic components include biogas. Such leftovers are positioned through an oxygen-free biogas plant. The organic material decomposes with the aid of a variety of microorganisms, creating a mixture of gases that contains 45–85% of methane (CH_4) with 25–50% of carbon dioxide (CO_2). The end product is a renewable gas that has a variety of uses. Biomethane may be produced by upgrading biogas. This raw biogas that has been filtered is used in place of natural gas; when biomethane is produced, CO_2, H_2O, H_2S, as well as other contaminants are eliminated, providing a clean gas with a high caloric content [2].

The ever-growing industry and t increasing energy needs, along with the simultaneously decreasing traditional fossil energy resources (e.g., oil, coal, etc.), lead to the search for alternative, renewable resources for meeting humanity's emerging energy needs. The development of biomass sources is becoming an increasingly important area of energy policy. These are natural resources, the emergence and renewal of which are determined by natural processes. However, the challenge lies in determining the best path from the farmer to the energy need along the distribution chain. The amount of each input, the best pretreatment method, and the best energy usage of biogas must all be determined in relation to transportation costs. It involves the entire process of plant cultivation, including field preparation, planting, the application of fertilizer and pesticides, the harvesting and conversion of plant material at a centralized biogas plant, and, finally, the return of the digestate to the crop production areas as fertilizer and a soil-improving medium [3–5]. The storage of biomass presents a significant challenge, particularly when it is defined by seasonal availability [6]. Since most biogas facilities require continual feeding, storing would be a pertinent issue for the anaerobic process. The most effective method of biomass preservation to date is ensiling [7].

The average energy output for every hectare, which is determined primarily by biomass production and biomass substitutability along with cultivation inputs, seems to be the most crucial factor when selecting energy crops for biogas generation. It has been shown that using perennial crops for energy crops is considered more environmentally friendly than using crop production [5]. The benefit of perennial crops versus annual crops is that they use limited resources but can have a greater positive or less negative environmental effect per unit of production [8,9]. The prospect of producing agricultural bioenergy in a more ecologically responsible manner exists with perennial crops such as the cup plant. Essentially, this crop seems to be a good exciting substitute for producing biomethane [10,11]. The likelihood of erosion is decreased, soil carbon is accumulated, and soil fertility is increased by perennial crops. Since they produce more consistently over time than annual crops, which are more impacted by weather conditions in terms of establishment and development, they lower the risks associated with the production of biomass. Therefore, perennial species mixes maintained with minimum inputs encourage the synergy between production and diversification in the context of producing biomass that is climate-smart as well as multipurpose [10,12–14]. In order to solve the problems related to climate change, an important aspect is the full use of energy biomass in a sustainable way arising from varied kinds of biofuel, hence biorefinery is the proper route to defeat climate change and other social, economic and environmental problems. The important aspect obtained from processing biofuel is that low-value biomass waste does not compete with human food [15]. However, for building new biorefineries, it is necessary to take into account spatial development plans for the location [16]. Authors Ximenes et al., 2021 [17] showed that the economic feasibility of biogas production depends on different locations and environmental demands, and is a major factor in reducing the energy expenses in the biogas plant.

The aim of this study is to analyze the supply chain for the utilization of perennial energy crops (Miscanthus, Switchgrass, Perennial Ryegrass (P. Ryegrass), Common Sainfoin (C. Sainfoin), and Lucerne) biomass for biogas production. This study uses the cost–benefit analysis to disclose the attractiveness of perennial energy crop production in the renewable gas supply chain. The analysis could support decision-making for a sustainable bioeconomy.

2. Estimation of Costs and Revenue by Supply Chain

The estimation of perennial energy crop production by the supply chain considers the applied total energy input (costs) from perennial energy crop cultivation versus the total energy output (revenue). The activities required to supply perennial energy crop biomass from its production point to the biogas power plant include those illustrated in Figure 1. This process consists of two main objects: direct and indirect energy consumption costs. Direct energy costs are applied in soil preparation, sowing, and fertilization, usually only in the first year of perennial energy crop biomass cultivation. The second and other years consist of cultivation, harvests, raking, chopping and collection, transportation to a single location, ensiling, and supply of this biomass to the biogas power plant. Indirect energy costs are defined in terms of the evaluation of the consumption of agricultural equipment, fertilizer, and seed. The other stage involves the processing of biomass into biogas. Biogas can be utilized directly in combined heat and power units or can be upgraded to biomethane. The digestate shows feedback. Digestate is the element in the increase of the yield of energy plants fertilized and reduces the expenditure incurred on agriculture production [17]. This is the secondary use of a recycled substrate to fertilize perennial crops. Recycled biomass is a good fertilizer rich in nutrients such as nitrogen, potassium, and phosphorus that are necessary for plants. There are also added benefits, including reduced energy consumption for fertilizer production and transport, less pollution, and improved soil properties [18–21].

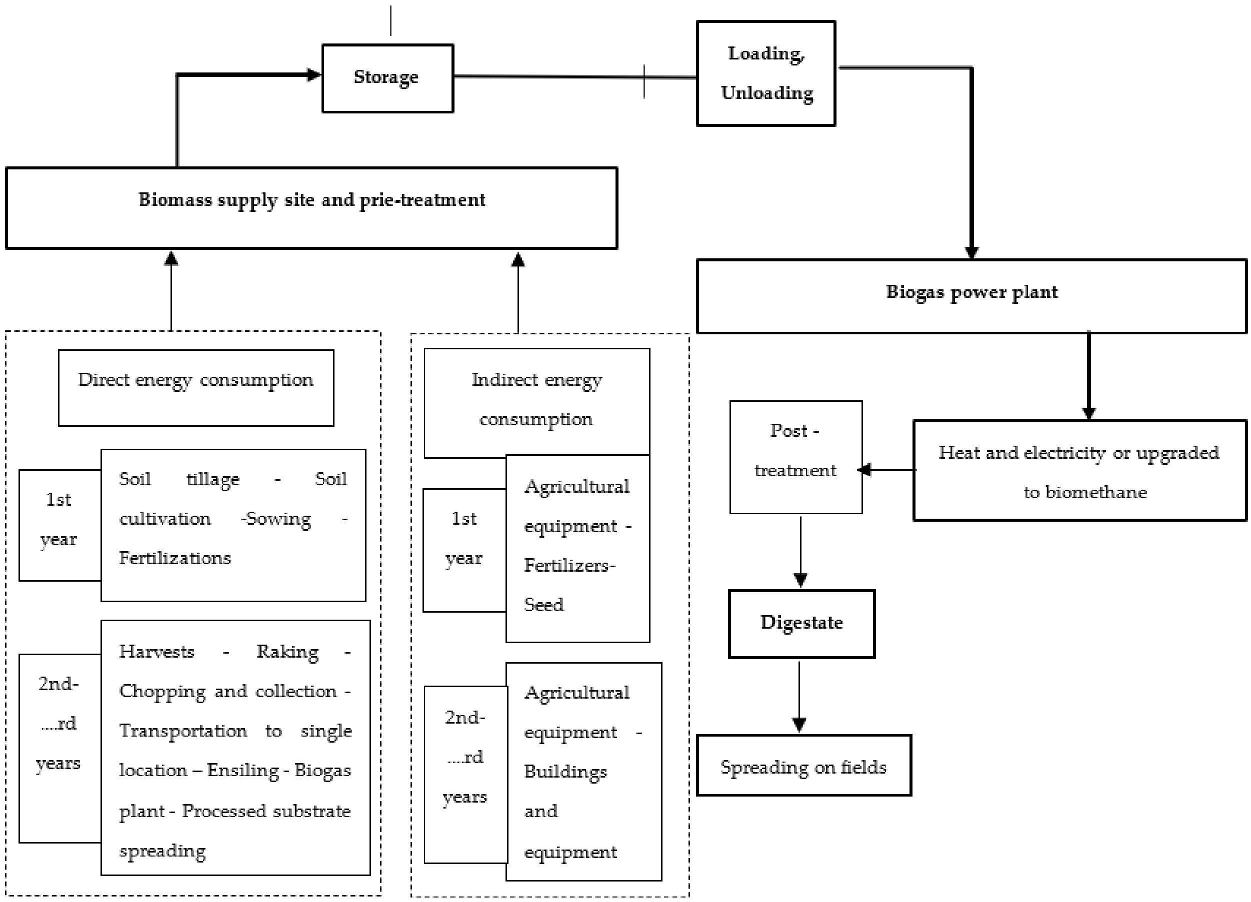


Figure 1. The supply chain of perennial energy crop production.

Since perennial energy crops biomass (PEC) is gathered at a given time of the year but needed at the biogas power plant all year long, various varieties of the PEC biomass are defined by seasonal availability; as a result, it is ideal to store them. This storage location might be on the farm, at the biogas plant, or even in a middle location. The PEC biomass must be placed on road transportation trucks after it has been relocated to the roadway to be transported to the biogas plant. Hence, at the biogas power plant, all PEC biomass will also have to be collected from cars. As for planting and harvesting of energy crops to the storage or pre-treatment of PEC biomass, the production and use of biogas, the handling, post-methanation, as well as digestant's post-treatment, and finally the return of the digestate to the crop production areas as fertilizer and soil-improving medium, the assessment of energy costs can be carried out [9,19–21].

Grass species, agrotechnology, and the biogas plant technological process all affect direct and indirect expenses [21]. Direct energy cost depends on the area of cultivated land. With low yields, larger areas need to be cultivated to achieve the desired amount of energy in biogas plants [22]. Fuel and electricity are usually available direct energy costs. The effect of the supply chain for biogas production also depends on realistic hourly variations in electricity prices [18]. Additionally, the major problem of biogas production is the rising direct cost of logistics operations for varied kinds of biofuel productions [21]. Indirect energy consumption consists of energy used by machinery and equipment production and maintenance, as well as energy embedded in buildings [20]. It is possible to categorize the energy used for perennial grass cultivation, harvesting, transporting to one place, PEC biomass preservation, further processing in a biogas digester, and final distribution on a field by year [22]. The following Equation (1) may be used to represent the costs of PEC biomass energy for production and processing:

$$E_{cult} = \sum_{1}^{n} E_d + \sum_{1}^{n} E_{ind} \quad (1)$$

where,

E_d—direct energy costs for biomass of perennial energy crop cultivation and processing, EUR/ha;

E_{ind}—indirect energy costs for biomass of perennial energy crop cultivation and processing, EUR/ha.

Direct energy costs for the growing and processing of biomass from perennial energy crops are connected to technical activities and are determined by adding them together to get the total operations [23–25]. Direct energy consumption—E_d, EUR/ha—for biomass of perennial energy crop production is expressed by the following Equation (2):

$$E_d = E_{dd} + E_{pn} + E_{tb} + E_s + E_{sv} + E_{zp} + E_{zs} + E_{sm} + E_t \quad (2)$$

where,

E_{dd}—direct energy input for soil cultivation before sowing, EUR/ha;

E_{pn}—direct energy input for weed control before sowing, EUR/ha;

E_{tb}—direct energy input for fertilization, EUR/ha;

Es—direct energy input for crop sowing, EUR/ha;

E_{sv}—direct energy input for rolling after sowing, EUR/ha;

E_{zp}—direct energy input for yield harvesting, EUR/ha;

E_{zs}—direct energy input for crop shredding, EUR/ha;

E_{sm}—direct energy input for ensiling, EUR/ha;

E_t —direct energy input for transportation, EUR/km.

Indirect energy consumption—E_{ind}, EUR/ha—for biomass production is expressed by the Equation (3) presented below [26]:

$$E_{nts} = E_{tr} + E_{zds} + E_{me} \quad (3)$$

where,

E_{tr}—application rate of fertilizers and herbicides, EUR/kg;

E_{zds} —human labor energy costs (for cultivation and harvesting of energy crops);

$E_{zds} = \sum_{i=1}^{r} E_{zdsi}$, EUR/h;

E_{me}—energy intensity of agricultural machinery, $E_{me} = \sum_{i=1}^{r} E_{me}$, EUR/l.

Indirect energy consumption is calculated on the basis of the exploitation of agricultural machinery, the weight and the energy equivalent of the indirect energy consumption of agricultural machinery used in the technological operation [26,27].

The energy output (revenue) (R) associated with energy perennial crops is calculated using crop production PT_i—the price for i-th crop, in euros per tons (EUR/t);

AP_i—agricultural production for the i-th crop, in tons per hectare (t/ha), as shown in Equation (4) below:

$$R_i = \sum_i PT_i \; x \; AP_i \quad (4)$$

Cost–Benefit Analysis

A cost–benefit approach was applied to the economic analysis of the supply chain of renewable gases from perennial energy crops. Economic feasibility is an important factor in making the final go/no-go decision. One technique used as part of sustainability assessments is economic cost–benefit analysis (CBA), which aims to help the farmer deal with the shortage of environmental assets [28]. In this section, the value of costs (energy input) and revenue (energy output) of the supply chain of technological processes for the preparation of energy perennial crops for biogas production is discussed. The whole system includes direct and indirect energy cost components: biomass preparation, operation and maintenance costs, and intake and end-use. The data of the analysis are shown in Table 1 [29–32].

Table 1. Characteristics of the perennial energy crop used in the cost–benefit analysis (*the sample average is used for the practical analysis of the data*).

Operations	Unit	Miscanthus	Switchgrass	Perennial Ryegrass	Common Sainfoin	Common Lucerne
Biogas plant productivity	CH_4 m^3/h	500	500	500	500	500
Full load hours	h	8000	8000	8000	8000	8000
Productivity of biomethane production	thousand m^3/yr	4000	4000	4000	4000	4000
Dry matter yield	t/ha	20.8	11.3	5.15	5.32	7.9
Methane yield	m^3 CH_4-yr/ha	4774	2712	1060	1453	1326
Amount of grass required for the biogas plant	t/ha	17,429	16,542	19,434	14,646	23,831
Agricultural land required for the biogas plant	ha	840	1556	3774	2753	3017
Nitrogenous N	kg/ha	80	80	30	30	30
Potassium K_2O	kg/ha	128	137	68	68	68
Phosphorus P_2O_5	kg/ha	32	37	27	25	25
Herbicides	kg/ha	1.375	1.32	1.35	1.35	1.35
Number of staff required		2	2	2	2	2
Biomass growth period	yr	6	6	6	6	6

The study focused on five perennial energy crops: Miscanthus, Switchgrass, P. Ryegrass, C. Sainfoin, and Lucerne. These crops are most popular in agriculture in Lithuania. The economic values of direct energy costs of the preparation of perennial energy crops for biogas are shown in Table 2 [33].

The economic values of indirect energy costs of the preparation of perennial energy crops for biogas are presented in Table 3.

Energy output is generated by sales of mass perennial energy crops. The economic value of the revenue of the preparation of perennial energy crops for biogas is shown in Table 4 [34].

Table 2. Economic values of direct energy costs of perennial energy crop preparation.

Direct Energy Costs	Unit	Value
Plowing	EUR/ha	80
Cultivation	EUR/ha	40
Herbicides	EUR/ha	14.8
Mineral fertilizers 2 "x"	EUR/ha	11.2
Sowing	EUR/ha	50
Rolling	EUR/ha	23.2
Harvest	EUR/ha	37.5
Grass shredding	EUR/ha	75
Transportation to the biogas plant	EUR/km	0.5

Table 3. Economic values of indirect energy costs of perennial energy crop preparation.

Indirect Energy Costs	Unit	Value, EUR
Labor	EUR/h	4.47
Exploitation of machines, operation	EUR/l	2
Use of fertilizers	EUR/kg	2.5

Table 4. Economic values of energy output of perennial energy crops.

Revenue	Unit	Value
Purchase price of mass perennial energy crops	EUR/t	25.0

The following presumptions are used to abstract the calculations: (1) all field activities are outsourced; (2) most production inputs are acquired; (3) agricultural lands are held with farmers; and (4) the perennial energy crops are also cultivated just on fields for six years. These factors are all taken into account in the economic analysis.

The discounted total of the predicted values of the revenue stream over a specific time period is used to determine the economic net present value (*eNPV*) of an investment, which represents its economic feasibility. With the aid of the studies, it is possible to predict whether a project will result in a profit ($eNPV \geq 0$) or a loss ($eNPV \leq 0$) [35,36]. The formula used to calculate the *eNPV* is as follows; Equation (5):

$$eNPV = \sum_{t=0}^{n} \frac{R_t - C_t}{(1+r)^t} \tag{5}$$

where,

n—number of time periods (years);

t—time period (years);

R_t—income for year t (EUR/t);

C_t—costs of year t (EUR/t), includes start-up expenses through C_0;

r—discount rate (%).

The term "payback time" (*PBT*) describes the period of time necessary to achieve the break-even point. It happens once the cumulative revenues exceed the cumulative expenses, so it denotes the point at which the *eNPV* starts to turn a profit. The *PBT* is computed using the following Equation (6) for unequal cash inflows:

$$PBT = A + \frac{B}{D} \tag{6}$$

where,

A—the time period of the end year when a cumulative cash flow ended up being negative for the final time;

B—the total value of a cumulative cash flow by the time A has ended;

D—the discounted period A of estimated cash flow.

The internal rate of return (*IRR*) is an amount of the efficient interest on investments that results in zero *eNPV*. This *IRR* is usually computed applying the formula presented in Equation (7) to provide an indicator of the profitability of the project:

$$0 = NPV = \sum_{t=0}^{n} \frac{R_t - C_t}{(1 + IRR)^t} \tag{7}$$

where,

n—number of time periods (years);

t—time period (years);

R_t—income for year t (EUR/t);

C_t—costs of year t (EUR/t), includes start-up expenses through C_0.

The benefit-cost ratio (*BCR*) is a measure that shows how discounting benefits compare to their costs, which aids in decision-making. The *BCR* of less than one (1) suggests that benefits outweigh costs and enables assessment of the sustainability of the project. This *BCR* could be stated in terms of money or quality. The following Equation (8) is used to determine the *BCR*:

$$BCR = \frac{(discounted\ output + subsidies)}{discounted\ input} \tag{8}$$

In most cases, in the basic scenario, a discount rate of 5% was used for all calculations (r = 5); the normal rate of inflation was included as well. For the analyzed perennial energy crops, annual expenses and earnings from agricultural operations were computed. To determine whether and to what degree an investment in the supply chain of renewable gases from perennial energy crops was beneficial without specific subsidies, this research disregarded possibly available incentives (in the form of property grants available under the Lithuanian system).

3. Results

3.1. Costs and Revenue Analysis of Perennial Energy Crop Production

Based on available data sources, a cost analysis was performed to evaluate profitability. Both direct and indirect costs disclosed different results of the supply chain of renewable gases from five perennial energy crops. Figure 2 describes the assessment results of energy costs of Miscanthus, Switchgrass, P. Ryegrass, C. Sainfoin, and Lucerne over a period of 6 years. The total direct costs of perennial energy crops considered over a life cycle of 6 years amounted to 11,851 kEUR, and the total indirect costs were 552.0 kEUR. The highest direct and indirect costs were generated over the first year of the cultivation of perennial crops. P. Ryegrass amounted to the highest direct costs (DC) of 1149.8 kEUR (during the first year) and of 485.7 kEUR (during the sixth year). The indirect costs (IC) of P. Ryegrass amounted to 22.1 kEUR (during the first year) and to 17.4 kEUR (during the sixth year).

The lowest costs were observed in the case of Miscanthus and Switchgrass—255.9 kEUR (DC during the first year)—118.0 kEUR (DC during the sixth year); 18.5 kEUR (IC during the first year)—17.4 kEUR (IC during the sixth year) and 475.2 kEUR (DC during the first year)—202.3 kEUR (DC during sixth year); 19.3 kEUR (IC during the first year)—17.4 kEUR (IC during the sixth year), respectively. Direct and indirect costs of C. Sainfoin and Lucerne were 838.8 kEUR (DC during the first year)—351.8 kEUR (DC during the sixth year); 22.1 kEUR (IC during the first year)—17.4 kEUR (IC during the sixth year) and 919.2 kEUR (DC during the first year)—390.1 kEUR (DC during the sixth year); 21.2 kEUR (IC during the first year)—17.4 kEUR (IC during the sixth year), respectively. Based on the comparison of the revenue with costs covering a period of 6 years, Figure 2 shows a positive net cash flow (net benefit) generated by the perennial energy crops, Miscanthus and Switchgrass.

Miscanthus provided a net benefit of approximately 681.5 kEUR, with revenue ranging from 42 to 437.7 kEUR. The revenue of Switchgrass ranged from 116.7 to 427.8 kEUR, and its net benefit was approximately 392 kEUR. The net benefit of P. Ryegrass, C. Sainfoin, and Lucerne over a 6-year period was negative: 1541 kEUR (the revenue ranged from 188.7 to 485.5 kEUR); 1282 kEUR (the revenue ranged from 138 to 366 kEUR), and 183 kEUR (the revenue ranged from 151 to 603 kEUR), respectively.

The data in Figure 3 shows results for the structure of energy costs in the supply chain of renewable gases by five perennial energy crops.

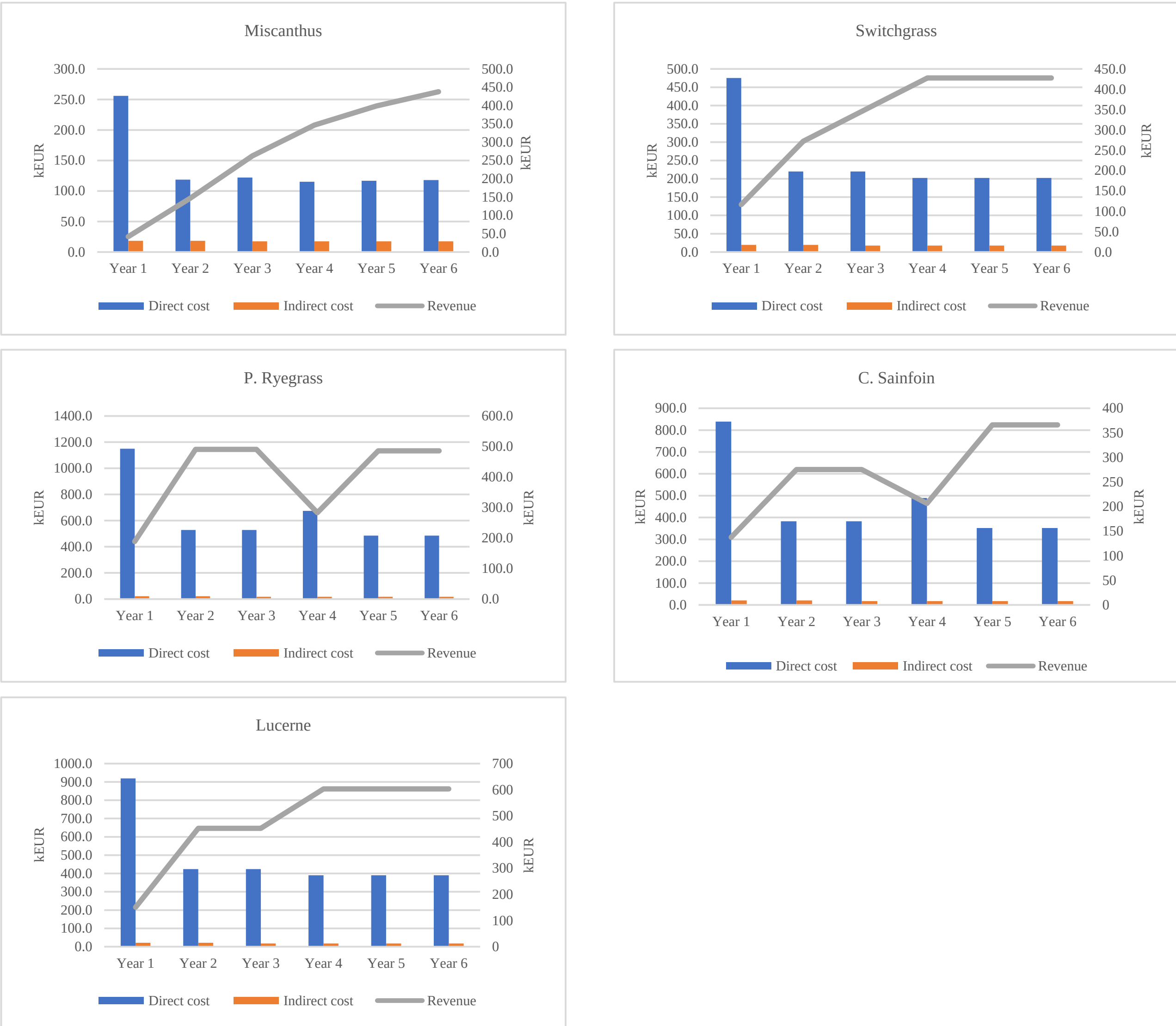
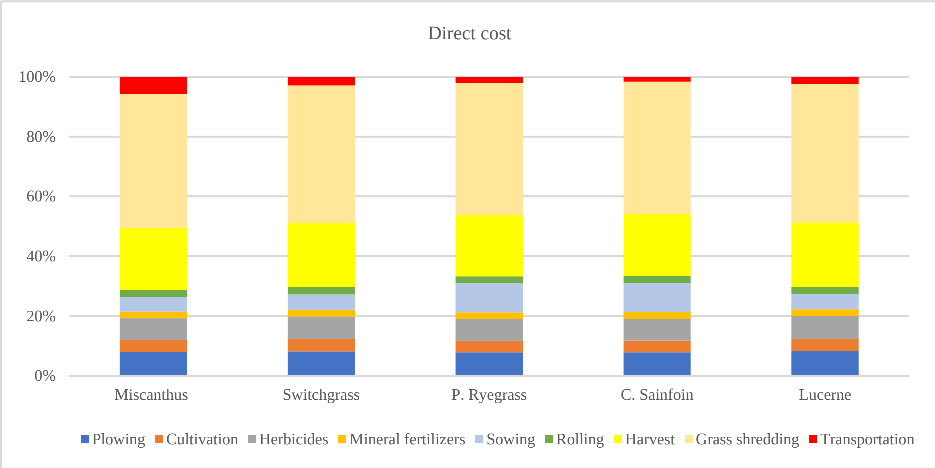
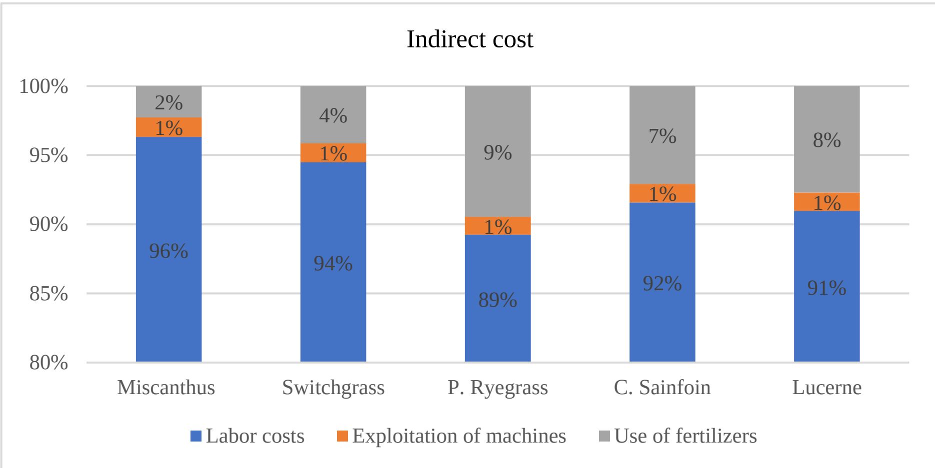


Figure 2. The costs of the production of perennial energy crops.

According to the data on the structure of the direct costs related to perennial energy crops, the first highest cost factor is grass shredding, ranging from 44% to 46%, and the second-highest cost factor is harvest, ranging from 21% to 22%. The lowest energy costs were generated by rolling and mineral fertilizers—2%. Other energy costs included amounts generated by cultivation—4%, herbicides—7%, sowing—ranging from 5% to 10%, and transport—ranging from 5% to 6%. According to the data on the structure of indirect costs, labor is one of the largest cost factors, ranging from 89% to 96%. The lowest energy costs were amounts generated by the exploitation of machines and the use of fertilizers—1% and from 2% to 9%, respectively.



(**a**)



(**b**)

Figure 3. The structure of energy costs of perennial energy crops in the renewable gas supply chain: (**a**) direct costs; (**b**) indirect costs.

The estimation of costs of perennial energy crop production shows the highest value per hectare for all five plants during the first year (Table 5).

Table 5. The costs of perennial energy crop production, euro per hectare.

Plants	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6
Miscanthus	326.7	163.2	166.1	157.9	159.8	161.2
Switchgrass	317.9	153.7	152.5	141.3	141.3	141.3
P. Ryegrass	310.6	145.8	144.5	183.3	133.3	133.3
C. Sainfoin	312.3	146.6	145.3	184.1	134.1	134.1
Lucerne	311.7	147.5	146.3	135.1	135.1	135.1

The Miscanthus production system, considered over a life cycle of 6 years, had the highest total costs, i.e., 189 EUR/ha, followed by the C. Sainfoin with 176 EUR/ha, P. Ryegrass—175 EUR/ha, Switchgrass—174 EUR/ha, and the Lucerne production system with the lowest costs of production of 169 EUR/ha.

Different plant species disclosed different energy costs of the supply chain of renewable gases from perennial energy crops per ton. The direct cost per ton amounted to 129.0 EUR/t. The indirect cost per ton amounted to 6.0 EUR/t (Figure 4).

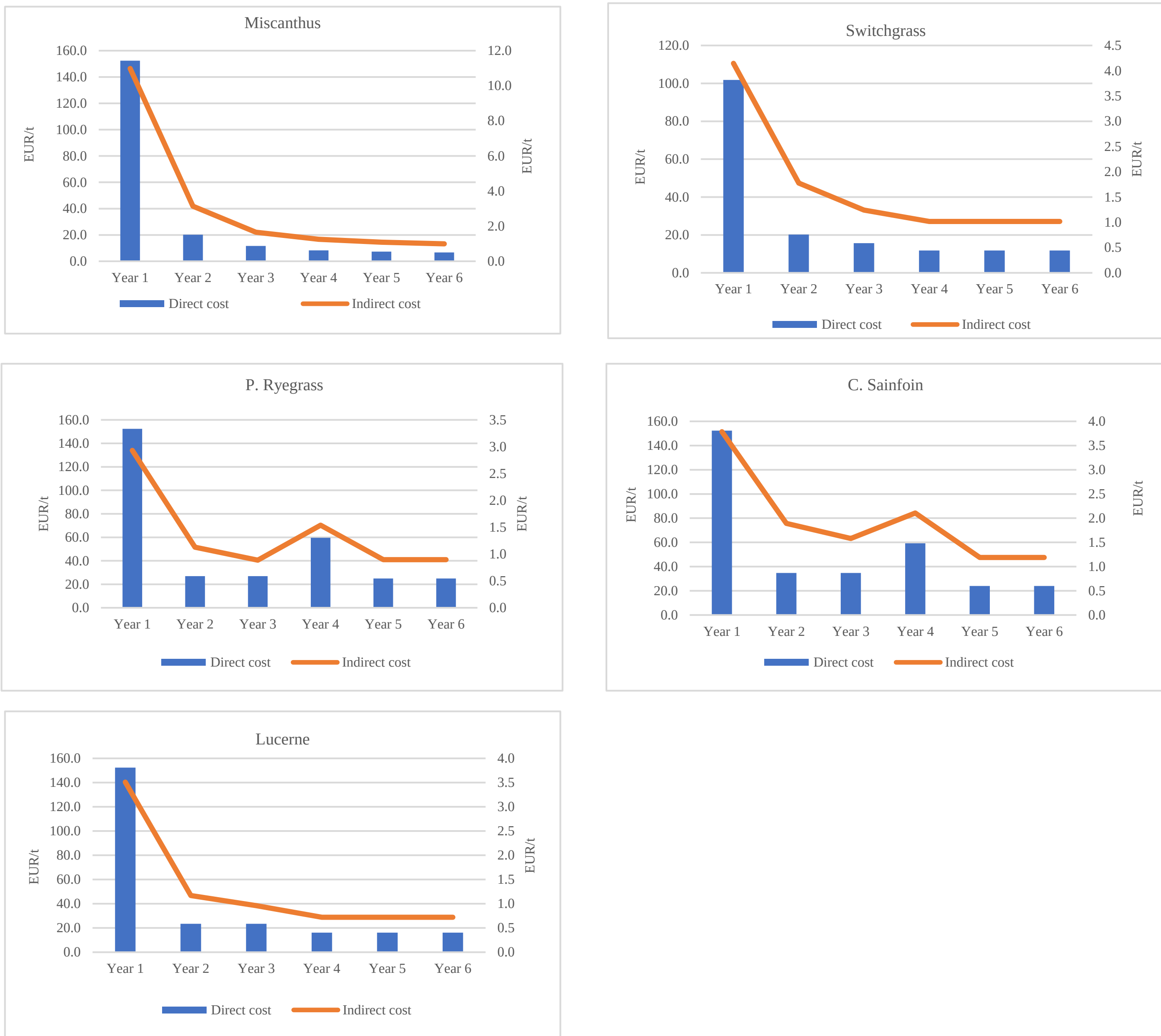


Figure 4. The costs of perennial energy crop production, euro per ton.

The results indicate that the highest energy costs per ton were observed in the case of C. Sainfoin, ranging from 152.4 to 24.0 EUR/t (DC) and from 3.8 to 1.2 EUR/t; followed by P. Ryegrass, ranging from 152.4 to 25.0 EUR/t (DC) and from 2.9 to 0.9 EUR/t (IC), and Lucerne, ranging from 152.4 to 16.2 EUR/t (DC) and from 3.5 to 0.7 EUR/t (IC). The lowest energy costs per ton were amounted by Miscanthus and Switchgrass, i.e., from 152.4 to 6.7 EUR/t (DC) and from 11.0 to 1.0 EUR/t (IC); from 101.8 to 11.8 EUR/t (DC) and from 4.1 to 1.0 EUR/t (IC), respectively. The research results show that P. Ryegrass and C. Sainfoin are the most expensive green biomass for the production of renewable gases in the supply chain. They continue to grow actively until the third year. After the third year, they need to be sown again. As a result, the input cost increases. The cultivation of Lucerne is also expensive, and its revenue by net yield is too small to cover the costs. The best results are those of Miscanthus and Switchgrass, which, when grown for the production of renewable gases in the supply chain, may generate positive results in the second year.

3.2. Effect of Net Present Value on Perennial Energy Crop Production

The net present value (NPV) tells us whether the supply chain of renewable gases from perennial energy crops is actually worthwhile as a whole (Table 6). The results indicate that two land use regions have positive net present values (with a discount rate of 5% and taking into account yearly inflation and price rises). The production of Miscanthus is likely to have the greatest beneficial effect on the NPV, followed by that of Switchgrass. The negative effect was observed in three land use forms. The biggest negative effect of NPV was discovered in the scenario of P. Ryegrass production, followed by C. Sainfoin and Lucerne production (Figure 5).

Table 6. Cost–benefit analysis for the production of five perennial energy crops (*x—It does not pay for itself in 6 years*).

Plants	eNPV [EUR/ha]	PBT [years]	IRR [%]	BCR [ratio]
Miscanthus	371,201	5	13.6%	1.39
Switchgrass	36,655	6	5.6%	1.02
P. Ryegrass	−1,827,022	x	−11.1%	0.53
C. Sainfoin	−1,560,033	x	−13.2%	0.46
Lucerne	−684,891	x	−1.5%	0.78

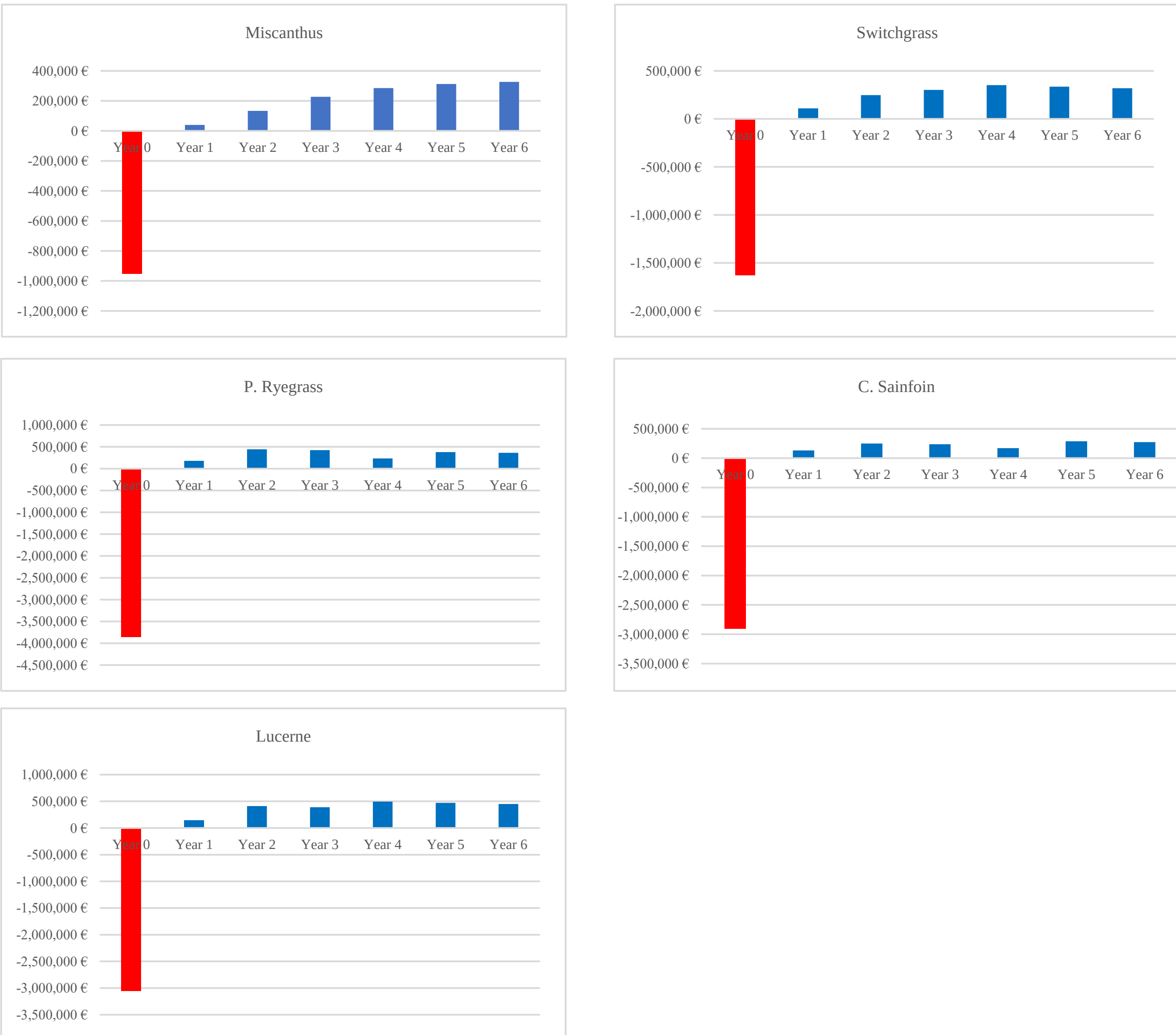


Figure 5. Display of the net present value for each area unit (ha) (negative NPV in red, positive NPV in blue).

The payback time of Miscanthus production is 5 years, whereas that of Switchgrass production is 6 years. The payback time of P. Ryegrass, C. Sainfoin, and Lucerne could not be evaluated, as no positive cash flows were calculated. Due to this, it was decided that the internal rate of return (IRR) was not negative. However, the IRR for the Miscanthus and Switchgrass production accounted for 13.6% and 5.6%, respectively. According to the benefit-cost ratio (BCR), the outcomes of Miscanthus production have the highest ratio over both output and input (1.39), followed by the outcomes of Switchgrass production (1.02). This suggests a lower investment risk compared to other manufacturing methods that can earn the same profit. The lowest BCR was reached for P. Ryegrass, C. Sainfoin, and Lucerne production, namely 0.33, 0.4 and 0.78, respectively. The results show that the BCR is less than 1, which means that these projects cannot be attractive for the production of these perennial energy crops in the renewable gas supply chain.

4. Discussion

The results of the study in Section 3 revealed that Miscanthus is the most economically viable crop under the assumed characteristics of perennial energy crops. The second position is taken by Switchgrass production. Studies on the process of the preparation and processing of perennial energy crops into biogas have been undertaken by many researchers. There are many kinds of perennial crops, such as miscanthus giganteus, amur silver grass, common cocksfoot, sweet sorghum, sida hermaphrodita, switchgrass, tall fescue, reed canary grass, legumes, and other mixtures of perennial grasses, which might be utilized in the production of bioenergy [29,36–48]. Some researchers presented that cultivating Miscanthus on farmland such as a platform for the generation of biogas could have the maximum energy potential and make sense from a financial and environmental standpoint [37,47]. However, some researchers discovered that the conversion into biogas production shows much lower specific methane yields for miscanthus and willow due to their lignocellulosic structure. When applying wet oxidation to the perennial crops, however, the specific methane yield increases significantly [47].

Comparing the research results with the research of other authors, it can be observed that the results obtained in Section 3 are similar, except for some studies, including that of Jensen et al., 2017, which tested a model on a case study with co-digestion of straw, sugar beet, and manure, considering natural gas, heat, and electricity as end products. They noticed that important factors in the profitability of biogas production are the possibility of optimizing the processes [43]. Another method of analysis was presented by Dressler et al., 2012, who evaluated the parameters that influence the results of a life cycle assessment (LCA) of biogas production from maize and the conversion of biogas into electricity. They discovered the environmental impacts of biogas vary according to regional farming procedures and, therefore, the soil, climate conditions, crop yield, and cultivation management [3].

Other researchers noticed most energy-efficient perennial crops include the grass cocksfoot [39–45] and sida hermaphrodita [22,38,41]. Sida is an exciting woody perennial plant that can be successfully cultivated. Sida can be used to produce biomass for a variety of adjustable and multifunctional energy applications, and it can also change the way agriculture is done in Central Europe today to make it more resilient to upcoming challenges and more sustainable [38,41]. The option of producing agricultural bioenergy in a way that is more ecologically benign exists with perennial crops such as perennial grass combinations and cup plants [10]. Due to their greater methane yield per hectare, cordgrass and large bluestem have been proven to be feedstock superior to switchgrass for the production of biogas under Polish climatic conditions [5]. Several studies found that the greatest results of biomethane yields were demonstrated by common sainfoin, common lucerne, and perennial ryegrass [29]. Five distinct perennial plants were used in a different assessment of methane capability (cup plant, virginia mallow, tall wheatgrass, giant knotweed, and reed canary grass). Tall wheatgrass as well as reed canary grass were more productive than maize within optimum situations in terms of methane output per area. Therefore, for Central Europe or regions with a similar climate, we advise using both species as biogas sources [49]. Napier grass and cattle slurry-based biogas production applications could be applied more cost-effectively to more sustainable production of biogas and to increase methane content [50]. There is the possibility of increasing the efficiency of biogas production from perennial grasses by their co-fermentation with maize or waste from the agro-food industry. Ensiled perennial grasses can be alternative sources of biogas and may be successfully used as substitutes or supplements to the main substrates used in agricultural biogas plants based on maize silage. Silages may also be made from sugar beet pulp and particular grasses mixed with maize or apple pomace in a weight ratio of 50:50 [5].

Unfortunately, the research results show that the profitability of the production of P. Ryegrass, C. Sainfoin, and Legume cannot be expected in the renewable gas supply chain. Other researchers found that alfalfa with timothy grass, virginia fanpetals, tall fercue, reed canary grass, legumes lucerne, and fodder galega had the lowest efficiency ratio value of energy [19,39,45]. The value creation (energy potential) of perennial energy crops per hectare depends directly on the grass yield for biogas production [8,19,51,52]. This has been confirmed by the results of the study. The perennial energy crop yield depends on important growing conditions such as fertilizers, herbicides, and the usefulness of regional ground. Other authors, e.g., Corno et al., 2016 [53], notice that the yield from biomass silage mostly depends on the type of grass and the number of cuts during the growing season; for example, grant reed could be successfully ensiled by using the following two approaches: trench and silo-bag.

Some studies show a considerable impact of N fertilization doses (between 40 and 120 kg/ha and 80 and 160 kg/ha, respectively, depending on crops). The use of larger fertilizer dosages did not significantly reduce energy use efficiency, but it did improve biomass and dry matter production (DMP), as well as methane production [36,40]. Nevertheless, it has also been found that the most energy-efficient agricultural production techniques used minimal doses of nitrogen fertilizer [54]. Additionally, it was shown that mixes of unfertilized perennial plants with a high species content may produce biomass on marginal land with minimal resource use, which helps to reduce climate change [13]. However, the biomass output is a constraint on the economic viability. Therefore, the choice must be made separately by taking into consideration site-specific factors such as regional biodiversity [9,22,37,40].

5. Conclusions

The analysis of the results revealed that the production of P. Ryegrass amounted to the highest direct and indirect costs. The costs of the production of C. Sainfoin were slightly higher than those of the production of Lucerne. The lowest costs were determined in the case of Miscanthus and Switchgrass. The analysis of the structure of cultivation suggests that the most expensive direct cost factors include grass shredding and harvesting, whereas labor costs are the most expensive indirect cost factor. The comparison of revenue with costs over a period of 6 years showed that Miscanthus and Switchgrass generated positive net cash flow.

The cost–benefit analysis indicated the positive effect of Miscanthus and Switchgrass on biogas production. This suggests that the cash flow of the production of these perennial energy crops generates more money flowing into the renewable gases of the supply chain than out of it over a specified period. Therefore, Miscanthus and Switchgrass are the most prospective perennial energy crops for the production of renewable gases in the supply chain under the climate conditions of Lithuania. Unfortunately, the analysis also showed that P. Ryegrass, C. Sainfoin, and Lucerne production had a negative effect on biogas production. The costs of these perennial energy crop cultivation exceed revenues. Thus, the analysis revealed that the energy potential depends significantly on the yield of perennial energy crops per hectare for biogas production that guarantees a positive cash flow of renewable gases in the supply chain.

The novelty of the research in the analysis of using the energy potential depends significantly on what yield per hectare of perennial energy crops for biogas production guarantees a positive cash flow of renewable gases in the supply chain. For the further expanding direction of research, it is recommended to take into account some minimum and maximum errors in the economic analysis by the timeline. It would also be interesting to disclose the main disadvantages and advantages of additional results of the research study.

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